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Mineralization of plant residues and native soil carbon as affected by soil fertility and residue type

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Abstract

Purpose Crop residue return is an effective and low-cost agricultural approach for soil organic carbon (SOC) sequestration. Yet, it is largely unknown to what extent the soil fertility and residue type affect the mineralization of maize (*Zea mays* L.) residue carbon (C) and the decomposition of native SOC. Therefore, a better understanding of the mineralization of C derived from residues and its priming on native SOC is crucial to accurate assessment of the benefits of crop residue returning in agricultural systems.

Materials and methods A 360-day laboratory incubation experiment was carried out with a Cambisol of low and high fertilities amended with three types of ^{13}C-labeled maize residues (root, stem, leaf). The abundance of ^{13}C ($\delta^{13}C$) in the soil samples was measured during different incubation stages.

Results and discussion The results showed that the total mineralization of residue C was significantly higher in the low fertility soil than in the high fertility soil, but there were no significant differences among residue types. For the high fertility soil, all the residue types induced a negative priming on native SOC mineralization during the early incubation stage, but a significant total positive priming by the end of incubation, whereas for the low fertility soil, there was no significant effect of residue return on SOC mineralization. The accumulated priming by the end of incubation did not vary across residue types. Moreover, the sum of mineralization of residue C and native SOC in the high fertility soil was 1.4 times as large as that in the low fertility soil.

Conclusions We conclude that mineralization of crop residue C and native SOC is affected by soil fertility rather than residue type.

Keywords C sequestration · Decomposition · Priming · Residue return · Soil organic carbon

1 Introduction

The degradation of soil fertility and decline of SOC is a general trend in global cultivated fields and negatively impacts productivity and sustainability of agriculture (Lal 2004; Agegnehu et al. 2016). One of the critical factors for the decline of SOC is the removal of organic material by harvest but no C input to soil (Liu et al. 2010). Return of crop residues has been practiced for a long time and is recommended as an effective strategy to enhance SOC sequestration and compensate for SOC loss (Studdert and Echeverria 2000; Whitbread et al. 2003). However, the return of crop residues does not necessarily lead to increase SOC sequestration (Kirkby et al. 2014; Shahbaz et al. 2017a, b). For example, it was reported that the return of crop residues may induce a reduction of SOC (Kirkby et al. 2014), and the loss of "old" SOM may exceed the formation of "new" SOC (Fontaine et al. 2004; Aye et al. 2018). Residue management practices should aim to reduce long-term C mineralization and minimize soil degradation (Wang et al. 2017). In this context, it is important to investigate and clarify the effects of crop residues on different C pools and C sequestration.

Crop residues play a key regulatory role in soil C sequestration by modulating the balance between the input and mineralization of residue C (Leavit 1998; Hewins et al. 2017). Different types of crop residues, i.e., roots, stems, and leaves, have different chemical compositions and C/N ratios (Abiven et al. 2005; Redin et al. 2014). Leaves usually contain larger

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amounts of readily decomposable compounds and a high N but low lignin content (Bertrand et al. 2006) and thus tend to mineralize faster than roots and stems (Abiven et al. 2005; Thippayarugs et al. 2007).

Crop residues can change the decomposition of native SOC, a process known as the priming effect (Bingeman et al. 1953). Studies have demonstrated that addition of organic substances not only can accelerate the mineralization of native SOC (i.e., positive priming) but also could retard the mineralization (i.e., negative priming) (Dalenberg and Jager 1989; Kuzyakov et al. 2000; Kirkby et al. 2014; Zhang et al. 2018). It has been reported that the priming effect is affected by the recalcitrance (indicated by N concentrations, C/N, phenol/lignin, and so on) (Castellano et al. 2015) and the labile C amount of the amended residue (Hessen et al. 2004). Shahbaz et al. (2017b) observed a stronger priming effect of wheat root than stem and leaf. Contrastingly, another study concluded that the type of wheat residue showed no effect on priming (Shahbaz et al. 2017a). This inconsistency may be explained by variation in residue recalcitrance, amount of added C substrate in relation to the existing SOC pool, and different background soil properties (Aye et al. 2018).

Soil fertility is another important factor controlling the C fluxes after residue return (Ehaliotis et al. 1998). Soils with high fertility generally possess larger microbial biomass, higher enzyme activities, and better soil structure, compared to those with low fertility (Huang 2000; Fontaine et al. 2011; Lang et al. 2012), and this could provide a suitable environment for substrate utilization by microbes. Thus, the residue C mineralization is assumed to be faster in the soils with higher fertility, but only few studies have compared and quantified the residue C mineralization in soils with different fertilities. Furthermore, in soils with low fertility, the energy sources needed for microbial growth are often limited (Bell et al. 2003), which then limits the mineralization of native SOC and possibly weakens the priming effect on native SOC decomposition. However, previous studies provided little information for comparison of the priming of residue amendment between different soil fertilities. Internal (residue types with various qualities) and environmental factors (soil fertilities) may interactively affect the biochemical transformation of residue C and thus alter the residue C mineralization and its priming on native SOC decomposition.

Integrated laboratory incubation studies on C mineralization with different types of crop residues and their priming on native SOC decomposition in different fertility soils are limited. Here, a 360-day laboratory incubation study was conducted with soils of low fertility and high fertility, where $^{13}C^{15}N$-labeled maize roots, stems, or leaves were added separately. The low and high fertility soils were obtained from a temperate cropland that continuously received no fertilizer and manure for 27 years, respectively. We compared the mineralization of residue C and the priming on native SOC decomposition among different residue types and soils with different fertilities. Our objective was to test the hypotheses that (1) residue C mineralization would be faster and induced greater positive priming in the high fertility soil than the low fertility soil and (2) the priming on native SOC decomposition would vary among roots, stems, and leave additions.

2 Materials and methods

2.1 Site and soil sampling

The soil samples were collected from a long-term fertilizer experimental site on a conventional maize cropping field (41° 49′ N, 123° 34′ E) established in 1987 in Shenyang, Liaoning Province, China (Liang et al. 2009). The site has a temperate, continental monsoon climate with a mean annual temperature of 7.6 °C and mean annual precipitation of 705 mm. The soil is classified as a Hapli-Udic Cambisol (FAO Classification). The cropping system is monoculture with maize (*Zea mays* L.), which is sown in early May and harvested in October. The experimental plots were arranged in a split-plot design with or without plastic mulching as main plots and three levels of fertilizer as subplots. The subplots were 69 m^2 and arranged in a completely random design with three replicates.

Two fertilization treatments (without mulching) were chosen in this study as the following: (1) the treatment without any fertilizer (denoted as the low fertility soil) and (2) the treatment with manure (pig compost, 270 kg N ha^{-1} $year^{-1}$) (denoted as the high fertility soil). Pig compost contained 150 g kg^{-1} total organic C, 10 g kg^{-1} TN, 10 g kg^{-1} P_2O_5, and 4 g kg^{-1} K_2O on a dry weight basis and was basally applied before sowing. The samples were collected from the topsoil (0–20 cm horizon) in the October 2014 after the harvest of maize. All visible coarse fragments, including roots and stones, were removed by hand. Microbial biomass carbon in the fresh soil was measured by the chloroform-fumigation extraction method according to Vance et al. (1987). The soil was then air dried, ground, and passed through a 2-mm sieve. A portion of the air-dried soil sample was further ground and passed through a 100-mesh sieve for determination of SOC and total nitrogen (TN) contents and $\delta^{13}C$ and $\delta^{15}N$ values. The remaining portion was preserved for the subsequent incubation experiment. The chemical properties of the soil samples are presented in Table 1.

2.2 Pulse labeling experiment for $^{13}C^{15}N$ enriched maize residues

Enriched $^{13}C^{15}N$ dual-labeled maize residues were obtained from a pulse $^{13}C^{15}N$ dual labeling experiment conducted in 2014. The labeling methods were described in detail by An et al. (2015). Briefly, an enclosed transparent chamber was placed over the subplots and covered 20 plants, and an

Table 1 Chemical properties of soil samples and $^{13}C^{15}N$ dual-labeled maize residues

	Total organic C (g kg^{-1})	Total N (g kg^{-1})	$\delta^{13}C$ value (‰)	$\delta^{15}N$ value (‰)	C/N	Total P (g kg^{-1})	Total K (g kg^{-1})	pH (H_2O)	Total Ca[a] (g kg^{-1})	Total Mg[a] (g kg^{-1})	Microbial biomass C (mg kg^{-1})	Clay[b] (%)	Lignin (g kg^{-1})
Low fertility soil	11.1 ± 0.B	1.1 ± 0.0B	17.9 ± 0.0B	8.1 ± 0.1A	10.1 ± 0.1A	0.6 ± 0.0B	20.7 ± 1.2A	6.0 ± 0.1A	3.9	5.9	281.9 ± 8.3B	28.9	–
High fertility soil	17.8 ± 0.1A	2.2 ± 0.0A	19.5 ± 0.0A	1.5 ± 0.1B	8.1 ± 0.1B	2.2 ± 0.2A	21.4 ± 1.4A	6.2 ± 0.1A	5.6	6.6	423.2 ± 14.6A	31.0	–
Root	400.8 ± 0.1c	12.6 ± 0.2a	393.9 ± 0.5c	19,522.8 ± 9.2a	31.9 ± 0.4a	–	–	–	–	–	–	–	135.3 ± 7.1a
Stem	440.1 ± 0.0a	14.5 ± 0.1a	696.4 ± 1.0a	19,268.8 ± 7.0b	30.5 ± 0.3a	–	–	–	–	–	–	–	79.0 ± 5.1b
Leaf	420.8 ± 0.0b	12.7 ± 0.1a	662.4 ± 0.5b	16,787.1 ± 13.4c	33.1 ± 0.4a	–	–	–	–	–	–	–	45.7 ± 3.0c

Different uppercase letters denote significant difference between different fertility soils ($P < 0.05$). Different lowercase letters denote significant difference among different residue ($P < 0.05$)

[a] The data of total Ca and Mg was from Wang et al. (2013)

[b] The data of clay content was from Pei et al. (2015)

environment with high $^{13}CO_2$ concentration was generated through a reaction between HCl and Na_2CO_3 (99 atom% ^{13}C). An air pump and absorption bottle filled with sodium hydroxide were attached to the chamber to remove atmospheric CO_2 and facilitate $^{13}CO_2$ assimilation by maize plants. The labeling process proceeded from 9:00 am to 3:00 pm on a bright and sunny day and was repeated at ten discontinuous days throughout the growing cycle. The ^{15}N was labeled through an injection of 0.2 mol L^{-1} $(NH_4)_2SO_4$ solution (98 atom% ^{15}N) into the rhizosphere soil of each maize plant with two times at the early booting stage (July 6 and July 10). In autumn, roots, stems, and leaves were separately harvested and oven dried at 60 °C to a constant weight. The residues were ground and passed through a 40-mesh sieve for the subsequent laboratory incubation. The chemical properties of maize residues are presented in Table 1.

2.3 Laboratory incubation and measurement

The laboratory incubation experiment consisted of a combination of the soils (low and high fertilities) and three types of maize residues plus the non-amended soils, resulting in eight treatments: low fertility soil amended with root (LF + R), stem (LF + S), and leaf (LF + L) residues, high fertility soil amended with root (HF + R), stem (LF + S), and leaf (LF + L) residues and non-amended controls with low fertility soil (LF) and high fertility soil (HF). Each treatment contained three replicates per sampling date; these replicates corresponded to the soil samples taken from the three plots of the low fertility and high fertility treatments in the field. Specifically, 120 g of air-dried soil sample was added into a glass jar (1 l) and the soil was brought to a gravimetric moisture content of 7%. The jars were covered by a piece of breathable parafilm (PM-996, Bemis Company, USA) to maintain soil water content and a free air space above soil samples (Wang et al. 2015). The jars were pre-incubated at 25 °C for 7 days prior to maize residue addition in order to allow soil microbes to accustom to the laboratory incubation condition (Abbasi and Khaliq 2016). After the pre-incubation, the soil samples in the jars were poured onto a weighing paper; 1.2 g of $^{13}C^{15}N$-labeled maize residue (roots, stems, or leaves, 1% of dried soil weight) was mixed homogeneously into each soil sample and then placed back into the jar. The same mixing procedure was done with the non-residue amended controls to maintain uniform disturbance across all treatments. Soil moisture content was then adjusted to 60% of water-holding capacity and maintained during the incubation by weighting the jars every 5 days and adding sterilized deionized water as needed. At days 1, 7, 28, 56, 180, and 360 of incubation, we destructively sampled three replicates per treatment. The sampled soils were thoroughly homogenized and dried at room temperature, ground, and passed through a 100 mesh sieve to determine SOC and TN contents and $\delta^{13}C$ and $\delta^{15}N$ values.

The contents of C and TN and the values of $\delta^{13}C$ and $\delta^{15}N$ for soil samples and maize residues were determined using EA-IRMS (Elementar vario PYRO cube coupled to IsoPrime 100 Isotope Ratio Mass Spectrometer, Germany). The soil pH (soil:water, 1:2.5) was measured using a Thunder Magnetic pH Meter (PHS-3B, Shanghai, China). Total soil phosphorus (TP) and potassium (TK) were digested by HF-$HClO_4$ (Jackson 1958) and determined by molybdenum-blue colorimetry and flame photometry, respectively. The lignin content in maize residues was measured using the oxidation-reduction method according to Fan et al. (2008).

2.4 Data analysis

The mineralization of residue C and native SOC was estimated as the subtraction between their initial C amount and respective remaining C amount at a given sampling time. The proportions of remaining residue-derived C ($F_{residue}$) and native SOC (F_{soil}) in total C of the residue treatments at a given sampling time were calculated according to De Troyer et al. (2011):

$$F_{residue} = \frac{\delta^{13}C_{sample} - \delta^{13}C_{control}}{\delta^{13}C_{residue} - \delta^{13}C_{control}} \quad (1)$$

$$F_{soil} = 1 - F_{residue} \quad (2)$$

where $\delta^{13}C_{sample}$ represents the abundance of total ^{13}C for the residue treatments, $\delta^{13}C_{control}$ represents the abundance of ^{13}C for the control soil (without residue addition), and $\delta^{13}C_{residue}$ represents the abundance of ^{13}C for the corresponding residue.

The proportion of residue C mineralization ($M_{residue}$) and native soil C mineralization (M_{soil}) was calculated as follows:

$$M_{residue} = \left(1 - \frac{F_{residue} \times C_{total}}{C_{residue}}\right) \quad (3)$$

$$M_{soil} = \left(1 - \frac{F_{soil} \times C_{total}}{C_{soil}}\right) \quad (4)$$

where C_{total} is the amount of total C (g) in the residue treatment, $C_{residue}$ is the amount of initial C (g) of the residue, and C_{soil} is the amount of initial C (g) of the native soil.

The cumulative priming effect (PE, mg C kg^{-1} soil) was calculated as follows:

$$PE = \left[\left(C_{soil,0} - C_{total,t} \times M_{soil}\right) - \left(C_{control,0} - C_{control,t}\right)\right] \times 1000 \quad (5)$$

where $C_{soil,0}$ represents the content of initial native soil C (g C kg^{-1} soil) for the residue treatment, $C_{total,t}$ represents the content of total C (g C kg^{-1} soil) in the residue treatment at a sampling time (t), $C_{control,0}$ represents the content of initial C (g C kg^{-1} soil) in the control treatment, and $C_{total,\ t}$ represents the content of C (g C kg^{-1} soil) in the control treatment at a sampling time (t).

All results were reported as means of three replicates with standard error. Chemical properties (C, N, C/N, $\delta^{13}C$, $\delta^{15}N$, Total P, Total K, pH, Microbial biomass C, Lignin) were compared using the LSD (least significant difference) multiple range test in between different soils or plant residues. A two-way ANOVA was used to test the effects of residue type and soil fertility on the accumulating amounts of residue C mineralization, native SOC mineralization, priming effect, and total C mineralization till the end of incubation. Significance was reported at $\alpha = 0.05$. All data were analyzed with SPSS 19.0 statistical software, and the graphs were drawn using Origin 8.

3 Results

3.1 Changes of C and N isotope values

The $\delta^{13}C$ values of all the residue treatments decreased with incubation time, with a sharp drop in the first 7 days and then a slow tendency after that (Fig. 1a, b). However, the $\delta^{15}N$ values only showed small fluctuations with incubation time (Fig. 1c, d). For the controls (without residue addition), $\delta^{13}C$ and $\delta^{15}N$ remained essentially unchanged. The root treatment had a significant smaller $\delta^{13}C$ value than the stem and leaf treatments ($P < 0.05$) both for LF and HF soils. Moreover, all the residue treatments generally showed larger $\delta^{13}C$ and $\delta^{15}N$ values in LF soil than in HF soil, as a result of a stronger dilution for residue C and N isotopes in the HF soil with higher C and N contents.

3.2 Mineralization of maize residue C

After 360 days of incubation, C of root, stem, and leaf were mineralized by 66.4% ± 1.0%, 63.0% ± 1.3%, and 67.4% ± 4.0% in LF soil, respectively, whereas they were 54.2% ± 1.4%, 55.8% ± 2.6%, and 61.7% ± 1.4% in HF soil, respectively (Fig. 2). The total mineralization of residue C till the end of incubation was significantly affected by fertility level ($P < 0.01$; Table 2) and was 9.3–22.5% higher in LF soil than in HF soil (Fig. 2). However, the total residue C mineralization was not significantly affected by residue type ($P = 0.19$; Table 2). The residue C mineralization sharply increased during the initial 7 days of incubation and then slowly increased during the late incubation. During the first 7 days (rapid mineralization phase), the proportion of residue C mineralization was more than 30% for all treatments.

3.3 Mineralization of native SOC and priming effect

Native SOC mineralization till the end of incubation was significantly affected by soil fertility ($P < 0.01$; Table 2). The proportion of total native SOC mineralization was significantly higher in HF soil (16.1–17.9%) than in LF soil (5.5–10.1%) (Fig. 3a, b). However, native SOC mineralization was not

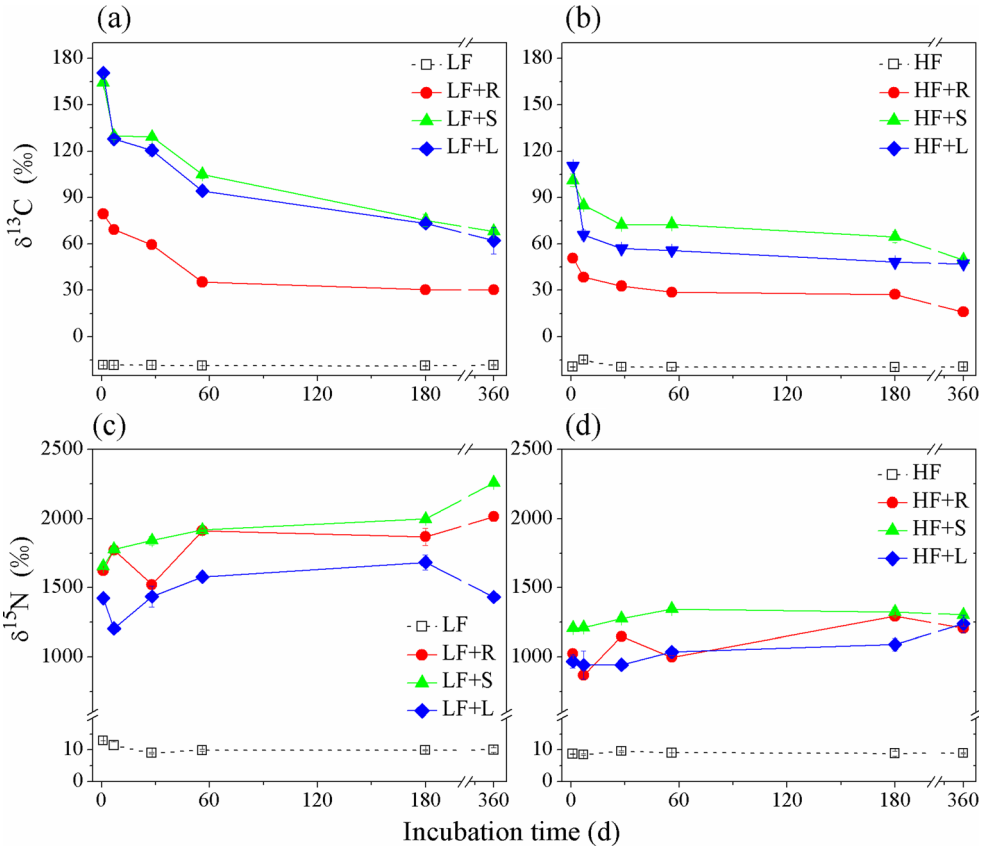

Fig. 1 Temporal change in $\delta^{13}C$ and $\delta^{15}N$ values in the treatments of low (**a**, **c**) and high fertility (**b**, **d**) soils amended with residues. LF low fertility soil (control), LF + R low fertility soil + root, LF + S low fertility soil + stem, LF + L low fertility soil + leaf, HF high fertility soil (control), HF + R high fertility soil + root, HF + S high fertility soil + stem, HF + L high fertility soil + leaf. Error bars are standard errors ($n = 3$)

significantly affected by residue type ($P = 0.27$; Table 2) and was similar among leaf stem, and root treatments (Fig. 3a, b).

Similarly, the total C priming till the end of incubation was significantly affected by soil fertility ($P < 0.05$; Table 2), but not by residue type ($P = 0.47$) and their interaction ($P = 0.79$). In HF soil, maize residues resulted in a positive total priming, i.e., root (406 ± 187 mg C kg^{-1} soil), stem (268 ± 255 mg C kg^{-1} soil), and leaf (590 ± 203 mg C kg^{-1} soil) till the end of incubation (Fig. 3d). However, in LF soil, they induced a negative priming or close to no priming, i.e., root (94 ± 124 mg C kg^{-1} soil), leaf (−65 ± 105 mg C kg^{-1} soil), and stem (−423 ± 280 mg C kg^{-1} soil) till the end of incubation. Specifically in HF soil, there were negative priming in the early stage but turned into positive priming at the late stage.

3.4 The sum of residue C and native SOC mineralization

The total C mineralization (the sum of residue and native SOC mineralization) in HF soil (5.1–5.3 g C kg^{-1}

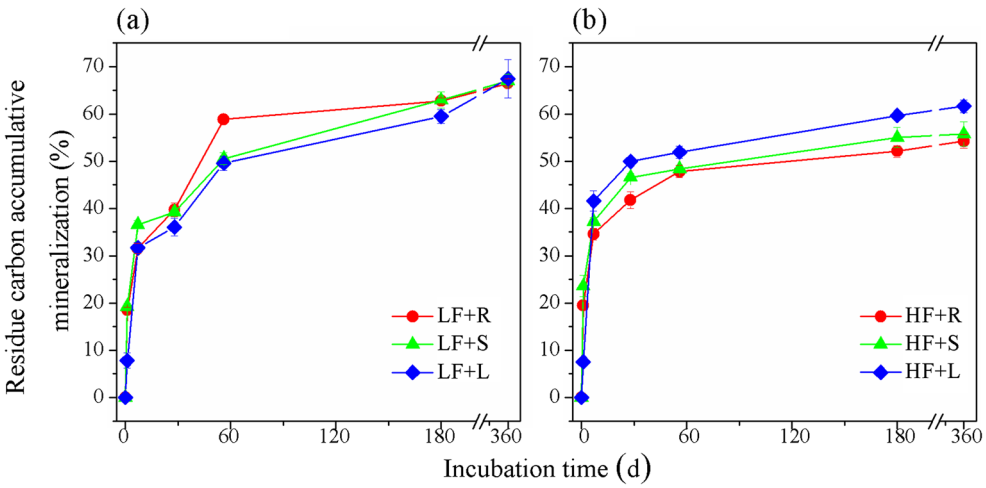

Fig. 2 The proportion of residue C mineralization relative to the initial added residue C in the low (**a**) and high (**b**) fertility soils. LF low fertility soil (control), LF + R low fertility soil + root, LF + S low fertility soil + stem, LF + L low fertility soil + leaf, HF high fertility soil (control), HF + R high fertility soil + root, HF + S high fertility soil + stem, HF + L high fertility soil + leaf. Error bars are standard errors ($n = 3$)

Table 2 Results of ANOVA analysis for the effect of residue type and fertility on C mineralization of different pools

Factor	df	Residue C mineralization		Native SOC mineralization		Priming effect		Total C mineralization	
		(%)		(%)		(mg C kg^{-1} soil)		(g C kg^{-1} soil)	
		F ratio	*P*	*F* ratio	*P*	*F* ratio	*P*	*F* ratio	*P*
Fertility level (*F*)	1	28.82	< 0.01	37.58	< 0.001	4.95	0.04	513.71	< 0.001
Residue type (*R*)	2	1.94	0.19	1.46	0.27	0.80	0.47	2.48	0.13
F × *R*	2	1.24	0.32	0.61	0.56	0.24	0.79	0.99	0.40

Residue C Mineralization: the proportion of total residue C mineralization to the initial added residue C till the end of incubation; native SOC mineralization: the proportion of total native SOC decomposition to the initial soil C till the end of incubation; priming effect: the total priming induced by residue addition till the end of incubation; total C mineralization: the sum of total residue C mineralization and total native SOC decomposition till the end of incubation

soil) were significantly higher than in LF soil (3.6–3.8 g C kg^{-1} soil) ($P < 0.05$; Table 2; Fig. 4). Total C mineralization was not affected by residue type ($P > 0.05$). Residue C mineralization was the major portion (70–83%) in total C mineralization in LF soil, but residue C mineralization and native SOC mineralization contributed almost equally to the total C mineralization in HF soil.

4 Discussion

4.1 Plant residue C mineralization

In our study, the proportions of residue C mineralization relative to initial C were 54–67% in the two soils after 360-day incubation. This amount of residue C mineralization was comparable to previous published studies. Gao et al. (2016)

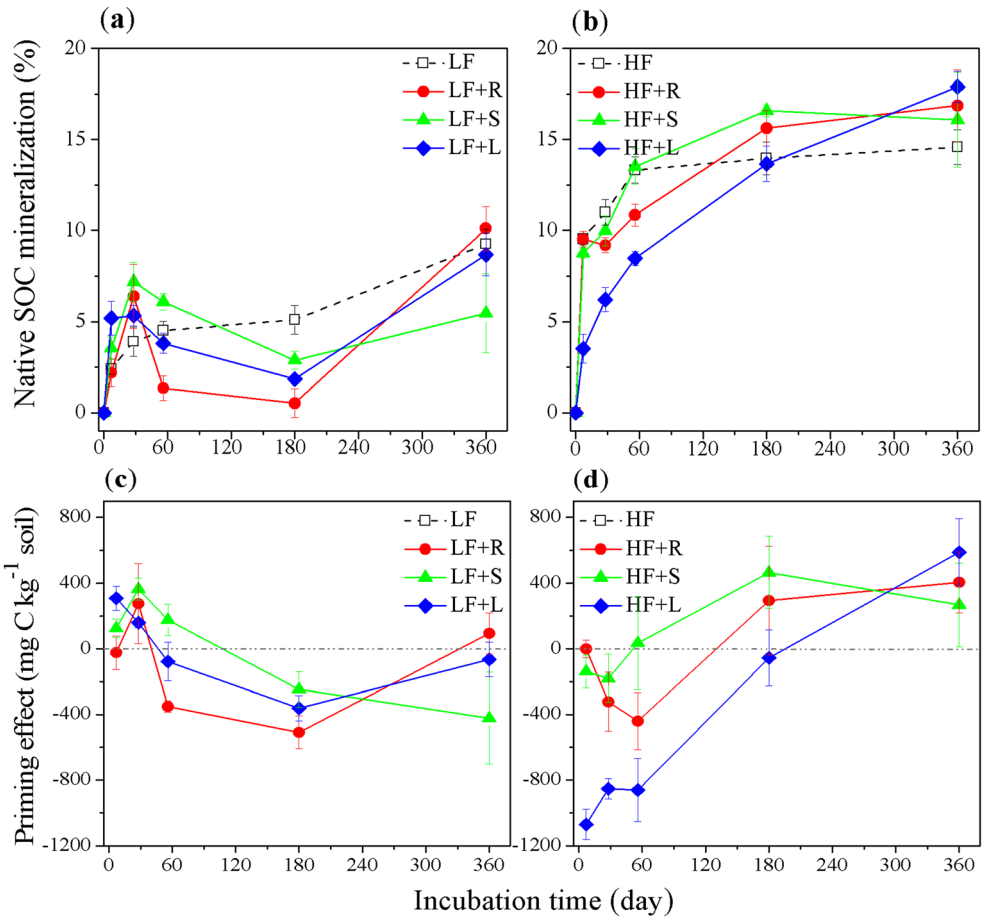

Fig. 3 The proportion of native SOC mineralization relative to initial soil C (**a**, **b**) and cumulative priming effect (**c**, **d**) in the soils with low and high fertilities, respectively. LF low fertility soil (control), LF + R low fertility soil + root, LF + S low fertility soil + stem, LF + L low fertility soil + leaf, HF high fertility soil (control), HF + R high fertility soil + root, HF + S high fertility soil + stem, HF + L high fertility soil + leaf. Error bars are standard errors ($n = 3$)

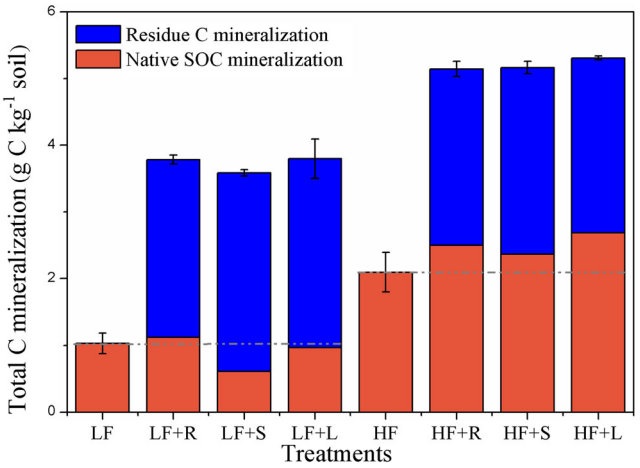

Fig. 4 Total C mineralization (the sum of residue C mineralization and native SOC mineralization) at the end of incubation. LF low fertility soil (control), LF + R low fertility soil + root, LF + S low fertility soil + stem, LF + L low fertility soil + leaf, HF high fertility soil (control), HF + R high fertility soil + root, HF + S high fertility soil + stem, HF + L high fertility soil + leaf. Error bars are standard errors ($n = 3$)

reported that about 70% of wheat residue C was mineralized under anaerobic as well as aerobic conditions in a Hapli-Udic Cambisol after 12-month in a field experiment. Johnson et al. (2007) showed that about 50–60% of C had mineralized for both C_3 and C_4 crop residues in a Calcic Hapludoll after a 498-day indoor incubation. Zech et al. (1997) concluded that 55–70% of plant residue C were released as CO_2 after 1 year among different soils with various SOM conditions.

Our results showed that the mineralization of residue C was higher in a low fertility soil than in a high fertility soil after 360 days' incubation (Fig. 2). This did not support our hypothesis that residue C mineralization would be faster in a high fertility soil compared to a low fertility soil, considering that a high fertility soil has greater microbial and enzyme activities (Table 1). Two possible reasons could explain this unexpected result. First, the low fertility soil could be deficient in N nutrient for soil microbes, as indicated by the higher C/N ratio as compared to the high fertility soil (Table 1). In this case, soil microorganisms will use N derived from the more easily decomposable residue pool and thus will preferentially degrade maize residues to satisfy their N requirements. Indeed, microbial communities enhance the production of nutrient acquiring enzymes in N limited soils (Craine et al. 2007). Second, physical protection in soil aggregates may hinder residue C mineralization (Wang et al. 2017). According to a previous study at our experimental site, the percentage of large aggregates (> 2 mm and 2–1 mm) in the high fertility soil was 25% higher than that in the low fertility soil (Xu et al. 2018). A large amount of fresh residues may have been incorporated into large aggregates of the high fertility soil, where they were protected from mineralization by microbial (Tisdall and Oades 1982). This is supported by research of Li et al. (2016) who found that macro-aggregates contained more residue C compared to micro-aggregates after maize residue incorporation.

Previous studies reported that leaves are usually decomposed faster than roots and stems (Abiven et al. 2005; Thippayarugs et al. 2007), because the lignin content decreases in the order of root > stem > leaf (Table 1). Unexpectedly in our study, residue types did not significantly affect the amount of residue C mineralization till the end of incubation (Table 2). Nevertheless, we cannot conclude that residue type does not affect the whole process of residue C mineralization. During some early incubation stages, residue C mineralization was evidently different among residue types (Fig. 2). Previous studies also reported differences in residue C mineralization during initial stages, but no differences in the later stages. For example, Wang et al. (2017) found that the long-term (48 months) decomposition of residues was less affected by residue type (canola, chickpea, and wheat). Overall, our results indicate that residue C sequestration is similar among roots, stems, and leaves after 1 year of incubation.

4.2 The priming of mineralization of native soil C

In our study, residue addition induced positive priming of SOC mineralization after 1-year incubation in the high fertility soil, but negative or no priming in the low fertility soil (Fig. 3). This is similar with Kuzyakov and Bol (2006), who found that the magnitude of the priming effect was positively correlated with SOC content. Larger amounts of C substrate and higher microbial activities in the high fertility soil compared to the low fertility soil (Table 1) would partly explain the phenomenon. Furthermore, soils with different fertility may have different microbial communities (Fontaine et al. 2003; Blagodatskaya et al. 2007). Low residue C mineralization but high native SOC mineralization in the high fertility soil (Figs. 2 and 3) suggests that microorganisms feeding on SOM (the microbial population which can use the almost inexhaustible SOM; Fontaine et al. 2003) may occupy a dominant role in the high fertility soil, whereas high residue C mineralization but low native SOC mineralization in the low fertility soil suggests that microorganisms specialized in fresh organic matter decomposition may dominate. It was suggested that SOM feeding microorganisms are usually *K*-strategists, and yet *r*-strategists dominate in fresh organic matter mineralization (Fontaine et al. 2003; Luo et al. 2011, 2013). This speculation was supported by Zhang et al. (2007) who found that long-term organic fertilizer and chemical fertilizer applications were more conductive to increase *K*-strategist microorganisms compared with *r*-strategist microorganisms. Microorganisms specialized in decomposition of fresh organic matter preferentially utilized residues rather than native SOC in the low fertility soil, thus we observed a negative or no priming effect (Fig. 3c). In the high fertility soil, the dominance of SOM feeding microorganisms led to a positive total priming (Fig. 3d).

We found that the total priming of native SOC decomposition was similar among root, stem, and leaf additions (Table 2; Fig. 3). Numerous studies have suggested the quality of C substrates and the C availability to decomposers as a controlling factor of the priming effect (Fontaine et al. 2007; Shahbaz et al. 2017a, b; Zhang et al. 2018). But the results of these reports are controversial, i.e., some studies have revealed that addition of more recalcitrant substrates showed a greater priming than the addition of labile C substrates (Kuzyakov 2010; Shahbaz et al. 2017a, b); however, others observed the reverse (Mary et al. 1993; Nottingham et al. 2009; Aye et al. 2018). In our study, the three residue types had similar N contents and C/N ratios, and this was one possible reason for their similar C priming. It was reported that the priming on native SOC was affected by these residue parameters (Justes et al. 2009). Although the three residue types varied in lignin contents (Table 1), it seemed that the priming was not influenced by lignin (Justes et al. 2009). Moreover, the priming on native SOC was reported to be related to residue C mineralization (Shahbaz et al. 2017b), which was similar among the three residue types (Fig. 2). In summary, we highlighted that the biochemical recalcitrance of added residue had limited effect on priming.

5 Conclusions

Our study demonstrated that the mineralization of residue C and its priming on native soil C decomposition were significantly affected by soil fertility, but not by residue types. The low fertility soil had faster residue C mineralization but slower native SOC decomposition compared with the high fertility soil. These results suggest that a low fertility soil is more favorable to the protection of native SOC, whereas a high fertility soil is more conducive to the sequestration of residue C. Totally, the sum of residue C mineralization and native SOC decomposition was larger in the high fertility soil than in the low fertility. Therefore, we concluded that crop residues returning is more helpful for C sequestration in low fertility soil compared with high fertility soil.

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