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Crop residue decomposition and nutrient release are independently affected by nitrogen fertilization, plastic film mulching, and residue type

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ABSTRACT

The return of crop residues to the soil is a common agricultural management practice for nutrient recycling and carbon sequestration. It is known that nitrogen (N) fertilization can influence crop residue decomposition and nutrient release. However, it is unclear whether the effect of N fertilization interact with plastic film mulching (PFM) or residue type. We conducted a two-year field study to quantify the main and interactive effects among N fertilization (including no input (N_0), 135 kg N ha^{-1} yr^{-1} (N_{135}), and 270 kg N ha^{-1} yr^{-1} (N_{270})), PFM (with and without mulching) and residue type (roots, stems, and leaves) on the decomposition and nutrient releases of crop residues in a long-term field experiment with combined mulching and fertilization treatments. We did not observe any interactive effects among N fertilization, plastic film mulching and residue type on crop residue decomposition and nutrient releases. Crop residue decomposition was delayed at N_{135} but remained unchanged at N_{270} when compared to N_0. The positive correlation between decomposition and soil available phosphorus (P) suggest that soil P status played an important role for crop residue decomposition. The two levels of N fertilization both slowed down N release from crop residues, but did not change P release. PFM accelerated crop residue decomposition by 10% in the first growing season but did not affect the release of N and P. Decomposition and N release rates were higher for leaves than for roots and stems. Overall, this study highlights the independent effects of cropland management on the fate of crop residue returned to soil.

1. Introduction

Decomposition of plant litter releases nutrients (*e.g.*, nitrogen and phosphorus) for soil organisms and plant growth. In turn, nutrient status in the soil controls microbial activity, thereby influencing the decomposition and nutrient release from plant residues (Craine et al., 2007). In agroecosystems, the return of crop residues to cropland is an inexpensive agricultural management practice but vital for sustainable agriculture (Liu et al., 2014). Crop residues are not only a critical source of soil organic matter formation (Kumar and Goh, 1999), but also provide mineral nutrients supporting crop growth. The rate of crop residue decomposition is linked with soil nutrient supply and carbon (C) sequestration, and can influence many follow-up agricultural operations, *e.g.*, tillage, sowing, and pest management (Li et al., 2018). Accordingly, it is vital to understand the pattern of decomposition and nutrient release after crop residue returning to the field.

As one of the most ubiquitous agricultural management practices, mineral nitrogen (N) fertilization dramatically changes the status of soil nutrients for microbial demand (Xiao et al., 2018), thereby affecting the decomposition of crop residues. N fertilization would retard the decomposition and N release from crop residues, when soil N enrichment satisfies the microbial N demand and thereby decreases the need for microbes to decompose crop residue for obtaining N (Nottingham et al., 2015; Feng and Zhu, 2021). Furthermore, N fertilization can induce soil phosphorus (P) limitation, and most long-term N fertilization experiments show evidence of P limitation for plants or soil microorganisms (Harrington et al., 2001; Shen et al., 2004; Pinsonneault et al., 2016; Ding et al., 2019). If the P deficiency limits the growth of microorganisms (Hobbie and Vitousek, 2000; Cui et al., 2018), this would further inhibit crop residue decomposition. The rate of N release would

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Abbreviations: PFM, plastic film mulching; C, carbon; N, nitrogen; N_0, The plots without N fertilization; N_{135}, The plots applied with 135 kg N $ha^{-1}yr^{-1}$; N_{270}, The plots applied with 270 kg N $ha^{-1}yr^{-1}$.

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keep pace with the decomposition, as C and N are stabilized together and mineralized through biological mineralization (McGill and Cole, 1981). Whereas, organic P is stabilized independently of the main organic moiety and is mineralized through biochemical mineralization, which is independent with the process of decomposition and N release (McGill and Cole, 1981). Accordingly, P release from crop residue could be less affected by N fertilization than N release.

Plastic film mulching (PFM) is an agricultural practice that protects crops from low temperature, drought, and weeds (Kasirajan and Ngouajio, 2012). Reports have indicated that PFM can enhance crop residue decomposition due to its soil warming effect (Jin et al., 2018; Wang et al., 2019). However, it is unclear whether the effects of PFM on crop residue decomposition interact with N fertilization, *i.e.,* whether N fertilization effects depend on PFM, or vice versa. Our previous study observed that N fertilization increased root biomass and soil organic C and total N only with PFM, as PFM retains more of the N fertilizer within soil under the plastic mulch (Ding et al., 2022). As soil N status determines microbial N demand and the need for microbes to decompose crop residue for obtaining N, the different responses of soil N to N fertilization with and without PFM would likely lead to similar different responses of decomposition of crop residue.

Moreover, it is unclear whether the effects of N fertilization on crop residue decomposition interact with residue type. Crop residues include roots, stems, and leaves, and it is well known that these components have different decomposition rates (Abiven et al., 2005; Xu et al., 2019; Berenstecher et al., 2021). In general, leaves decompose readily due to their relatively high cellulose and low lignin content (Abiven et al., 2005). In contrast, stems and roots have larger amounts of lignin and decay less readily than leaves (Abiven et al., 2005; Freschet et al., 2013). Previous studies that the decomposition of low and high lignin plant tissues have contrasting response to external N addition (Carreiro et al., 2000; Sinsabaugh et al., 2002; Knorr et al., 2005). Accordingly, the decomposition of leaves may have different responses to N fertilization with stems and roots residues.

In this study, we conducted a two-year field study on the decomposition of maize residue (roots, stems, leaves) using the litterbag method in a long-term N fertilization and PFM experiment. The aim was to determine the main and interactive effects among PFM, N fertilization, residue type on the decomposition and nutrient release from crop residues. We tested the following three hypotheses: (i) N fertilization would retard litter decomposition and N release from crop residues, but would have less effect on P release; (ii) the effect of N fertilization on decomposition would vary with and without PFM; (iii) the effect of N fertilization on decomposition would interact with the type of crop residues, where maize leaves decomposition would have different responses to N fertilization with stems and roots residues.

2. Materials and methods

2.1. Study site and experimental design

The study was conducted in a long-term PFM and fertilizer field experiment initiated in 1987 in Shenyang, Liaoning Province, China (41°49′N, 123°34′E). Mean monthly precipitation and mean monthly temperature of the study site in 2015 and 2016 were shown in Fig. S1. The crop is monoculture maize with traditional ridge-tillage and a growing season from May to October. The soil is classified as a Hapli-Udic Alfisol (Soil Survey Staff, 1999). The top soil (0–20 cm) is classified as silt loam, with 16.7% sand, 58.4% silt and 24.9% clay. At the start of the long-term experiment, the top soil had a pH of 6.4, and the organic matter content was 9.05 g kg^{-1} with 1.00 g kg^{-1} total N, and 0.50 g kg^{-1} total phosphorus (Wang et al., 2006).

The experiment was a split-plot design with or without PFM as main plots with three replicates in a randomized arrangement. Within each main plot, there were three levels of N fertilization as subplots. N fertilization treatments consisted of (i) no input (N_0); (ii) input of 135 kg N ha^{-1} yr^{-1} (N_{135}); (iii) input of 270 kg N ha^{-1} yr^{-1} (N_{270}). The N fertilizer was urea. There were in total 12 plots and the area of each plot was 69 m^2. No phosphorus, potassium or other nutrients were provided, and no irrigation was applied to the plots. In the fall of every year, maize was harvested and the aboveground biomass was removed from the field. A detailed description of the field experiment is provided in our previous study (Ding et al., 2019).

2.2. Litterbag experiment and measurements

The decomposition of crop residues was measured using the litterbag method (Olofsson and Oksanen, 2002). Crop residues were collected from the site with regular fertilization (135 kg N ha^{-1} yr^{-1} and 29.5 kg P kg ha^{-1} yr^{-1}) but without PFM in the fall of 2014. Five whole plants were dug out, divided into roots, stems, and leaves, and then oven-dried at 60 °C. We acknowledge that N fertilizer and PFM treatments can affect litter quality, and thereby litter decomposition and nutrient release, but here we used the same litter types for all treatments to isolate effects caused by treatment-induced changes in environmental and soil conditions. Each type was cut into 3 cm-long pieces to simulate the straw crushing. Although the traditional practice in this region is to remove plant residues (*e.g.*, for winter heating), there is an increasing awareness by farmers in the region to improve soils by returning plant residues to the field. Ten grams of each type of crop residues were placed in a polyamide litterbag. The litterbag was 12 cm long × 12 cm wide, with mesh sizes of 3 mm on the top (permitting entry of micro-, meso- and macro-fauna) and of 100 μm on the bottom (avoiding leaching of small crop residue).

After fertilization and seeding in May 2015, four litterbags were buried in the 0–5 cm soil layer at each plot for each type of crop residue. Then, the plastic film mulching plots were covered by a layer of new polyethylene film (colorless and transparent) (Ding et al., 2019). In October (after 140 days), all litterbags were collected and brought back to the laboratory. For each plot, two of the four litterbags were randomly chosen for each type of crop residue. Material inside the bags was carefully cleaned with deionized water. Crop residue was oven-dried at 60 °C to constant weight to measure the mass loss of the crop residue, then stored until the measurements of C, N, P, cellulose, and lignin concentrations. The remaining two litterbags were air-dried and stored in the laboratory during the winter. In 2016, they were placed back to the previous plots in spring and collected back in fall for the second growing season. We removed litterbags from the field during the winter because rotary tillage and ridging occurred during this period, which would damage the litterbags. We therefore did not assess litter decomposition during the winter period, but which would likely to be relatively small.

All crop residue samples were pulverized by a ball mill and then measured for C, N, P, cellulose, and lignin concentrations. C and N concentrations were measured by dry combustion using a Vario EL III Elementar Analyzer (Germany). P concentration was measured by using the vanadate-molybdate-yellow colorimetric method after digestion with concentrated H_2SO_4-H_2O_2 (Lu, 2000). Litter cellulose and lignin concentrations were determined gravimetrically using the acid-detergent fiber digestion method (Gessner, 2005) with a fiber analyzer (SLQ-6A, China). We note that some microbial byproducts could be included in the lignin fraction (Baker and Allison, 2015). The properties of the initial crop residues are shown in Table 1.

Soil samples at 0–5 cm depth were collected using an auger (4 cm diameter) after maize harvest in October 2015. Three cores were randomly sampled and composited to one soil sample at each plot. The soil samples were passed through a 2-mm sieve to remove identifiable plant debris and gravel. Soil available N was determined with the alkaline hydrolysis diffusion method (Lu, 2000). Soil available P was determined with a 0.5 mol L^{-1} $NaHCO_3$ extraction and colorimetry based on the molybdenum blue reaction (Lu, 2000).

Table 1
Properties of initial crop residues.

Crop residues	C (g kg^{-1})	N (g kg^{-1})	P (g kg^{-1})	Cellulose (g kg^{-1})	Lignin (g kg^{-1})	C/N	C/P	Lignin/N
Roots	404	8.2	1.4	260	163	49	289	20
Stems	436	3.9	3.2	311	130	112	136	33
Leaves	407	8.2	1.9	357	29	50	214	4

2.3. Calculations and statistical analyses

The loss rates of crop residue mass, C, N, P, cellulose, and lignin after one and two growing seasons were calculated as (Zhang et al., 2020):

$$R_{\text{loss}} = (M_0 - M_i) / M_0 \times 100\% \quad (1)$$

$$E_{\text{loss}} = (e_0 M_0 - e_i M_i) / e_0 M_0 \times 100\% \quad (2)$$

Where R_{loss} is the loss rate (%) of crop residue mass, M_0 is initial mass of the crop residue (g), M_i is the remaining mass of the crop residue after one or two growing seasons (g), E_{loss} is the loss rate (%) of a certain element or compound (C, N, P, cellulose, or lignin), and e_0 and e_i are the concentration (%) of a given element or compound in the crop residue at initial stage and over one or two growing seasons, respectively. The N and P release rates were assumed to be equal to their loss rates from crop residues (Wei et al., 2020).

Two-way analysis of variance (ANOVA) was performed for the effects of N fertilization and PFM on soil parameters (*i.e.*, available nutrients). Three-way ANOVA was performed for the effects of N fertilization, PFM, and residue type on decomposition or nutrient releases from crop residues. Regression analyses were conducted to analyze the relationships between soil parameters and mass loss of crop residue. All statistical analyses were performed with the SPSS 17.0 package (SPSS, Chicago, IL).

3. Results

3.1. Soil available nitrogen and phosphorus

N fertilization significantly altered available N and P concentrations in soil (Fig. 1a, b). Soil available N concentrations increased following N fertilization, particularly at the highest level (N_{270}). Soil available P concentration was lower in N_{135} treatment compared to N_0 and N_{270} treatments ($p = 0.007$). PFM increased available N and P concentrations across the N fertilization treatment ($p < 0.01$), but where PFM particularly increased available N at high N fertilization levels (N * PFM interaction, $p < 0.001$).

3.2. Mass, cellulose, lignin losses during residue decomposition

In general, the average mass loss of crop residue across all treatments was 47% and 70% after one and two growing seasons, respectively (Fig. 2a, d, g). Notably, the mass loss did not change monotonously with the rate of N fertilization. Across the PFM and residue type treatments, low N fertilization (N_{135}) reduced mass loss compared to no fertilization (N_0), but high fertilization (N_{270}) had no difference with N_0, both after one and two growing seasons ($p = 0.001$, Fig. 2a, d, g). Across the N fertilization and residue type treatments, PFM accelerated mass loss by 10% as compared to no mulch after one growing season ($p = 0.021$, Table 2), but did not change it after two seasons ($p = 0.076$, Table 2, Fig. 2a, d, g). On average, the mass loss varied with the type of crop residue, with leaves having the highest mass loss (58% and 77%), followed by stems (44% and 68%) and roots (39% and 64% after one and two growing seasons, respectively) (Fig. 2a, d, g). We found no significant treatment interactions on mass loss, both after one and two growing seasons (Fig. 2a, d, g).

Cellulose losses (average values of 59% and 76%, after one and two growing seasons, respectively) were faster than lignin losses (−13% and 4%, respectively) for all three crop residues. Leaves had higher loss of cellulose and lower loss (or greater increase in some treatments) of lignin than stems and roots, both after one and two growing seasons (all $p < 0.001$, Table 2). The leaves were no longer recognizable after decomposition during the first growing season in 2015 (Fig. S2). We only observed a few significant interactive effects between PFM, N fertilization or residue type on cellulose and lignin loss after one growing season, but that disappeared after two growing seasons.

3.3. Carbon loss, nitrogen and phosphorus release during residue decomposition

Expressed as a percentage of the initial content in crop residue, the average P release of all treatments was highest (60% and 81%), followed by C loss (52% and 68%) and N release (17% and 26% after one and two growing seasons, respectively, Fig. 3). Although PFM accelerated mass loss (Fig. 2a, d, g), it did not change the loss (or release) rates of C, N, and P (Fig. 3). However, N fertilization affected C loss and N release after one and two seasons, but did not affect P release ($p > 0.05$, Table 3).

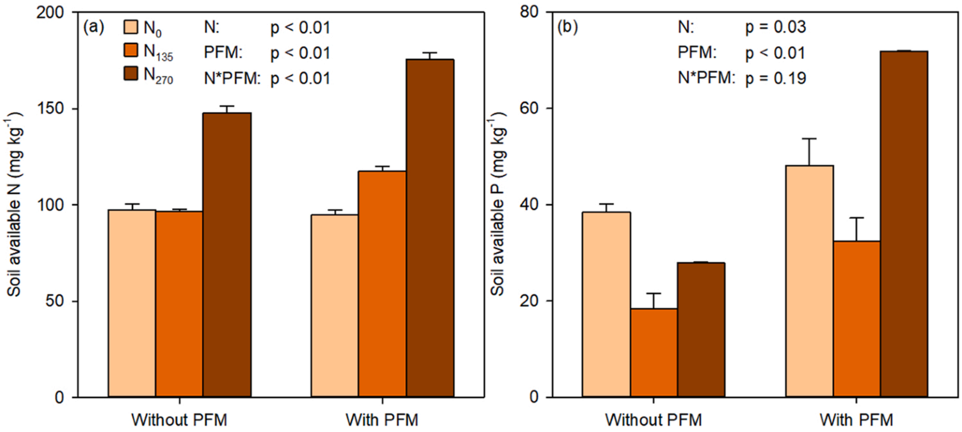

Fig. 1. Soil available nitrogen (N) and phosphorus (P) contents (a, b) in the different plastic film mulching (PFM) and N fertilization treatments. Bars represent mean ± standard error ($n = 3$). The p values behind 'N', 'PFM' and 'N * PFM' show the ANOVA results for main effects of N fertilization and mulching and their interaction.

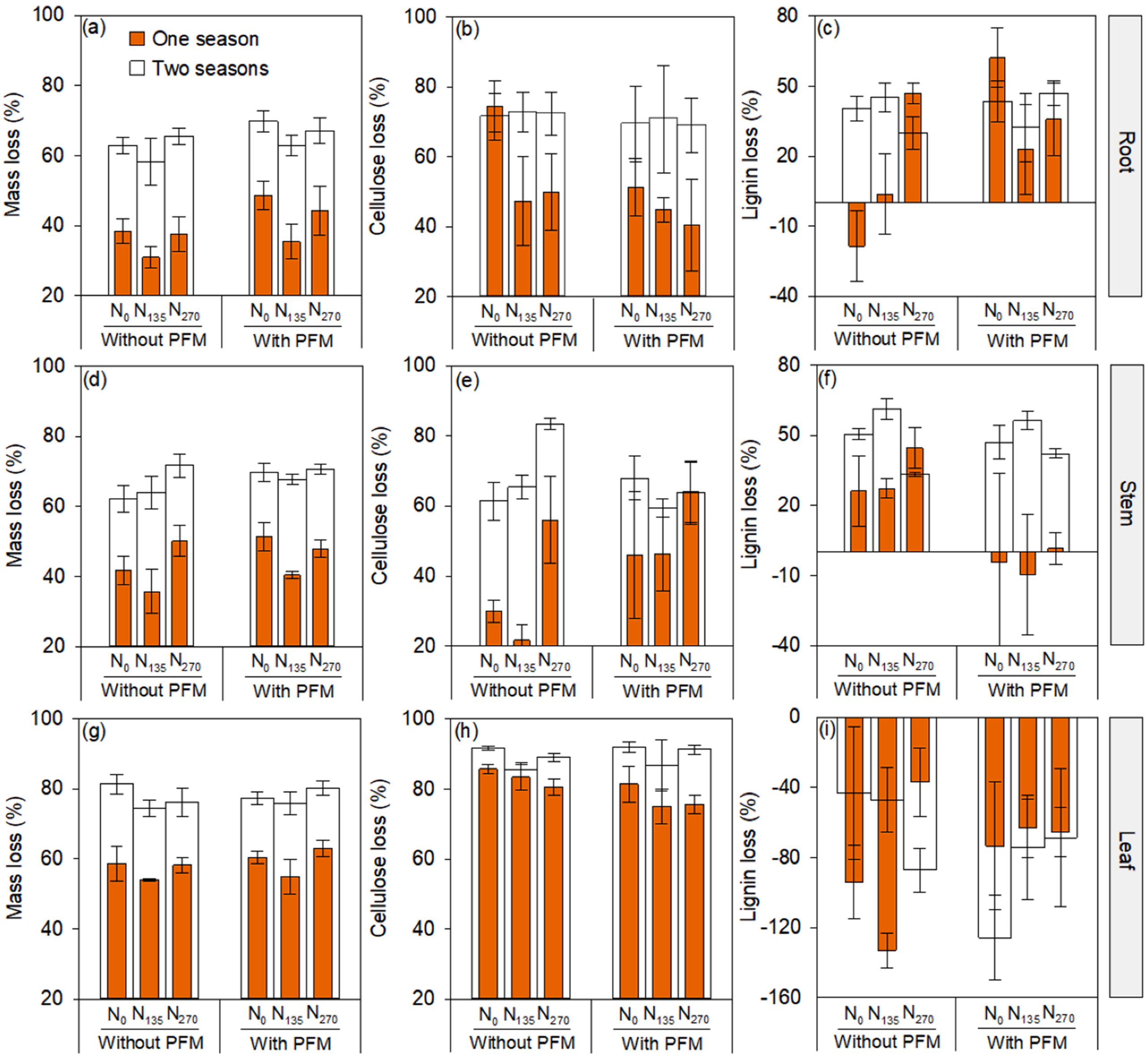

Fig. 2. Effects of plastic film mulching, nitrogen fertilization, and residue type on maize residue mass, cellulose and lignin losses (relative to initial mass) on roots (a, b, c), stems (d, e, f), and leaves (g, h, i) after one and two growing seasons, respectively. Bars represent mean ± standard error ($n = 3$). PFM: plastic film mulching. N_0, N_{135}, N_{270} denoted zero, 135, and 270 kg N ha^{-1} yr^{-1} application, respectively. Significant tests by three-way ANOVA can be seen in Table 2.

Table 2
The *p* values of three-way ANOVA of plastic film mulching, nitrogen fertilization, and residue type on maize residue mass, cellulose and lignin losses.

Treatments	Mass loss		Cellulose loss		Lignin loss	
	1 season	2 seasons	1 season	2 seasons	1 season	2 seasons
PFM	0.021	0.076	0.918	0.417	0.620	0.281
N	0.001	0.045	0.186	0.476	0.029	0.423
R	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
PFM × N	0.623	0.839	0.669	0.542	0.053	0.128
PFM × R	0.604	0.571	0.021	0.599	0.009	0.221
N × R	0.801	0.609	0.028	0.634	0.822	0.806
PFM × N × R	0.749	0.449	0.805	0.594	0.203	0.361

PFM: plastic film mulching; N: nitrogen fertilization: R: residue type.

Consistent with the trend found for crop residue mass loss, C loss was lower for the N_{135} treatment than for the N_0 and N_{270} treatments after one growing season ($p = 0.023$, Table 3), but no significant difference was observed after two growing seasons ($p = 0.153$, Table 3). Notably, crop residue N release did not follow the trends of mass and C loss across the N treatments. N release was greater for the N_0 treatment than for the N_{135} and N_{270} treatments both after one ($p = 0.108$, Table 3) and two growing seasons ($p = 0.002$, Table 3), and was similar between N_{135} and N_{270} plots. Following the trend of crop residue mass loss, C loss and N release were greater for leaves than for roots and stems (both $p < 0.001$,

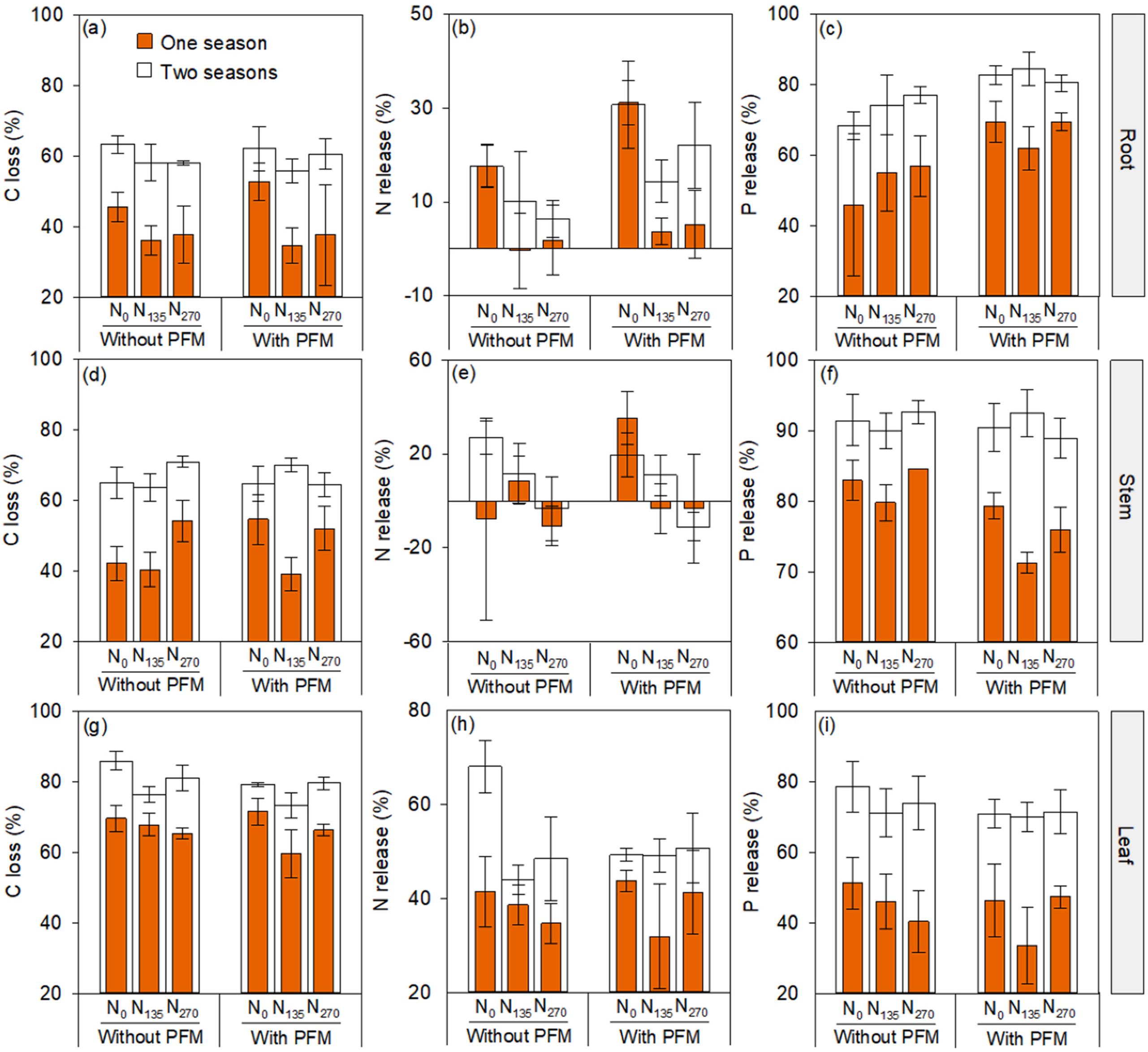

Fig. 3. Effects of plastic film mulching and nitrogen fertilization on carbon (C) loss, and nitrogen (N) and phosphorus (P) release (relative to initial C, N and P content) on roots (a, b, c), stems (d, e, f), and leaves (g, h, i) after one and two growing seasons, respectively. Bars represent mean ± standard error ($n = 3$). PFM: plastic film mulching. N_0, N_{135}, N_{270} denoted zero, 135, and 270 kg N ha^{-1} yr^{-1} application, respectively. Significant tests by three-way ANOVA can be seen in Table 3.

Table 3
The *p* values of three-way ANOVA of plastic film mulching, nitrogen fertilization, and residue type on maize residue carbon (C) loss, and nitrogen (N) and phosphorus (P) release.

Treatments	C loss		N release		P release	
	1 season	2 seasons	1 season	2 seasons	1 season	2 seasons
PFM	0.709	0.408	0.288	0.861	0.754	0.281
N	0.023	0.153	0.108	0.002	0.564	0.423
R	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
PFM × N	0.282	0.738	0.302	0.638	0.565	0.128
PFM × R	0.762	0.597	0.742	0.150	0.090	0.221
N × R	0.355	0.335	0.836	0.199	0.904	0.806
PFM × N × R	0.941	0.437	0.699	0.616	0.860	0.361

PFM: plastic film mulching; N: nitrogen fertilization; R: residue type.

Table 3). In contrast, P release was the fastest for stems and the slowest for leaves ($p < 0.001$, Table 3). Interestingly, we did not observe any significant treatment interactions on C loss and N and P release after both one and two growing seasons.

3.4. *The relationship between decomposition and nutrients release and soil available nitrogen and phosphorus*

The rates of mass loss for all three residue types were positively correlated with soil available P (Fig. 4b, f, j). Except for a quadratic relationship between stem N release and soil available P ($p < 0.05$), the rates of N release were negatively correlated with soil available N (Fig. 4c, k), but only the relationship for roots was significant ($p < 0.01$) (Fig. 4c). In addition, there were no correlation between soil available N and mass loss, soil available P and P releases (Fig. 4a, e, i, d, h, l).

4. Discussion

We did not observe any interactive effects among N fertilization, plastic film mulching, and residue type on the decomposition and nutrient release (all $p > 0.05$, Tables 2 and 3), indicating that the three factors independently affected the dynamics of crop residues. Supporting our first hypothesis, N fertilization retarded N release from crop residues, but had less effect on P release (Fig. 3 and Table 3). However, the retardation of decomposition by N fertilization only occurred in N_{135} plots but not in N_{270} plots (Fig. 2 and Table 2), partly supporting the first hypothesis. The second hypothesis was not supported, as the effect of N fertilization on crop residue decomposition was similar with and without PFM (Fig. 2), and N fertilization and PFM did not have an interactive effect (all $p > 0.05$, Table 2). The third hypothesis that the decomposition of maize leaves and roots would have different responses to N fertilization was not supported by the data either (Fig. 2 and Table 2). In the following, we separately discuss the three factors affecting the decomposition and nutrient release from crop residues.

4.1. *Effect of N fertilization*

For all types of crop residues, the rate of decomposition was non-linearly related to N fertilization level: decomposition was lower for the N_{135} treatment compared to N_0 and N_{270} (Fig. 2). In other words, the retardation of decomposition by N fertilization only occurred in N_{135} plots but not in N_{270} plots. We speculated that N fertilization would satisfy microbial N demand and thereby decrease the need for microbes to decompose crop residue for obtaining N, also referred to as the “N mining mechanism” (Craine et al., 2007; Feng and Zhu, 2021). Moreover, long-term N fertilization reduced soil pH of the site (Ding et al., 2019), which could inhibit microbial growth and crop residue decomposition (Carreiro et al., 2000; Chen et al., 2018). However, these two mechanisms cannot explain why decomposition only decreased in N_{135} plots but not in N_{270} plots. Soil available P status likely regulated the effect of N fertilization on the decomposition in our study, as the decomposition of all the three types of residues positively correlated with soil available P (Fig. 4). There was less available P (Fig. 1), but generally larger activities of P degrading enzymes (Ding et al., 2022) in the N_{135} plot compared to N_0 and N_{270} plots, both indicating that microbial P limitation occurred in the N_{135} plots. Less available P in N_{135} than in N_{270} plots also corresponded to less P content in crop biomass (the sum of P amounts in stem, leaf, seed and root) in the N_{135} plots (Ding et al., 2019). Microbial P limitation suppresses microbial growth and metabolism (Cui et al., 2018, 2020), and this may have slowed down the decomposition rate in the N_{135} plots. Therefore, we conclude that soil available P plays a dominant role in the decomposition of residues after long-term N fertilization.

N and P releases from crop residues had different responses to N fertilization (Fig. 3). On the one hand, N fertilization decreased N release

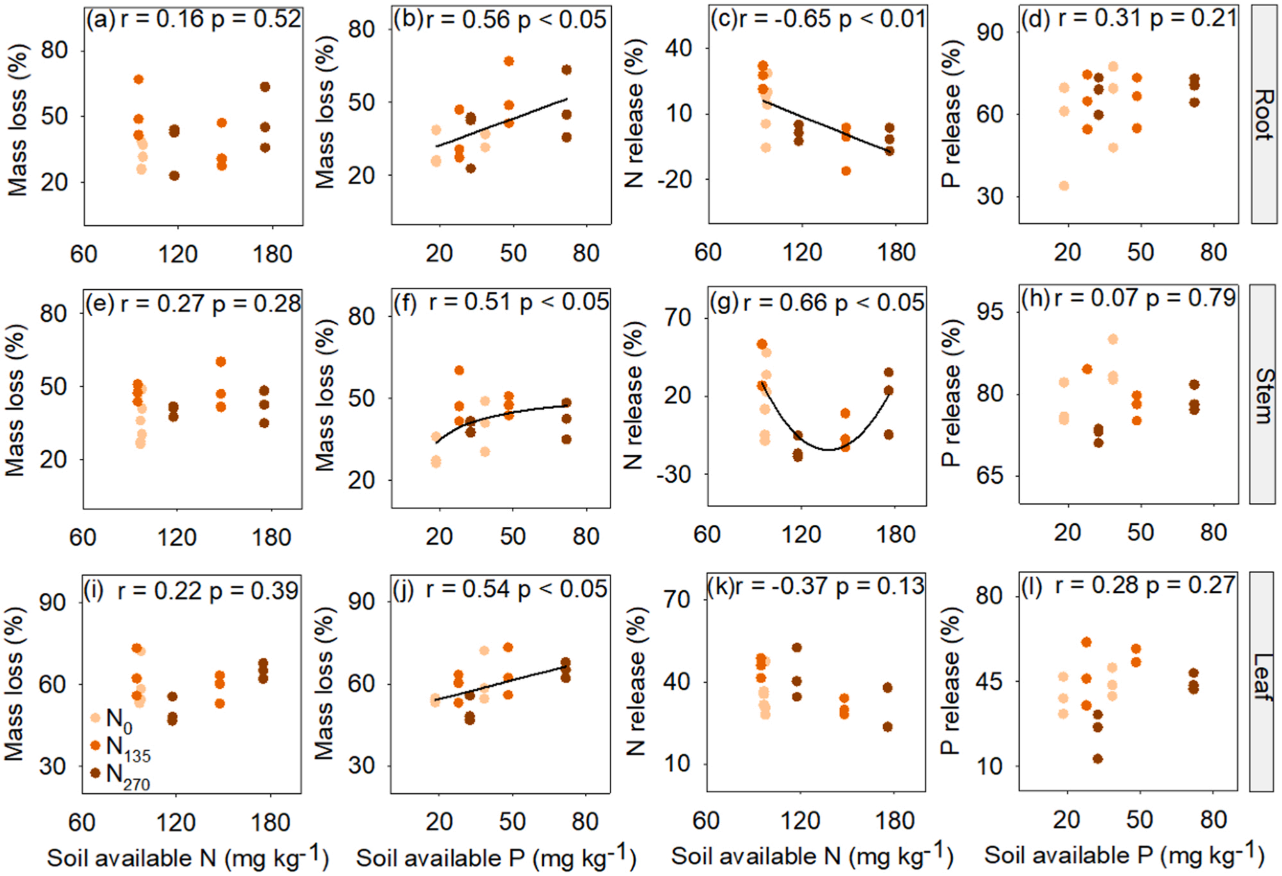

Fig. 4. Relations of mass and nutrient losses in roots (a, b, c, d), stems (e, f, g, h), and leaves (i, j, k, l) with soil available N and P concentrations. Because soil properties were measured in 2015 only, the mass and nutrient losses of crop residues were plotted after the first growing season only.

(Fig. 3), which was consistent with the findings from others (Aerts et al., 2006; Huang et al., 2017), supporting the "N mining hypothesis" (Craine et al., 2007). Increases in soil N availability led to a decrease in N release from all plant residues except for stems (Fig. 4). On the other hand, in support of our hypothesis, N fertilization did not affect P release from crop residues (Fig. 3), and there was no relationship between P release and soil available N (Fig. 4). This agrees with Craine et al. (2007), where no P mining was found under N addition, possibly because P release does not require microbial oxidation of organic matter but can mostly be released through hydrolysis mechanisms (McGill and Cole, 1981). Our results indicate that P release from crop residue does not keep pace with its rate of decomposition and N release.

4.2. *Effect of plastic film mulching*

We did not observe the interaction of N fertilization and PFM on crop residue decomposition ($p > 0.05$, Table 2), *i.e.*, the effects of N fertilization on residue decomposition were similar with and without PFM (Fig. 2). However, in the same experiment site, the responses of soil total N to fertilization varied with PFM, *i.e.*, it increased with PFM but it remained unchanged or was reduced without PFM (Ding et al., 2022). Similarly, soil available N was also affected by the interaction of N fertilization and PFM ($p < 0.01$, Fig. 1a). Moreover, mass loss did not correlate with soil abailable N for all the three types of crop residues (Fig. 4). These results further affirmed above discussion that a soil N mining mechanism can not explain the pattern of crop residue decomposition.

As expected, PFM accelerated the mass loss of crop residue after the first growing season (Fig. 2, $p = 0.021$, Table 2). PFM can markedly increase soil temperature and water content, and soil microbial biological activities (Donnelly et al., 1990; Liu et al., 2017; Wang et al., 2021), thereby enhancing residue decomposition (Li et al., 2004; Jin et al., 2018). In our experiment, soil temperature increased on average by about 3 °C with plastic film mulching (Ding et al., 2019). However, the effects of PFM on decomposition of crop residue after two growing seasons disappeared (Fig. 2, $p = 0.076$, Table 2). This is similar with the results reported by Xu et al. (2020) who found differences in residue C mineralization during initial degradation stages but no differences at the later stages among soils with different fertility. A possible reason is that decomposition of the remaining refractory substances in the later stage may be less susceptible to warming under PFM after labile compounds have been depleted. This was also evident from the lack of a PFM treatment effect on lignin loss after one and two growing seasons (Fig. 2, $p > 0.05$, Table 2).

Although PFM increased the mass loss of crop residue, PFM did not change the rate of nutrient release, especially for P ($p > 0.05$, Fig. 3, Table 3). This can be attributed to higher soil N and P availability in PFM plots compared to the plots without PFM (Fig. 1), which corresponded to the lower activities of N and P degrading enzymes in PFM plots (Ding et al., 2022). In PFM plots, the soil itself could readily satisfy microbial nutrient requirements, thereby minimizing the demand for microorganisms to assimilate N and P from crop residues. Higher soil available N and P in PFM plots can be explained by the following reason. PFM prevents precipitation from infiltrating into the soil and thereby minimizes leaching, and thus available N and P will remain in the topsoil (Liu et al., 2006).

4.3. *Effect of residue type*

There was a lack of significant interactive effects of residue type with N fertilization on mass loss of crop residues (Table 2), and the decomposition of maize leaves and roots had similar responses to N fertilization (Fig. 1). This seem to be contradictory with the results in previous studies that the decomposition of plant tissues in response to external N addition depends on their lignin contents (Carreiro et al., 2000; Knorr et al., 2005). The reason could be that the difference in lignin content between leaves and roots (Table 1) was not as large as that between the litter materials in their studies. Notably, the negative values for lignin loss in leaves (Fig. 2i), suggest there was an increase in lignin-like compounds following decomposition. This was also observed by Baker and Allison (2015), who explained that microbial byproducts can be classified as lignin-like compounds when analyzing litter chemistry (Berg and McClaugherty, 1987; Berg and Laskowski, 2005; Cotrufo et al., 2015). In our study, we observed some brownish black materials (seemingly microbial byproducts) on the surface of leaves after field placement (Fig. S2), but they were not seen on stems or roots.

As expected, the decomposition and N release from leaves were faster than those from roots and stems (Fig. 2 and Fig. 3, Table 2 and Table 3). The reason is that leaves had the lowest lignin/N ratio (Table 1), which is usually negatively associated with the rate of decomposition (Carreiro et al., 2000; Yanni et al., 2011). However, the rate of P release was the highest from stems but the lowest from leaves (Fig. 3, $p < 0.001$, Table 3), likely because of a higher initial P concentration and a lower C/P ratio in stems than in the other two types of residues (Table 1). These results are similar to results reported by Mooshammer et al. (2012), who showed that microbial P cycling was faster for litter with low C/P than that with high C/P ratio.

5. Conclusions

This study demonstrates that crop residue decomposition and nutrient release are independently affected by N fertilization, plastic film mulching, and residue type. Crop residue decomposition was retarded by low N fertilization (N_{135}), but was not affected by high N fertilization (N_{270}), compared to N_0. Both low and high N fertilizer rates slowed down N release from crop residues, but did not change P release, as compared to no fertilizer. Plastic film mulching promoted crop residue decomposition after one growing season, but did not affect the release of N and P. Decomposition and N nutrient release rates from leaves were faster than for roots and stems. Overall, this study provides important insights on the effects of N fertilization and plastic film mulching on decomposition and nutrient release of crop residues returned to the soil.

CRediT authorship contribution statement

Dechang Ji: Investigation, Formal analysis, Writing – original draft preparation. **Fan Ding**: Conceptualization, Methodology, Formal analysis, Visualization, Writing – review & editing. **Feike A. Dijkstra:** Writing – review & editing. **Zhaojie Jia**: Investigation. **Shuangyi Li:** Methodology. **Jingkuan Wang**: Supervision.

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. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.eja.2022.126535.

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