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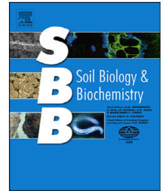

Nitrogen fertilization decreases the decomposition of soil organic matter and plant residues in planted soils

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A B S T R A C T

Nitrogen fertilization may affect the decomposition of soil organic matter (SOM) and plant residues in soil, but this effect is still very uncertain and depends on living plants. We investigated the effects of mineral N (N_{min}) availability on SOM and plant residue decomposition in wheat (*Triticum aestivum* L.) growing soils in a pot experiment. Five treatments were assessed: (1) Control [no maize (*Zea Mays* L.) residues and no N fertilization]; (2) ^{15}N-urea addition; (3) ^{15}N maize leaves; (4) ^{15}N maize leaves + urea; and (5) ^{15}N-urea + maize straw. The decomposition of SOM and plant residues was traced by the changes of N and C in the light fraction (density < 1.80 g cm^{-3}) during the 127 days. Urea fertilization decreased the decomposition of SOM and maize residues, as indicated by remaining N and C in the light fraction compared to soil without urea. The C decomposition was tightly coupled to that of N in the light fraction SOM. In soils with maize residues, both maize- and SOM-derived light fractions decomposed slowly with N fertilization. Soil microbial biomass N content was increased by maize residues but was unaffected by urea addition. Under low soil N_{min} levels, microbes met their N demand by increasing an acquisition from accelerated decomposition of organic sources. To mine N in the N_{min} limited soils, soil microbes might have directly taken up more N-containing organics and thus facilitated SOM decomposition. For such an acceleration of SOM decomposition, the presence of N uptake by living plants was especially important, which decreased the N_{min} in soil and so, increased N limitation for microorganisms. We concluded that N fertilization decreases SOM decomposition and increases the efficiency of C sequestration in soil through higher portion of un-decomposed crop residues.

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1. Introduction

Aboveground crop residues are byproducts of agriculture. One benefit of returning crop residues to soil is C sequestration and soil organic matter (SOM) formation. The higher C/N ratio of crop residues than the soil microbial biomass implies that mineral N (N_{min}) availability may affect the microbial decomposition of crop residues (Sinsabaugh et al., 2013; Cyle et al., 2016; Zang et al., 2016). N fertilization may impact the efficiency of C sequestration through crop residue incorporation. Numerous studies (Recous et al., 1995; Mary et al., 1996; Henriksen and Breland, 1999; Neff et al., 2002; Potthoff et al., 2005) have suggested that high N_{min} level stimulates the decomposition of plant residues and SOM. Some studies (Neff et al., 2002; Hobbie, 2005; Hobbie et al., 2012; Kaspari et al., 2008) have suggested that the effect of the N_{min} level on plant residues and SOM decomposition is variable, depending on N content in residues and soil, abundances of other nutrients, organic compound's composition, N leaching and microbial community structure. N fertilization reduces microbial biomass in many ecosystems (Treseder, 2008) and decreases soil CO_2 emissions (Treseder, 2008; Janssens et al., 2010; Spohn et al., 2016; Zang et al., 2016). The decrease in the N_{min} content changes the decomposer community and accelerates SOM mineralization, resulting in reduced SOM accumulation (Fontaine and Barot, 2005).

The effects of soil N_{min} on SOM and plant residue decomposition may be biased by the study approach. Current studies on the effects of N_{min} level on SOM and plant residue decomposition have two limitations: (1) the most of these studies have been conducted in short-term incubation experiments, with mineralization dynamics deduced from CO_2 efflux and N_{min} changes. In the short-term, the releases of CO_2 and N_{min} reflect the decomposition kinetics of readily labile compounds (Gunina and Kuzyakov, 2015; Cyle et al.,

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2016), and thus poorly represent the complex components, which dominate plant residues and SOM. (2) In all incubation studies, the decomposition proceeds in soils without plant growth. In terrestrial ecosystems, microbial decomposition and plant nutrient uptake take place simultaneously, with yielded N_{min} being removed continuously from decomposition sites.

The present paper quantified the effects of soil N_{min} availability on the decomposition of SOM and pant residues in the presence of root N uptake. We hypothesized that N fertilization would decrease SOM and plant residue decomposition in soils with growing plants. Despite the fact that soil microbes preferentially use N_{min}, N_{min} deficiency leads to organic N uptake by microbes (Hobbie, 2005; Geisseler et al., 2009, 2010, 2012), which would facilitate N mineralization of SOM and plant residues. The increased N mineralization under low N_{min} would be linked with increasing organic C mineralization (Jonasson et al., 1999; Manzoni et al., 2010). We investigated the dynamics of various soil N pools, N uptake by wheat (*Triticum aestivum* L.) and traced the fate of N from applied plant residues and urea fertilizer by using ^{15}N as a tracer. The decomposition of SOM and plant residues was traced by the changes in light fraction N (LFN) and organic C (LFOC) during 127 days.

2. Materials and methods

2.1. Experimental design

The experiment was conducted from March to July 2016 in a large rainproof shelter at the Yuzhong Experimental Station (35°51′N, 104°7′S, altitude of 1620 m above sea level) of Lanzhou University. Soil was collected from the 0–20 cm depth in a cropland with wheat and soybean (Glycine max L. Merrill) growing for four years after conversion from native C3 grassland (no C4 species). The soil was developed from loess and had silt loam texture, with a pH value of 8.38 (water: soil = 2.5). Total SOC content was 7.43 g kg^{-1}, total N 0.64 g kg^{-1}, total P 0.70 g kg^{-1}. The C/N ratio of SOM was 11.6. Soil N_{min} and Olsen P were 12 and 6 mg kg^{-1}, respectively.

The pot experiment had five treatments: (1) Control (no plant residues and no N fertilization); (2) ^{15}N-urea (amended with ^{15}N labeled urea at 129 mg N kg^{-1} soil); (3) ^{15}N-leaves [amended with ^{15}N labeled maize (*Zea Mays* L.) leaves at 115 mg N kg^{-1} soil]; (4) ^{15}N-leaves plus urea (amended with ^{15}N labeled maize leaves at 115 mg N plus urea at 129 mg N kg^{-1} soil); and (5) ^{15}N-urea plus straw (amended with ^{15}N labeled urea at 129 mg N plus maize straw at 108 mg N kg^{-1} soil). In the fifth treatment (^{15}N-urea plus straw), we used the maize straw (mixture of maize leaves and stems) instead of maize leaves, because it corresponds more to the agriculture practice. The ^{15}N labeled maize leaves and (non-labeled) straw were collected at maturity, respectively from two field experiments conducted in 2015 at a high-altitude site (2013 m a. s. l.). In that ^{15}N labeling experiment, the maize was fertilized at sowing with ^{15}N labeled urea (^{15}N abundance: 10.15%). The ^{15}N labeled maize leaves contained 1.40% N (^{15}N abundance: 1.97%) and 45.2% C, with a C/N ratio of 32.4. The (non-labeled) maize straw had N content of 1.10% and C 43.0%, with a C/N ratio of 39.1. Maize residue materials were pulverized into powders (<1 mm). The urea application rate in this pot experiment was equivalent to 290 kg N ha^{-1}, maize leaf and straw application rates were equivalent to 19 and 22 t plant residues ha^{-1}, respectively.

Air-dried soil (equivalent to 6.72 kg oven-dry weight, sieved through 5 mm) was mixed with maize residue and/or fine urea powders (for Control, without residues or no N fertilizers) and then put in a plastic pot (height 22.5 cm; volume 6.8 L), resulting in a bulk density value of about 1.2 g cm^{-3}. In order to avoid the potential phosphorus deficiency for wheat growth, KH_2PO_4 (monopotassium phosphate) was added at 20 mg P kg^{-1} soil to all treatments (including control). Each treatment had five replicated pots (5 treatments × 5 replicates = 25 pots in total). After setup, all pots were watered. Twenty days later, 10 wheat (cultivar: Dingxi 24) seeds were sown in each pot. At the two-leaf stage, the crops were thinned to five seedlings per pot. Throughout the pot experiment, from setup to the time of wheat maturity, soil moisture was maintained at 70% of field capacity, with supplementation of distilled water every 1–3 days according to the water loss estimated by weighing. At day 63 after sowing (booting stage), a 1-cm layer of polythene polyfoam balls (3–4 mm in diameter) was placed on the soil surface and kept until the wheat's harvest time, to reduce soil water evaporation. Twenty-five pots were randomly placed in an area of 4 m^2 in the rainproof shelter. During the experiment, the air temperature measured daily at 09:00 varied from 10 °C to 36 °C.

2.2. Soil sampling

Five pots of each treatment were randomly divided into two groups: sampling group (three pots) and supplemental group (two pots). At days 32 (seedling stage), 63 (booting) and 107 (maturity) after sowing, soil samples were taken using an auger (inner diameter: 20 mm) from three pots of each sampling group, for measuring soil N_{min}, microbial biomass N (MBN) and LFN content, and ^{15}N abundances in all these pools. In each sampling pot, four sub-samples (from four points) were mixed to form a composite sample. After each sampling at days 32 and 63, the holes in the three sampling pots, formed due to the soil sampling, were filled with soils taken from two supplemental pots of the same treatment using the same auger. Plugging those holes with the substitute soils from the supplemental group reduced potential influence of disturbance of soil sampling on microbial activity and wheat growth.

For measuring the initial LFN and LFOC contents at the beginning of the experiment (at 20 days before wheat sowing), samples were taken from treated soils prior to being put into plastic pots. Each 100-g air-dried sample from those relative to the sampling group was placed in a beaker and incubated for 24 h under room temperature, after being moistened to 70% of field capacity. All incubated soils were then air-dried and prepared for analyses.

2.3. Soil analyses

Total N_{min} and MBN were determined from fresh soil samples. N_{min} was extracted using 0.5 M K_2SO_4 and total N_{min} in the extracts was distilled using Kjeldahl apparatus, in the presence of MgO (magnesium oxide) and Devarda alloy (Keeney and Nelson, 1982). Ammonium N in the distillate was titrated using H_2SO_4 solution. After titration, the distillate was condensed under acidic conditions in a water bath to 2–3 ml, to analyse ^{15}N isotope ratio via a gas isotope mass spectrometer (MAT-271, Thermo Fisher, America). The soil N_{min} derived from ^{15}N labeled sources (^{15}N-N_{min}) was calculated as:

$$^{15}N - N_{min} = \text{total } N_{min} \times (^{15}N\%_{treatment} - {}^{15}N\%_{control}) / \times (^{15}N\%_{source} - {}^{15}N\%_{control})$$

where $^{15}N\%_{treatment}$ and $^{15}N\%_{control}$ were ^{15}N abundances of total N_{min} in the ^{15}N source-added treatment and (non-added) control, respectively; $^{15}N\%_{source}$ was ^{15}N abundance in the ^{15}N source. The soil N_{min} derived from non-labeled sources was the difference between total N_{min} and ^{15}N-N_{min}.

Total soil MBN was extracted via the chloroform

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