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Carbon and nitrogen mineralization patterns of two contrasting crop residues in a Mollisol: Effects of residue type and placement in soils

Lu-Jun Li*, Xiao-Zeng Han*, Meng-Yang You, Ya-Ru Yuan, Xue-Li Ding, Yun-Fa Qiao

Key Laboratory of Mollisols Agroecology, Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, 138 Haping Rd, Harbin 150081, China

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ABSTRACT

Predicting carbon (C) mineralization of crop residues returned to soils is important for forecasting carbon dioxide (CO_2) emissions into the atmosphere and soil nitrogen (N) availability. In this study, a laboratory incubation experiment was conducted to investigate C mineralization of residues of soybean (*Glycine max*), maize (*Zea mays*), and their mixture placed on the soil surface and incorporated into the soils in a Mollisol in northeast China. Both the residue type and placement significantly affected C and N mineralization, while no significant interactions between them were observed on cumulative C mineralization. The soybean residue had a higher decomposition rate than the maize residue regardless of their placements; decomposition rates for both soybean and maize residues placed on the soil surface were higher than those of the same residues incorporated into the soils. Moreover, non-additive effects on the contribution of each residue type to C mineralization of the residue mixture were not observed. Our results suggest that crop residue with a low N concentration and a high C/N ratio (such as maize) can be incorporated into soils to immobilize N and decrease CO_2 emissions in comparison with crop residue placed on the soil surface.

1. Introduction

Crop residues returned to croplands can sustain soil organic carbon (SOC) content and improve soil fertility and biological activity [1]. Carbon mineralization of crop residues is an important process because it regulates carbon dioxide (CO_2) emissions into the atmosphere and releases nutrient elements essential to crop growth [2,3]. It is therefore important to predict the C mineralization of residues returned to soils and the associated nitrogen (N) mineralization.

Mollisols, characterized by high SOC and nutrient contents, have a vast C pool in northeast China. Long-term cultivation and increased surface erosion have induced remarkable decreases in topsoil organic C of croplands in the Mollisols of northeast China [4]. To maintain SOC and supply nutrients essential to crop growth, returning crop residues to soils has been gradually accepted by local farmers. To break the plow pan resulted from unreasonable tillage in the fine-textured Mollisols, people usually choose to incorporate crop residues into soils but not cover on the soil surface. The initial location of crop residues placed in soils (e.g., the soil surface vs. incorporation into the soils) appears to influence C and N mineralization processes by modifying soil physical, biological and chemical properties [5]. However, the effects of residue location on C mineralization appear unclear and are sometimes contradictory. For example, Abiven and Recous [6] found no significant effect of residue placement on C mineralization. However, many other studies have shown that crop residues incorporated into the soil decompose faster than those placed on the soil surface [5,7]. The differences in residue type and soil nutrient availability may have resulted in the discrepancies among trials [5,8]. To our knowledge, however, there is no information about the effects of residue placement on C mineralization in the Mollisols in northeast China, although the effects may differ from those in other soil types [9,10] due to the high SOC and nutrient contents.

The mineralization of crop residues returned to soils is controlled by numerous factors [5,11], of which residue type has long been recognized as an important factor [12,13]. Residues with a high N concentration and low C/N and lignin/N ratios often show high C mineralization rates [2]. Soybean (*Glycine max*) and maize (*Zea mays*) are widely distributed crops in northeast China, and intercropping of legumes and cereal crops is commonly practiced in this region. When crops are grown in association, the residues of different crops usually become mixed and decompose simultaneously within the same soil volume [14]. Carbon mineralization of mixed residues with contrasting residues can be more complex than

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* Corresponding authors. Tel.: +86 451 8660 2940; fax: +86 451 8660 3736.
E-mail addresses: lilujun@neigaehrb.ac.cn (L.-J. Li), xzhan@neigaehrb.ac.cn (X.-Z. Han).

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that of single residue, and additive effects of residue mixtures on C mineralization may occur when contrasting residues are mixed [15,16]. Moreover, studies on the interactive effects of residue type and placement on C mineralization remain limited [6,10].

Therefore, we performed a laboratory incubation experiment to investigate C mineralization patterns of the two residues and their mixture placed on the soil surface and incorporated into the soils in the Mollisols. We measured CO_2–C emissions during the incubation to assess C mineralization. The specific objectives were to investigate the effects of residue placement and type on C mineralization and to examine whether non-additive (positive or negative) effects on C mineralization between the two crop residues exist in the decomposition process of mixed crop residues. The study may have implications on the choice of residue type and placement in soils when people return crop residues to soils in practice. Due to the limited contact between residues and soils, and the consequent decrease in soil N availability to residue decomposers on the soil surface as shown by Giacomini et al. [5], we hypothesized that residues incorporated into the soils would evolve more CO_2 than those placed on the soil surface. Additionally, we expected that C mineralization of mixed residues would be different from that predicted by single residues.

2. Materials and methods

2.1. Soils and crop residues

Soils and crop residues used for the incubations were collected from the National Observation Station of Hailun Agroecology System (47°26′N, 126°38′E, 240 m above sea level), Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences. The mean annual precipitation is 550 mm, with more than 80% occurring in May–September. The mean annual temperature is 1.5 °C, with the lowest mean monthly temperature occurring in January (−23 °C) and the highest in July (21 °C). The duration of the free-frost period is approximately 120 days. The soil, derived from loamy loess, is classified as a Mollisol (Typic Hapludoll). The field is on a flat plain and was a native prairie before the land was cleared for cropping more than 100 years ago.

Soils (0–15 cm) were sampled in early October 2010 after crop harvest. After the visible crop and residue debris were removed, the sampled soils were sieved (<2 mm) and divided into two subsamples. One subsample was used to conduct the incubation experiment. Another subsample was air-dried at room temperate and used for chemical analyses. A portion of the air-dried samples was used for soil pH measurement, whereas the other part was ground (<0.25 mm) prior to analyses of SOC, total N (TN), and total phosphorus (TP). The used soil contained 27.9 g kg^{-1} organic C, 1.95 g kg^{-1} TN, 0.74 g kg^{-1} TP, and 13.2 μg N g^{-1} inorganic N (NH_4^+–N + NO_3^-–N), and the pH was 5.9. The soil bulk density was ~1.0 g cm^{-3}.

Soybean and maize residues were collected during the harvest in early October 2010. Four replicate samples were collected per crop type. All of the crop residues were mixed together for each replicate and air-dried. A portion of the samples were oven-dried at 60 °C to determine the moisture content and were further ground (<0.25 mm) prior to determining the concentrations of organic C, TN and TP. Other samples were also ground (<0.25 mm) and stored in desiccators for the incubation experiment. The chemical compositions of the residue mixtures described below were calculated based on the mass ratios of the individual components.

2.2. Chemical analyses

Organic C and TN concentrations in the soils and crop residues were analyzed using an elemental analyzer (Vario EL III, Elementar, Germany). The TP concentration was determined using the molybdenum-blue method after digestion with concentrated $HClO_4$–H_2SO_4 [17]. Air-dried soil samples (<2 mm) were used to determine soil pH on a 1:2.5 (w/v) mixture of soil and water. The inorganic N (NH_4^+–N, NO_3^-–N) was extracted from fresh soils with a 2 M KCl solution (60 min of agitation at 20 °C, 1:5 soil/solution ratio) and analyzed colorimetrically with a continuous-flow autoanalyzer (San^{++} System, Skalar, The Netherlands).

2.3. Incubation experiment

Previous studies have shown that the results of short-term laboratory experiments agree well with those of field experiments [18], although the conditions in incubations are different from field conditions. The controlled incubation experiments provide meaningful information in relating the kinetics of C mineralization of residues with varying characteristics and locations in soils [19]; thus, C mineralization was determined by a laboratory incubation experiment in our study.

In the incubation experiment, seven treatments were included with four replicates: soybean surface-applied (T1); soybean incorporated into the soils (T2); maize surface-applied (T3); maize incorporated into the soils (T4); soybean + maize surface-applied (T5); soybean + maize incorporated into the soils (T6); and residue-unamended treatment (control, T7). Additionally, four containers without soils and plant residues were considered as blanks. The ratio of the residues in the mixed residue treatments was 50:50 by mass.

Carbon mineralization was measured under controlled conditions using a modified laboratory incubation method similar to that described by Angers and Recous [9]. Briefly, fresh soils were pre-incubated at 25 °C for 1 day to allow microbes to acclimatize to the laboratory incubation condition. One tenth of a gram of crop residue was incorporated homogeneously into the fresh soil (equivalent to 20 g oven-dried soil) or placed as a single layer on the soil surface. Soils with or without residues were placed in a conical flask (300 ml in volume, 12 cm in height) and incubated at a constant temperature (25 °C) and a constant soil moisture content (60% of water-holding capacity) for 56 days. A beaker (3 cm in diameter, 8 cm in height) containing 10 ml 1.0 M NaOH was connected to each flask to trap the evolved CO_2. The traps were changed periodically (1, 3, 7, 14, 28, 42 and 56 day) to renew the air in the flasks and prevent saturation of the NaOH solution. The CO_2 production was determined by back titration of the NaOH solution with 0.5 M HCl in an excess of $BaCl_2$, using phenolphthalein as an indicator. After the NaOH beaker was taken out, the air in the flasks was replenished by opening it for 2 h. The soil moisture was checked by weighing the flasks and was adjusted with distilled water when necessary. The rate of C mineralization was calculated as the difference between the amount of CO_2 produced from the samples containing residues and those without residues. The amount of CO_2 determined after 1, 3, 7, 14, 28, 42, and 56 days was added together to determine the cumulative C mineralization for the 56-day incubation period. The values of CO_2 evolved were divided by the mass of the soil samples (on an oven-dried weight soil basis) and were expressed as μg CO_2–C g^{-1} soil. It was assumed that soil C mineralization was not modified by the residue addition; that is, there was no priming effect, or the priming effect was of the same order of magnitude for different residues [20].

The potential net N mineralization was also measured by a laboratory incubation experiment, where the incubation condition was the same as for the CO_2 emission measurement. Four containers with soil but without plant residue were used as controls. The initial inorganic N concentration was analyzed before the incubation as described above. During the incubation, the soils