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Short communication

Soil respiration and litter decomposition responses to nitrogen fertilization rate in no-till corn systems

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ABSTRACT

Litter decomposition dynamics are influenced by soil nutrient status, yet the specific effects of soil nitrogen (N) on litter decomposition in agricultural systems are not well understood. We explored litter decomposition and related soil organic matter dynamics in no-till, corn-based Midwestern U.S. cropping systems receiving 0, 134, and 291 kg N ha^{-1} y^{-1}. We found that total soil carbon (C) and N, light fraction organic matter, and permanganate oxidizable C were similar among treatments, but N fertilization at rates of 134 and 291 kg N ha^{-1} y^{-1} reduced potentially mineralizable C by as much as 37% and 58%, respectively, compared to the unfertilized treatment. Litter mass remaining after one year of field decomposition was greater with wheat litter (37%) than with corn litter (23%), but was not influenced by N fertilizer rate. In litter, N fertilization led to increases in the activities of two hydrolase enzymes involved in simple carbohydrate metabolism (β-D-cellobiohydrolase and β-1,4-glucosidase) and periodic increases in one related to N metabolism (β-1,4-N-acetylglucosaminidase), but had no effects on enzymes regulating the breakdown of aromatic compounds (phenol oxidase), or on enzymes measured in the soil. N fertilization also decreased arthropod densities in decomposing litter. We found contrasting effects of N fertilizer on processes regulating decomposition, but altogether our results were consistent with a limited or nil role for N fertilization in accelerating litter and soil C turnover, and thus do not support N fertilization as a contributor to depletion of C stocks in agricultural soils.

1. Introduction

Litter decomposition regulates soil organic matter (SOM) dynamics and nutrient cycling, yet the influence of agricultural litter quality and N availability on litter remains contentious. For example, recent long-term field experiments (e.g. Khan et al., 2007; Mulvaney et al., 2009) and new insights into the priming effect highlight the uncertain relationships between fertilizer use, increased plant residue inputs and SOM accumulation (Conde et al., 2005; Cong et al., 2012). Indeed, Khan et al. (2007) found that inorganic N fertilizer use in the Morrow Plots in Illinois corresponded with both increases in plant productivity and declines in SOM. Other studies have shown that synthetic N application in agricultural systems can increase soil CO_2 emissions and soil C loss (Al-Kaisi et al., 2008), but results are mixed and reports show accumulation (Reay et al., 2008; Al-Kaisi et al., 2008; Poirier et al., 2009; Ladha et al., 2011), loss (Hofmann et al., 2009; Khan et al., 2007; Mulvaney et al., 2009) or no change in soil C (Halvorson et al., 2002; Liang et al., 2012).

One explanation for such inconsistency is that N fertilization may fundamentally alter litter decomposition dynamics at the same time that it increases litter C inputs. In forest and grassland ecosystems, studies have shown changes in soil communities, enzymatic activities, and litter decomposition rates following simulated N enrichment (Deforest et al., 2004; Knorr et al., 2005; Garland et al., 2012). N generally inhibits oxidase enzymes and litter lignin decomposition, while accelerating the activity of hydrolases and the degradation of plant litter-derived carbohydrates (Carreiro et al., 2000; Sinsabaugh et al., 2002; Frey et al., 2004; Hofmann et al., 2009; Tiemann and Billings, 2011). Thus, the specific effects of N fertilization in forests appear to depend on initial litter quality, but in agricultural systems the biological mechanisms underlying soil and litter C responses to N availability remain uncertain.

Given the widespread and expanding use of inorganic N fertilizer and the uncertainties surrounding its effects on litter

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decomposition and SOM dynamics, our objectives were to: (1) investigate the effects of initial litter quality and N fertilizer application rates on litter decomposition rates; (2) examine the relationships between litter decomposition dynamics and litter biological processes; and (3) determine whether soil C pools with short to intermediate turnover times respond to N fertilizer rate in corn-based grain systems in the Upper Midwest.

2. Materials and methods

2.1. Site description and design

Our research was carried out at the N Fertility Gradient Study established in 2005 at the Michigan State University W.K. Kellogg Biological Station (KBS) Long-Term Ecological Research (LTER) site. The mean annual precipitation at the KBS LTER site is ~890 mm and soils are classified as Kalamazoo (fine-loamy) and Oshtemo (coarse-loamy) mixed, mesic, Typic Hapludalfs (Alfisols) developed on glacial outwash.

The study consists of a no-till corn–soy–wheat rotation, with winter wheat produced in 2007, corn in 2008, and soybean in 2009. Experimental plots are 5 m × 30 m, replicated four times, and arranged in a randomized complete block design. Overhead irrigation at the site is used to maintain soil water content at or near optimum levels for crop production. During the course of our study, monthly measurements of gravimetric soil moisture content ranged from 12% to 16% between June and September and increased to 17% in October and November. On 07/28/2008, 2.2 cm of irrigation water was applied, but irrigation was not necessary at any other time.

There are nine different N levels used in the experiment, ranging during the wheat phase from 0 to 180 kg N ha^{-1} y^{-1}, and during the corn phase from 0 to 291 kg N ha^{-1} y^{-1}. We examined three of the nine N fertilization rate treatments, corresponding with 0, 134, and 291 kg N ha^{-1} y^{-1} in corn and 0, 90, and 180 kg N ha^{-1} y^{-1} in wheat. Given our experiment was initiated in 2008 during the corn phase of the rotation, hereafter we refer to the N treatments as 0 N, 134 N, and 291 N. Our rationale for using these rates of N fertilizer was to have experimental treatments with very different levels of soil N availability, representing: (1) N limitation, in which crop N demand exceeds soil N availability (0 N); (2) Best management practices, in which N application rates are based on crop N requirements (134 N); and (3) N excess, in which N availability exceeds crop demand through the season (291 N). Corn (Pioneer 36W66) was planted on May 16 2008 at a rate of 69,000 seeds ha^{-1}. Nitrogen fertilizer was applied during May and June of 2008. In May, N was injected subsurface at 34 kg N ha^{-1} in all plots except for the 0 kg N ha^{-1} treatment; in June, fertilizer was applied at 0, 100 or 257 kg N ha^{-1} as 28% urea-ammonium-N using subsurface, side-dress injection when corn was at a height of 10–25 cm.

2.2. Litterbags and soil sampling

Standing dead corn plants and wheat straw were collected in fall 2007 from nearby, non-experimental sites managed using Michigan State University Best Management Practices. Wheat and corn were selected because they represent litter types with different initial chemistries (e.g., C:N ratios of 111 ± 5.0 in wheat and 60.9 ± 4.9 in corn), but also because they represent the majority of litter C entering SOM pools of field cropping systems in the Northern Central U.S. Moreover, we used litter sourced from the same field, rather than using residues grown under different levels of N application, to isolate N effects on decomposition processes independent of potential changes in litter quality. Air dried corn leaves and stems or wheat straw were cut into 2–4 cm pieces and homogenized. Corn or wheat litter (7 g) were placed into 18 cm × 18 cm nylon mesh litter bags with a mesh size of 1.4 mm and secured to the soil surface on June 17, 2008. Each plot received six litter bags containing each type of litter (12 bags total per plot) in order to sample six times over the following 12 months. The placement of the litterbags on the soil surface mimics the deposition of aboveground residues in no-till systems, which typically accumulate as surface litter. In spring 2009, litterbags remained on the soil when 80 kg K ha^{-1} liquid fertilizer was broadcast over the plots on May 23 prior to soybean planting. Given the possible effects of soil-injected N on soil processes and their feedbacks to litter decomposition, we also made intensive measurements of soil responses to different fertilizer rates. At sampling, we collected 10 soil cores per plot to a depth of 10 cm and combined them into a single representative soil sample. Soil cores from each plot were sieved to 6 mm, mixed and stored at 4 °C until analyses. Soil and litter bags were collected for physical and biological analyses during the growing season in 2008 (July, August, and September) and early in 2009 (May and June) and transported to the lab on ice where they were sub-sampled. Soil samples used to determine inorganic N concentrations were collected monthly between June and November in 2008.

2.3. Litter and soil C and N dynamics

Litter decomposition rate was determined by mass loss on five dates between July 2008 and July 2009 using the method described in Wickings et al. (2012). Any roots attached to the litter bags were carefully removed and litter was air dried. The mass of the air dried litter was recorded and a 0.5 g sub-sample of the ground litter was incinerated at 500 °C for 4 h in a muffle furnace to determine the ash content of the sample. All masses were converted to a percentage of ash-free dry mass remaining. Light fraction organic matter (LF) was separated from soil by density fractionation using sodium polytungstate (NaPT; $d = 1.7$ g cm^{-3}; Grandy and Robertson, 2007). Total C and N in whole soils and in LF were analyzed after grinding using an elemental analyzer (Costech ECS 4010, Costech Analytical Technologies, Inc, Valencia, CA). We measured permanganate oxidizable carbon (POXC) spectrophotometrically using small modifications of the method by Weil et al. (2003) described in recent publications (Culman et al., 2012; http://lter.kbs.msu.edu/protocols/133). Soil inorganic N concentrations were determined monthly between June and November 2008 in 1 N KCl soil extracts analyzed colorimetrically (SmartChem 140, Westco Scientific, Danbury, CT; McSwiney et al., 2010).

A laboratory incubation experiment was set up to measure potentially mineralizable C (PMC) using soil CO_2 flux as described previously (Grandy and Robertson, 2007). We placed 20 g of air-dried soil into 60 ml serum vials and brought the soil moisture content up to 60% of the water holding capacity. The vials were tightly capped with rubber septa and water was added as needed during the incubation period of 114 d to keep moisture levels constant. On each of 42 sampling dates over a 125 d period, three headspace samples were drawn over 60 min and CO_2 concentrations determined with an infrared gas analyzer (Li-Cor 820). Potential C mineralization kinetics were calculated for each sample using a 2-pool, first-order kinetics model: $C_{min} = C_1 e^{k1^* t} + C_2 e^{k2^* t}$, where C_1, k_1 are parameters of the active pool and C_2, k_2 are parameters for the slow pool.

2.4. Enzyme activities and microarthropods

The activities of four extracellular enzymes involved in C and nutrient cycling were determined following well established methods (e.g. Saiya-Cork et al., 2002; Grandy et al., 2007;