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Effects of nitrogen fertilizer on the composition of maize roots and their decomposition at different soil depths

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ABSTRACT

The objective of this study was to determine the effect of nitrogen (N) application on the carbon (C) and N composition of maize roots and their decomposition dynamics at the depths of 15 cm and 45 cm. Maize roots were collected from 0, 120, and 240 kg N ha^{-1} fertilized plots (R_0, R_{120}, and R_{240}, respectively) of a 7-year long-term field experiment. Maize roots were mixed (2% w/w) with soil samples taken from depths of 15 and 45 cm. The mixtures were added to litter bags and buried at 15 and 45 cm depths in the field for 386 days. The root N content was 90–104% greater, the C to N ratio was 43–50% less, and the lignin to N ratio was 51–57% less in the roots of N fertilized (R_{120} and R_{240}) compared with no N fertilized (R_0). Compared to the R_0 addition soil samples, the contents of mineral N, microbial biomass C, and soluble organic C in soils mixed with R_{120} and R_{240} were greater by 23–37%, 143–297%, and 20–118%, respectively. After 386 days, the remaining C content in roots ranged from 25 to 31% in the R_{120} and R_{240} samples compared to 36–38% in R_0 samples. Therefore, the increased N content and decreased C to N ratio with fertilization resulted in slightly faster root decomposition. Nevertheless, maize roots from N fertilized plots left more organic C in the soil due to their much greater biomass; therefore, N fertilization led to a greater C input. We conclude that N fertilization affects not only the composition of maize roots, but also their decomposition in soil.

1. Introduction

Root decomposition is a fundamental ecological process that corresponds to a large C loss in plants, as well as a potential C sink in soil. Thus, root decomposition plays a critical role in the C budget in terrestrial ecosystems, particularly in ecosystems with high belowground allocation [1]. Root decay is also an important source of mineral nutrients in the soil and therefore affects the net primary productivity in nutrient-limited environments [2].

Estimation of rates of root decay is challenging because roots are hidden, and studies of their turnover often must consider disturbances within the analysis. Therefore, there are many more studies describing the decay of aboveground plant matter than studies of root decay. Root litter usually decomposes more slowly than leaf litter, and root C has a longer residence time in soil than shoot C does [3]. The belowground processes are considered to be key for the maintenance of stable soil C content [4].

The contribution of root C to soil C depends on root decomposition in soil, which is controlled by both biotic and abiotic factors. The major biotic factors include the endogenous chemical properties of the roots, such as the contents of C, N, and lignin, and the ratios of C to N and lignin to N [5], as well as the microbial communities present in the soil and their colonization patterns. Abiotic factors that affect root decomposition include soil temperature, moisture, aeration, and others [6]. These factors vary with soil depths, and water, oxygen, and nutrient conditions in the subsoil also may affect microbial activity. Spatial separation of organic matter, microorganisms, and extracellular enzymes also plays an important role in root decomposition [7]. However, results characterizing root litter degradation at different soil depths remain scarce and contradictory [8,9].

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Labile organic C pools, including soil microbial biomass carbon (SMBC) and soluble organic C, represent sources and sinks of biologically mediated nutrients. They are mobile sources of energy and C for soil microbial communities [10] and may respond more rapidly to management activities and perturbations [11]. Therefore, they are commonly used to evaluate the effect of litter decay on C and N transformations in soil. One study reported that a high proportion of root C transfers to soil C components after addition of crop residues, especially as soluble organic C and SMBC [12]. However, the effects of maize root decomposition on these labile C pools in soil remain incompletely understood.

The global use of N fertilizer in agriculture has increased greatly since the 1960s [13], because N fertilization increases crop yields, as well as the allocation of plant photosynthates to roots [14]. Exogenous N supplies also can affect decomposition rates and nutrient cycling by controlling litter nutrient quality (chemical and structural characteristics) [15]. However, information about the effect of N fertilization on the initial C, N, and lignin compositions of crop roots and then particularly the decomposition of those roots in farmland is limited. Therefore, the aims of this study were: (1) to evaluate the effect of different N fertilization rates on the nutrient composition of maize roots, and (2) to estimate the decomposition of differentially N fertilized maize roots at various soil depths during 1 year of decay.

2. Materials and methods

2.1. Study site

A long-term crop rotation experiment with different cultivation and N fertilization treatments was initiated in June 2003, at the Experimental Station of Northwest A&F University, Yangling, Shaanxi province, China (34°17′56″N, 108°04′07″E). The site, which has an elevation of 523 m, is located on the southern edge of the Loess Plateau. The average annual temperature at the site is 13 °C. The annual precipitation is 600–650 mm. Approximate 60% of the precipitation is received between July and September. The silt clay loam soil at the site is classified as Lou soil (Eum-Orthic Anthrosols in the Chinese taxonomic system and Terric Anthrosols in the WRB system). Lou soil has been cultivated for more than 2000 years. The soil of the uppermost 20 cm had the following properties at the beginning of the long-term experiment: pH, 8.25; organic C, 8.83 g kg^{-1}; total N, 0.67 g kg^{-1}; Olsen-P, 17.2 mg kg^{-1}; and available K, 169.4 mg kg^{-1}.

The field trial was conducted in a split-plot design. The four main plot treatments included: (1) conventional flood irrigation, (2) deficit irrigation, (3) straw mulch + deficit irrigation, and (4) plastic film-mulched ridge and straw mulched furrows + deficit irrigation. The last three treatments are water-saving management practices. The sub-plot treatments were three N fertilizer rates: 0, 120, and 240 kg N ha^{-1}. Each sub-plot was 4 × 4.5 m. Each treatment was replicated four times. The cropping rotation was winter wheat (*Triticum aestivum* L.) and summer maize (*Zea mays* L.). Wheat was sown in early October and harvested in early June of the following year. Then maize was planted by hand immediately after the wheat harvest without tilling the soil and was harvested in early October. The conventional treatment consisted of level seedbeds with no straw or plastic film mulch. Wheat received 40 mm of flood irrigation during the winter, and maize was irrigated during the early growing stage after planting to promote stand establishment and plant growth. The amount of irrigation water applied to the maize varied among years (from 0 to 60 mm/yr), depending on the amount of rainfall each year. The details of other three management treatments were described by Zhou et al. [16]. Nitrogen fertilizer was applied as urea (46% N), and P (80 kg P_2O_5 ha^{-1}) was applied as superphosphate (16% P_2O_5). All fertilizers were spread uniformly across the soil surface and then chiseled into the upper 15 cm of soil just before wheat planting. In the maize season, one-third of the N fertilizer for each treatment was applied at the seedling stage and the remaining two-thirds were applied at the booting stage. No P fertilizer was used during maize growth. Potassium fertilizer was not applied throughout this experiment.

2.2. Maize root and soil sampling

In October 2010, five maize plants were randomly selected and their roots were collected from the 0–20 cm soil depth after harvesting from subplots of three N application rates in the conventional treatment. This sampling depth of maize roots was chosen because more than 60% of root biomass has been found in this soil layer [17]. Furthermore, disturbance of the soil profile during sampling should be kept to a minimum to exclude the deeper root system from sampling. Each root sample was immediately wrapped in a plastic bag and then brought back to the laboratory. Maize roots were placed into a 0.15-mm sieve and washed in clean water by hand to remove soil and prevent the loss of fine roots. After soil removal, maize roots were washed with distilled water three times, then dried at 60 °C, weighed, and ground to pass through a 1-mm sieve. Roots from 20 maize plants were mixed to create one composite sample for each N fertilization rate (5 plants per plot, 4 replicated plots). The abbreviations R_0, R_{120}, and R_{240} represent maize roots from the plots that received 0, 120, and 240 kg N ha^{-1}, respectively. Soil samples were collected at depths of 15 cm and 45 cm in a plot near the long-term trial, and coarse roots were removed. The soil samples were air-dried and passed through a 2-mm sieve. The gravimetric soil water content was determined by drying the soil at 105 °C for 12 h. The selected basic properties of the tested soils and maize roots are given in Tables 1 and 2.

2.3. Root decomposition experiment

The litter bag technique was used to determine root decomposition at different soil depths [5]. Six root-amended treatments were prepared by mixing 2 g of roots exposed to each N fertilization condition (R_0, R_{120}, and R_{240}) with 100 g oven-dried soil collected from both 15 and 45 cm depths ($soil_{15}$ and $soil_{45}$). Two non-amended treatments were prepared with 100 g soil as the control (no roots added). Therefore, eight treatments were included in this study: $soil_{15}$, R_0+$soil_{15}$, R_{120} + $soil_{15}$, R_{240} + $soil_{15}$; $soil_{45}$, R_0+$soil_{45}$, R_{120} + $soil_{45}$, and R_{240} + $soil_{45}$. Each mixture was put into a 14 × 14 cm nylon bag (mesh size: 80 μm). The mesh size was too small to allow fauna and roots to penetrate; however, it allowed water and gas exchange. Twelve bags (i.e., replicates) were prepared for each treatment. Thus, a set of 96 litter bags (8 treatments, 12 replications) was used for determining root decomposition in the field.

In November 2010, these bags were buried in eight pits (45 cm wide × 100 cm long) that had been dug in the plot from which soil samples were collected. The four pits were 15 cm deep, and 12 bags per treatment containing soil collected from a depth of 15 cm were

Table 1
Basic properties of soil samples used in this study (mean ± SE, $n = 3$).

Soil depth (cm)	Organic C (g kg^{-1})	Total N (g kg^{-1})	C/N	Soil $CaCO_3$ (g kg^{-1})	Soil pH
15	9.15 ± 0.2a	0.90 ± 0.01a	10.1	67.9 ± 1.6a	7.8 ± 0.01b
45	4.35 ± 0.1b	0.41 ± 0.01b	11.4	10.7 ± 0.7b	8.0 ± 0.02a

Values with different letters within a column are statistically significantly different at $P < 0.05$.