

Fresh root decomposition pattern of two contrasting tree species from temperate agroforestry systems: effects of root diameter and nitrogen enrichment of soil

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Abstract Fresh tree root decomposition induced by tillage is an important source of soil nutrients in agroforestry systems. Here we examined the effects of tree species, root size and soil N enrichment on fresh root decomposition under laboratory conditions. Fresh roots with two diameters (<2 and 2–5 mm) of *Populus euramericana* cv. ‘N3016’ (poplar) and *Pinus tabulaeformis* (pine) collected from agroforestry systems in Northeast China were used in the experiment. For each root treatment, four N levels (0, 50, 100 and 150 $\mu\text{g N g}^{-1}$ soil) were added. We recognized N concentration and C/N ratio as the root quality variables, and determined decomposition rates as cumulative CO_2 production and mass loss. Poplar roots had higher N concentration and lower C/N ratio and decomposed faster than pine roots, and smaller roots decomposed faster than the corresponding larger roots. The effect of N addition on root decomposition varied from positive to negligible to negative, and depended on root quality

and N addition rates. Increased N availability did not accelerate and even suppressed poplar root decomposition, whereas generally stimulated pine root decomposition. Our results suggest that root quality should be incorporated into the design of agroforestry systems. Moreover, the differential responses of N addition on decomposition of fresh roots with different quality provide insights into soil nutrient management in agroforestry practices.

Keywords Cumulative CO_2 production · Mass loss · *Pinus tabulaeformis* · *Populus euramericana* cv. ‘N3016’ · Root quality

Introduction

Plant root decomposition is a critical component of C and nutrient cycling in terrestrial ecosystems, and hence plays an important role in maintaining soil fertility and plant productivity (McClougherty et al. 1984; Gill and Jackson 2000; Silver and Miya 2001). Root decomposition depends on both biotic and abiotic factors; the most important is root quality (Silver and Miya 2001). Root quality generally varies with soil nutrient conditions (Cotrufo and Ineson 1995), plant species (Lehmann et al. 1995; Gholz et al. 2000) and root diameter (Scheu and Schauerermann 1994; King et al. 1997).

In agroforestry systems, tree can increase organic matter input and improve soil nutrient availability

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through root and leaf litter decomposition (Lehmann and Zech 1998; Jose et al. 2000; Jose 2009). Munoz and Beer (2001) found that, in Costa Rica, tree fine root turnover contributed from 6% to 13% and from 3% to 6% of total nutrient input to soils in the *Cordia alliodora*- and *Erythrina poeppigiana*-*Theobroma cacao* agroforestry systems, respectively. Moreover, Jose et al. (2000) observed that tree fine roots may play a more significant role in nutrient cycling in temperate agroforestry systems, due to their faster nutrient release as compared to tree leaf litters. However, most of the previous studies about root decomposition in agroforestry systems have focused on naturally senesced tree roots, and there is little information on decomposition dynamics of fresh tree roots (Schroth 2003). In agroforestry systems, fresh tree root decomposition usually occurs when superficial tree roots are destroyed by tillage at the beginning of a cropping season. Tree roots cut off during soil tillage may have higher nutrient contents than roots that die naturally (Schroth 2003). Therefore, knowledge about the decomposition pattern of fresh tree roots can guide our decisions on tree species selection and nutrient management in agroforestry systems.

Root decomposition is generally affected by soil N availability, which can alter root N concentration and decomposer activity and abundance (Fog 1988; Manning et al. 2008). While the correlation between initial root N concentration and decay rates has been well documented (Berg 1984; Silver and Miya 2001), the relationship between root decomposition and external N availability is still unclear. Several studies have found significantly faster decay rates under increased N availability (Van der Krift et al. 2001; King et al. 2002), whereas some other studies have observed no significant change (King et al. 1997; Ludovici and Kress 2006). In agroforestry systems, mineral N fertilizer application is widely used as the conventional agronomic management to improve soil N status and increase system productivity (Jose et al. 2004). Since soil microbial growth and activity are generally limited by N (Schimel and Weintraub 2003), increased soil N availability following fertilization may alter the decomposer activity and impact fresh root decomposition in agroforestry systems.

In semiarid regions of Northeast China, poplar (*Populus* spp.) and pine (*Pinus* spp.) are widely adopted in agroforestry systems. In this paper, we used fresh tree roots (<2 and 2–5 mm in diameter)

from poplar (*Populus euramericana* cv. 'N3016')- and Chinese pine (*Pinus tabulaeformis*)-based agroforestry systems in the laboratory decomposition experiment. The poplar is a fast-growing tree with a rotation period of 20–25 years, while Chinese pine is a comparatively slow-growing tree with a rotation of over 60 years. We recognized initial N concentration and C/N ratio as the main root quality variables. The specific objectives of our study were (1) to assess the effect of tree species on fresh root quality and thus decomposition rates. We hypothesized (hypothesis one) that poplar fresh roots would have higher quality (high N concentration and low C/N ratio) than pine fresh roots, and decompose faster; (2) to examine the effect of root diameter on root quality and decomposition dynamics. We hypothesized (hypothesis two) that smaller roots would have higher quality than larger roots and decompose more rapidly; and (3) to investigate the responses of fresh tree root decomposition to soil N enrichment. We hypothesized (hypothesis three) that N addition to soils would stimulate fresh tree root decomposition due to the N limitation during decomposition.

Materials and methods

Root and soil sampling and analysis

Fresh tree root samples and soil used for the incubation experiment were collected from a farm in Taipingzhuang Town (41°47'N and 119°15'E, 632 m above sea level), Jianping County, Liaoning Province, Northeast China. The study site belongs to the temperate, semiarid continental monsoon climate, with a mean annual temperature of 6.5°C, precipitation of 467 mm (more than 60% falling between June and August), and the frost-free period of 148 days. The poplar- and Chinese pine-based agroforestry systems were established in April 2004 and 1995, respectively. The spatial arrangement of tree and crop rows in agroforestry systems is shown in Fig. 1. All the agroforestry systems were tilled before seeding.

In order to avoid the occurrence of home-field advantage during fresh tree root decomposition, soil samples were collected at 0–15 cm layer in maize (*Zea mays*)-based sole cropping systems in April 2009 when fields were fallow. During the periods of soil sampling, crop stubs were remained in the field,

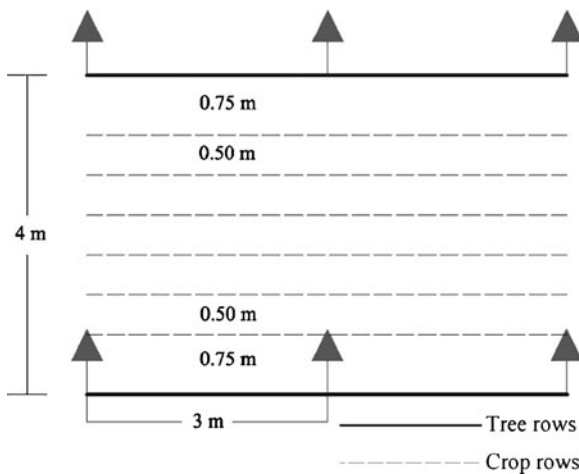


Fig. 1 Diagram showing the spatial arrangement of tree and crop rows in semi-arid agroforestry systems of Northeast China

and would be removed from the systems during tillage. After removing roots, macrofauna and visible debris, the soil was sieved (2 mm) and was stored at 4°C for one week until the laboratory incubation experiment commenced. The soil was a sandy loam with pH in a 1:2.5 (weight:volume) water suspension of 8.26; organic C of 5.01 mg g⁻¹; total N of 0.47 mg g⁻¹; and C/N ratio of 10.7.

In April 2009, fresh tree root samples were collected by excavating soil (0–15 cm depth) from agroforestry systems, separated by sieving and carefully washed. In the present study, we only collected small roots <5 mm in diameter, because coarse roots >5 mm in diameter were scarce in 0–15 cm soil layer. Fresh roots were separated into two diameter size classes (<2 mm and 2–5 mm in diameter) and cut into 2 cm in length. Fresh roots were mixed carefully and divided into two subsamples for each size class. The first group of subsample was stored at 4°C for 2 days and used for the incubation experiment. The second group of subsample was analyzed for initial water content and chemical composition. The subsamples were weighed, oven-dried to a constant mass at approximately 65°C for 48 h, reweighed, and milled (<0.25 mm) for measurement of organic C and N concentration. Organic C was determined using the K₂Cr₂O₇–H₂SO₄ wet oxidation method (Walkley and Black 1934). To determine the total N, the samples were first mineralized using the Kjeldahl method (Bremner 1996). The total N concentration in the digested solution was assessed using a continuous-flow autoanalyzer (AutoAnalyzer III, Bran+Luebbe GmbH, Germany).

Experimental design

Two tree species—poplar and Chinese pine were selected with two root size classes (<2 and 2–5 mm) and four N addition levels (0, 50, 100 and 150 µg N g⁻¹ soil) for a total of 16 treatments. An unamended treatment (containing only soil) was included as a control. Each treatment was replicated four times. In addition, four containers without soil and fresh tree roots were considered as blanks.

Fresh root decomposition

Root decomposition was studied in laboratory microcosms using a modified method based on that described by Cotrufo and Ineson (1995) and Robinson et al. (1999), and we determined root decomposition rates as cumulative CO₂ production and mass loss. Fresh soil (80-g, oven-dried), previously stored at 4°C, was placed in a 500 mL glass flask and N was added as (NH₄)₂SO₄ solution for N addition treatments. Distilled water was added to each microcosm to adjust its moisture content to 60% water-holding capacity (Wilke 2005). Three grams of roots were placed on the surface of fresh soil in the flask. A plastic vial containing 20 mL 1 mol L⁻¹ NaOH solution was placed in each flask to trap the evolved CO₂ and the total weight of the glass flask containing the incubation soil and the CO₂ traps was recorded. The flasks were incubated at 25±1°C in darkness for 119 days (approximately equivalent to the length of a complete growing season). After 2, 7, 14, 28, 42, 56, 84 and 119 days of incubation, the evolved CO₂ trapped in NaOH was determined by back titration with 0.5 mol L⁻¹ HCl after precipitating the carbonate with 1 mol L⁻¹ BaCl₂ solution. After the CO₂ traps were taken out, the flasks were left open for 4 h to allow the air in the flasks to be replenished. In order to maintain at 60% water-holding capacity throughout the incubation, soil moisture content was checked by weighing the flask every 3–5 days and adjusted by adding distilled water when necessary. After 119 days, the roots were separated from the soil, oven-dried to a constant mass at approximately 65°C and weighed. For each fresh tree root treatment, the CO₂ production was calculated as the difference between the CO₂ produced from the treatment (soil containing fresh roots) and that from the control (soil without fresh roots), and expressed as mg CO₂-C g⁻¹ root. Mass loss was calculated as the

difference between the initial and final root mass, and expressed as a percentage of initial root mass.

Kinetic models and statistical analyses

Cumulative CO₂ production kinetics were fitted with a simple compartment negative exponential model (Stanford and Smith 1972):

$$C_t = C_0(1 - e^{-kt})$$

where C_t is the cumulative CO₂ production at time t , C_0 is the potential cumulative CO₂ production, k is the decomposition rate constant, and t is time in days.

Data were statistically analyzed using SPSS (v. 13.0) for Windows software package (SPSS Inc. 2004), and the accepted significance level was $\alpha = 0.05$. Standard errors of the treatment means were calculated from the one-way analysis of variance (ANOVA). Three-way ANOVA was used to examine the effects of tree species, root diameter and N addition rate on cumulative CO₂ production, potential cumulative CO₂ production, decomposition rate constant and mass loss. Multiple comparisons among means of cumulative CO₂ production, potential cumulative CO₂ production, decomposition rate constant and mass loss of different treatments were performed with Tukey's HSD (Honestly Significant Difference) test. Data were tested for normality using the Kolmogorov-Smirnov test (SPSS Inc. 2004), and all data were conformed to a normal distribution (data not shown).

Results

The initial chemical composition of fresh tree roots

Poplar fresh roots had higher N concentration and lower C/N ratio than pine fresh roots, and for each tree species, <2 mm fresh roots had higher N concen-

tration and lower C/N ratio than 2–5 mm fresh roots (Table 1). For all fresh tree roots, <2 mm poplar fresh roots had the highest N concentration (9.75 mg g⁻¹) and the lowest C/N ratio (46.1), while 2–5 mm pine fresh roots had the lowest N concentration (3.44 mg g⁻¹) and the greatest C/N ratio (148.5) (Table 1).

Effect of tree species and root diameter size on fresh root decomposition

During 119 days of laboratory incubation, tree species, root diameter size and their interaction had significant effects on cumulative CO₂ production (Table 2) and mass loss (Table 3). Poplar fresh roots decomposed faster than pine fresh roots, and for both poplar and pine, <2 mm fresh roots decomposed faster than the corresponding 2–5 mm fresh roots (Fig. 2). At the end of incubation (day 119), cumulative CO₂ production (305 mg CO₂-C g⁻¹ root) and mass loss (38.9%) of <2 mm poplar roots were 92% and 86% higher than those of the corresponding pine ones, respectively (Table 4). Similarly, cumulative CO₂ production (228 mg CO₂-C g⁻¹ root) and mass loss (30.4%) of 2–5 mm poplar roots were 74% and 99% greater than those of the corresponding pine ones, respectively (Table 4). In addition, <2 mm poplar roots had 34% and 28% greater cumulative CO₂ production and mass loss than 2–5 mm ones, respectively; and <2 mm pine roots had 21% and 37% higher cumulative CO₂ production and mass loss than 2–5 mm ones, respectively (Table 4).

Tree species, root diameter size and their interaction produced significant effects on potential cumulative CO₂ production and decomposition rate constant (Table 3). Poplar roots had greater potential cumulative CO₂ production than pine roots, and <2 mm roots had greater potential cumulative CO₂ production than the corresponding 2–5 mm roots (Tables 3 and 4). For all tree roots, <2 mm poplar roots had the greatest potential cumulative CO₂ production (320 mg CO₂-C g⁻¹ root), whereas 2–5 mm pine roots had the lowest (143 mg

Table 1 Initial C, N and C/N ratio of root samples

Values are means (standard errors in parentheses) of $n = 4$ samples. Means with different letters in the same column are significantly different at $P < 0.05$

Root type	Total organic C (mg g ⁻¹)	Total N (mg g ⁻¹)	C/N ratio
<2 mm poplar roots	449(3)d	9.75(0.11)a	46.1(0.2)d
2–5 mm poplar roots	460(2)c	8.73(0.06)b	52.7(0.1)c
<2 mm pine roots	474(2)b	4.51(0.04)c	105.3(0.6)b
2–5 mm pine roots	511(1)a	3.44(0.02)d	148.5(1.0)a

Table 2 Results (*P*-values) of three-way ANOVAs on the effects of tree species (S), root diameter (D), N addition level (N) and their interactions on cumulative CO₂ production during fresh tree root decomposition

Sources of variation	Incubation period (days)							
	2	7	14	28	42	56	84	119
S	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
D	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
N	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	0.029
S × D	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
S × N	0.796	0.017	0.582	<0.001	<0.001	<0.001	<0.001	<0.001
D × N	0.146	<0.001	0.022	0.114	0.048	0.038	0.047	0.017
S × D × N	0.047	<0.001	0.001	0.087	0.761	0.994	0.475	0.005

CO₂-C g⁻¹ root) (Table 4). However, decomposition rate constant showed no consistent trend with tree species and root diameter. For the poplar, <2 mm roots (0.0243 day⁻¹) had higher decomposition rate constant than 2–5 mm roots (0.0145 day⁻¹), while the decomposition rate constant of pine showed a reverse trend (Table 4).

Effect of N addition on fresh root decomposition

During the incubation, N addition affected cumulative CO₂ production and mass loss, and the effects varied with root quality and N addition level (Tables 2 and 3). For <2 mm poplar roots, N addition caused a 14% reduction in mass loss only at a rate of 150 μg N g⁻¹, and had no effects on cumulative CO₂ production and mass loss in other cases (Table 4). Cumulative CO₂ production of 2–5 mm poplar roots decreased by 12% when 150 μg N g⁻¹ was added, while N addition at 100 and 150 μg N g⁻¹ caused 16% and 22% declines in mass loss, respectively. During the entire incubation period, cumulative CO₂ production of <2 mm

pine roots increased by 10% and 17% with the N addition at 100 and 150 μg N g⁻¹, respectively, and mass loss increased by 19% and 18%, respectively (Table 4). However, N addition increased cumulative CO₂ production and mass loss of 2–5 mm pine roots, irrespective of addition levels (Table 4). For 2–5 mm pine roots, N addition at 50, 100 and 150 μg N g⁻¹ caused 24%, 31% and 39% increases in cumulative CO₂ production, respectively, and 35%, 25% and 42% in mass loss (Table 4).

Tree species, root diameter size, N addition level and their interaction affected potential cumulative CO₂ production and decomposition rate constant (Table 3). N addition level had no effects on potential cumulative CO₂ production of <2 mm poplar and pine roots, whereas N addition decreased potential cumulative CO₂ production of 2–5 mm poplar roots, and increased potential cumulative CO₂ production of 2–5 mm pine roots (Table 4). However, for all tree roots, N addition generally increased decomposition rate constant (Table 4).

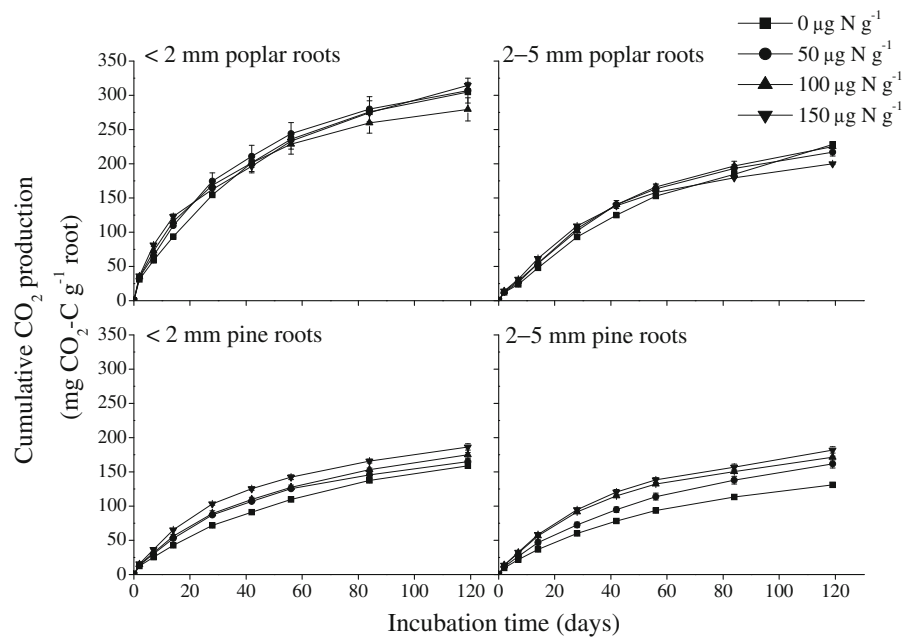
Table 3 Results (*P*-values) of three-way ANOVAs on the effects of tree species (S), root diameter (D), N addition level (N) and their interactions on potential cumulative CO₂ production (*C*₀), decomposition rate constant (*k*) and mass loss during fresh tree root decomposition

Sources of variation	<i>C</i> ₀	<i>k</i>	Mass loss
S	<0.001	0.006	<0.001
D	<0.001	<0.001	<0.001
N	0.533	<0.001	0.028
S × D	<0.001	<0.001	<0.001
S × N	<0.001	0.366	<0.001
D × N	0.063	0.011	<0.001
S × D × N	0.001	<0.001	0.036

Discussion

Our data supported the first hypothesis that poplar fresh roots decomposed faster than pine fresh roots during the incubation period, due to the higher root quality. Our result confirmed the observations of Silver and Miya (2001), who used a global data-set of root decomposition and reviewed that, root chemical composition, especially root C/N ratio and Ca concentration was the main controller of root decomposition. High N concentration and low C/N ratio in poplar roots may stimulate microbial growth and hence root decomposition rates, whereas pine roots with high C/N ratio had low decomposition

Fig. 2 Cumulative CO₂ production during the decomposition of fresh roots with two diameters (<2 and 2–5 mm) of two tree species *Populus euramericana* cv. ‘N3016’ (poplar) and *Pinus tabulaeformis* (pine) under different N addition levels (0, 50, 100 and 150 μg N g⁻¹ soil) in a microcosm study. Error bars represent ±SE (n=4)



rates due to the great amounts of structural woody materials as well as low available N for decomposer organisms (Silver and Miya 2001). In temperate agroforestry systems, root litters with high quality can decompose rapidly and stimulate nutrient cycling and replenish soil fertility (Jose et al. 2000). Therefore, root quality should be considered in the design of agroforestry systems in temperate regions from the viewpoint of sustaining soil fertility. Moreover, our results suggest that poplar can enhance nutrient cycling through decomposition of high quality roots, and have an advantage over Chinese pine during the species selection in semiarid agroforestry systems of Northeast China.

According to our second hypothesis, for both poplar and pine, <2 mm fresh roots had higher quality than the corresponding 2–5 mm fresh roots, and hence decomposed more rapidly. Previous studies also found that root decomposition rates decreased with increased diameter size (e.g. Camiré et al. 1991; Ludovici and Kress 2006). However, some studies observed that larger diameter roots decomposed faster than smaller ones albeit lower N concentration and higher C/N ratio (McClaugherty et al. 1984; Lin et al. 2011), because high level of N concentration in roots may stimulate the formation of N-lignin complexes and slow decomposition rates (Camiré et al. 1991). In our study, high levels of N in smaller tree roots may stimulate the growth of microorganisms and thus enhance decom-

position rates (Camiré et al. 1991; Silver and Miya 2001). In addition, slower leaching rates of water-soluble compounds (Fahey et al. 1988), a longer time required for fungal hyphae penetration (Berg 1984), or increased proportions of resistant organic substances and structural mass (King et al. 1997; Silver and Miya 2001) may suppress decomposition of larger diameter fresh roots. The greater decay rates of smaller tree roots imply that fine roots play an important role in nutrient cycling in temperate agroforestry systems.

Inconsistent with our third hypothesis, N addition had variable effects on the fresh root decomposition rates: varying from positive via negligible to negative (Fig. 2 and Table 4). Indeed, the effect of soil N enrichment on decomposer activity was yet contradictory. Previous studies found that increased N availability had positive (Allen and Schlesinger 2004), negligible (Keeler et al. 2009) or negative (Hu et al. 2010) effects on soil decomposer activity. Consequently, N addition either resulted in an increase in root decay (Van der Krift et al. 2001; King et al. 2002) or had no significant effect (King et al. 1997; Ludovici and Kress 2006). In addition, Laiho et al. (2004) found that root decomposition rates did not vary systematically with soil nutrient levels in boreal peatlands. Therefore, in our study, the various responses of fresh root decomposition to N addition may be resulted from the differences in fresh root quality and fertilization rate.

Table 4 Effects of N addition on cumulative CO₂ production (C_{119}), potential cumulative CO₂ production (C_0), decomposition rate constant (k) and mass loss at the end of fresh tree root decomposition

Root type	N addition level ($\mu\text{g N g}^{-1}$ soil)	C_{119} ($\text{mg CO}_2\text{-C g}^{-1}$ root)	C_0 ($\text{mg CO}_2\text{-C g}^{-1}$ root)	k (day^{-1})	Mass loss (%)
<2 mm poplar roots	0	305(2)a	320(2)a	0.0243(0.0003)b	38.9(0.5)a
	50	307(13)a	310(16)a	0.0295(0.0019)ab	37.1(0.5)a
	100	279(12)a	274(14)a	0.0355(0.0014)a	38.7(0.4)a
	150	315(14)a	310(17)a	0.0283(0.0017)b	33.4(0.5)b
2–5 mm poplar roots	0	228(3)a	279(18)a	0.0145(0.0013)c	30.4(0.9)a
	50	217(6)ab	238(5)ab	0.0205(0.0005)b	30.4(0.3)a
	100	225(7)a	252(11)ab	0.0190(0.0007)b	25.6(0.6)b
	150	200(1)b	207(2)b	0.0260(0.0007)a	23.7(0.9)b
<2 mm pine roots	0	159(3)c	179(7)a	0.0183(0.0010)c	20.9(0.3)b
	50	165(5)bc	171(8)a	0.0253(0.0020)ab	20.5(0.3)b
	100	175(3)ab	182(1)a	0.0233(0.0012)abc	24.8(0.5)a
	150	186(3)a	187(4)a	0.0278(0.0005)a	24.6(0.7)a
2–5 mm pine roots	0	131(3)c	143(4)b	0.0195(0.0003)b	15.3(0.7)c
	50	162(6)b	178(8)a	0.0193(0.0016)b	20.6(0.7)ab
	100	171(2)ab	174(2)a	0.0260(0.0004)a	19.2(0.3)b
	150	182(4)a	185(5)a	0.0250(0.0001)a	21.7(0.5)a

Values are means (standard errors in parentheses) of $n=4$ samples. For each root type, means with different letters in the same column are significantly different at $P<0.05$

Based on a meta-analysis, Knorr et al. (2005) found that increased external N input generally stimulates the decomposition of leaf litters containing low lignin and other recalcitrant compounds, while inhibiting the decay of leaf litters with high lignin concentration. Although we did not measure tree root lignin concentration, Berg and McClaugherty (2008) pointed that the lignin content of deciduous species was generally lower than that of evergreen species. However, in our study, increased N availability did not accelerate and even suppressed the decomposition of poplar fresh root, but generally stimulated the decay of pine fresh roots. These inconsistent results illustrate that the effect of N addition on decomposition of fresh roots may be different from the leaf litters. For poplar roots with low C/N ratio, increased N availability may aggravate C-limitation for microbial degradation (Schimel and Weintraub 2003), depress microbial activity (Fog 1988) and form recalcitrant complexes (Camiré et al. 1991), and hence slow decomposition rates. However, for pine roots with high C/N ratio, N addition may stimulate microbial growth and activity and increase root decay rates (Schimel and Weintraub 2003). In addition, the

effect of N addition on fresh root decomposition may depend not only on chemical quality, but also on physical quality (e.g. tissue architecture) (Lindedam et al. 2009). Still now, we cannot fully explain such contrasting effects of increased N availability on decomposition of fresh roots with different quality. Further studies are needed to better understand the interactive effects between N addition and root quality on fresh root decomposition, due to the poor knowledge of the mechanism behind these processes and the lack of adequate related studies. The differential responses of decomposition of fresh tree roots with different quality to N addition may be benefit to improve our understanding of nutrient cycles in agroforestry systems.

During the period of fresh tree root decomposition, in some cases, the effect of N addition on cumulative CO₂ production was different from that on mass loss (Table 4). For example, N addition at 100 $\mu\text{g N g}^{-1}$ decreased mass loss of 2–5 mm poplar fresh roots, but did not affect cumulative CO₂ production (Table 4). No changes in cumulative CO₂ production may be attributed to the enhanced microbial C utilization efficiency (Schimel and Weintraub 2003) and altered

microbial community composition and abundance (Hu et al. 2010). These contradictory data also suggest that, during fresh tree root decomposition, N addition causes a shift in pathways of decay from cumulative CO₂ production to mass loss through leaching and loss as fine particulate matter (Robinson et al. 1999; Zeng et al. 2010). Increased mass loss through leaching and fragmentation under N addition caused greater decomposition rates of fresh tree roots, although there was no significant change in cumulative CO₂ production.

Generally, incorporation of fresh tree roots into soils may produce a priming effect, the stimulation of soil organic C mineralization induced by the addition of organic substances (Kuzyakov et al. 2000). During the incubation period, we did not separate the soil-derived CO₂ from the root-derived CO₂, and distinguish the sources of CO₂ production. Consequently, we cannot examine the influence of priming effect on CO₂ production during fresh tree root decomposition. We acknowledge that priming effect would exaggerate the amount of CO₂ release derived from the decomposition of tree fresh roots. However, we expected that CO₂ produced from both root decomposition and priming effect would be the overall result of tree fresh root addition to soils. In the further studies, application of ¹⁴C-labelled tree roots to soils should be used to trace the source of CO₂ and assess the priming effect induced by fresh root addition in the decomposition process.

In the present study, we investigated fresh tree root decomposition rates under constant soil humidity and incubation temperature using laboratory-based methodology. This approach can accurately examine the effects of root quality and N addition rates on fresh tree root decomposition in the absence of anthropogenic and natural disturbance. However, laboratory-based methodology does not mimic many abiotic factors controlling root decomposition in the field, such as periodic drying and wetting of the soil. Moreover, fresh tree root decomposition rates in the laboratory may be greater than those in the field in the semiarid temperate regions, due to the higher soil humidity and incubation temperature. Further studies are needed to examine the effects of root quality and N addition on fresh tree root decomposition and nutrient release in the field.

This study, reporting on fresh tree root decomposition induced by tillage, found that root quality was

the primary factor controlling fresh tree root decomposition in temperate agroforestry systems. Therefore, root quality should be incorporated into the design of agroforestry systems in temperate regions. In semiarid regions of Northeast China, poplar can produce high quality root litters and have an advantage over Chinese pine during the design process of agroforestry systems. In addition, the effect of N addition on fresh tree root decomposition rates varied from positive via negligible to negative, and depended on root quality and N addition rates. This may help us make better decisions on nutrient management and sustain system productivity in temperate agroforestry practices. Our results also highlight the complex of the interactive effects of N addition and root quality on fresh root decomposition. In order to reveal the mechanism of root decomposition response to increased N availability, further studies should focus on the dynamics of decomposer community composition and activity during root decomposition.

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