Turnover and Life Spans of Fine Root Carbon in a ^{14}C-labeled Forest Ecosystem.

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INTRODUCTION

A multi-year experiment is quantifying pathways and rates of C transfer by studying upland-oak plots in a mature forest in eastern Tennessee, USA, which was fortuitously labeled with a large spike of carbon-14 in 1999 (Trumbore et al. 2002).

This labeling event (Figure 1) allows a unique opportunity to trace C flows through this ecosystem on timescales of 2 to many years. This multi-disciplinary experiment (the Enriched/Background Isotope Study [EBIS]) is using labeled litter, roots, and soils to study transfers of this ^{14}C from sources (leaf, root litter) to sinks (respiration, leaching, or stable soil forms).

The reconstructed ^{14}C concentration timeline in Figure 1 indicates:

- The spike was very strong in 1999.
- Levels have returned to near-background subsequently.

The study presented here–part of this larger research project—focuses on the quantification of the turnover rates for fine roots in this forest.

The quantification of these rates of fine root turnover have major implications for:

1. the quantity of C allocated below ground by trees
2. the residence time of this C in various soil horizons and various ecosystems
3. the short-, medium-, and long-term sequestration of C in roots and other forms of soil C
4. the immobilization and release of nutrients through the decomposition of root mortality.

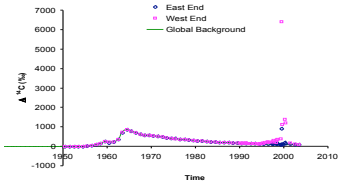

Figure 1. A timeline of the concentrations of ^{14}C in the vicinity of two upland oak sites on the HIGHLY-EXPOSED WEST END and two sites on the mildly-exposed east end of the Dept. of Energy's Oak Ridge Reservation.

METHODS

Soil cores from 8 plots at 2 sites were collected at 5 depth intervals to 90 cm in January/February of 2000, 2001, and 2002. Fine roots (< 2 mm) were sorted into two size classes and live and dead.

Radiocarbon labeling—expressed as $\Delta^{14}C$ (‰), the per mil deviation from the 1950 standard $^{14}C/^{12}C$ ratio—were determined on graphite targets of composited root samples.

Values of $\Delta^{14}C$ for new roots produced in the 2000 and 2001 growing seasons were determined from roots growing into planted wire mesh at 28 locations across the sites.

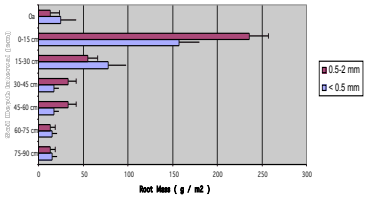

Figure 2. The depth distribution of fine root (< 2 mm) biomass averaged across 16 plots at the two west end sites. The sizes of live and dead pools were approximately equal at most depths both years (data not shown).

RESULTS

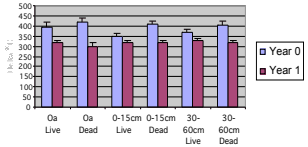

Figure 3. The mean $\Delta^{14}C$ in both dead and live fine roots (< 2 mm) at different depths in 2000 (Time Zero) and 2001 (Year 1).

- **Dead roots at Time Zero consistently had higher $\Delta^{14}C$ values than living roots.**

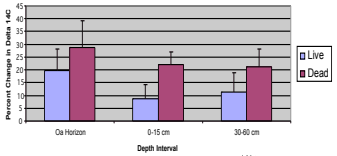

Figure 4. The contrast in mean percent change in $\Delta^{14}C$ between dead and live roots from Time Zero to Year 1 for three depth intervals.

- **Dead roots showed a greater decline than living roots in $\Delta^{14}C$ between 2000 and 2001.**
- **These patterns held across all depth intervals examined.**

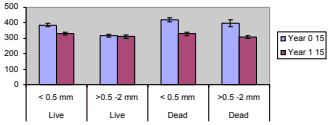

Figure 5. The contrast in $\Delta^{14}C$ between dead and live roots from Year Zero to Year 1 for two different root diameter sizes and live vs. dead at one depth interval (0 to 15 cm).

Figure 5 also indicates that the difference between dead roots and live roots also occurred regardless of size class across different depth intervals.

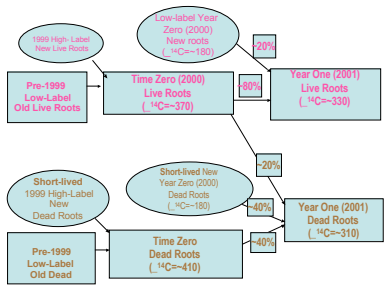

Figure 6. EBIS ^{14}C LABEL FLOW IN LIVE and DEAD ROOTS------
A simplified diagram of the flow of Carbon (and $\Delta^{14}C$ label) through Live and Dead Roots at highly-enriched sites from pre-1999 through 2001. Percentages transferred to create Year One pools are calculated estimates to balance changes in _ ^{14}C between all pools.

DISCUSSION of Figure 6

The diagram in Figure 6 demonstrates important implications of the patterns observed in Figures 3 and 4:

1. Dead roots from Year 0 (2000) had a higher mean $\Delta^{14}C$ (~410) than did live roots (~370). The dead root pool must have already received a high input of roots with high $\Delta^{14}C$ that formed during the 1999 spike year.
2. Live pools showed a very small change in $\Delta^{14}C$ between Year 0 and Year 1 (~370 to ~330. Turnover in this portion of the live pool must have been quite slow and life spans long (> 3 years).
3. Large changes in the dead $\Delta^{14}C$ between Year 0 and Year 1 (from ~410 to ~310) can only be explained by a large input of very short-lived roots that both formed and died during Year Zero (2000) growing season. These short-lived roots would have had a relatively low $\Delta^{14}C$ (~ 180)—capable of dropping the mean $\Delta^{14}C$ of the total dead pool this much—and a mean lifespan of about 3 months.
4. Note that implication # 3 is consistent with implication # 1.

Therefore 2 things must be true:

A large portion of the Year 1 dead root pools consist of very short-lived roots that both formed and died during Year Zero (2000) growing season.

The live root pool must contain both roots that both turnover very quickly and roots that live for several years.

DISCUSSION

Results from other recent studies support a wide range of life spans for fine roots of trees and considerable longevity (5-15 years) for portions of their fine root systems (Gaudinski et al., 2001; Pregitzer et al., 2002; Tierney and Fahey, 2002).

Furthermore, we and others speculate:

- Roots with long life spans (even though many are of very small diameter [< 0.5 mm]) may function as "structural network" roots.
- In contrast, short-lived roots might primarily serve an "exploratory" function in the search for water and nutrients.
- Fine root function may not be closely related to diameter but rather more related to fine root branching order, life span, and N concentration (Pregitzer (2002; Gaudinski, pers. comm.).

Modeling of root turnover that includes multiple root pools and consideration of the impact of stored carbohydrates in root production are being developed by the authors and others.

CONCLUSIONS

***** These data suggest the existence of at least two types of fine roots with radically different turnover times:**

(1) One type consists of fine roots that live less than the length of one full growing season—average turnover time is approximately 3 months.

(2) The other type is considerably longer-lived, probably living 2 to 15 years, averaging between 3 and 5 years.

**** Fine roots of the SAME diameter size class can have very different life spans, form, and function.**

ACKNOWLEDGMENTS

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