Quantifying sources of soil respiration using ^{14}C-enriched leaf litter and roots in a temperate forest

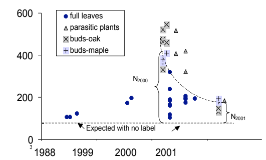
L. M. Cisneros Dozal[1], S. Trumbore[1], P. J. Hanson[2], X. Xu[1]

[1]Department of Earth System Science, University of California, Irvine, [2]Environmental Sciences Division, Oak Ridge National Laboratory

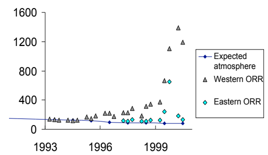
The ^{14}C labeling event

A large atmospheric release of ^{14}C labeled CO_2 was discovered on the Oak Ridge Reservation (ORR) in Oak Ridge, Tennessee during the summer of 1999. The incorporation of the label at the ecosystem scale was confirmed by the enrichment of radiocarbon measured in tree ring cellulose formed in 1999, and in leaves and buds from oak and maple trees formed in the spring of 2000 (Trumbore et al., 2002).

^{14}C signature of leaves, leaf buds and plants collected from the ORR after the labeled CO_2 release



^{14}C signature of tree ring cellulose



^{14}C-enriched leaf litter

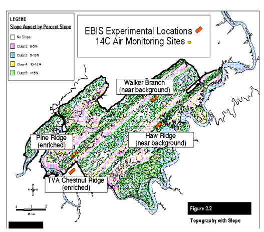
In the fall of 2000, leaf litter was collected from the western and eastern sides of the ORR using tarps. Repeated analysis of aliquots indicated greater ^{14}C enrichment on the western side. Leaf litter collected in the west of the ORR had $\Delta^{14}C$ values ranging from +952 ‰ to +1055 ‰ while the $\Delta^{14}C$ of the litter collected in the east ranged from +215 ‰ to +230 ‰ (hereafter referred as "enriched" and "background" respectively). After air-drying, the leaf litter samples were stored and used in a 3-year manipulation of ^{14}C inputs through litter additions and root turnover.

The experimental design

The "Enriched Background Isotope Study" (EBIS) was established in 4 sites to include two levels of ^{14}C input through roots (indicated as "enriched" and "near background" on the map) and two soil types (Ultisols in Walker Branch and TVA and Inceptisols in Haw Ridge and Pine Ridge).

In eight experimental plots (7 by 7 m) at each site, native leaf litter was excluded and replaced with either enriched or background litter (4 plots per treatment) in March 2001, February 2002 and February 2003.

EBIS is a multi-institutional project to trace the ^{14}C label through soil organic matter, roots, soil respiration and soil solution and further parameterize existing models of C cycling in forests.



Soil respiration

As part of EBIS we have measured soil respiration and its components at TVA and Walker Branch (preliminary measurements indicated no difference with soil type) to include two levels of ^{14}C-labeled roots. Six plots total (3 plots per treatment) are measured at each site. The results presented here are from measurements in May, July and September 2002 and March 2003.

Field measurements include:

- Collection of leaf litter samples and soil cores (first 5 cm)
- Measurement of total soil respiration rates using closed dynamic chambers and an infra-red CO_2 analyzer, and collection of CO_2 using molecular sieve traps
- Collection of root samples and CO_2 from root respiration using molecular sieve traps
- Collection of ambient CO_2 at each site using molecular sieve traps

Laboratory work include:

- Incubations of soil and leaf litter samples for collection of the CO_2 emitted
- Purification of CO_2 collected in the field and in the incubations and preparation of a ^{14}C target analysis
- Measurement of the ^{13}C signature of all CO_2 samples using mass spectrometry

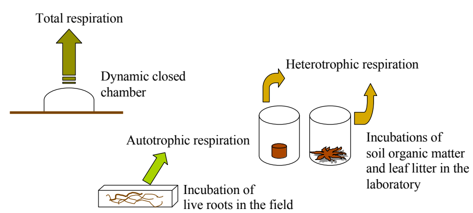
Approach

The contribution from root respiration (FRR)

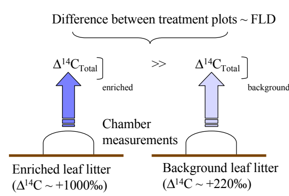
From our methods we obtained the ^{14}C signature of CO_2 from total soil respiration (collected from chamber measurements), heterotrophic respiration (collected from incubations of soil and leaf litter samples) and autotrophic respiration (collected from incubations of roots) for every treatment plot measured .

We applied a ^{14}C mass balance (Trumbore et al., 2002) to estimate the fraction of total soil respiration coming from root respiration (FRR)

$$\Delta^{14}C_{Total} = (FRR)\Delta^{14}C_{Autotrophic} + (1\text{-}FRR)\Delta^{14}C_{Heterotrophic}$$



The contribution from leaf litter decomposition (FLD)



Within any given site, the difference in the ^{14}C signature of total soil respiration between enriched and background plots should be directly proportional to the contribution of leaf litter decomposition only, since the other components (root and soil decomposition and root respiration) are assumed to remain the same for all plots.

To estimate this contribution, we applied the following mass balance:

$$\Delta^{14}C_{total} = \Delta^{14}C_{leaf\ litter} * FLD + (\Delta^{14}C_{root\ and\ soil\ decomposition} + \Delta^{14}C_{root\ respiration}) * (1\text{-}FLD)$$

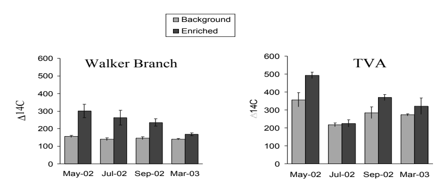
where $\Delta^{14}C_{total}$ is the ^{14}C signature of total respiration and $\Delta^{14}C_{leaf\ litter}$ is the ^{14}C signature of the leaf litter added to the plots

If the difference in $\Delta^{14}C_{total}$ between the two treatments is taken, the second term is eliminated and we can solve for FLD

Results to date

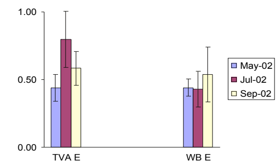
^{14}C signature of total soil respiration ($\Delta^{14}C_{total}$)

As expected, the $\Delta^{14}C$ of total respiration from enriched leaf litter treatment plots had a higher ^{14}C signature than the background treatment plots



The exception was July 2002 at TVA when soil moisture was markedly low (11% vs a minimum of 20% volumetric water content in any other period)

Fraction of total respiration coming from root respiration



Results shown here were calculated using enriched plots at each of the sites, (TVA E and WB E respectively) and for the 2002 growing season. In background plots the differences between the isotopic signature of sources and that of total respired carbon were too small to resolve the mass balance.

We estimated the fraction of total C respired by roots to vary from 0.43 to 0.80 across sites.

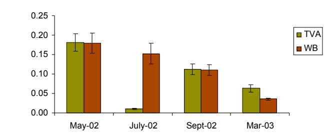
The highest value was observed in July at the TVA site when it appears heterotrophic contributions, especially leaf litter decomposition (see below) were reduced as a result of low moisture availability.

Fraction of total respiration coming from leaf litter decomposition

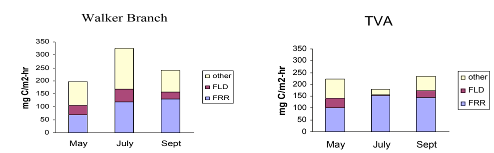
The fraction of total respiration coming from the decomposition of leaf litter in the growing season of 2002 (after two litter additions) was estimated to be from 0.18 to 0.11 in May and September respectively at both sites.

Very little contribution (0.01) was observed at TVA in July, the driest period at the site.

In March 2003, leaf litter decomposition was contributing 0.06 and 0.04 at TVA and Walker Branch respectively.



Absolute contributions to total soil respiration in the 2002 growing season



Total respiration fluxes reached a maximum in July at Walker Branch with all of the sources increasing with respect to May. By contrast, July total respiration was the lowest at TVA because of lower contribution from heterotrophic sources under drier soil conditions.

The contribution from root respiration (FRR) increased from May to September at both sites.

Conclusions

1) The ^{14}C mass balance approach has proven useful to estimate the relative contributions of different components of soil respiration with very consistent results across sites
2) In the 2002 growing season, leaf litter decomposition was estimated to contribute from 18 to 11% to the total soil C respired, likely reflecting the depletion of substrate with time. This contribution depends strongly on soil moisture and it was observed to be as little as 1% when soil moisture content reached a value of 11% by volume. Early in the 2003 growing season, this source was less than 10% of total soil respiration at both sites
3) The contribution of root respiration to the total C respired varied from 43 to 80% through the 2002 growing season. This component of soil respiration increased from May to September and was the highest contribution in the driest period at the TVA site. Further research is needed to elucidate the role of phenology and changes in soil microclimate on the observed variation

Future work

- Determination of the pool of C being respired by roots by measuring the ^{14}C signature of carbohydrates and the ^{14}C signature of ambient air on the day of root sampling
- A manipulation experiment to vary moisture availability to evaluate the effect on leaf litter decomposition
- Test the model of Hanson et al., (2003) to predict soil respiration at this temperate forest that includes independent estimates of decomposition of leaf litter, root growth costs, and maintenance respiration of roots and heterotrophs

Trumbore S., Gaudinski J., Hanson P., Southon J. (2002). Quantifying ecosystem-atmosphere carbon exchange with a ^{14}C label, *EOS* 83:265-268

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Hanson PJ, O'Neill EG, Chambers MLS, Riggs JS, Joslin JD, Wolfe MH (2003). Soil respiration and litter decomposition. In: Hanson PJ, Wullschleger SD, Eds, *North American Temperate Deciduous Forest Responses to Changing Precipitation Regimes.* Springer, New York, pp. 163-189