Carbon Flow from Roots to Microbes to Soil Humic Substances

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Summary

Soil microorganisms mediate decomposition processes, and rates of decomposition are impacted by the presence of living roots. Little is known, however, about how living roots and the soil microbial community associated with roots impact the conversion of plant material into humic substances. This project is asking how:

- Living roots affect the conversion of belowground plant carbon into humic substances.
- Alteration of microbial community composition and activity by living roots regulates humification of belowground carbon.
- The impact of living roots is dependent on N-availability.

A common California annual grass, *Avena barbata* (wild oats), was grown in an Argonaut silt loam collected from the UC Sierra Foothills Research Center, Schubert Watershed. Seeds were first planted in February 2002; however, due to technical difficulties in the ^{13}C labeling process, this first season of plant growth was lost. In December 2002, the experiment was restarted using newly sampled soil. Uniformly ^{13}C–labeled root material was highly enriched in ^{13}C after plant senescence and soil dry-down in June 2003. After surface litter removal, the intact soil-root systems was exposed to a four-month warm, dry Mediterranean summer. Fall wet-up began in September 2003 and the intact, labeled belowground system was exposed to a four-way treatment matrix: planted x unplanted and N-fertilized x nonfertilized. Total recovery of ^{13}C was followed in recognizable root debris (> 2 mm), bulk soil (< 2 mm), and SOM fractions (light fraction and heavy fraction) for one year after initiation of treatments. In addition, we determined the ^{13}C flux into and through the total microbial biomass (CFE) and microbial community components (PLFA).

Keywords: Avena barbata, humification, microbial community composition, rhizosphere, soil organic matter

Research Highlights

The presence of young fertilized plants appears to accelerate the rate of decomposition of pre-existing root litter and root-derived soil organic materials.

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Objectives

This research project asks how:

- Living roots affect the conversion of belowground plant carbon into humic substances.
- Alteration of microbial community composition and activity by living roots regulates humification of belowground carbon.
- The impact of living roots is dependent on N-availability.

The first five objectives of the research plan were accomplished.

1. *Avena barbata* (slender wild oats) was grown under enriched $^{13}CO_2$ in a greenhouse to uniformly label root materials (^{13}C enrichment of 1888 $^{0}/_{00}$).
2. Surface litter was removed by clipping after plants naturally senesced due to onset of dry period.
3. Soil cylinders with intact belowground root systems were exposed to 4-month, hot, dry Mediterranean summer.
4. Imposition of a four-way treatment matrix began in September 2003:

Replanted	x	Unplanted
N fertilized	x	Unfertilized

5. Harvest of pots after labeling (T_1), after summer fallow (T_2) and five weeks after germination (T_3) (pre-N treatment).
6. Harvest of pots after maturity of planted treatment (T_4).

Approach and Procedures

Avena barbata, wild oats, was grown in a grassland soil (Mollic haploxeralf) under enriched $^{13}CO_2$ to yield uniformly labeled plant material. After the plants senesced, the soil-root systems were exposed to a four-month, hot, dry summer. The intact, labeled belowground system was exposed to a four-way treatment matrix: replanted x unplanted and N-fertilized x unfertilized. ^{13}C from the original labeled root material is being followed through: recognizable root debris (> 2 mm); bulk soil (< 2 mm); total microbial biomass (PLFA and CFE); microbial community components (PLFA); and SOM fractions (light fraction and heavy fraction) over the growing season (Fall 2003-Spring 2004). Soil moisture was continuously monitored using dielectric constant moisture probes and will be maintained at constant water content of 60% of field capacity during the treatment period.

^{13}C enrichment determinations of the whole soil, microbial biomass (CFE), LF, and heavy fraction were determined on an Isotope Ratio Mass Spectrometer with a Roboprep C/N analyzer (PDZ Europa, Ltd, Crewe, U.K.) at UC Berkeley. To determine how microbial community structure and size affect humification rates and outcome, C isotope ratios of individual FAMEs were also determined. The instrumentation was a Hewlett-Packard (HP) GC coupled via a Europa ORCHID on-line combustion interface to a Europa 20/20 MS (GC-C-IRMS) operating in continuous flow mode (Waldrop et al. 2003).

Results

Production of Labeled Root Material

Uniformly ^{13}C–labeled *A. barbata* root material was highly enriched in ^{13}C (1888 $^{0}/_{00}$) after plant senescence and soil dry-down in June 2003, enabling long-term monitoring of C fluxes in labile and recalcitrant pools over time.

Table 1. *Biomass, C and N content, and ^{13}C enrichment of above- and below-ground wild oats in June 2003 (N=4).*

^{13}C enriched *A. barbata*							
Shoots			Roots				
biomass	C	^{13}C	biomass	N	C	C:N	^{13}C
g m^{-2}	g kg^{-1}	$^{0}/_{00}$	g m^{-2}	— g kg^{-1} —			$^{0}/_{00}$
1617	403	1751	637	8.6	318	37	1888

Partitioning of ^{13}C Among Soil Pools: June 2003

At the end of the first growing (and labeling) season, and post plant senescence (June 2003), bulk soil (> 2 mm) was enriched in ^{13}C (55 $^{0}/_{00}$), reflecting the new C contributed to soil from root exudates and root turnover during the growing season (*table 1*). The ^{13}C enrichment of the light fraction soil organic material removed from the bulk soil ($430^{0}/_{00}$) was less than that of roots ($1888^{0}/_{00}$) but more enriched than the total bulk soil. Microbial biomass measured by both PLFA and CFE was relatively high for a soil with 5% SOM concentration (*table 2*). ^{13}C enrichment of the microbial biomass ($320^{0}/_{00}$) was similar to that of the light fraction and more enriched than the bulk soil.

Table 2. *Microbial biomass C, N, and ^{13}C enrichment of bulk soil (< 2 mm) in June 2003. (N=4).*

Microbial biomass				
PLFA	CFE			
C	N	C	^{13}C	C:N
—	kg ha^{-1} —		$^{0}/_{00}$	
102	118	854	320	7.2

Partitioning of ^{13}C Among Soil Pools: October 2003

The ^{13}C enrichments of bulk soil at the end of the first growing season (June 2003) and five weeks into the second growing season (October 2003) are shown in figure 1. The ^{13}C enrichment of the soil containing young, N-fertilized Avena plants was less than that of unplanted soil with no N-fertilizer additions. It appears that the presence of active young roots

and ample nitrogen accelerates the rate of decomposition of the soil organic material that was labeled by the previous year's isotopic labeling.

Microbial Community Dynamics

PLFA analysis will provide a quantitative measure of changes in the broad soil microbial community composition in the bulk soil due to the effects of living roots and N additions. In conjunction with ^{13}C determinations, ^{13}C-PLFA will enable the comparison of the activity of microbial groups. The amount of *A. barbata* root ^{13}C converted into microbial biomass and its turnover rate is being quantified among broad cell-type groups. The Argonaut soil has a relatively high PLFA-defined fungal:bacterial ratio of 0.29 (*fig. 2*).

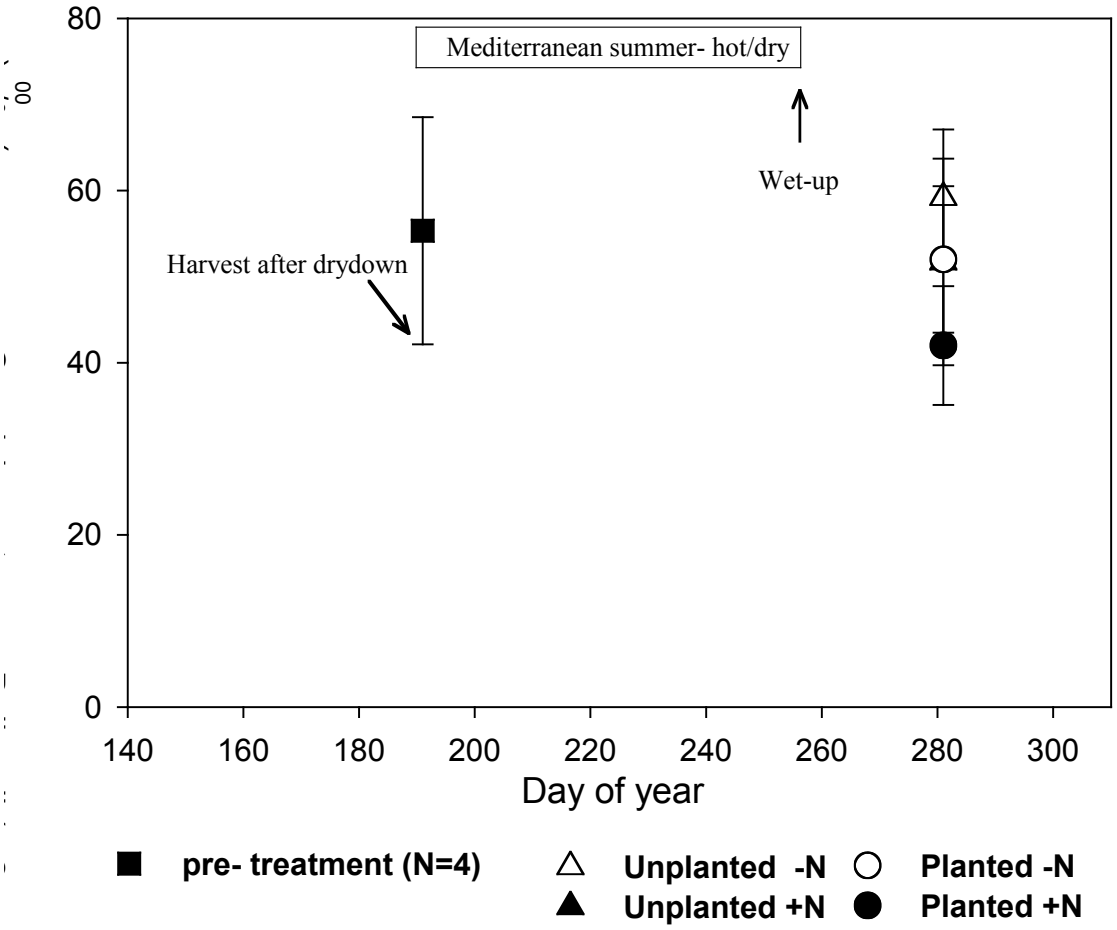

Figure 1. ^{13}C enrichment of bulk soil at the end of the first growing season (June 2003) and five weeks into the second growing season (October 2003).

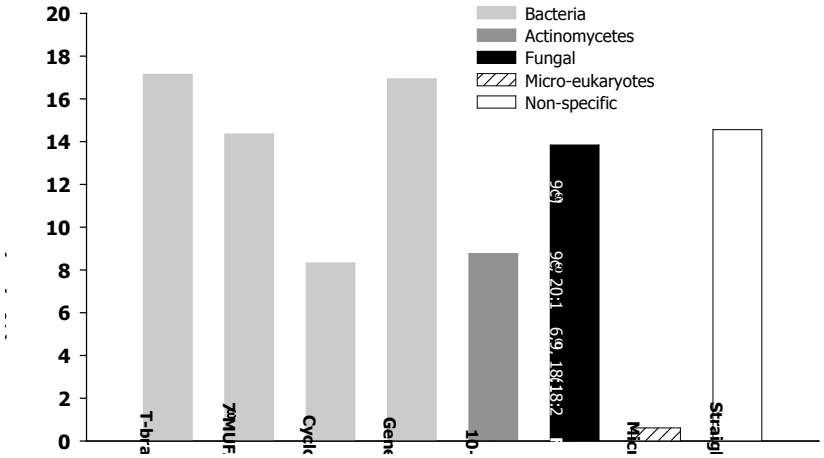

Figure 2. Mole fraction of selected phospholipid fatty acids (PLFA) extracted from soil prior to the first growing season.

Discussion

Plant residue decomposition rates in soils have been shown to be increased and decreased in the presence of living roots and their exudates (Bottner et al. 1999; Jenkinson 1977; Shields and Paul 1973). Living roots also have been shown to promote the conservation or mineralization of native soil organic matter (SOM) (Cheng 1999; Cheng et al. 2003). Plant effects on soil water status and N availability may partly explain many of the contradictory results from greenhouse and field studies. The actual mechanisms involved, however, are still elusive.

Microorganisms mediate decomposition and humification processes in soil. A recent review of the effect of living roots on SOM turnover emphasized that the diversity of the microflora present at all stages of interaction comprise a critical unknown in the process (Dormaar 1990). Our current understanding of how belowground life (living roots/microbial communities and their activities) controls decomposition and humification processes remains extremely limited.

In this Kearney project, we developed a quantitative road map of the flow of C from plant roots to soil microorganisms to humic materials. The impact of living roots on the pathways and outcomes of humification and the effects of microbial community composition and activity will be quantified. A better understanding of the mechanisms involved in the effects of living roots on C dynamics in soil will enhance the development of management strategies that increase C sequestration rates in grasslands and agricultural ecosystems.

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