Carbon Flow from Roots to Microbes to Soil Humic Substances

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Introduction

Plant residue decomposition rates in soils have been shown to be increased and decreased in the presence of living roots and their exudates. Living roots also have been shown to promote the conservation or mineralization of native soil organic matter (SOM). 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 (Fig. 1). 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 below-ground life (living roots/microbial communities and their activities) controls decomposition and humification processes remains extremely limited.

In this Kearney project we are developing 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.

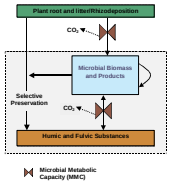


Fig. 1. Humification processes in soils begin after the initial phase of residue decomposition and transformation. Decomposition is driven by activity of microorganisms and their enzymes. The conceptual model depicts the microbial community control of humification processes through the incorporation of an array of microbial products as SOM precursors and their metabolic capacity (MMC), which we define as the utilization and resynthesis of C, turnover of the biomass, and loss of C via CO_2.

Research Questions

This research project asks how:

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

Approach

We are using a ^{13}C tracer approach to follow the fate of C in the root system of *Avena barbata* (wild oats) and to determine the effects of

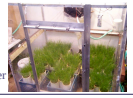
√ **Living roots (with and without subsequent crops of wild oats)**

√ **Nitrogen availability (with and without added N)**

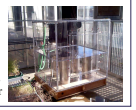
Experimental Design: 2 x 2 factorial design with 3 replicates
Soil moisture is continuously monitored using dielectric constant moisture probes and will be maintained at a constant water content of 60% of field capacity during the treatment periods.

- **In Fall 2002, soil from the Schubert watershed at the Sierra Foothills Research and Extension Center, located 30 km east of Marysville, CA, was excavated from a Oak Woodland ecosystem. Wild oats are the dominant grass species (80%).**
- **The soil was sieved (6-mm screen) and packed into eighty-eight 10 cm x 30 cm PVC cylinders to a bulk density of 1.21 g cm^{-3} (field bulk density).**
- ***A. barbata* seeds were planted using a seed density of ~24,000 seeds m^{-2}, similar to field densities. Plant labeling with $^{13}CO_2$ began when plants were 3 weeks old, using 8-hr exposures to the labeled atmosphere. A 10% ^{13}C enrichment of CO_2 automatically re-supplied the plant-induced CO_2 drawdown to maintain limits of 375-402 ppm CO_2 in the chamber. The plant labeling was carried out at UC Davis.**
- **A climate controlled ^{13}C labeling chamber was constructed at UC Berkeley to complete the plant labeling.**

Oats in UCD chamber



UCB labeling chamber



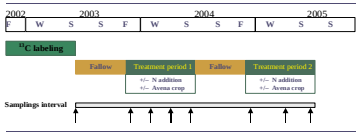


Fig. 2. Timeline of activities. After the ^{13}C enriched oats production, the above-ground biomass was removed and the pots were exposed to a dry, warm summer fallow. The initial treatments were applied in Sep. 2003. The N treatment is a split application of urea-N added 3 and 8 weeks after germination (20 kg N ha^{-1} total). Pots will be excavated periodically and the soil analyses listed below will be conducted.

Soil Analyses

- **Total ^{13}C in recognizable root debris (> 2 mm) and bulk soil (< 2 mm)**
- **Light fraction ^{13}C and N (density fractionation)**
- **Humic, fulvic and humin fraction ^{13}C**
- **Microbial biomass ^{13}C and N (CFE)**
- **Microbial ^{13}C in community groups (PLFA)**
- **Inorganic N (K_2SO_4 extractable)**

Results

Table 1. Selected biochemical and physical soil properties (0-9 cm soil depth).

Soil property						
pH	Total C	Total N	Mineralizable C	Mineralizable N	Nitrification potential	Bulk density
	g kg^{-1}		kg ha^{-1}		mg N kg d^{-1}	g cm^{-3}
5.42	25	2.5	320	9.6	5.70	1.21

- **Soil used for this study is an Argonaut silt loam (Mollic Haploxeralf).**
- **Research from this site suggests that both microorganisms and wild oats are a significant sink for nitrate, leading to low extractable nitrate levels during the Fall and Winter grass growing season (Herman et al., 2003).**
- **During the Fall and Winter, N limitation may affect the efficiency of decomposers and reduce decomposition of the previously produced roots and/or increase native SOM N mineralization. The N fertilization treatment tested here, may shed light on this potentially regulating factor.**

Table 2. 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	biomass	N	C	C:N	^{13}C
g m^{-2}		g kg^{-1}			‰
1617	637	8.6	318	37	1888

- **Uniformly ^{13}C–labeled *A. barbata* root material was highly enriched in ^{13}C (1888 ‰) after soil dry-down in June 2003, enabling long-term monitoring of C fluxes in labile and recalcitrant pools over time.**
- **Bulk soil (> 2mm) was enriched in ^{13}C (55 ‰), reflecting new C contributed from root exudates and root turnover during the growing season.**
- **Light fraction ^{13}C extracted from the bulk soil (< 2 mm) (430 ‰) was less enriched than roots but more enriched than the total bulk soil.**

Table 3. Microbial biomass C, N, and ^{13}C enrichment of bulk soil (< 2 mm) (N=4).

Microbial biomass				
PLFA	CFE			
C	N	C	^{13}C	C:N
kg ha^{-1}			‰	
102	118	854	320	7.2

- **Microbial biomass size measured by both PLFA and CFE was relatively high for a soil with 5% SOM concentration.**
- **^{13}C enrichment of the microbial biomass was similar to that of the light fraction and more enriched than the bulk soil in June 2003 just after the production of the labeled oats.**

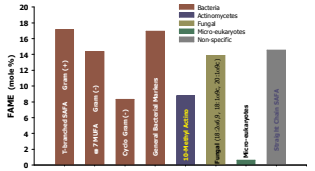


Fig. 3. Mole fraction of selected phospholipid fatty acids (PLFA) extracted from soil prior to establishment of wild oat crop.

- **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 will be quantified among broad cell-type groups.**
- **The Argonaut soil has a relatively high PLFA-defined fungal:bacterial ratio of 0.29.**

Future Research Direction

We are considering two additional methods to further define changes in the composition and activity of the soil microbial communities due to the presence of living roots and to complement the ^{13}C-PLFA analysis.

- **Soil C and N enzyme activity assays**
- **T-RFLP analysis of community DNA extracted from soil in conjunction with ^{13}C-DNA analysis.**

References

Dormaar, J.F. 1990. Effect of active roots on the decomposition of soil organic materials. Biol. Fertil. Soils. 10:121-126.

Herman, D.J., Halverson, L.J., and M.K. Firestone. 2003. Nitrogen dynamics in an annual grassland: oak canopy, climate and microbial population effects. Ecol. Appl. 13:593-604.