Dissolved Organic Matter Controls on Terrestrial Carbon Sequestration and Export in Contrasting California Ecosystems

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1. Introduction

The soil carbon cycle is commonly characterized by photosynthetic inputs of carbon by plants balanced by heterotrophic respiration of accumulated soil humic substances. The role of leaching in decomposition, transport, stabilization and loss of soil organic matter is rarely represented in conceptual or numerical models of belowground carbon cycling. This is despite the fact that leaching is known to be a dominant mechanism of transport and loss of numerous mineral and nutritive elements in humid forest soils. The relative importance of dissolved organic carbon (DOC) in these processes will depend largely on the hydrologic conditions of the soil, the chemical nature of the organic matter, and the edaphic properties of the soil.

We are conducting a detailed study of DOC dynamics in two contrasting coast California ecosystems: 1) a second-growth Redwood-Douglas Fir dominated swale in the Jackson State Demonstration Forest, Mendocino County, and 2) a grassland-coastal shrub dominated swale in the Tennessee Valley, Marin County. The amounts, fluxes, and residence times of total soil C, DOC and CO_2 are being examined using chemical, isotopic, and hydrological analyses.

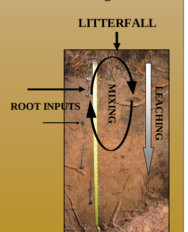
Caspar Creek, Mendocino
Typic Haplohumults
Redwood and Douglas fir forest
MAT = 11°C MAP = 1190 mm

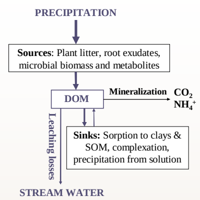
Tennessee Valley, Marin
Lithic à Oxyaquic Haploustolls
Mixed coastal shrubs and grasses
MAT = 14°C MAP = 760 mm

2. Distributing carbon within a soil profile

- •How important are DOC fluxes in determining the C distribution within a soil profile?
- •How do the concentration, composition and age of DOC change as it moves through the soil?

Root turnover and exudation represent direct inputs of C within the soil profile, while C originating from litterfall can be incorporated into the mineral horizons by 1) leaching of DOC and 2) biological and physical mixing of the soil. In a typically fertile and non-acidic grassland soil with a large NPP allocation to root production, DOC leaching may be a minor component. In contrast, coniferous forests concentrate roots in the surface horizons and production is returned to the soil as acidic litterfall, leading to distinct soil horizonation. Under these conditions, we would expect DOC to play a much greater role in C allocation.



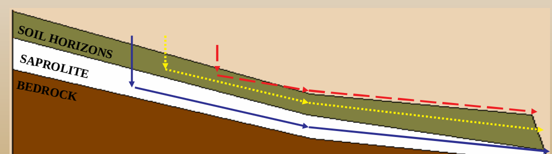


The 3 main sources of DOC are fresh litter, microbial biomass and humus, whereas sorption reactions and microbial decomposition are the primary mechanisms of removal. There is still an active debate over whether most DOC originates from fresh litter or from microbial products and more humified material deeper in the O horizon. As DOC percolates through the soil profile it is continually interacting with mineral surfaces and being degraded by microorganisms. Following this logic, we can hypothesize that DOC will become progressively more recalcitrant and have an older radiocarbon signature with increasing soil depth.

3. Catchment scale carbon fluxes

- •How important are DOC fluxes in transporting C to hollows?
- •How much C is lost annually as DOC flux from a small source area? How much as CO_2?
- •How do the concentration, composition and age of DOC vary with hydrologic flow path?

Estimated to be 0.6 PgC yr^{-1} or about 1% of annual NPP, DOC fluxes are a key link between terrestrial and aquatic ecosystems in the global carbon cycle. Much of this DOC originates from rainfall percolating through the soil of small, unchanneled valleys at the heads of channels. Montgomery and Dietrich (1995) found that at the Tennessee Valley site there are three distinct hydrologic flow paths: 1) Throughflow, 2) Macropore flow, and 3) Saturation overland flow. Based on these hydrologic observations, the following hypotheses regarding carbon dynamics can be drawn:

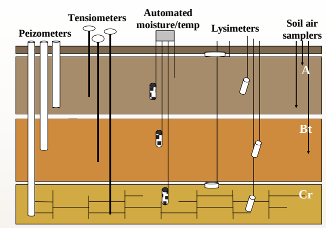


1. **Throughflow** transports C from the organic-rich surface soil deep into the subsurface horizons where it is sorbed to clay minerals resulting in low DOC concentrations entering the stream network.
2. **Macropore flow** picks up DOC in the surface soil and rapidly transmits this load to the channel head resulting in higher DOC concentrations entering the stream network.
3. **Saturation overland flow** will have the lowest DOC concentration due to the short contact time with soil organic matter before entering the stream network.

These differing flow paths also have implications for the chemical recalcitrance and age of the DOC that is entering the channel network. During throughflow conditions, the water takes a slow tortuous path through the clay-rich B horizon where there is ample opportunity for exchange on mineral surfaces. Fitting with our progressive alteration hypothesis, the DOC emerging at the channel head would be older and composed of more resistant and more degraded organic compounds. During times of macropore and saturation overland flow, we would expect the DOC entering the channel network to be composed of younger and more labile organic compounds because the water is flowing along a pathway that avoids most of the removal mechanisms.

4. Field methods

At each site, 4 plots are being established – 2 on the hillslopes and 2 in the hollows – with the pictured array of instruments. Unsaturated flow will be evaluated by installing tensiometers to measure soil-water potential or pressure head (h) and soil moisture sensors to measure water potential (Ψ). Saturated soil zones will be measured using a series of peizometers.



Rainfall, throughfall, soil solution, stream water, soil gas and soil CO_2 efflux will be collected on a regular basis throughout the year with more intensive sampling during an early and late season storm cycle.

5. Laboratory Methods

Method	Information gained	Hypotheses tested
^{13}C, ^{15}N and C/N ratio	Indexes of decomposition	**SOC** – progressive modification **DOC** – reflects OC source, shift with depth
^{14}C	Turnover time of SOC	**SOC** – τ increases with depth, pool and soil age
	Age of DOC and CO_2	**CO_2** – recent/labile C mineralized **DOC** – reflects OC source, older with depth
Fractionation	Distribution of C among distinct SOC[a] and DOC[b] pools	**SOC** – shift from labile to more recalcitrant C with depth **DOC** – HiA are enriched relative to HoA and all Neutrals with depth
^{13}C-NMR	Overall C composition of fractions and bulk samples	**SOC** – shift to more recalcitrant components with fraction and depth **DOC** – increase in recalcitrant components HiN < HoN < HoA < HiA
Sorption kinetics	Rate and percent of DOC sorbed to soils	**DOC** – high sorption/low desorption in clayey soil, high sorption and desorption (?) in SOM-rich soil

[a]SOC fractions by density and chemical separation
[b]DOC fractions by exchange resin – Hi = hydrophilic; Ho = hydrophobic; A = acid; N = neutral (bases are minor)

5. Conclusions

Currently, the importance of DOC in the overall C balance of an ecosystem is almost completely unknown. By examining DOC and CO_2 fluxes at the soil profile and catchment scales, we have a powerful opportunity to advance our mechanistic understanding of belowground C cycling.

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