Microbial physiology is an important control on soil respiration

Including microbial physiology response to temperature and substrate diffusion improves model predictions of soil respiration

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Key points

* Empirical functions of temperature and soil moisture alone cannot predict rapid changes in soil respiration
* Model predictions of soil respiration are improved by including a microbial biomass pool
* The model developed here is a general and parsimonious representation of C and N cycling in soil

# Abstract

Microbial populations are important agents of C and N mineralization in the soil. Soil organic matter can be broken down into monomers by extracellular enzymes and taken up into microbial biomass, where a portion of that matter is eventually mineralized as carbon dioxide or inorganic nitrogen. Most soil decomposition models, including those in earth system models, predict mineralization rates using empirical relationships with soil temperature and moisture, omitting microbes entirely. Though soil temperature and moisture explain a majority of the variation in C efflux measurements, linear combinations of temperature and moisture cannot predict rapid changes in soil C efflux, especially following wet-up events.

After wet-up events, drought-depleted microbial populations grow quickly, creating a positive feedback between increased substrate availability and microbial activity. We found that including a time-dependent microbial biomass pool improved predictions of soil respiration in a mid-latitude forest. The model developed here incorporates Arrhenius and either Michaelis-Menten kinetics or Equilibrium Approximation Kinetics to determine the effects of temperature and substrate availability on uptake and depolymerization rates, respectively. Microbes allocate substrate to enzyme production and biomass growth depending on the stoichiometry of the monomers that are taken up. Carbon and nitrogen cycling are explicitly tracked, and may be used to predict both C and N pools and fluxes.

Keywords: soil, modeling, decomposition, respiration, microbes

microbial physiology, C cycling, N cycling, diffusion

# Introduction

Soil microorganisms cycle C and N through the biosphere (REF Schlesinger), incorporating these elements into cellular materials that are eventually mineralized into carbon dioxide (CO2) and inorganic nitrogen (N). The rate of C and N mineralization is often correlated with changes in temperature and precipitation, and from this relationship one can construct an empirical relationship between soil temperature, moisture, and mineralization rates (Rodrigo et al., 1997). Empirical soil temperature and moisture functions are used in earth system models for the purpose of predicting future mineralization rates under global change scenarios (Parton et al., 1987). Some models consider the kinetics of substrate and/or enzyme concentration in the soil in order to constrain mineralization rates using a variety of kinetic approximations (e.g., Michaelis-Menten, Reverse Michaelis-Menten, Equilibrium Chemistry Approximation; Tang et al., 2015).

Recent studies have demonstrated that soil decomposition models, and those coupled to earth system models in particular, perform poorly using only empirical relationships with no mechanistic representation of microbial activity (Todd-Brown et al., 2013; Wieder et al., 2013, 2015).

Models that represent microbial physiology commonly conflate soil organic matter (SOM) decomposition with microbial uptake and mineralization, or make the simplifying assumption that these rates are identical (MIMICS, CORPSE).

Many models ignore the role of N in regulating C mineralization and vice-versa (REFS). Some use soil N concentration to empirically modify mineralization rates (REFS), while others do not consider N (Allison et al., 2010; Sulman et al., 2014; Wang et al., 2013). Microbes utilize C and N in plant litter and root exudates, as well as free monomers that have been cleaved from polymeric soil organic matter by extracellular enzymes ([Brzostek & Finzi, 2011](#_ENREF_6), [Frey *et al.*, 2013](#_ENREF_18)). Plant input and soil organic matter C-to-N ratios (C:N) range from # to #, and are significantly higher than that of microbial biomass (8-15) and extracellular enzymes (~3; REFS). As a result, microbial populations are often N-limited. This may explain why an increase in C-rich plant inputs can induce microbial population growth and nutrient limitation, which results in the production of extracellular enzymes that decompose SOM (i.e., priming; Brzostek et al. 2013, Kuzyakov, 2010).

Our objective is to develop a coupled C-and-N model that is as parsimonious as possible but can capture rapid changes in soil respiration due to wet-up events. We do this by building in complexity from simple empirical relationships to a semi-mechanistic model (DAMM) to a mechanistic microbial physiology model that integrates temperature, soil moisture, and substrate stoichiometry over time with updating C and N pools. We test different model structures against a common dataset of bulk soil respiration measurements collected at Harvard Forest during the growing season of 2009.

We discuss parametric sensitivity of the final model, the affect of different kinetics assumptions, and implications of coupling the C and N cycle.

# Methods

2.1 Model Descriptions

2.1.1 Empirical regression

2.1.2 Dual Arrhenius and Michaelis-Menten Model

2.1.3 DAMM and the Microbial Carbon and Nitrogen Physiology Model

2.2 DAMM-MCNiP model Performance

2.3 Empirical data

2.3.1 C efflux data

2.3.2 Root input data

2.4 DAMM-MCNiP priming test

# 3. Results

# 4. Discussion

# 5. Acknowledgements

# 6. Figures

1. Abstract
   1. Take home: Need to model substrate supply and microbial pools in order to represent seasonal C fluxes.
      1. Tried with various temperature relationships, empirical temp and moisture relationships, doesn’t work. Need updating pools.
      2. I can see why a function is more attractive, easier to fit etc, but necessary to have updating pools.
      3. MCNiP adds inertia.
2. Intro
   1. C important, substrate supply is important
   2. Birch effect theory – fast pulse after rain
   3. Important to represent diffusion constraints on substrate supply, even in a relatively wet ecosystem such as HF.
3. Methods
   1. Short description of HF data collection (include Kathleen?)
      1. Soil respiration
      2. Litter inputs and C:N (archive)
      3. Root exudates & turnover (me)
   2. Model equations
   3. Model diagnostics
      1. How sensitivity analysis
         1. SOBOL
         2. GLUE
   4. Model run lengths, spin-up, defaults
      1. Fake soil moisture data, timeline of response to pulse
         1. We isolated the first rain event of the year on DATE, and repeated it 1-4 times.
         2. We ran the model under idealized dry conditions (vwc = 0.15) and pulsed the same volume of water into the soil either in one slow pulse, or in 4 fast pulses within a weeklong span to test the affect of rain frequency on DOC accumulation.
            1. with soil moisture reaching a maximum over 2 days and diminishing to a minimum after 6 days. We repeated this pulse 1-4 times.
      2. Damm & damm-mcnip comparison
4. Results
   1. Model diagnostics
      1. **Activation energy is very important (in all models)**
   2. Fake moisture run (run all models, esp. damm and dmc)
      1. Need DAMM to respond to water
      2. Need MCNiP to “remember” growth induced by water
      3. Figure(s)
         1. **Track DOC**
         2. **Mic**
         3. **SOC**
   3. Model comparison with HF data
      1. **Comparison figure**
      2. **Regression/residuals figures?**
   4. Priming demo (will this fit?)
      1. Potential application of model
      2. **Priming figure that is now pulse change in C:N**
5. Discussion
   1. Model diagnostics & fake moisture run
      1. Parsimonious
      2. Activation energy important in all models
      3. Decomposition is major control on downstream processes such as uptake and respiration, implying that the representation of these processes could be simplified.
   2. Model comparison and priming demo
      1. Model sensitivity to soil moisture better in dmc compared to damm
         1. Need to model soil efflux
      2. Including N brings down C efflux due to limitation
      3. Something about N pulse experiment.
   3. Conclusions and Implications
      1. We developed simple model with water, temp, microbes, N
      2. Needs
         1. Recycling N pool
         2. Plant coupling
         3. Minerals
         4. Parameter estimation
      3. Flexible, easy to use, requires only temp, moisture and inputs.
      4. No oscillations?

\*\*\*Try instead of priming figure:

1. Steady state SOC at different temperature values/soil moisture values/C:N
2. CUE?
3. Can make flying carpet if need

\*\*\*After model comparison figures, before priming

1. Model root litter decomposition?
2. Model leaf litter decomposition?
3. Model variation in C efflux due to variation in root exudates measured over the year (is the range in C efflux right?)

\*\*\*Before model comparison figures

1. Compare linear regression based models using temp and moisture scalars (a la other ESMs) to show that they can’t reproduce C efflux measurements.
   1. Find the paper that Bill Riley sent me about this.
      1. Found it, now do some lit search to supplement (find more and more recent equations).
      2. Century (parton et al 1987 sssaj), Roth, Daycent, CLM-cn (Bonan et al 2013 GCB)