Microbial resource limitation: Enzyme dynamics, nitrogen, and the implications for C cycling

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Introduction & theoretical basis

Soil organic matter turnover almost invariably use 1st order decomposition kinetics:

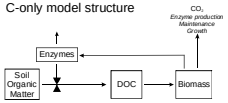
dC/dt = k * C

Such models assume:

1. You can exclude the "agent" of decomposition (microbes and their enzymes) in describing decomposition kinetics.
2. C is the limiting factor in decomposition kinetics.

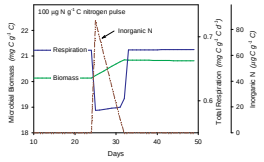
To explore these assumptions, we developed a simple model that allowed decomposition to be a function of enzyme concentration, as well as substrate. At high substrate C/N ratios, N availability limits microbial biomass, and excess C is respired.

C-only model structure



*Decomposition = k * SOM * Enz*

Effect of adding N to an N limited microbial system



The results of this model indicate that evaluating limiting resources to microbes is more complex than has traditionally been thought:

Adding C to soils will always increase respiration-
- If microbes are C limited, adding C stimulates growth
- If microbes are N limited, adding C stimulates waste metabolism

Adding N to an N limited soil could actually decrease respiration by shifting C flow from waste metabolism to microbial growth. This should be seen in increases in microbial biomass and substrate use efficiency.

We have been carrying out a variety of experiments to evaluate some of the predictions of the exo-enzyme based decomposition model. One experiment is to evaluate the effects of C and N additions to soils that represent a gradient of resource limitation from apparently C limited to apparently N limited (based on prior research).

Status	Soil	Environment	%C	%N	C/N ratio
C-limited	Sedgwick	California Grassland	2.7	0.25	11
Balanced	Sierra	Sierra conifer	13	0.47	28
N-limited	Tussock	Alaskan tussock tundra	48	0.74	64

Treatments

C source: powdered cellulose
Low C = 15 d of basal respiration-C as determined in pilot study
High C = 5 times Low C

N source: $(NH_4)_2SO_4$
Low N and High N = 1/50th of C additions (gN/gC)

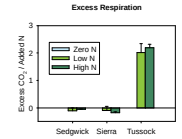
Incubate two weeks at 20 °C.

Soil	Low C (mg/g)	High C	Low N (µg/g)	High N	Low C/ Total C (%)	LowN/ Total N (%)
Grass	0.6	2.9	11	55	2.1	0.5
Conifer	3.5	17.5	70	350	2.7	1.3
Tundra	5.4	27.0	107	535	1.1	1.1

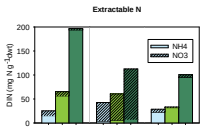
Measurements

Respiration
Extractable NH_4^+ and NO_3^-
Microbial biomass C and N (fumigation extraction)
Microbial biomass C (SIR)
Substrate use efficiency:
^{14}C-succinate labeled on C2,3
Ratio of incorporated to respired ^{14}C
Cellulase activity potential.

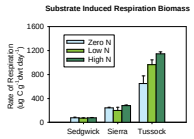
Responses to N addition



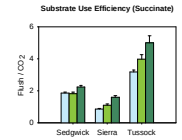
Adding N stimulates respiration in N poor soil. Slightly decreases respiration in richer soils.



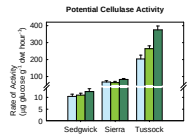
Adding N increases inorganic N pools. Only nitrifies in Sierra soil



Adding N increases SIR biomass in N poor soil only



Succinate SUE increases with N additions in N poor soils: suggests basal respiration is "waste" metabolism



Adding N increases cellulase in N poor soil BIOMASS Correlation?

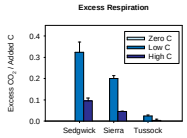
N addition data support model predictions: microbes show signs of C saturation at the N poor side of the gradient.

Sedgwick (C poor/N rich): Adding N has no effect.

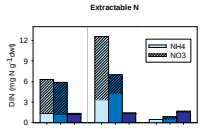
Sierra (moderate): Adding N slightly decreases respiration but increases biomass and SUE: C is diverted from waste respiration to biomass production.

Tussock: (C rich/N poor): Adding N shifts up all aspects of the decomposition system- even exoenzyme synthesis is N limited.

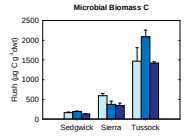
Responses to C addition



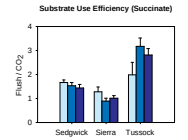
The relative response to C addition declines from the most to least C limited soil



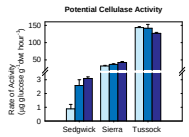
Adding C induces N immobilization, as expected



Biomass C is relatively unresponsive to C addition. This is surprising, but CFE biomass is insensitive to small changes and increased growth could be balanced by increased turnover



Succinate SUE does not respond strongly to increased C availability. However, in the C poor sites, there is some decrease in SUE as would be expected- alleviating a limitation should decrease use efficiency



Cellulase responds to cellulose additions in the C limited soil but not in the C rich soil

C addition data are less clear: biomass doesn't respond to C additions under C limited conditions, yet most of the data do support model predictions.

Sedgwick (C poor/N rich): Adding C stimulates respiration and cellulase, slightly decreases SUE, but doesn't affect biomass.

Sierra (moderate): Adding C stimulates respiration and may slightly decrease SUE, but doesn't stimulate cellulase or biomass.

Tussock: (C rich/N poor): Adding C has substantially no effect.

Sedgwick Reserve annual grassland

Overall Conclusions:

C flow to microbes and the effects of resource limitation are not as simple as traditional models have predicted.

Increases in respiration alone are not adequate to evaluate which resource limits soil microbes: microbes will process and respire simple dissolved compounds, even if they can't use them for building biomass.

Limitation must be assessed through changes in microbial growth and substrate use patterns.

Soil microbes can be so limited by N that even the pools of exoenzymes are constrained by N availability, producing C saturation.

Arctic tussock tundra