Mechanisms for seasonal patterns in NH_4^+ and NO_3^+ consumption in semiarid sagebrush and cheatgrass soils

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Abstract:

Changes in the quantity and quality of plant detrital inputs may be an important mechanism controlling soil C and N dynamics in sagebrush rangelands affected by annual grass invasion. However, seasonal patterns in environmental conditions may also affect soil C and N availability. We investigated the response of soil NH_4^+ and NO_3^- consumption rates to stimulated substrate pools across a seasonal gradient of soil moisture. Soil mesocosms were collected beneath cheatgrass and sagebrush vegetation, and were planted with cheatgrass, incubated in the field, and harvested five times over 17-months. Soil C and gross N cycling rates were determined on intact cores during 72-h laboratory incubations.

Soil moisture content ranged from 9 to 28% across sampling dates, and strongly affected C and N cycling rates. C mineralization rates and microbial biomass increased with soil moisture from summer to autumn, while C mineralization rates further increased in spring – possibly resulting from microbial turnover of plant rhizodeposits. Gross rates of NH_4^+ production and immobilization were significantly greater in spring than in summer or autumn, consistent with greater C availability. Gross rates of NO_3^- cycling, on the other hand, were insensitive to seasonal variation, although both NO_3^- production and consumption rates were relatively more important components of N cycling during autumn than in summer or spring. The relative increase in both nitrification (in low C-availability microsites) and NO_3^- consumption (in high C-availability microsites) from summer to autumn suggests that there is an important temporal component to microsite heterogeneity.

Both NH_4^+ and NO_3^- consumption rates were significantly related to production rates (r^2 = 0.72 and 0.60, respectively), indicating that cycling of both N-forms were well-coupled, and that consumption rates were likely limited by substrate availability. However, comparisons of ^{15}N-stimulated versus unstimulated NH_4^+ and NO_3^- assimilation rates reveal that microbial N immobilization was not always substrate-limited. First, $^{15}NO_3^-$ addition had no significant effect on NO_3^- consumption rates, regardless of season. Second, the fate of mineralized NH_4^+ (to nitrification or microbial NH_4^+ assimilation) in response to $^{15}NH_4^+$ additions differed strongly among seasons. In summer and autumn, $^{15}NH_4^+$ addition significantly stimulated nitrification rather than assimilation rates. In spring, the reverse was true. These results suggest that seasonal patterns of soil moisture, C availability, and plant activity have complex effects on the rates and controls of soil N transformations in semiarid ecosystems.

Methods

- Soil mesocosms (25-cm diameter x 34-cm tall steel cylinders) were collected intact from soils beneath Cheatgrass (*Bromus tectorum*) and Sagebrush (*Artemisia tridentata* subsp. *wyomingensis*) vegetation, and grown with ^{13}C-labeled cheatgrass in a greenhouse as part of a larger study
- Mesocosms were returned to the field in early summer 2004 (mid-June), and 2 mesocosms per soil type were harvested five times over the next 17-months
- Soil C and gross N cycling rates were measured daily from intact soil cores (3.5-cm diam. x 10-cm tall) during 72-h laboratory incubations
- Gross N cycling rates were determined using ^{15}N isotope pool dilution methodology

Soil cores received 1 of 3 solutions:

1. $(^{15}NH_4)_2SO_4$ ⟶ **Gross N Mineralization**
   (3.0 mg N/kg was added which increased initial pool sizes by 160%)
2. $K^{15}NO_3$ ⟶ **Nitrification**
   (NO_3^- pools fluctuate seasonally, 1.9 to 7.5 mg N/kg added, increased initial pools by 78 to 400%)
3. Dilute K_2SO_4 ⟶ **Un-stimulated net rates**
   (ionic strength equal to average of $^{15}NH_4$ and $^{15}NO_3$ solutions)

- Gross N consumption rates were calculated from the difference of gross and net production, e.g.:

NH_4 consumption = N mineralization - net ammonification (1)

NH_4 assimilation = NH_4 consumption - nitrification (2)

N immobilization = N mineralization - net N mineralization = NH_4 assimilation + NO_3 consumption (3)

- ^{15}N additions may stimulate consumption rates, if N availability limits process rates.
- Stimulated and Un-stimulated rates calculated using net rates with and without added ^{15}N.
- Stimulated nitrification rates determined by tracing added $^{15}NH_4$ into the NO_3^- pool

Objective:

- **Investigate whether seasonal changes in soil moisture and C availability affect N-cycling processes in semiarid rangeland soils**
- **Previous work suggests that:**
  1. **Soil moisture regulates C availability**
  2. **Microbial inorganic N immobilization is limited by NH_4-availability**

? Is this pattern consistent across seasons ?

We hypothesize that microbial NH_4 assimilation rates will be stimulated by NH_4 addition, and the stimulation-response will increase with seasonal changes in soil moisture and C availability.

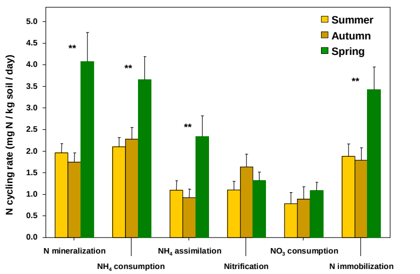
Table 1. Field conditions during study

Sampling Date	Temperature (C) Air	Temperature (C) 10-cm soil	14-day PPT	Soil H2O	NH_4^+	NO_3^-	Season
8/2/04	23.0	20.6	< 0	0.07	1.9	4.8	Summer
11/8/04	7.5	6.8	32.6	0.18	1.3	0.8	Autumn
5/8/05	10.3	12.8	53.6	0.25	2.2	0.5	Spring
9/5/05	22.0	24.6	< 1	0.04	1.9	6.2	Summer
11/19/05	-0.6	2.1	~ 30	0.13	2.0	5.0	Autumn
			mm	g H_2O / g soil	mg N / kg soil		

Table 2. Mean Soil C cycling rates

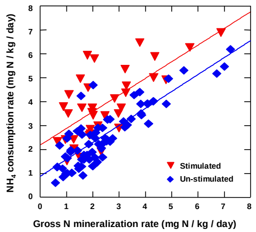
	Summer	Autumn	Spring
Soil H2O (g H2O / g soil)	0.10 C	0.21 B	0.26 A
Microbial Biomass C (mg C / kg soil)	274.5 B	429.5 A	471.2 A
C mineralization rate (mg C kg soil^{-1} day^{-1})	11.1 C	23.1 B	40.2 A

Seasonal patterns of gross N cycling



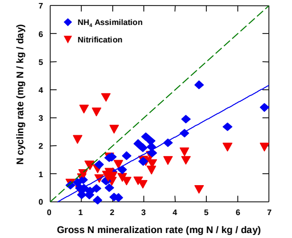
- **Soil C availability (as microbial biomass and C mineralization rates) increased with soil moisture**
- **Higher C mineralization rates in Spring vs. Autumn may be due to turnover of plant rhizodeposits**
- **NH_4 production and consumption rates were significantly higher in Spring than Summer or Autumn**
- **NO_3^- production and consumption rates did not differ among seasons, but were important components of N-cycling in these soils - particularly in Autumn**

NH_4^+ was tightly cycled in these soils



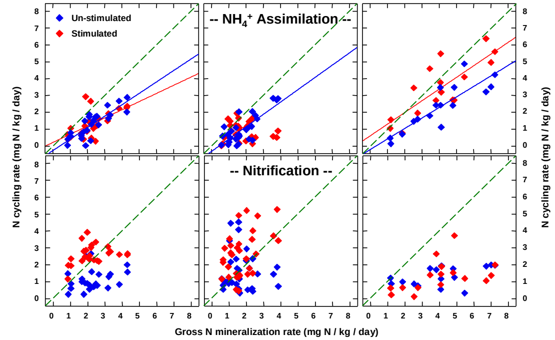
- **NH_4^+ consumption was tightly coupled to N mineralization** (r^2 = 0.71, slope = 0.69, $p<0.0001$)
- **NH_4^+ production-consumptionrelationships did not differ seasonally** (p=0.37)
- **NH_4^+ consumption was stimulated by $^{15}NH_4^+$ additions** ($p<0.0001$, slope = 0.70, shown in red)
- **Microbes appear to be NH_4^+ limited**

Variation in NH_4^+ assimilation and Nitrification vs. gross N mineralization



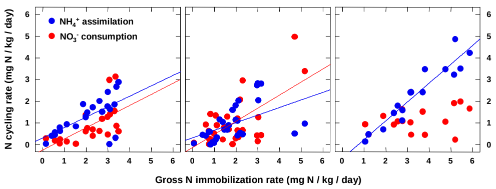
- **NH_4^+ assimilation tightly coupled with N mineralization** (r^2 = 0.75, slope = 0.64, $p < 0.0001$)
- **NH_4^+ production-assimilation relationships did not differ seasonally** (p = 0.85)
- **Nitrification rates did not co-vary with N mineralization** (p = 0.77, mean = 1.34)
- **Nitrification was a more important fate for mineralized NH_4 when N mineralization rates were low** (< 2 mg N / kg / day)

The fate of mineralized NH_4^+ shifts from nitrification to NH_4^+ assimilation as soil moisture and C availability increase



- **NH_4^+ Assimilation rates were coupled with N mineralization rates across seasons, while nitrification rates were not**
- **Nitrification rates appear to be substrate (NH_4^+) limited during Summer and Autumn**
- **NH_4^+ assimilation rates were substrate-limited *only* in Spring**
- **NO_3^+ consumption rates were not significantly stimulated by substrate addition** (data not shown)

Microbial immobilization of NH_4^+ versus NO_3^-



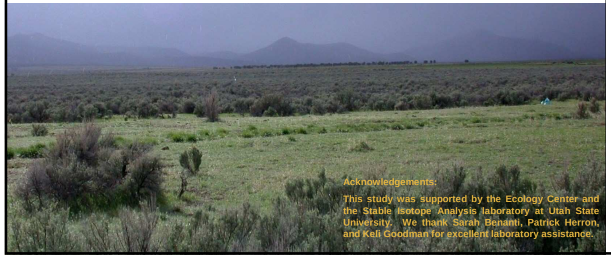
Mean source of N immobilized by microbes (% of N immobilization)

	Summer	Autumn	Spring
NH_4	63%	51%	68%
NO_3	37%	50%	32%

- The relative importance of microbial NO_3^- consumption to N immobilization is greater in Autumn than Summer or Spring
- This occurs at the same time that nitrification consumes a large proportion of mineralized N
- Since nitrification is presumed to dominate in low C-availability microsites, and NO_3^- consumption in high C-availability microsites, there may be a temporal component to the dynamics of microsite processes

The Bottom line:

1. Significant seasonal variation in soil C availability and gross N cycling rates was observed
2. Microbial NH_4^+ consumption and assimilation rates were tightly coupled with gross N mineralization, suggesting NH_4 limitation
3. However, NH_4^+ assimilation rates did not appear to be substrate-limited in Summer or Autumn, and were significantly stimulated only in Spring
4. In contrast, gross nitrification rates appear to be substrate-limited during Summer and Autumn
5. Our hypothesis that NH_4^+ assimilation rates would increase with soil C availability, and would be stimulated by added $^{15}NH_4^+$ was only partially supported
6. Seasonal patterns of soil moisture and C availability have complex effects on the controls of soil N transformations in semiarid ecosystems



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