2006-2011 Mission
Kearney Foundation of Soil Science: Understanding and Managing Soil-Ecosystem Functions Across Spatial and Temporal Scales
Final Report: 2006006, 1/1/2008-12/31/2008

Microbial and Hydrological Control of the N Flush at the Summer-Winter Seasonal Transition

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Objectives

The overall hypothesis of this project was:

> ***The amount of NO_3^- entering ground and stream water is controlled by the linkage between microbial processes that directly control nitrogen processing and hydrological processes that regulate nitrogen and water movement with the soil and within the catchment.***

To address this overarching hypothesis governing summertime processes and their ramification at the summer-winter transition we framed the following specific hypotheses.

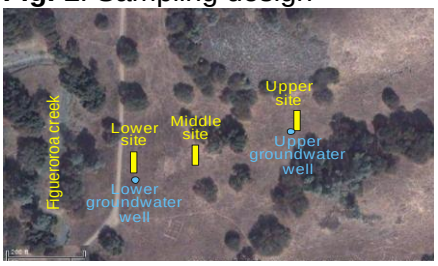
1. A large pool of bioavailable N accumulates in the soil over the summer as a result of microbial osmolyte production - an acclimation strategy for surviving the summer drought.
2. Nitrifier populations increase over the summer despite the breakdown in NH_4^+ supply that results from the loss of hydrological connectivity at the micro-scale.
3. The combination of a large pool of labile osmolyte N and an active nitrifier population allows a rapid flush of mineralization and nitrification at the dry season/wet season transition.
4. An abrupt seasonal transition will emphasize rapid surface flow and NO_3^- transport to streams. A slower transition will move a larger proportion of soil NO_3^- into shallow groundwater where it may be denitrified before it enters deeper water supplies or flows into streams.
5. Through the winter season, water tables will rise and the contribution of the groundwater to streamflow will increase. Because denitrification in shallow groundwater can be a significant NO_3^- sink, the older groundwater is, the more of its NO_3^- will have been lost.

Approaches and Procedures

We have carried out work to address all these hypotheses, although the drought we have been experiencing has limited our ability to fully evaluate the catchment scale hydrological issues.

In summer 2007, we established three sampling sites in a small side catchment to Figueroa Creek in the Sedgwick Reserve. In winter 2007, we established FDR soil moisture loggers, suction lysimeters at 20, 50, and 90 cm depths, plots for regular soil sampling, and we installed groundwater sampling wells at two locations (Fig. 1). To determine fungal turnover, we examined sequences of hyphal images recorded by a

Fig. 1. Sampling design



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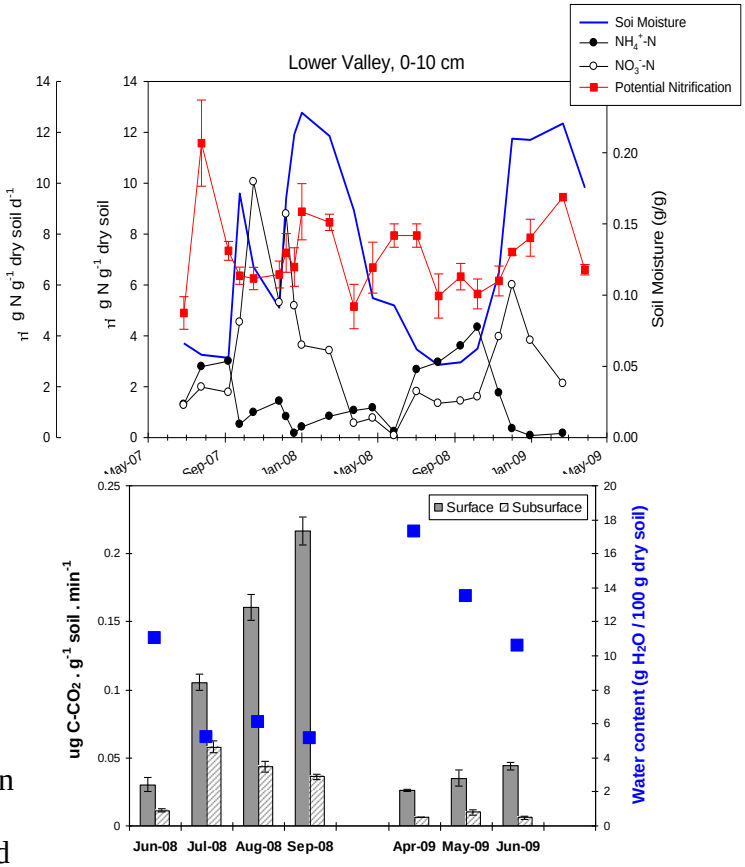
minirhizotron microscope. In April 2007, we installed 17 clear plastic 1-m long minirhizotron tubes at 45° angles to the soil surface in three plots of a Sedgwick grassland. We used a minirhizotron camera (BTC-100X, Bartz Technology, Santa Barbara, CA) to record images of mycorrhizal structures visible from the tubes on April 13, April 30, May 29, June 30, July 25, October 15, October 16, October 17, October 18, October 19, October 20, and October 21 2008. This model of minirhizotron camera is equipped with 100x magnification, and single hyphae are visible at these magnification levels.

The year 2008 was a primary year for analyzing patterns of microbial dynamics through an entire dry down—drought—rewetting, although this past winter was quite dry. During the year we focused our efforts on measuring the patterns of a) biogeochemical parameters, b) microbial osmolytes, and c) microbial dynamics. During the past year, we have perfected the analysis of amino acid osmolytes and have begun development of quaternary amines and polyols (slightly delayed by a postdoc's maternity leave).

Results

The basic summertime biogeochemical patterns have remained robust. Ammonium increases through the summer at the expense of NO_3^-, although nitrification potentials increase during the summer. However, with even very light rains, NH_4^+ is rapidly nitrified—in fact it is surprising how little additional moisture it takes to allow nitrifiers to access soil NH_4^+.

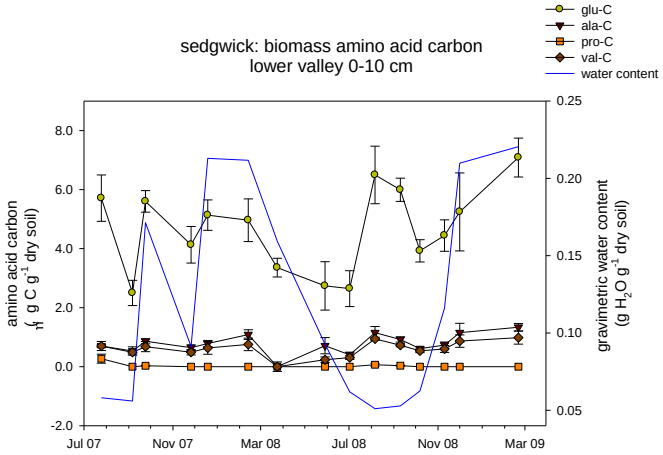
The patterns of nitrification potential are more complex than we had previously seen—there appears to be a double peak through the year. Potentials increase with the onset of summer but appear to decline later in the summer, only to increase again with the onset of the wet winter. The increase in winter makes sense as paralleling the overall increase in N turnover with the increase in soil moisture. The increase during the dry summer remains somewhat puzzling and the experiments to evaluate that are only beginning.

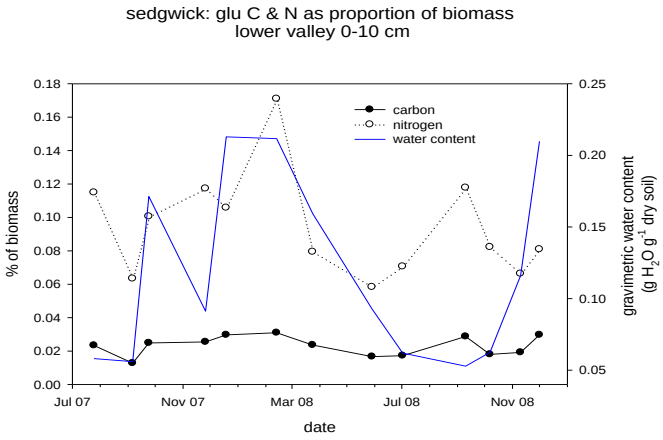


We measured the magnitude of the pulse of respiration on rewetting through the summer season. As soils dried, this increased, but continued to increase through the dry season. This is consistent with earlier work by Miller and Schimel showing an ongoing production of labile material under dry conditions. The question remains whether this increase in bioavailable C causes the increase in biomass over the season or rather, is a result of that increase. Is the respired C the hypothesized

loss of osmolytes? On the surface, this seems an unlikely explanation, as osmolyte concentration should be a function of the soil moisture, rather than of the time the soil has been dry.

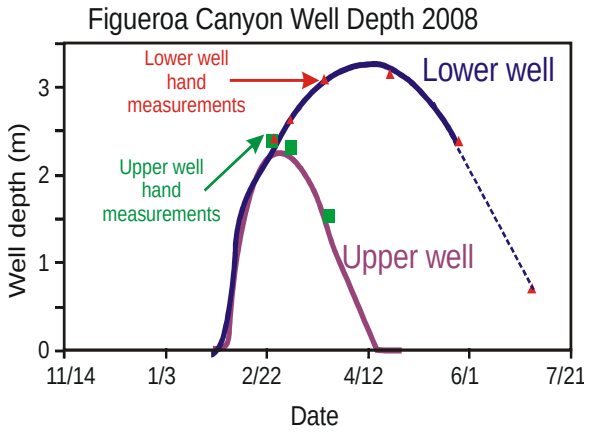
The biggest surprise in this research has been in the microbial osmolyte analyses. Much literature from pure culture suggests that many bacteria synthesize amino acid osmolytes (with proline a common one) and that they do it in response to water stress. That is unequivocally not the case in these soils (Fig. 3). There is no specific amino acid synthesis in response to water stress and proline is a minor component of the cellular amino acid mix. By far the dominant amino acid is glutamate and its concentrations are remarkably stable relative to microbial biomass. It is possible that betaines dominate the microbial osmolyte pool and that we have simply missed the story thus far. However, our current hypothesis is based on the fact that the microbial community in this soil appears to be dominated by gram negative bacteria, which tend not to use proline as an osmolyte and frequently produce osmolytes constitutively, maintaining high internal concentrations of amino acids through periods of both high and low water potential. This is a life history strategy that may reduce growth potential during "good conditions" when both water and resources are plentiful but which reduces the risk when soil moisture declines. Inducible production requires a major resource investment at the time of stress, when reduced moisture reduces diffusion and resource supply. Thus, the inducible strategy is a high-risk strategy that might be selected against in an environment where drought is common.

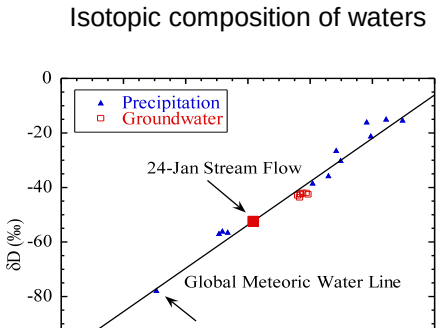




That amino acids appear to be constitutively produced suggests that the increasing respiration pulse through the dry season may not be microbial osmolytes, but Fierer et al. (2003) showed that the C released on rewetting comes from microbial biomass. Thus, these results appear to contradict each other. Resolving these issues becomes a major question for future research.

Developing the linkages between soil and groundwater dynamics, however, has been challenging because of the dry conditions. Initially, groundwater wells were dry even to 20 m depth. During the winter, however, the water table rose. Groundwater was relatively uniform with a $\delta^{18}O$ = -6.3‰, while rainwater $\delta^{18}O$ varied from –2‰ to –14‰, falling along the Global Meteoric Water Line. Because of the dry conditions, there was only one stream flow event we could analyze (24-Jan-08). The $\delta^{18}O$ of the creek water was –7.8‰ in $\delta^{18}O$, significantly heavier than the rain that caused the stream flow ($\delta^{18}O$ = -10.9‰). Thus, the stream was composed of at least two sources of water (event and pre-event waters—i.e. groundwater). The pre-event water had to have been isotopically light with mass balance calculations indicating that the stream flow was one third event and two-thirds groundwater.





Discussion

Fully evaluating the hydrological connection between surface soil and water systems was made challenging by the ongoing drought. Even though we worked in a watershed that had a stream that in earlier years ran perennially, we found only occasional streamflow and a water table that had retreated to extraordinarily low levels. We only found measurable groundwater during the wettest portions of the winter and then only at depth. Given the depths of the soil, and the challenges of achieving groundwater recharge, an important conclusion of this work is that the rooting zone and the deep vadose zone are likely disconnected from each other most of the time. Water that penetrates the surface soil early in the winter does not easily or quickly percolate to depth and thence to streams. Where the water entering the groundwater comes from remains a question. This supports aspects of our initial Hypothesis 4—a rapid onset winter is likely to have more impact via surface flow. Water and NO_3^- entering the soil profile is likely to be processed biologically in the soil—in the competition between biology and hydrology, biology wins.

The data surrounding Hypothesis 1 are core to this research and remain somewhat perplexing. The bioassay data all support the hypothesis—there is a flush of material released on rewetting and the magnitude of that flush increases with the length of time the soils are dry. However, we have not yet identified the nature of that material. It remains unclear whether the material accumulates outside microbial cells, as the result of exoenzyme activity or desorption and is then taken up and respired, or whether it is accumulated within the cells as osmotic agents

or storage compounds and then respired on rewetting, as we had hypothesized. The amino acid data were surprising.

This research was funded by the Kearney Foundation of Soil Science: Understanding and Managing Soil-Ecosystem Functions Across Spatial and Temporal Scales, 2006-2011 Mission (http://kearney.ucdavis.edu). The Kearney Foundation is an endowed research program created to encourage and support research in the fields of soil, plant nutrition, and water science within the Division of Agriculture and Natural Resources of the University of California.