

Synthesis Working Group Report

Soil Biogeochemistry: Synthesis of Past Data and Development of Protocols for a New Long-Term, Network-Wide Data Stream

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Summary

A working group met to discuss the need to synthesize existing data within the LTER network on nitrogen mineralization, nitrification, soil respiration and soil moisture and to develop protocols for a new tightly coordinated, network-wide effort to develop a long-term data stream on these variables. The workshop was held at the Cary Institute of Ecosystem Studies on March 5 – 6, 2013. This report describes two proposals for future work, one focused on synthesis of existing data and one on a program for new data collection going forward.

Introduction

Soil biogeochemistry is critical to ecosystem function and highly responsive to environmental change. Nitrogen mineralization and nitrification are key processes in the ecosystem nitrogen cycle and are critical controllers of net primary production, soil acidification and reactive nitrogen transport to water (nitrate) and air (nitrous oxide, nitric oxide). Soil respiration is a major pathway of carbon transport from ecosystems back to the atmosphere. Soil moisture is a critical regulator of these processes and is highly responsive to climate change. Indeed, the response of all these variables to environmental change is one of the key uncertainties in our ability to assess the trajectory of ecosystem structure, function and services in a changing world.

Many LTER sites have made measurements of nitrogen mineralization, nitrification, soil respiration and soil moisture but with widely varying protocols. There is thus a strong need to assess the state of network-wide measurements of these variables and to develop a protocol for more coordinated data collection going forward.

1. Synthesis of past data on nitrogen mineralization, nitrification, soil respiration and soil moisture.

Our analysis began with an initial effort led by a graduate student at Boston University, Allison Gill, who has collected about +/-250 estimates of annual N mineralization rates from the published literature. This collection is an excellent starting point for this synthesis as it includes both LTER and non-LTER data and provides useful context for just what data are/are not present within the network. After publication, this compilation will be added to the LTER network information system.

We propose an effort to compile soil biogeochemistry data, including both LTER and non-LTER data. Such an effort could be funded through the National Center for Analysis and Synthesis (NCEAS), the National Social Environmental Synthesis Center (SESync), the John Wesley Powell Center for Analysis and Synthesis, or an NSF Research Coordination Network (RCN) grant. The effort would require a full time postdoctoral researcher (two years) and/or a graduate student and support for Information Management (it is important to not underestimate the time required to pull the data together and clean it up). Sources of data that we would compile include published papers and WWW sites as well as legacy data in danger of being lost, e.g., theses, filing cabinet, that would be identified through personal contacts.

We argue that such a data compilation would be of great interest to several audiences. In ecosystem ecology, there is great interest in understanding how nitrogen availability to plants and loss to the environment are being affected by global environmental change. Nitrogen mineralization is the best general measure of this availability, and it has been measured in many studies in many locations. There is similar intense interest in soil respiration, which has emerged as a critically uncertain, highly dynamic component of the global carbon cycle. As with nitrogen mineralization, soil biogeochemists have been measuring soil respiration for a long time and a compilation of results would be very useful. Finally, soil moisture has emerged as a critical uncertainty in ecosystem response to climate change, as this is affected by changes in precipitation, temperature and plant performance.

Major questions that could benefit from this compilation include attempts to reconceptualize ideas about nitrogen availability, mobilization and depolymerization, and the importance of the non-growing season. There is particular potential for the compilation to benefit modelers interested in analysis of the key drivers of nitrogen and carbon mineralization and how they respond to environmental change, to fill in gaps in existing analyses, and to facilitate method comparisons e.g., lab versus field and cores versus resins. Expressing results in terms of net N mineralization per unit of carbon mineralization will foster analysis of relationships between carbon and nitrogen cycles. A major interest is in determining how these cycles have changed through time in response to changes in atmospheric deposition, atmospheric CO₂ increases, acid rain, forest succession/ species composition, changes in weather patterns and phenology, and in long-term experiments at multiple sites.

Variables that we would want to include in the compilation:

1. N mineralization/nitrification:
 - a. In situ, e.g. buried bags.
 - b. Potential, e.g., 14 day laboratory incubations
 - c. Gross, e.g. isotope dilution
2. C mineralization:
 - a. In situ, e.g., flux chambers and towers
 - b. Potential, e.g., 14 day laboratory incubations
3. Soil moisture:
4. Ancillary variables:
 - a. Bulk density
 - b. Sampling depth
 - c. Total C

- d. Total N
 - e. pH
 - f. Texture
 - g. Temperature
 - h. Topography
 - i. Full soil classification
 - j. Litterfall
 - k. Plant uptake
 - l. Microbial biomass
 - m. Treatment
 - n. Plant community:
 - Species composition
 - Root N content
 - Litter chemistry
 - Root biomass
5. Data format:
- a. Calculated rates:
 - mg N/g/d
 - g N/m²/d

A preliminary/informal inventory of ideas for data sources based on discussions at the workshop:

6. LTER sites:
- a. Andrews:
 - No LTER data except some “questionable” lab and field data.
 - Specific lab studies (Myrold work on DIRT plots, Hart on OTTER transect).
 - b. Arctic
 - Giblin hillslope study (1991)
 - Many short term studies, e.g., Schimel, Weintraub, Hobbie, Chapin
 - c. Baltimore:
 - Forest versus grass comparisons
 - New Macrosystems Biology project will produce comparable data for six cities.
 - Two year in situ dataset.
 - d. Bonanza Creek
 - Boone
 - Ruess
 - e. Cedar Creek
 - Pastor data from old fields, with fertilization
 - Reich has long-term data from oak savannah with fire treatments
 - Long-term experiments, e.g., BIOTRON
 - Lots of lab incubations
 - Grigal studies
 - f. Central Arizona – Phoenix
 - 200 point samples – Darrel Jenerette, Weixing Zhu

- Jason Kaye
- g. Coweeta:
 - Jennifer Knoepp – gradient plots with topography (1991 – 1996)
 - Blowdown experiment – Yeakley
 - Regionalization stuff
- h. Florida Coastal Everglades
 - Childers? Boyer?
 - New Macrosystems Biology project.
- i. Georgia Coastal
 - Meryl Alber?
- j. Harvard Forest
 - Warming experiments (Nov – Dec)
 - Blowdown
 - Chronic N
 - Finzi has a list
- k. Hubbard Brook:
 - Melillo
 - Groffman winter climate
 - Elevation studies
 - Long-term net rates
 - Successional sites throughout NH lab (Fisk)
- l. Jornada:
 - Hartley, Schlesinger, lots of old data
 - John Anderson
 - Lajtha data from 1980s
 - Transect data – very old
 - Whitford era stuff
 - Ross Virginia
 - Fecal pellets
- m. Kellogg
 - Ag versus old fields
 - Treatments
- n. Konza:
 - Lots of plot level studies: Burning, grazing, RAMPS?, tree expansion, belowground plots, Groffman studies, Seastedt, Rice – long-term incubations
 - Blair, Rice
 - McCulley – across the plains
- o. Luquillo:
 - Whendee Silver
 - Older stuff – Lugo, Rich Bowden, Perakis?
 - Porder student
- p. McMurdo:
 - Ross Virginia and Diana Wall
- q. Niwot:

- Fisk
 - Bowman
 - Brooks
 - Williams
- r. North temperate Lakes
- Floodplain work (Stanley, Turner)
- s. Plum Island:
- New Macrosystems Project
 - Some marsh stuff (David Johnson in the TIDE experiment)
- t. Santa Barbara:
- Work at Sedgwick
 - Postfire work in the LTER
- u. Sevilleta:
- Microbial observatory
 - Long-term experiments
 - Collins
- v. Shortgrass steppe:
- Indy Burke
 - Parton
 - Schimel, D.
 - Woodmansee
- w. Virginia Coast:
- Wetland stuff? – Should we stay aerobic
- x. Other sources of data:
- Indy Burke and students did a series of Great Plains transects (McCulley, Maryann Vinson)
 - Data from Europe, South America:
 - NITREX
 - Nancy Dise
 - Data from Spain
 - NERC database – Kathy Crowley/Gary Lovett
 - Templer ¹⁵N metanalysis
 - The Sierra Foothills station (Mary Firestone) grasslands, also Blodgett. Eric Davidson.
 - Duke Forest and FACE sites. Adrien.
 - Calhoun Forest – Dan Richter, Elaine Birk, Evan DeLucia
 - Kathleen Treseder, Steve Allison, Michelle Mack in Alaska
 - Peter Reich 1997 Ecology paper with lots of Midwestern Data.
 - Work at Fernow (Beth Adams)
 - Work at Bear Brooks Maine (Ivan Fernandez)
 - Huntington Forest
 - Catskills - Lovett
 - Wisconsin:
 - Nadelhoffer
 - Aber

- Pastor
- Rustad warming metanalysis
- Pastor Isle Royale
- Fisk Upper Peninsula rates
- Tropical stuff
 - Neill et al. in Rondonia
 - Verchot and Davidson
- High Plains Research Lab – PHACE
- All Ameriflux sites might have N mineralization. They definitely have foliar N and soil respiration.
- Oak Ridge – Dale Johnson

II. Develop protocols for a new tightly coordinated, network-wide effort to develop a long-term data stream on soil biogeochemistry.

Our proposed new effort is based on the “Nutrient Network: A Global Cooperative” which is a grassroots research effort to address questions about nutrient limitation within a coordinated research network comprised of more than 40 grassland sites worldwide (<http://www.nutnet.umn.edu/>). NutNet aims to collect data from a broad range of sites in a consistent manner to allow direct comparisons of environment-productivity-diversity relationships among systems around the world. NutNet membership is open to ecologists who are committed to either initiating a new NutNet node or collaborating with researchers at an existing network site and are willing to carefully follow the research protocol for the core sampling.

We suggest that a NutNet approach would be quite easy to implement for soil biogeochemistry within the LTER network as the sites already have quite a bit of field, laboratory and cyber-infrastructure in place. Below we propose a series of protocols that the vast majority of sites will be able to conveniently implement with low cost. The payoff for such an effort could be enormous – a long-term continental-scale dataset on variables that are of critical interest in assessments and models of global environmental change. In ecosystem ecology, there is great interest in understanding how nitrogen availability to plants and loss to the environment are being affected by global environmental change. Nitrogen mineralization is the best general measure of this availability, but it has been measured in many different ways in different places, with no standardization or coordination. There is similar intense interest and variability in measurements of soil respiration. Soil moisture has been measured in many studies, but there are few coordinated, multi-site long-term datasets on this critically important variable. Major questions that could be addressed with this new network include analysis of how nitrogen and carbon mineralization have changed through time in response to changes in atmospheric deposition, atmospheric CO₂ increases, acid rain, forest succession/ species composition, changes in weather patterns and phenology during both the growing and non-growing seasons.

Below we outline a preliminary protocol for this new effort:

1. Sampling. We propose multiple options for field sampling that can vary with site interest and resources:

- Sample just once, at the height of the growing season, i.e., when plants are maximally in control of the system.
 - Sample two times; in mid-summer plus an integrated non-growing season measurement or
 - Sample four times: early, mid, late growing season, plus an integrated non-growing season measurement.
 - All sites would run the proposed lab assay once (mid-summer).
2. Incubation:
- 14 day incubation.
 - Wet to 60% field capacity and then dry.
 - Sample at 0, 4 and 14 days:
 - The day 4 sample will quantify any “flush” associated with rewetting. Sites with no concern about this may wish to skip this sample.
 - Production over day 0 – 14 will quantify potentially mineralizable N
 - Production over days 4 – 14 will represent a substrate quality index
3. What to measure in the lab incubation:
- Net mineralization and nitrification.
 - CO₂ production. Not everyone can measure this. May need to send gas samples to a central facility.
 - Total C and N. May need to send samples to a central facility.
 - pH. Centralized. Once. Every five years.
 - Texture. Centralized. Once.
 - Gravimetric soil moisture. Each time.
 - Bulk density. Once. Beware of 2:1 clay soils. Use “pin block” for organic horizons
4. Optional measurements:
- Light fraction – important controller of variance in time and space. Not so easy to do. Make this an optional measurement? Send dry samples to a central facility?
 - Soluble C – optional or centralized.
 - Microbial biomass:
 - SIR
 - CFIM
 - CFEM
 - Something about P, e.g. bicarbonate extractable.
5. Field incubation:
- Covered core. This is our baseline, recommended method. Sites can continue with what they have been doing, as long as they compare with this recommended method.
 - 5 cm (2 inch) diameter, split PVC, 15 cm core, will sample 10 cm of soil.
 - Freshly fallen litter that is not part of the soil should be cleared. Hard to do this in conifer forests.
 - Holes at top of core to facilitate removal and to allow oxygen in.
 - Caps. Several options (specimen caps, red “solo” beer cups, cheap PVC caps)

- At the dry sites, where pulses of rainfall are important, do parallel incubations with artificial rainfall (typical rainfall event) and unamended sites.
- Length of incubation – 28 or 30 days:

6. Extraction:

- Extract within 24 hours.
- Minimize temperature disturbance
- Extractant – anything is ok (0.5 M K_2SO_4 , 1N KCL, 2 N KCL) as long as comparisons are done at each site
- Ratio of soil:KCL. Standard is 5:1, can use different if comparisons are done. Some sites need to go higher due to high CEC.
- Shaking time – enough to break up all aggregates:
 - Give one good hand shake at the beginning.
 - Some soils can then just sit.
 - Others require a shaker table.
 - Standard is one hour on a shaker table @ 150 rpm, or occasional hand shaking.
- Separate by horizons:
 - Very important to separate forest floor versus mineral soil. The transition is hard, might require some local training/expertise.
- Coarse sieving (6 or 8 mm) or hand mixing to homogenize and remove big roots and rocks.
- Extracts can settle for whatever is convenient; up to 60 minutes is recommended and standard.
- Filter:
 - Whatman #42 – recommended standard.
 - Must run blanks!

7. Soil respiration in the field – totally optional:

- Li-Cor or some other fast response IRGA is standard
- Soda lime
- Chambers and GC

8. Sampling locations:

- How many sites:
 - One ecosystem type that is most representative and do true replicates (or as best they can).
 - Encompass natural or inherent landscape variation at site.
 - Need to stay in context of the overall LTER site and experiment.
- Experiments
 - What manipulations are most useful to the questions that we are addressing. Is it best to avoid these? Or would this really help us to define controls? On the other hand these plots are small. Maybe only sample these very occasionally. Or when they are being sampled for something else.
 - Nitrogen manipulations. Might really help to define controls, links to decomposition, relevant to deposition questions.
 - A simple new N and N+P manipulation?

- Carbon?
 - Six DIRT experiments (HFR, AND, Bousson, Santa Rita, Michigan Bio Station, Hungary, Germany)
 - Urban CO₂ domes
 - Climate?
 - RAMPS
- Need a big plot that no one else is going to be working in. This is a 50 year study:
 - Refill holes with aquarium sand
 - Consider places where measurements have been made in the past.
- How many reps:
 - One representative reference area, e.g., 100 m². Need to be clear that if this is a 50 year experiment, the plots have to be big. If each core disturbs 25 cm² and if you take 1000 cores over a 50 year experiment, that is 2.5 m² of removed area. Keep in mind that lots of the area is not usable due to trees, rocks.
 - Some sites might want to have some smaller replicate plots and take a smaller number of cores from each of these plots.
- Pooling to reduce variability for lab incubations:
 - For field incubations the cores must be paired.
 - For lab incubations, also need to keep the individual cores separate so that there is at least some replication if you are sampling just one big plot. You could pool over subplots or replicate plots if you have them. This should motivate some replication.

9. Ancillary measurements:

- Continuous temperature and moisture:
- What if the measurements are not in the same location as the exact plots?
 - It is essential if we are doing soil respiration.
 - It would be a useful soil moisture dataset in any case.
 - And it would help interpret the Nmin data that we are collecting.
 - Decagon dataloggers (\$400) with five replicate 5TM probes.
 - Many sites may not want to duplicate measurements that they are already making in another location.

10. Central processing – there is a strong sense that this is better for QA/QC and for recruitment of sites. We can make a list of what measurements we want and shop it around to different labs, e.g., Southern Illinois, Georgia, Cary Institute, UC Davis:

9. Time and \$\$ budget: Per site

a. Cost to set up:

- Soil temperature and moisture - \$1,000
- PVC cores - \$500
- Mallet
- Bags
- Plot markers

- b. Cost to sample:
 - 2 days per sampling event or 2 – 8 days/year.
- c. Cost to process
 - 4 days per sampling event or 4 - 16 days/year.
 - Total labor for sampling and processing = 6 days per event or 6 to 24 days/year.
- d. Chemical analysis:
 - Bulk density – 2 days of work (unpleasant)
 - Five year analyses:
 - Texture - \$300 (3 plots x 5 reps)
 - pH - \$300 (3 plots x 5 reps)
 - Yearly analyses:
 - \$400 (1 time) - \$1600 (4 times). Field inorganic N (10 cores x 2 sample times x 2 analytical reps x 2 horizons) = 80
 - \$400. Lab inorganic N (10 cores x 2 sample times (4 and 14 days) x 2 reps x 2 horizons) = 80
 - \$330. CO₂ analysis: (10 cores x 2 sample times (4 and 14 days) x 2 reps x 2 horizons) = 80
 - Exetainers - \$80
 - Shipping - \$50
 - Analytical - \$100
 - Supplies - \$100
 - Total C and N (10 cores x 2 horizons):
 - Packing. 0.5 days of weighing.
 - \$1600. Analysis (10 cores x 2 horizons x 2 carbonate x 2 reps) = 80.
- e. Total costs:
 - Setup - \$2,000
 - Labor 6 – 24 days
 - Five year chemistry = \$1,000 (really \$200/year)
 - Lab inorganic N = \$400
 - Field inorganic N = \$400 – 1600
 - CO₂ = \$330
 - C and N = \$1600 – Could pool or do LOI or no carbonate or on 5 year basis).
 - TOTAL: \$5,730 - \$7,330, 6 – 24 days of labor. For comparison, Nutnet costs - \$2000 setup, 10 person days/year, no analytical costs just drying and weighing. Fertilizer \$200.

10. Information management – must be centralized.

11. Where to get funding:

- a. Macrosystems Biology
 - Could we convince them into a 10 year grant?
 - Include NEON sites?
- b. NASA/DOE:
 - C cycle RFP on belowground processes and C:N links.

c. NSF WSC

12. Recruiting and advertising:

- a. Nutnet gave talks at meeting, an article in science, lots of word of mouth.
- b. We should put articles in Journals, e.g. Biogeochemistry
- c. Other networks:
 - USFS
 - ECOLOG
- d. Sites need to be spread across a range of soils and temperatures to be most interesting. So emphasis on getting good tropical, subtropical and arctic sites as well as temperate forest.