Nitrogen Deposition Effects on Denitrification in Humid Tropical Forest Soils

Keywords: nitrous oxide (N_2O); dinitrogen (N_2); dinitrogen to argon elemental ratio (N_2:Ar)

Denitrification to N_2O and N_2 is one of the most poorly understood fluxes of the terrestrial nitrogen (N) cycle, limiting our ability to constrain N exports from ecosystems to construct reasonable N budgets. This is particularly important in humid tropical forests, which likely have high denitrification ($N_2O + N_2$) rates [1] and are the largest natural terrestrial source of N_2O, a potent greenhouse gas and catalyst for stratospheric ozone depletion [2]. Industrial and agricultural development is rapidly increasing N deposition rates in the tropics [3] and likely to alter denitrification dynamics. Thus, a better understanding of controls on denitrification is critical to predict and reduce the impacts of increasing N deposition in this region.

Denitrification is an anaerobic microbial process responsible for nitrate (NO_3^-) reduction to N_2O and subsequent N_2O reduction to N_2. Environmental factors, such as NO_3^- and oxygen (O_2) availability, influence the ratio of N_2O to N_2 produced by denitrification (N_2O:N_2), thus affecting the relative importance of reactive N_2O or inert N_2 emissions as N loss pathways [4]. Dissimilatory NO_3^- reduction to ammonium (DNRA) may compete with denitrification for NO_3^- [5], thereby moderating anthropogenic N deposition effects on N_2O emissions. Experimental N additions in humid tropical forests greatly stimulated N_2O emissions [6-9]. However, the effects on denitrification to N_2 are unknown because the high background N_2 concentration in the atmosphere impedes measurement of N_2 production from soils. I will use a novel method for measuring N_2 emissions from upland soils to test the following hypotheses:

Hypothesis 1: Nitrogen deposition to N-rich humid tropical forests increases N_2O emissions through enhanced N cycling rates, decreased competitiveness of DNRA as an alternative fate of NO_3^-, and an increased ratio of N_2O to N_2 produced by denitrification.

Hypothesis 2: Dinitrogen production greatly exceeds net N_2O production from denitrification at low soil O_2 concentrations, so that the relative importance of N_2 versus N_2O emissions will be predicted by soil O_2 availability at an annual scale.

Approach

I have collaborated with Drs. Ralph Keeling (UC-San Diego) and Robert Rhew (UC-Berkeley) to develop the N_2:Ar method to measure surface N_2 fluxes from upland soils. Argon is a biologically inert gas found in relatively low atmospheric concentrations; thus, it can serve as a conservative tracer for measuring N_2 production. Keeling et al. [10] developed a mass spectrometry technique to measure changes in atmospheric Ar:N_2 with a precision of 11 per meg (per meg = 10^{-3} per mil). I have modified their sampling protocol to measure surface N_2 fluxes using a closed dynamic chamber (Figure 1). The sensitivity of the method depends on the chamber height to footprint ratio and the sampling period. For example, a 10 cm tall chamber and a 6 hour sampling period yields a detection limit of 18.0 ng-N cm^{-2} hr^{-1}. Using this method, I measured N_2 emissions of 3.4-3.7 µg-N cm^{-2} hr^{-1} from irrigated and fertilized grasslands at UC-Berkeley [11]. I am continuing to test and refine the N_2:Ar method by comparing N_2 production rates measured by this method and the ^{15}N and acetylene inhibition methods.

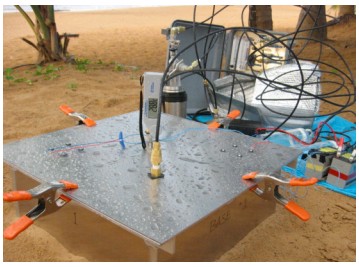

Fig. 1. Surface N_2 flux chamber.

Study Site: I will conduct my research at the Luquillo Experimental Forest (LEF), a NSF-sponsored Long-Term Ecological Research site in Puerto Rico. The study site has little seasonal variation in rainfall (~4000 mm/yr) and temperature (21 ºC). Soils are clay-rich ultisols with low NO_3^- concentrations and experience frequent and high amplitude fluctuations in soil O_2

concentrations [12]. I will use N fertilized and control plots (n= 3, each 20 m x 20 m) initiated in January 2002 by Dr. William McDowell. Each treatment plot receives 50 kg-N ha^{-1} yr^{-1} as NH_4NO_3. To estimate N loading level effects on denitrification, I will establish 9 new plots (5 m x 5 m) in the same watershed that will receive 2, 10, and 50 kg-N ha^{-1} yr^{-1} (n=3) as NH_4NO_3.

H1: I will intensively measure field N_2O and N_2 emissions, soil NO_3^- and O_2 concentrations, and soil moisture in all plots following four fertilization events. I will use field ^{15}N tracer experiments to estimate rates of NO_3^- supply and utilization via denitrification and DNRA [5]. I expect that denitrification rates will increase with increasing N addition because more N will be cycling through the soil and at faster rates; N_2O:N_2 will also increase with increasing N inputs because NO_3^- inhibits N_2O reduction. Furthermore, theory suggests that decreasing labile C to NO_3^- ratio favors denitrification over DNRA [14], so I predict N inputs will increase the ratio of denitrification rates to DNRA rates.

H2: I will measure field N_2O and N_2 emissions, soil NO_3^- and O_2 concentrations, and soil moisture in the treatment and control plots on a weekly basis to estimate annual N_2O and N_2 fluxes. I will measure net N mineralization and nitrification several times during the year to estimate NO_3^- supply. I expect that annual N_2 emissions will be important relative to annual N_2O emissions because of the dominance of N_2 over N_2O emissions at low soil O_2 concentrations that occur frequently in humid tropical forest soils. To study the effects of O_2 availability on denitrification in a more controlled environment, I will perform lab experiments with factorial combinations of four N addition (0, 2, 10, 50 kg ha^{-1}) and five O_2 (0, 5, 10, 15, 21%) treatments. I will use the ^{15}N, acetylene inhibition, and N_2:Ar methods to measure N_2 production in the lab. I will also measure N_2O production and gross nitrification. I predict that N_2O:N_2 will be dominantly a function of soil O_2 availability, but the shape of this relationship will depend on direct effects of O_2 on denitrification and indirect effects on NO_3^- supply by nitrification.

Expected Results

This study will explore key controls on denitrification and be one of the first to use the N_2:Ar method to measure N_2 production in upland soils. I became interested in this topic because N_2 production is widely recognized as a major gap in our understanding of the global N cycle. My original research will help fill this important gap and contribute to our understanding of N deposition effects in humid tropical forests. This new knowledge will help improve N cycling models to predict N_2O emissions for climate change and ozone depletion projections.

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