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EDITED AND REVIEWED BY
Frank Hagedorn,
Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Switzerland

*CORRESPONDENCE
Maya Almaraz
✉ mma9047@princeton.edu

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Editorial: New frontiers and paradigms in terrestrial nitrogen cycling

Maya Almaraz[1]*, Michelle Y. Wong[2] and Wendy H. Yang[3]

[1]High Meadows Environmental Institute, Princeton University, Princeton, NJ, United States, [2]Cary Institute of Ecosystem Studies, Millbrook, NY, United States, [3]Departments of Plant Biology and Earth Science and Environmental Change, University of Illinois, Urbana, IL, United States

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Editorial on the Research Topic
New frontiers and paradigms in terrestrial nitrogen cycling

The nitrogen (N) cycle is an incredibly complex cycle of redox sensitive biotic and abiotic transformations for which new processes are regularly discovered. Nitrogen has implications for primary productivity and food production, as well as a cascade of environmental impacts such as soil acidification, air pollution, greenhouse gas production, drinking water contamination, and eutrophication. Because of the important health, environmental, and economic ramifications associated with the N cycle (Sobota et al., 2015), it is imperative that we have a fundamental understanding of biogeochemical cycling to better manage N inputs and remove excess N from ecosystems. Despite this urgent societal need, advances in knowledge about N cycling have remained slow relative to the vast number of publications produced on this topic each year.

Nearly 20 years ago, Dr. James Galloway posited that "the largest uncertainties in our understanding of the N budget at most scales are the rates of natural biological N fixation, the amount of reactive N storage in most environmental reservoirs, and the production rates of dinitrogen (N_2) by denitrification" (Galloway et al., 2004). One could argue that this remains true to this day, despite decades of research. Nonetheless, important advances have been made in our understanding of N pools and fluxes. Novel methods are being developed to quantify N_2 emissions (e.g., Yang et al., 2011; Yeung et al., 2019; Lewicka-Szczebak et al., 2020). There have been unified efforts to quantify highly variable fluxes of biological N fixation (Winbourne et al., 2018; Soper et al., 2021). And researchers are beginning to investigate N storage in deep soils (e.g., Huddell et al., 2023). Still though, underrepresented fluxes remain and require attention. Ammonia, nitric oxide, and other N emissions from agriculture and livestock systems have been underestimated, however, inquiries at local, regional, and global scales are beginning to gain momentum (Almaraz et al., 2022; Liu et al., 2022).

The link between processes and drivers further complicates the N cycle. Multiple processes can produce any form of N (Butterbach-Bahl et al., 2013) and each process can have different drivers, which makes creating generalizable predictive models that translate across ecosystems difficult. Overcoming such complex challenges requires innovative approaches, however, much of the research in this area has been similar—conducted in the same places, using the same methods, and using similar experimental designs—in essence, variations of the same experiments are repeated with hopes of new insights (Almaraz et al., 2020). Methodological advances or changes in approach can potentially help us overcome stagnation in intellectual insight. More commonly used methods still have their place but could be better utilized on along natural gradients or by coupling multiple methodological approaches together (Almaraz et al., 2019).

Advancing the field of N biogeochemistry will require a collective initiative that engages new methods and innovative perspectives. New methodology is often rare and involves specific training. Efforts that connect new researchers to resources and training will be vital to extend the breadth of knowledge produced from cutting edge methodological approaches. Diverse perspectives promote scientific innovation, thus coupling N research and training with diversity, equity, and inclusion efforts will be key to generating new ideas (Hofstra et al., 2020). Finally, most previous N cycling research has taken place in the US and Europe, limiting our ability to make broader generalizations across a diversity of soil conditions (Almaraz et al., 2020). Expanding research into underrepresented regions, such as tropical, boreal, or desert ecosystems will shed light on understudied N cycling dynamics and exceptions that currently puzzle the field. In addition, since the majority of N pollution and much of future agriculture is likely to take place in the Global South or low-income countries, extending the geographic distribution of data collection will help serve communities and engage governments where an understanding of the N cycle is most needed.

This collection of papers on "*New frontiers and paradigms in terrestrial nitrogen cycling*" represents a range of knowledge gaps and new insights about terrestrial N cycling. First, because nitrous oxide (N_2O) emissions occur in hot spots and hot moments, capturing these rare but impactful events using traditional sampling methods with limited replication makes constraining fluxes challenging. O'Connell et al. highlight new opportunities to measure N_2O emissions through high-frequency cavity ring-down spectroscopy alongside high-frequency sensors and across a diversity of ecosystems and field conditions, a methodological approach which can contribute to a predictive understanding of greenhouse gas production. Second, despite the critical role that N plays in structuring ecosystem function, we know very little about how plant communities respond to and modify their nutrient environment, making it difficult to predict how terrestrial ecosystems will respond to increased N deposition or nutrient limitation from elevated CO_2. Martinelli et al. utilize an impressive dataset of 3,668 plant specimens across Brazil to investigate whether environment or taxonomy better predict foliar carbon and N concentrations and isotopic signatures, finding that taxonomy better predicts foliar nutrient concentrations, but that environment better predicts foliar isotopes. Third, rocks have been found to be an important source of N to some ecosystems, but the relative importance of rock-derived N can differ across the landscape. Bingham et al. use geochemical mass balance coupled with isotopic mixing models to estimate rock-derived N across a hillslope and found the highest contributions on ridge crests with declines downslope, still, rock represents a smaller source than N deposition or fixation in this grassland ecosystem. Fourth, while invasive plants have been documented to accelerate N cycling in non-native ecosystems (e.g., Vilà et al., 2011; Castro-Díez et al., 2014), the mechanisms driving these changes remain uncertain because measurements are often limited to changes in pools or net rates of N transformations. Edwards et al. measured changes in gross N cycling rates to learn that both increases in soil pH and direct plant influence on soil microbial community composition likely contribute to accelerated N cycling in garlic mustard invaded temperate forests. These papers highlight recent N biogeochemistry research that has generated innovative perspectives on methods, fluxes, and drivers, and accelerate the field forward.

Author contributions

MA conceptualized and led the writing of the manuscript. WY and MW contributed to the conceptualization and provided input on writing the manuscript. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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