N-VISIBLE

A Nitrogen Balance Framework

A Robust and Practical Way to Measure Excess Nitrogen

Nitrogen (N) is essential for life on Earth, but excess N causes pollution — in the form of nitrous oxide and ammonia in the atmosphere and nitrate in the water — that has a major impact on human and ecosystem health. Annual damages from N pollution are estimated to exceed $200 billion in the U.S.[1] and up to $500 billion in Europe.[2]

N losses to the environment are invisible and have historically been difficult to measure and monitor. N balance — the difference between N inputs to and N outputs from a field over the course of a year or crop rotation — overcomes those challenges. It provides a user-friendly, scientifically robust way to assess environmental results.

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Finding the ways that work

Previous methods of measuring N losses

Over the years, Environmental Defense Fund has assessed and tried many approaches to helping farmers and supply chain companies measure progress in reducing N pollution at scale. Time and again, we found that existing ways to measure excess N are expensive, inaccurate and difficult to scale.

Direct measurement

Directly measuring changes in emissions of nitrous oxide to air and nitrate to water is prohibitively expensive to do at the scale needed. For nitrous oxide, the fact that most is emitted at highly variable "hot spots" and "hot moments"[3] means that a dense network of continuously running sensors would need to be installed. For nitrate, in-stream monitoring can aggregate losses across many fields, meaning that fewer sensors are needed than for nitrous oxide, but legacy or time lag effects[4] may make it difficult to discern the signal of present-day changes from the background of historic losses.

Practices as proxy

Because of the downsides of direct measurement, public and private entities have tended to rely on a "practices as proxy" approach to tracking N losses. This approach assumes that a given agricultural conservation practice has a fixed effect on nitrous oxide or nitrate losses. Thus, it would be possible to estimate total impacts on N losses by counting the acres on which those practices have been adopted.

Unfortunately, the scientific literature shows that the impact of a practice on N losses is highly variable over space and time, depending on soil type, weather, landscape position and previous management history.[5] A practice that reduces nitrous oxide or nitrate losses in one field in one year may increase them in the next year, reduce them in one field while increasing them in an adjacent field, or have opposite effects on different N loss pathways.

Complex models

Faced with the highly variable and unpredictable relationship between conservation practices and N losses, EDF and others explored the use of complex "process-based" biophysical models to track changes in N losses. These models — for example DayCent for nitrous oxide emissions and the Soil and Water Assessment Tool for nitrate losses — can be incredibly powerful when used properly.

The models are most effective when used at local scales where large amounts of input data are available. Relying on these models at a supply chain scale, however, is fraught with difficulties. The models have rarely been calibrated and validated for the array of cropping systems, soil types and climates that are represented in even a simple supply chain, and the local input data needed to make the models run properly is usually lacking.[6]

[1] Sobota et al., 2015.

[2] Van Grinsven et al., 2013.

[3] McClain et al., 2003.

[4] Puckett et al., 2011.

[5] Eagle et al., 2017; Venterea and Coulter, 2015.

[6] Tonitto et al., 2018; Ehrhardt et al., 2019; Olander, 2013.

Scientific consensus that N balance is a better approach

N balance is widely accepted by scientists as the preferred metric for measuring the risk of N losses to the environment, reflecting impacts on both climate and water quality.

EDF brought together scientists and agriculture sector stakeholders[7] for a 2017 workshop to consider a different approach to measuring N losses, one that would improve upon the challenges related to direct measurement, practice as proxy and biophysical models.

Our criteria were that the approach had to be:

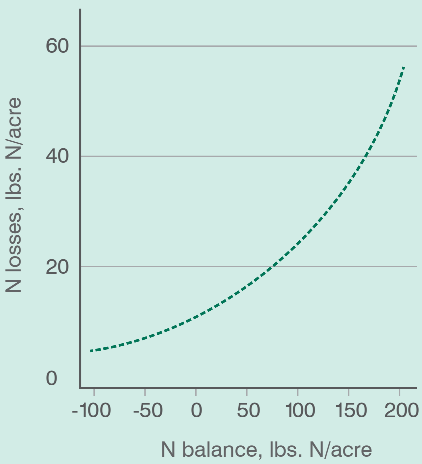
1. Scientifically robust (i.e., linked strongly to N losses to the environment).
2. Easy to implement in the supply chain context (i.e., capable of being aggregated at a large scale, across multiple soil types, climates and cropping systems and using very limited input data).
3. Meaningful to farmers (i.e., based on N input variables that are within farmers' control and helpful for showing the connection between management changes and N losses at the field and farm scale).

The outcome of that workshop was agreement that N balance was a promising approach. The next step was to review the evidence showing a relationship between N balance and N losses to the environment.

EDF convened a wide array of scientists from across North America and Europe in 2019 to do just that.[8] We discovered numerous peer-reviewed publications in which scientists reported on this relationship over a wide array of cropping systems and climates in Europe, North America and Asia. Participating scientists agreed that the existing science showed a consistent relationship between N balance and N losses (Figure 1).

In addition, we learned that in Europe, where farmers have significantly reduced their N balance scores over the past 25 years, improvements in N balance led to improvements in water quality — average nitrate levels in groundwater and loads in rivers have declined — at regional and national scales.[9]

Figure 1: N balance is a robust and consistent measure of N losses to the environment



This relationship applies to all rainfed cropping systems in temperate regions. It doesn't necessarily apply to irrigated systems or tropical regions.

This body of evidence has led to a scientific consensus that the relationship between N balance and N losses to the environment is robust at a variety of scales.

[7] Attendees represented: Agricultural Retailers Association, American Society of Agronomy, Cornell University, The Fertilizer Institute, Field to Market, International Plant Nutrition Institute, Iowa Soybean Association, Iowa State University, Michigan State University, National Association of Wheat Growers, National Corn Growers Association, The Nature Conservancy, Nebraska Corn Board, NC State University, Soil Health Partnership, United Soybean Board, US Agency for International Development, US Department of Agriculture, University of California-Davis, University of Illinois, University of Maryland, University of Minnesota, University of Missouri, University of Nebraska-Lincoln, University of Wisconsin, and World Wildlife Fund.

[8] Attendees represented Cornell University, International Plant Nutrition Institute, MyFarms, Plantierra, Purdue University, University of California – Davis, University of Guelph, University of Illinois, University of Maryland, University of Nebraska – Lincoln, Wageningen University.

Environmental models measure environmental outcomes at scale

EDF developed two empirical models that enable supply chain companies, policymakers and others to translate aggregated[10] field-level changes in N balance into improvements in environmental outcomes, specifically reductions in nitrous oxide emissions and nitrate leaching.

Working with scientists from Cornell University and the University of Nebraska, we published preliminary models for the relationship between N balance, nitrous oxide and nitrate for corn grown with synthetic fertilizer on silt loam soils in the Corn Belt.[11]

Since then, we have collaborated with scientists from land-grant universities, government agencies and other institutions across North America[12] to refine the models using additional data from more diverse cropping systems, soils, regions and N sources.[13]

As a result, we have developed a refined model for the relationship between N balance and nitrous oxide emissions, which can be used broadly across all cropping systems in temperate climates, regardless of soil type and N source. This model was published in a peer-reviewed journal in September 2020.[14] A similar generalized model representing the relationship between N balance and nitrate leaching has also been submitted for peer review, with publication expected in early 2021.

To account for the impacts of annual weather variability, we recommend monitoring changes in N balance and modelled environmental outcomes over a three-to-five-year moving average to best understand progress toward environmental goals.

EDF and partners will continue to refine these environmental models over time to meet the ever-increasing demand for their implementation across crops and regions within and beyond North America. We are confident that food supply chain companies, agricultural stakeholders and policymakers will embrace N balance as a scientifically robust, easy to implement way of measuring progress, improving water quality and reducing greenhouse gas emissions.

[9] Hansen et al., 2017; Windolf et al., 2012.

[10] Our models are statistically robust when data are aggregated across hundreds of fields, for example across a grain company's sourcing region.

[11] McLellan et al., 2018.

[12] EDF scientists collaborated with scientists from Purdue University, University of California-Davis, University of Illinois, University of Maryland, University of Nebraska, as well as Agriculture and Agri-Food Canada and the International Plant Nutrition Institute.

[13] We refined the models with data from: 1) additional cropping systems — barley, canola, corn-grain, corn-silage, oilseed rape, sugar beet, and wheat — 2) additional soil types — clay, clay loam, fine sandy loam, loam, loamy sand, sand, sandy clay loam, sandy loam, silty clay loam and silt loam — 3) additional regions — eastern and central Canada, eastern and central U.S. and Europe — and 4) additional N sources — ammonia nitrate, anhydrous ammonia, calcium ammonium nitrate, cattle manure, hog manure, polymer-coated urea, SuperU, UAN and urea

[14] Eagle and McLellan, et al. 2020

References

Eagle, A. J., McLellan, E. L., Brawner, E. M., Chantigny, M. H., Davidson, E. A., Dickey, J. B., et al. (2020). Quantifying On-Farm Nitrous Oxide Emission Reductions in Food Supply Chains. *Earth's Future,* 8, e2020EF001504. https://doi.org/10.1029/2020EF001504

Eagle, A. J., Olander, L. P., Locklier, K. L., Heffernan, J. B., & Bernhardt, E. S., 2017. Fertilizer management and environmental factors drive N_2O and NO_3 losses in corn: A meta-analysis. *Soil Science Society of America Journal*, 81(5), 1191-1202. https://doi.org/10.2136/sssaj2016.09.0281

Ehrhardt, F., Soussana, J.-F., Bellocchi, G., Grace, P., McAuliffe, R., Recous, S., et al., 2018. Assessing uncertainties in crop and pasture ensemble model simulations of productivity and N_2O emissions. *Global Change Biology*, 24(2), e603-e616. https://doi.org/10.1111/gcb.13965

Hansen, B., Thorling, L., Schullehner, J., Termansen, M. & Dalgaard, T., 2017. Groundwater nitrate response to sustainable nitrogen management. *Scientific Reports*, 7(1), 1-12.

McClain, M.E., Boyer, E.W., Dent, C.L., Gergel, S.E., Grimm, N.B., Groffman, P.M., et al., 2003. Biogeochemical hot spots and hot moments at the interface of terrestrial and aquatic ecosystems. *Ecosystems*, 6, 301-312.

McLellan, E.L., Cassman, K.G., Eagle, A.J., Woodbury, P.B., Sela, S., Tonitto, C., et al., 2018. The nitrogen balancing act: Tracking the environmental performance of food production. *Bioscience*, 68(3), 194-203.

Olander, L.P., 2013. Using biogeochemical process models to quantify greenhouse gas mitigation from agricultural management, in *Climate Change Mitigation and Agriculture*, edited by E. Wollenberg, M.-L. Tapio-Bistrom, M. Grieg-Gran & A. Nihart, Routledge, London, UK.

Puckett, L.J., Tesoriero, A. J., & Dubrovsky, N.M.,2011. Nitrogen contamination of surficial aquifers – a growing legacy. *Environmental Science & Technology* 45(3), 839-844

Sobota, D.J., Compton, J.E., McCrackin, M.L. & Singh, S., 2015. Cost of reactive nitrogen release from human activities to the environment in the United States. *Environmental Research Letters*, 10(2), 025006.

Tonitto, C., Woodbury, P.B. & McLellan, E.L., 2018. Defining a best practice methodology for modeling the environmental performance of agriculture. *Environmental science & policy*, 87, 64-73.

Van Grinsven, H.J., Holland, M., Jacobsen, B.H., Klimont, Z., Sutton, M.A. & Jaap Willems, W., 2013. Costs and benefits of nitrogen for Europe and implications for mitigation. *Environmental science & technology*, 47(8), 3571-3579.

Venterea, R.T., & Coulter, J.A., 2015. Split application of urea does not decrease and may increase nitrous oxide emissions in rainfed corn. *Agronomy Journal*, 107(1), 337-348. https://doi.org/10.2134/agronj14.0411

Windolf, J., Blicher-Mathiesen, G., Carstensen, J. & Kronvang, B., 2012. Changes in nitrogen loads to estuaries following implementation of governmental action plans in Denmark: A paired catchment and estuary approach for analysing regional responses. *Environmental Science & Policy*, 24, 24-33.