

## ENVIRONMENT

# Latin America's Nitrogen Challenge

A. T. Austin,<sup>1</sup> M. M. C. Bustamante,<sup>2</sup> G. B. Nardoto,<sup>2</sup> S. K. Mitre,<sup>2</sup> T. Pérez,<sup>3</sup> J. P. H. B. Ometto,<sup>4</sup> N. L. Ascarrunz,<sup>5</sup> M. C. Forti,<sup>4</sup> K. Longo,<sup>4</sup> M. E. Gavito,<sup>6</sup> A. Enrich-Prast,<sup>7</sup> L. A. Martinelli<sup>8\*</sup>

Latin America (LA) has many social indicators similar to those of highly developed economies but most frequently falls midway between least developed countries and industrialized regions. To move forward, LA must address uncontrolled urbanization, agricultural production, social inequity, and destruction of natural resources. We discuss these interrelated challenges in terms of human impact on the nitrogen (N) cycle. Human activity has caused unprecedented changes to the global N cycle; in the past century, total global fixation of reactive N (Nr) has at least doubled (1). Excess Nr leaked into the environment negatively affects soils, atmosphere, and water resources in temperate zones (1). In addition to N excess from human impact, mining of natural soil N creates N deficits in some regions (2, 3).

Agriculture resurged in LA with marked growth in soybean cultivation in the 1990s (3) and recent expansion of the biofuel market (4). Soybean cultivation in LA is 40% of global production, larger than any other world region (3). Because of the natural fertility of soil in Argentina's Pampa region, N fixation is not strongly stimulated; thus, N exported in soybeans is mostly from soil N, rather than fixation, causing a net loss of N (3, 5). In Brazil converting pristine ecosystems with high natural N fixation rates to fields can lead to negative N balance (6). In contrast, soybean crops that replace other cropping or grazing ecosystems, N in areas of low soil N and heavy application of phosphorus (P) fertilizer (7).

Biomass burning to clear land for agriculture has been estimated at >150,000 km<sup>2</sup> annually in LA (8). This transfers a large amount of Nr from the land to the atmosphere, which is then redistributed regionally (9). In addition to direct health effects of biomass burning (10), part of the Nr returns from the atmosphere to aquatic and terrestrial ecosystems via wet and dry deposition. Total N deposition in major

agricultural areas and urban zones in LA is on par with developed countries. By 2050, four of the eight LA biodiversity hotspots are projected to have potentially harmful levels of N deposition (11).

Because of lack of basic infrastructure, especially in low-income areas of megacities, most domestic sewage is released into water bodies without treatment, causing N and P enrichment (12), affecting trophic interactions (13), and increasing public health risks (14). Exacerbating the problem is rural-urban migration, a result of marginalization and extreme poverty faced by many small farmers.

Ecosystem and human health in LA depends on managing human impact on the N cycle. Antiquated political institutions inherited from European colonization concentrate political and economic power in a small fraction of the population. These must be replaced by inclusive political, economic, and academic institutions that enforce property rights, maintain a strong and independent judicial system, combat corruption, and encourage new technologies and skills (15).

Destruction of some of the world's largest intact areas of highly diverse tropical ecosystems must halt (16). It has been argued that sufficient land has been cleared for sustainable production of goods and services, but that most of the land is inefficiently used, especially in the livestock sector (17). Although deforestation in the Amazon basin has declined (16), recent environmental legislation may allow a resurgence of land-clearing (18). Increased efficiency of land already under cultivation should be a priority, without increasing inputs of N fertilization (19). Commitments from local governments and agriculture sectors, especially beef and soybean, are critical, acting in concert across LA. International mechanisms like REDD (Reducing Emissions from Deforestation and Forest Degradation) and financial support from developed nations would increase the likelihood of success (16).

Public agriculture policies must include small farmers and less-favored groups (20). Secure land rights are crucial (21), with potential to decrease land violence that constrains rural development (22). Agricultural practices must increase functional diversity, mimicking natural ecosystems. Techniques include no-

Human impacts on the N cycle require sustainable ecological solutions to preserve ecosystem and human health.

till agriculture, cover crops, crop rotation, and enhancement of natural N fixation (23). Intensification must only be encouraged under sustainable practices, where agroecosystems and neighboring landscapes provide key ecosystem services (24).

Basic science must address LA's ecological and social systems and their interactions. For example, long-term consequences of widespread practices of no-till agriculture and intense cultivation of a single species are not well understood (3, 5). We must improve our understanding of the terrestrial-aquatic interface, particularly in tropical zones, because models estimate that N discharge from untreated sewage will at least double in developing countries between 2000 and 2050 (25).

International policies related to N management and pollution across LA, similar to those in parts of Europe (e.g., the Nitrates Directive) and North America, could increase regional political consensus, a necessity considering the transboundary effects of N atmospheric deposition and water pollution.

## References and Notes

1. J. N. Galloway *et al.*, *Science* **320**, 889 (2008).
2. L. A. Martinelli *et al.*, *Biogeochemistry* **79**, 3 (2006).
3. A. T. Austin *et al.*, *Biogeochemistry* **79**, 45 (2006).
4. R. Janssen, D. D. Rutz, *Energy Policy* **39**, 5717 (2011).
5. F. Salvagioti *et al.*, *Field Crops Res.* **108**, 1 (2008).
6. E. M. A. Smaling, R. Roscoe, J. Lesschen, A. Bouwman, E. Comunello, *Agric. Ecosyst. Environ.* **128**, 185 (2008).
7. S. Filoso *et al.*, *Biogeochemistry* **79**, 61 (2006).
8. E. Chuvieco *et al.*, *Ecol. Appl.* **18**, 64 (2008).
9. I. Trebs *et al.*, *Atmos. Chem. Phys.* **6**, 447 (2006).
10. M. F. Alonso *et al.*, *Atmos. Environ.* **44**, 5072 (2010).
11. A. Bleeker *et al.*, *Environ. Pollut.* **159**, 2280 (2011).
12. M. H. B. Daniel *et al.*, *Water Air Soil Pollut.* **136**, 189 (2002).
13. J. P. H. B. Ometto *et al.*, *Freshw. Biol.* **44**, 327 (2000).
14. P. J. Hotez *et al.*, *PLoS Negl. Trop. Dis.* **2**, e1757 (2008).
15. D. Acemoglu, J. Robinson, *Why Nations Fail* (Crown, New York, 2012).
16. D. Nepstad *et al.*, *Science* **326**, 1350 (2009).
17. M. Herrero *et al.*, *Science* **327**, 822 (2010).
18. L. A. Martinelli, *Nature* **474**, 579 (2011).
19. X. P. Chen *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **108**, 6399 (2011).
20. L. A. Martinelli *et al.*, *Agric. Syst.* **104**, 419 (2011).
21. D. Acemoglu, G. Gancia, F. Zilibotti, *J. Econ. Theory* **147**, 570, 601.e3 (2012).
22. C. Kay, *Third World Q.* **22**, 741 (2001).
23. A. L. Cerdeira *et al.*, *J. Agric. Food Chem.* **59**, 5799 (2011).
24. J. Ferreira *et al.*, *J. Appl. Ecol.* **49**, 535 (2012).
25. L. F. van der Struijk, C. Kroeze, *Global Biogeochem. Cycles* **24**, n/a (2010).

**Acknowledgments:** The authors acknowledge support from C. Palm at the Inter-American Institute for Global Change Research and the New Phytologist Trust. R. Howarth, K. Cassman, and participants in the International Nitrogen Initiative, provided comments.

<sup>1</sup>Universidad de Buenos Aires, IFEVA-CONICET, Buenos Aires, Argentina. <sup>2</sup>Universidade de Brasília, Brasília, Brazil. <sup>3</sup>Instituto Venezolano de Investigaciones Científicas, Caracas, Venezuela. <sup>4</sup>Instituto Nacional de Pesquisas Espaciais, São José dos Campos, Brazil. <sup>5</sup>Instituto Boliviano de Investigación Forestal, Santa Cruz, Bolivia. <sup>6</sup>Universidad Nacional Autónoma de México, Distrito Federal, México. <sup>7</sup>Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil. <sup>8</sup>CENA-Universidade de São Paulo, Piracicaba, Brazil

\*Author for correspondence: martinelli@cena.usp.br