CROP PRODUCTION

Nitrogen management and air quality in China

Farm management strategies for alternatives to nitrogen application can reduce greenhouse gas emissions, improve air quality, and increase crop yields in China.

Timothy J. Griffis and John M. Baker

The discovery of the Haber–Bosch process, the method of converting inert nitrogen (N_2) and natural gas into ammonia (NH_3), is considered one of the most important scientific inventions in modern history. It removed what had previously been the primary limitation on global food production — the availability of nitrogen (N) in a form that plants can use, which enabled production of modern agricultural fertilizers. Global demand for nitrogen fertilizer now exceeds 110 Tg N per year, and is steadily increasing, but the dramatic N-fuelled surge in crop production has had some decidedly negative environmental consequences. In this issue of *Nature Food*, Guo et al.[1] provide a comprehensive analysis of mitigation strategies designed to reduce reactive N leakage from agricultural systems in China. They combined extensive research datasets, meta-analyses, and chemical transport modelling to evaluate how practical N mitigation efforts (that is, reduced N fertilizer application, deep placement of N fertilizer, enhanced-efficiency N fertilizers, and improved manure N management) impacted greenhouse gas emissions, NH_3 emissions and $PM_{2.5}$ (particulate matter with a diameter less than 2.5 µm) formation, nitrogen use efficiency (NUE), and crop yields. Such syntheses are critical for diagnosing reactive N leakage in these complex systems, with several potential transformation pathways and unintended consequences, which must be considered when developing policy.

Nitrogen fertilizer is produced in either oxidized (nitrate-based) or reduced (ammonia-based) forms. Once applied, they are highly reactive, and subject to further biotic and abiotic transformations that result in the release of a variety of N compounds to the environment. Due to these transformations, in concert with the tendency of excessive N application by many farmers, global NUE is remarkably low (~40%)[2]. Consequently, a significant fraction of the applied synthetic N leaks out of agricultural systems and is detrimental to water resources, ecosystem health, and the atmosphere's composition and function.

Globally, about 4% of applied synthetic N leaks into the atmosphere as nitrous oxide (N_2O) (ref. [3]) — a greenhouse gas with a global warming potential that is 270 times that of carbon dioxide[4], and is implicated in destroying the protective stratospheric ozone layer[5]. Synthetic N fertilizer also leaks into the environment in the form of NH_3, a precursor of atmospheric aerosols. Agricultural activities led to the NH_3 concentration increase of about 500% during the 20th century[6], with aerosols linked to an increase in adverse impacts on human health. In the United States alone, health costs associated with agricultural NH_3 are estimated at $36 billion (in 2006 US$) annually[7], despite a national NUE that has varied from about 0.6 to 0.7 since 1960[2]. The NUE in China has declined from about 0.65 in 1960[2] to a current estimate of 0.38[1]. Thus, the reactive nitrogen leakage rate is nearly two times greater in China, and environmental and health consequences have been severe, with $PM_{2.5}$ alone associated with 1.3 million premature deaths each year[1].

Direct N_2O emissions from synthetic N fertilizer applied to farm fields exhibit a non-linear emission response, with an exponential increase in emission factor as rates of N fertilizer application exceed crop demand[8]. Given that synthetic N fertilizer application rates in China are 50 to 150% higher than in the United States[1], there is significant potential to lower direct N_2O emissions with N management strategies that are relatively easy to implement. Here, the meta-analyses of field observations by Guo et al. indicate that N_2O emissions could be reduced by 4.7 and 18.8 megatonnes of CO_2 equivalent, by more broadly adopting machine application and applying enhanced-efficiency N fertilizers, respectively. This represents a 9% and 36% reduction of N_2O emissions from total grain crop production in China. Such management strategies could be adopted quickly with appropriate policy and education directives. Thus, with some modest adjustment to the agricultural system, reduced N_2O emissions in China could help to offset the global rise of N_2O concentrations. Guo et al. also help to unravel how better N management on farms can reduce regional $PM_{2.5}$ concentrations and thus lower the risk of cardiopulmonary disease and premature death. Improved manure N management was identified as a key pathway to lower NH_3 emissions by 15%. Their atmospheric model analyses showed that $PM_{2.5}$ concentrations would likely decrease on average by 4.4 mg m^{-3} because of this reduction. The majority of current NH_3 mitigation efforts in China have focused on point source emissions,

Fig. 1 | A meteorological tower measuring greenhouse gases and reactive nitrogen in the atmosphere at a rural site in the Yangtze River Delta, eastern China. This regional study was initiated at the Guandu International Observatory of the Yale–NUIST (Nanjing University of Information Science and Technology) Center on Atmospheric Environment. Credit: Timothy J. Griffis but here, the authors predict that addressing the diffusive sources from agriculture could result in an important 3% reduction in $PM_{2.5}$-related mortalities.

New policies in China, introduced under the Three-year Blue-sky Action Plan aim to reduce reactive N leakage and improve air quality. An important goal is to freeze the total amount of synthetic N fertilizer use by 2020. Guo et al. show that, in addition to these efforts, by adopting alternative N management strategies, NUE for grain crops in China will increase from 41% to 48%, with yield increasing from of 7% to 9% for the major grain crops. Thus, there appears to be strong potential to freeze synthetic N use, while improving yields and reducing N leakage. These appear to be conservative estimates based on the best available field data and assumptions. There remain, however, key uncertainties regarding biophysical feedbacks associated with climate change and the need to directly assess if mitigation strategies are working. For example, it is unclear how higher air temperatures and changes in precipitation will impact N fertilizer management approaches including the use of enhanced efficiency fertilizers[9].

Will climate change conspire against mitigation efforts? There is concern that increasing air temperature and precipitation will exacerbate N losses from leaching and runoff, enhancing indirect and direct N_2O emissions[10]. Figure 1 illustrates a state-of-the-art meteorological tower, deployed in the Yangtze River Delta in eastern China, designed to make flux measurements and high-precision concentration measurements of greenhouse gases and ammonia. Such measurements are critical for directly assessing agricultural emissions and establishing benchmarks that will be crucial to evaluating if N mitigation efforts are having the intended benefits suggested by these meta-analyses and modelling studies. ❐

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References

1. Guo, Y. et al. *Nat. Food* https://doi.org/10.1038/s43016-020-00162-z (2020).
2. Zhang, X. et al. *Nature* **528**, 51–59 (2015).
3. Crutzen, P. J., Mosier, A. R., Smith, K. A. & Winiwarter, W. *Atmos. Chem. Phys.* **8**, 389–395 (2008).
4. Montzka, S. A., Dlugokencky, E. J. & Butler, J. H. *Nature* **476**, 43–50 (2011).
5. Ravishankara, A. R., Daniel, J. S. & Portmann, R. W. *Science* **326**, 123–125 (2009).
6. Bouwman, L. et al. *Proc. Natl Acad. Sci. USA* **110**, 20882–20887 (2013).
7. Paulot, F. & Jacob, D. J. *Environ. Sci. Technol.* **48**, 903–908 (2014).
8. Shcherbak, I., Millar, N. & Robertson, G. P. *Proc. Natl Acad. Sci. USA* **111**, 9199–9204 (2014).
9. Parkin, T. B. & Hatfield, J. L. *Agron. J.* **106**, 694–702 (2014).
10. Griffis, T. J. et al. *Proc. Natl Acad. Sci. USA* **114**, 12081–12085 (2017).

Competing interests

The authors declare no competing interests.