

Nitrous oxide (N₂O) emissions from soils are responsible for about 3 percent of greenhouse gas (GHG) emissions, which cause climate change, and contribute approximately one-third of non-CO₂ agricultural GHG emissions. N₂O is produced by microbial transformations of nitrogen in the soil, under both aerobic and anaerobic conditions. Therefore, emissions are often directly related to nutrients added to the soil in the form of mineral fertilizers and animal manure. These additions can be vital in maintaining soil fertility and crop production; about half of the world's population is dependent on food produced strictly because of mineral fertilizer inputs. However, the additions are also highly inefficient, leading to nitrogen losses via leaching, volatilization, and emissions to the atmosphere. By helping to maximize crop-nitrogen uptake, improved nutrient management has a significant and cost-effective role to play in mitigating GHG emissions from agriculture. Nutrient management can also help reduce methane (CH₄) emissions from rice production and increase carbon sequestration in agricultural soils.

Mitigation strategies

Mineral fertilizer use

Management strategies to improve the nitrogen use efficiency of crops, thereby reducing fertilizer requirements and associated GHG emissions, focus on fertilizer best management practices. These practices are based on the principle of the "right source, at the right rate, at the right time, and with the right placement." Such practices concentrate on the following:

Application type

- Researchers have argued that urea-based fertilizers lead to higher N₂O emissions than ammonia or nitrates do, but the most recent reviews suggest that both environmental factors, such as soil conditions and climate, and management factors, such as tillage, also play key roles in determining the proportion of applied nitrogen lost as N₂O. These confounding variables prevent valid comparisons between fertilizer types. Also, some forms of nitrogen fertilizer may reduce N₂O emissions but not improve overall nitrogen use efficiency due to other nitrogen losses, for example, through leaching. Although research into nitrogen sources has given mixed results, it is clear that "balanced" fertilization (that is, balancing nitrogen applications with other required nutrients, including phosphorus, potassium, and sulphur) is a major way of improving nitrogen use efficiency.

Application rates

- Appropriate nitrogen application rates are required to limit the buildup of nitrates in soil, which can accumulate when more nitrogen is applied than the crop demands at that time. Cutting nitrogen application rates below economic optimums risks long-term decline in soil productivity, a problem already occurring in places like Africa and parts of India that are chronically under-fertilized.

Managing nitrogen fertilizer levels is challenging because appropriate application rates will differ for each agroecosystem and growing season. The exact relationship between nitrogen input and N₂O emissions is debatable, but many studies have suggested that when an agronomic nitrogen-threshold level—an

amount based on the ecosystem uptake capacity determined by field measurements—is exceeded, N₂O emissions increase dramatically.

Application timing

- Nitrogen applications that are carefully timed to maximize crop uptake reduce application rates and N₂O emissions without decreasing crop yield. Applications should be avoided prior to planting and, instead, concentrated in the initial crop development phase at the time of, and shortly after, planting in order to maximize crop uptake and minimize nitrogen loss from the system.

Application placement

- Greater proportions of applied nitrogen are generally lost if fertilizer is applied at the surface, although this may be in the form of ammonia-volatilization rather than N₂O emissions. Researchers disagree as to the effect of application depth, which appears to be strongly influenced by the tillage regime, among other factors.

Best practice for fertilizer use is dependent, to a certain extent, on the exact agroecosystem under consideration, its management regime, and environmental factors. Thus, management plans need to reflect local conditions. Precision farming systems are already available to ensure farmers can draw up careful plans, and the most advanced systems can reduce fertilizer usage by about one-third. For small-scale farmers in the developing world, who have no access to modern farming equipment, the best solution for improving fertilizer practices is to increase access to independent advice from local experts such as research institutes.

Another possible mitigation strategy is the wider use of fertilizer additions such as controlled-release coatings and nitrification inhibitors, which also reduce CH₄ emissions from fertilized rice paddies. Controlled-release or enhanced-efficiency fertilizers generally work by controlling the speed at which fertilizer, or a coating applied to it, dissolves in soil water. By affecting the timing of nitrogen release from fertilizer, these compounds have the potential to reduce the loss of nitrogen and therefore improve nitrogen use efficiency.

Similarly, soluble fertilizers formulated with inhibitors reduce or block the conversion of nitrogen species by affecting specific types of microbes involved. This helps to keep nitrogen in the form of ammonium longer, encouraging uptake by crops and helping to prevent N₂O emissions from either nitrification or denitrification. Some inhibitors can be more than 90 percent effective in reducing N₂O emissions.

Mineral fertilizer production, distribution, storage, and application currently contribute approximately 2 percent of total global GHG emissions. Further research could clarify the best fertilizer additions to include under specific circumstances and develop new nitrogen-related products, including, for example, smart delivery mechanisms that are driven by factors related to temperature, water, or biotic properties, such as the host plant. Better understanding of the relationship between N₂O emissions and extreme weather events may also become increasingly important as our climate changes.

Organic nitrogen sources

With synthetic fertilizers inducing N₂O emissions from soils, requiring energy, and producing GHG emissions during their manufacture, another key mitigation strategy is to make better use of existing organic sources of nutrients, including animal manure, crop residues, and nitrogen-fixing crops such as legumes. Such organic nitrogen sources may also contribute to increasing carbon sequestration in soils.

Animal manure

- As well as reducing mineral fertilizer requirements and the GHG emissions associated with their manufacture, using animal waste may also reduce soil N₂O emissions. While nitrogen losses from liquid slurry are generally higher than from mineral fertilizers, many researchers argue that solid manures reduce emissions. Research also suggests that organic manures do not cause the spikes in emissions that occur with mineral fertilizers if there is heavy rainfall around the time of application, meaning manures can significantly mitigate N₂O emissions during wet growing seasons.

Crop residues

- Incorporating post-harvest plant remains into soil can increase levels of soil organic matter thereby assisting in soil carbon storage. However, these benefits can be offset by increased N₂O emissions in some cases, so residues with high nitrogen content could be composted prior to incorporation to minimize negative effects. Impacts are also dependent on tillage management and other fertilizer additions.

Nitrogen-fixing crops

- Introducing crops such as clover and other legumes into rotations can reduce fertilizer requirements by adding biologically fixed nitrogen into soils. While this tends to raise background emissions of N₂O from the soil, it can mitigate total emissions over a longer term (accounting for reductions in N₂O emissions from mineral fertilizers applied to the other crops in rotation). Planting nitrogen-fixing trees during fallow periods is another good option.

Much of the research into the effects of organic additions to date has focused either on N₂O emissions or on carbon sequestration, making it difficult to ascertain the net impact in terms of global warming potential (GWP). Further research in this area would be valuable, especially since organic additions are among the cheapest mitigation strategies available. The integrated use of organic and synthetic fertilizers may be the best option for improved soil fertility and crop production, as organic sources make it harder to synchronize nitrogen release with crop demands and may increase N₂O emissions in comparison with synthetic fertilizers under some circumstances. Particularly in many developing countries where there is pressure on organic resources—for example, in places where farmers need to use animal dung as fuel—agroforestry should be promoted. Planting trees will offer farmers an alternative fuel supply and benefit soils and crops.

Mitigation potential

More efficient use of mineral fertilizers is highly achievable; countries

such as China and India—the two largest consumers of synthetic nitrogen—currently have much lower crop-use efficiencies than areas like Europe, where fertilizer use has declined in recent years. Policies regarding heavy subsidies for nitrogen fertilizers have contributed to this inefficiency, and implementing fertilizer best management practices can help reduce inefficiency while also (1) reducing GHG emissions and other environmental damage, such as nitrification of waterways, (2) improving nutrient balance and efficiency, (3) lowering fertilizer costs to farmers, and (4) freeing up government spending for more beneficial projects. Reductions in the use of mineral fertilizers also have additional benefits in terms of GHG savings from their manufacture and transportation, which can be vastly higher from inefficient coal-powered plants in countries such as China and Russia, compared with the most advanced plants. Upgrading all fertilizer production plants to the best modern standards can also significantly reduce energy requirements and N₂O emissions.

Currently, crop production per unit of nitrogen applied is falling in many countries, such as China, because crops are vastly overfertilized, while soils in parts of Africa and India still suffer from chronic nutrient deficiency. This imbalance needs to be addressed. Increased and better use of organic material for fertilization can assist with this while also mitigating indirect emissions from synthetic fertilizer production, improving soil quality through more balanced nutrition, and sequestering more carbon into soil systems.

Suggested negotiating outcomes:

Sufficiently robust practices that should be implemented and rewarded with offset payments under current conditions include fertilizer best management practices (where they have not already been implemented); the use of controlled-release fertilizers and nitrification inhibitors; applying animal manure to and incorporating crop residues into the soil in areas where soil organic matter is declining; and introducing nitrogen-fixing crops into intensive rotations. Although not strictly a nutrient-management issue, agroforestry would also be significantly beneficial.

Further research funding could be targeted at better understanding the net effects of introducing nitrogen-fixing crops into less heavily fertilized crop rotations, using organic amendments in areas where soil organic matter is already well maintained, and finding new nitrogen products along the lines of controlled-release fertilizers. Better long-term field trials need to be established so that soil carbon gains and reduced nitrogen emissions can be quantified for the purpose of offset payments. ■

For Further Reading: J. Bellarby et al., *Cool Farming: Climate Impacts of Agriculture and Mitigation Potential* (Amsterdam: Greenpeace International, 2008); R. L. Desjardins et al., “Management Strategies to Sequester Carbon in Agricultural Soils and to Mitigate Greenhouse Gas Emissions,” *Climatic Change* 70 (2005): 283–297; C. S. Snyder et al., *Greenhouse Gas Emissions from Cropping Systems and the Influence of Fertilizer Management* (Norcross, Ga., U.S.A: International Plant Nutrition Institute, 2007).

Helen C. Flynn (h.c.flynn@abdn.ac.uk) is a research fellow at the Institute of Biological and Environmental Sciences, School of Biological Sciences, University of Aberdeen, Scotland, UK.



International Food Policy Research Institute

2033 K Street, NW • Washington, DC 20006-1002 • USA

Phone: +1-202-862-5600 • Skype: ifprihomeoffice • Fax: +1-202-467-4439 • Email: ifpri@cgiar.org

IFPRI® www.ifpri.org