The nitrogen cascade

EXCESS NITROGEN IN THE ENVIRONMENT

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Excess Nitrogen in the Environment
Changes in the global nitrogen cycle

Nitrogen is an essential nutrient for plant growth. The discovery a century ago of an industrial process that converted nitrogen in the air to ammonia made the manufacture of nitrogen fertilizers possible. This discovery was followed by a spectacular increase in global food production.

Nitrogen fertilizers: 100 years of using the Haber-Bosch process

There is an abundance of nitrogen in the atmosphere, but this nitrogen exists almost entirely in a form that is unusable by most organisms. Atmospheric nitrogen can be made usable or ‘reactive’ through natural processes (e.g. nitrogen fixation by legumes such as soybeans) or artificially. The Haber-Bosch process is essential for the manufacture of fertilizers containing nitrogen, which were first produced on an industrial scale in 1913.

Today nitrogen and other nutrients are used inefficiently in most of the world’s agricultural systems – resulting in enormous and largely unnecessary losses to the environment, with profound impacts ranging from air and water pollution to the undermining of important ecosystems (and the services and livelihoods they support). Such impacts are often more visible in developed regions than in developing ones.

The global nitrogen cycle has been profoundly altered by human activity over the past century. The amount of usable or ‘reactive’ nitrogen produced by humans (about 190 million tonnes per year) is now greater than the amount created through natural processes (112 million tonnes per year). In addition to inefficient application of nitrogen fertilizers, sources of excess nitrogen in the environment are inadequately treated animal and human wastes and fossil fuel combustion in transport and energy production, which creates nitrogen oxides.

As nitrogen moves through the environment, the same nitrogen atom can contribute to multiple negative effects in the air, on land, in freshwater and marine systems, and on human health. This sequence continues over a long period and is referred to as the ‘nitrogen cascade’.

Nitrogen does not move through all environmental systems at the same rate. For example, soil, forests and grasslands accumulate it, which can lead to slowing of the nitrogen cascade, while air transfers the nitrogen more rapidly. Excess nitrogen in the environment contributes to many health and environmental problems, including:

- Coastal dead zones and fish kills due to severe eutrophication or hypoxia resulting from nitrate run-off and leaching into river systems
- Biodiversity loss in terrestrial, freshwater and coastal water systems due to eutrophication and acidification
- Groundwater pollution by nitrates
- Freshwater pollution due to eutrophication and acidification
- Human health impacts resulting from the formation of aerosols and ground-level (tropospheric) ozone, a main component of smog, causing respiratory diseases
- Reduced crop, forest and grassland productivity due to nitrogen deposition and over-fertilization, as well as ground-level ozone exposure
- Global climate change and the depletion of stratospheric ozone, which protects life on Earth from harmful ultraviolet (UV) rays

Read more about the nitrogen cascade in the 2003 Year Book.

Simplified view of the nitrogen cascade

Source: Sutton et al. 2013
Increased coastal dead zones and climate change impacts

Ongoing research is improving our understanding of how excess nitrogen affects air, water and soil quality, puts pressure on ecosystems and biodiversity, leads to human health risks, and affects the global climate. Because of human modification of the nitrogen cycle, thresholds for reactive nitrogen have already been exceeded in some places – with the risk of bringing about abrupt or irreversible environmental changes.

Organisms require oxygen to grow and reproduce. ‘Dead zones’ are oxygen-depleted (hypoxic) areas that result from over-enrichment of waters with nutrients (especially nitrogen and phosphorus), for example from fertilizer run-off, industrial waste and sewage. Reported cases of coastal dead zones have doubled in each of the last four decades. There are currently over 500 known dead zones in the world, whereas in 2003 only around 150 such oxygen-depleted areas were reported. Close to 1000 other coastal and marine areas are experiencing the effects of eutrophication. The number of areas identified as suffering from hypoxia is increasing most rapidly in the developing world. Rapid increases in algae growth in aquatic systems (algal blooms) are stimulated by nutrient enrichment. They can include toxic algae or algae that, after deposition, cause damage to living coral reefs.

Nitrogen emissions to the air – notably those of nitrous oxide (N₂O) – are contributing to climate change. Nitrous oxide is naturally present in relatively small quantities in the atmosphere as part of the nitrogen cycle. However, human activities such as agriculture and deforestation, fossil fuel combustion, industrial processes and wastewater management are increasing the amount in the atmosphere.

More than two-thirds of atmospheric emissions of nitrous oxide arise from processes in soils, largely resulting from application of nitrogen fertilizers. Some countries are experiencing intense air pollution, much of which is due to nitrogen emissions. These emissions result in deposition of nitrogen in terrestrial and aquatic ecosystems, with implications for human and ecosystem health, biodiversity and climate change. Nitrogen deposition rates in the industrialized and agriculturally intensified regions of China are reportedly as high as the peak rates in northwestern Europe in the 1980s, before the introduction of nitrogen emission mitigation measures.

Nitrogen plays a critical role in climate change mitigation, adaptation and impacts. It has been suggested that nitrogen has a net cooling effect on climate change through the contribution of aerosols (suspensions of tiny particles formed from nitrous oxide, nitrogen oxide and ammonia that scatter sunlight) and biomass growth in terrestrial and aquatic systems due to nitrogen fertilization, which leads to greater carbon dioxide (CO₂) uptake. Climate warming results from increased nitrous oxide emissions, ground-level ozone production, and damage to vegetation because of over-fertilization with nitrogen. Even with the net cooling effect, therefore, much can be done to reduce nitrogen's warming impacts and contribute to efforts to tackle climate change.

Nitrous oxide: the ‘forgotten greenhouse gas’

Nitrous oxide (N₂O) emissions continue to increase globally. N₂O is a powerful greenhouse gas that causes stratospheric ozone layer depletion. Sometimes referred to as the ‘forgotten greenhouse gas’, it is over 300 times more effective at trapping heat in the atmosphere than carbon dioxide (CO₂) over a 100-year period.
What is being done to reduce excess nitrogen releases?

In 2011 governments agreed to address the nitrogen challenge by endorsing the Global Partnership of Nutrient Management (GPNM). Established in 2009, GPNM is a multi-stakeholder partnership made up of governments, the private sector, the scientific community, civil society organizations and UN agencies – all committed to promoting effective nutrient management in order to achieve food security (through increased productivity), conservation of natural resources and environmental protection. By means of GPNM, countries and other stakeholders identify opportunities for co-operative work across international and regional fora and agencies addressing nutrients.

In the 2012 UN Conference on Sustainable Development (Rio+20) outcome document ‘The Future We Want,’ governments also noted with concern that the health of oceans and marine biodiversity are negatively affected by (...) nitrogen-based compounds, from a number of marine and land-based sources.’ World leaders at Rio+20 made a commitment to act to reduce the incidence and impacts of such pollution on marine ecosystems. This commitment by the global community needs to be taken forward through a concerted programme of actions, including creating greater awareness of the urgent need for better nutrient management and waste treatment.

A number of tools have been developed in recent years to increase awareness of the nitrogen issue by decision makers and the general public, as well as to educate farmers and others in the agricultural sector on better nutrient management. These include the N-Calculator, a ‘nitrogen footprint’ model, N-Sink, a simple geo-spatial tool designed for watershed managers, and N-Visualisation, a tool with animations that helps users understand the effects of different measures on the environment, economies and land use.

Fertilizer best management practices are designed to maximize the benefits of using manufactured fertilizers worldwide and to minimize the negative impacts of their misuse or over-use. There is considerable scope for farmers using fertilizers to improve the efficiency of their nutrient management. For example, despite the 1991 European Union (EU) Nitrates Directive, which is intended to prevent nitrates from agricultural sources polluting ground and surface waters, only two EU countries, Denmark and the Netherlands, have reduced this type of nitrogen pollution so far.

One reason for inefficient nutrient use is the existence of fertilizer subsidies in many countries. Furthermore, education and extension services often focus on increasing production through fertilizer use, rather than on applying fertilizer more efficiently in view of the negative environmental impacts of excessive nitrogen inputs.

Better management practices are essential to improve nitrogen use efficiency. This is the most cost-effective option for reducing nitrogen losses to the environment from agricultural sources. There are large variations in farm types and sizes, climatic conditions, soils and other factors. Adequate and appropriate guidelines, educational programmes and independent extension services are required throughout the world.

Technological innovations can also limit the amount of nitrogen released to the environment, while ensuring food security for billions of people. Controlled-release fertilizers and fertilizer deep placement are examples. Such innovations are aimed at increasing crop yields and farmers’ incomes while reducing the amount of fertilizer used and lessening environmental damage.

The volume of sewage and industrial waste generated by a growing world population has increased nitrogen inputs to the environment. In developing countries, fewer than 35% of cities have any form of sewage treatment. Where such facilities exist, they often provide only primary treatment, which does little to remove nitrogen. Even in the developed world, many sewage treatment facilities do not include the tertiary treatment that removes most of the nitrogen.

There is wide recognition that the nitrogen issue needs to be better understood and communicated in order to reduce losses to the environment and create the momentum to take effective action. In particular, awareness is needed of the environmental and human health consequences of ever-increasing nitrogen inputs, including nitrogen’s critical role in climate change mitigation, adaptation and impacts.
Towards integrated nitrogen management

Our knowledge of the nitrogen cycle has improved in the last decade, along with our ability to quantify the sources, fate and impacts of nitrogen in the environment. However, because of the complexity of the nitrogen cycle and the different scales involved (from local to global), scientific understanding and measures to reduce nitrogen pollution are often focused on individual sectors.

There is also a fragmentation of the policies that address aspects of the nitrogen challenge. These policies typically focus on environmental compartments (e.g. air, water, soil), particular environmental issues (e.g. waste management, biodiversity loss, climate change) or a single form of nitrogen (e.g. nitrates, nitrogen oxides).

The scale on which stakeholders operate also differs, ranging from the global commodity level in the case of the fertilizer industry to small-scale farmers and local communities. More comprehensive, integrated management is needed to reduce the adverse effects of excess nitrogen in the environment while optimizing food production and energy use. There is an urgent need to:

• Develop joined-up approaches that take into account impacts on the nitrogen cycle in, for example, the production and consumption of food and energy, as well as the risks to ecosystems, biodiversity, the climate and human health
• Establish internationally agreed targets for integrated nitrogen management
• Coordinate (and collaborate) among regions and locations in order to make the large improvements needed in global nitrogen use efficiency

One of the key messages of the recent ‘Our Nutrient World’ report is that a 20% improvement in global nutrient use efficiency by 2020 would reduce annual use of nitrogen fertilizer by an estimated 20 million tonnes. This, in turn, could produce net savings of US$50-400 billion per year in terms of improvements in human health, climate and biodiversity.

Society faces profound challenges in trying to meet global demands for food, fibre and fuel while minimizing nitrogen’s unintended negative environmental and human health impacts. Effective management policies need to be in place to prevent or reduce air pollution, eutrophication and climate effects, among others. A number of key actions for more effective management have been proposed that could reduce the amount of nitrogen entering the environment, using an integrated approach. Generally these include the following:

• Focusing on natural production (nitrogen ‘fixing’) while limiting flows of reactive nitrogen
• Fixing nitrogen in such a way that it does not find its way back into the environment, and, if possible, reuse nitrogen
• Using technology that converts nitrogen back into unreactive nitrogen (N₂) as soon as possible

Technological innovations – and wide dissemination of these technologies and of good practices – are crucial. However, the immense impacts of human activities on the nitrogen cycle, especially since the mid 20th century, also call for re-evaluating 21st century consumption patterns – that is, our nitrogen footprint.

Source: Sutton et al. 2013
Further information about excess nitrogen in the environment


