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Human alteration of the nitrogen cycle

Threats, benefits and opportunities

The global nitrogen cycle represents one of the most important nutrient cycles that sustain life on Earth.

Today, humans add 1.5 times more nitrogen than do natural terrestrial processes combined altogether, through a combination of agriculture and fossil fuel use, and unduly influence the global nitrogen cycle.

The consequences are profound for the health of both ecosystems and people.

The challenge presented by the scope of the changing nitrogen cycle remains under-appreciated in both policy and scientific circles, but already-observed impacts of such changes on biodiversity, climate and human health provide compelling reasons to exploit more fully options for nitrogen management and policies.

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International Nitrogen Initiative

Ecological and Earth Sciences in UNESCO

A disproportionate
human influence on the nitrogen cycle

Nitrogen is an element essential to all life processes as it forms amino acids, proteins, nucleic acids and DNA that are vital for all living cells.

In its most common gaseous state (N_2), nitrogen comprises 78% of our atmosphere. But non-reactive N_2 gas must be converted through fixation to reactive forms (Nr), such as ammonia, amino acids, proteins, before being available to most life forms.

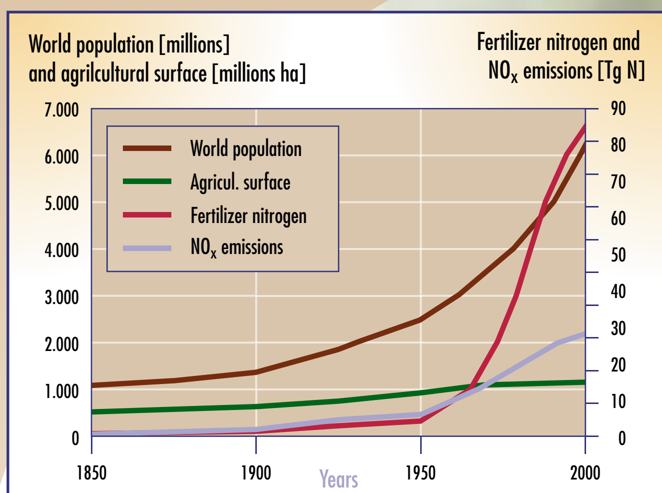
Before the 20th century, the fixation of nitrogen occurred only via a limited group of microorganisms and by lightning. With rapid population growth in the last century, natural Nr sources for food production were no longer sufficient. This led to the discovery of ways to convert non-reactive gaseous nitrogen (N_2) into reactive forms for agricultural purposes, mainly through industrial production of fertilizers. This Nobel-prize winning discovery* removed a major barrier to the rapid growth of the human population. At the same time, it marked the beginning of enormous changes in the global nitrogen cycle.

The industrial revolution's use of coal and other fossil fuels also caused human-induced conversion of N_2 into Nr (such as nitrogen oxides) at increasing rates, further disturbing the natural nitrogen cycle.

* Fritz Haber and Carl Bosch were German scientists who developed the process to combine nitrogen (N_2) with hydrogen (H_2) to produce ammonia (NH_3), and the ability to produce it at a commercial scale, respectively. For their efforts they were awarded Nobel Prizes in Chemistry in 1918 (Haber) and 1931 (Bosch).

Examples of reactive forms of nitrogen (Nr)

inorganic reduced forms of N	ammonia (NH_3) ammonium (NH_4^+)
inorganic oxidized forms of N	nitrite (NO_2^-) nitrate (NO_3^-) nitric oxide (NO) nitrous oxide (N_2O) nitrogen dioxide (NO_2)
organic compounds	urea amines proteins



Adapted from Galloway et al, 2003.

Societal response – Challenges and opportunities

It is a daunting task to improve nitrogen management because of the need to address two opposite extremes—too little nitrogen in some places and too much in others. For the former, more than 800 million people, or almost 15% of the world's population, suffer from hunger. The prevalence of widespread hunger and malnutrition is due to a number of factors. An important one that can be addressed is the lack of nitrogen to enable adequate production of enough, high quality food.

With regard to excess nitrogen, a number of global and regional factors need to be addressed. These include an increase in human population and urbanization, increased purchasing power and related changes in dietary preferences, globalization of agricultural trade and the associated movement of nutrients in traded commodities, and other aspects of environmental change.

The central challenge is how to optimize the use of nitrogen to sustain human life while minimizing the negative impacts on the environment and human health.

The complexity of Nr-related issues requires special attention in both regulatory and political domains. Reactive nitrogen is actively traded in commodities and is readily mobile through air, water, and soil. Policy integration—both geographical and across agencies that deal with air, water, soil, agriculture, and commerce—is therefore needed.

In addition, because some of the impacts of Nr occur on regional and global scales, policy responses to excesses and deficiencies of Nr are required at different scales, implying the need for collective responses that span the appropriate political jurisdictions.

Appropriate economic incentives are imperative. These may include models of emissions trading and cost savings related to nutrient best management practices (the right products at the right time, rate and place). Technological innovation in both agriculture and energy consumption will also contribute to more efficient nitrogen management.

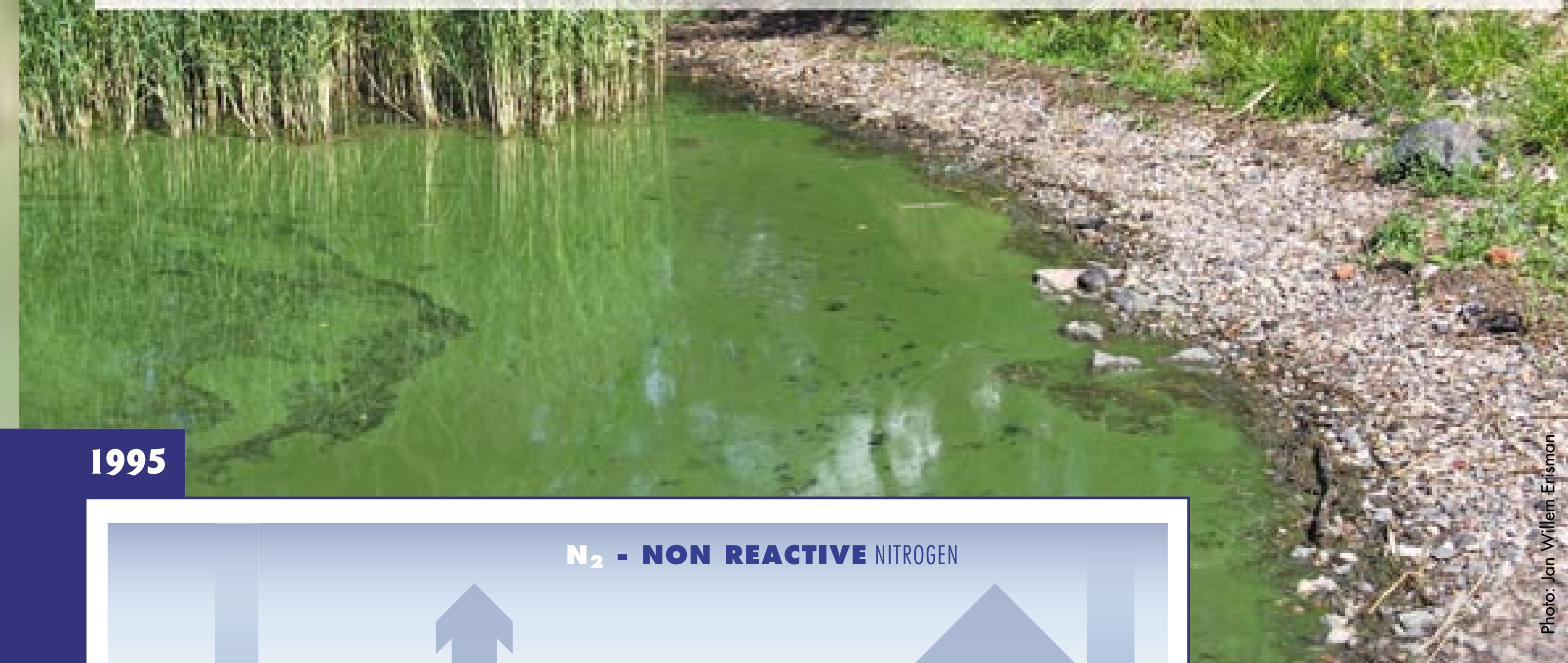


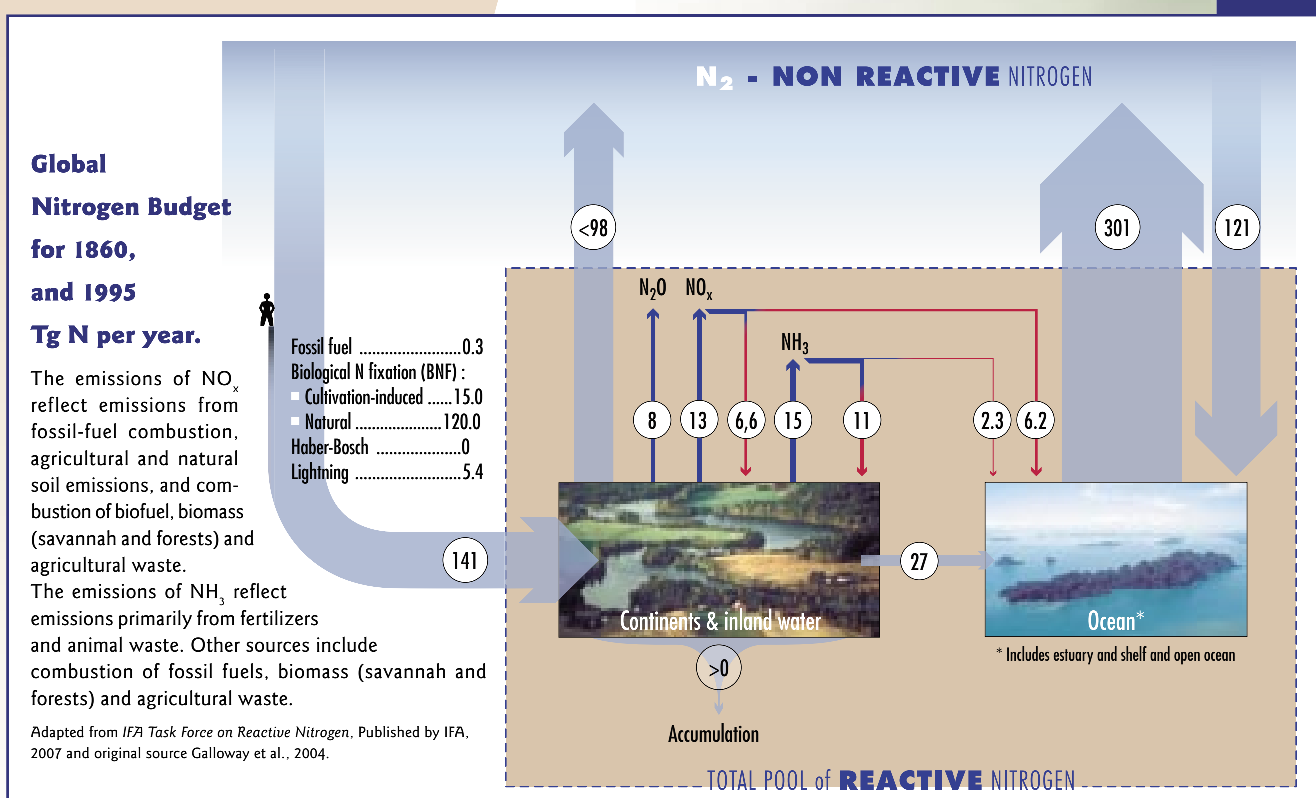
Photo: Jan Willem Erisman

Global Nitrogen Budget for 1860, and 1995 Tg N per year.

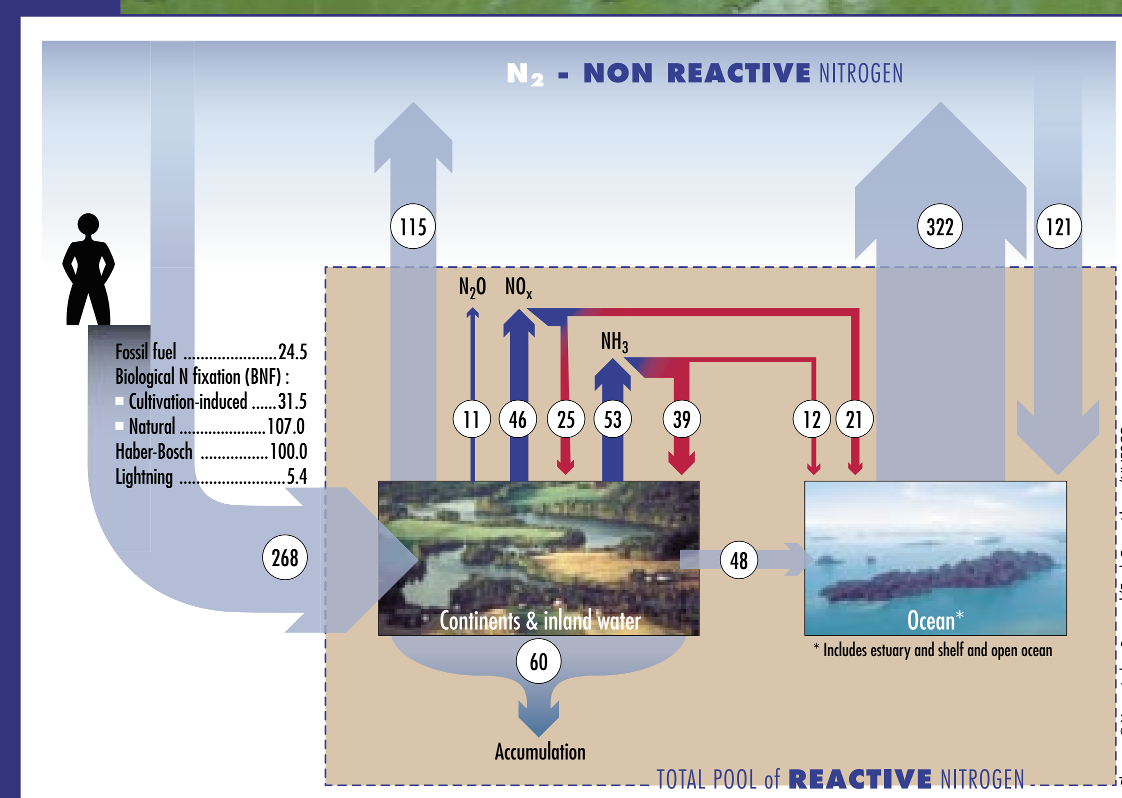
The emissions of NO_x reflect emissions from fossil-fuel combustion, agricultural and natural soil emissions, and combustion of biofuel, biomass (savannah and forests) and agricultural waste.
The emissions of NH_3 reflect emissions primarily from fertilizers and animal waste. Other sources include combustion of fossil fuels, biomass (savannah and forests) and agricultural waste.

Adapted from *IFA Task Force on Reactive Nitrogen*, Published by IFA, 2007 and original source Galloway et al., 2004.

1860



1995



Consequences of changes in global nitrogen cycle

In addition to facilitating population growth, advances of nitrogen production and use in both industry and agriculture have enhanced agricultural productivity, increased nutritional quality, and thus increased quality of life for society at large.

However, due to the inefficiencies of nitrogen use in agriculture, most of the N that is industrially fixed for human food production is lost to the environment before it is assimilated by humans.

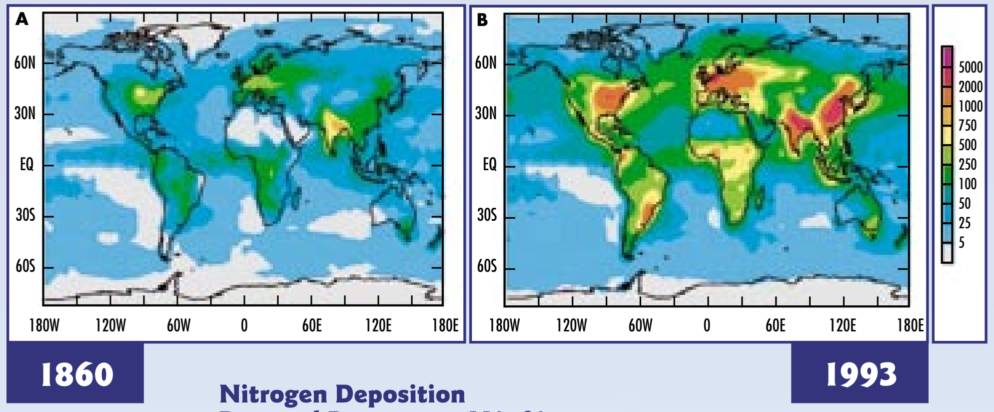
These losses, coupled with those from fossil fuel combustion, make human-derived nitrogen inputs to the environment far greater than natural rates for large regions of the world.

Rapidly expanding use of nitrogen in its reactive forms is linked to a growing number of environmental and social problems. These can be summarized as N deficiency or excess, in other words as 'too little or too much'.

Too little or too much nitrogen

In areas with too little Nr (e.g. large regions of Africa, Latin America) more is removed by cropping than is replenished by fertilizers and other sources of crop nutrients, leading to widespread depletion of soil nutrients and land degradation. Agricultural production often cannot meet the food needs of rapidly growing populations in those areas.

Where there is too much Nr (e.g. some regions of Europe, North America, Asia), food production is sufficient, but a large share of the nitrogen applied in agriculture is lost to the environment. For some regions, like North Western Europe, Eastern Asia, and Eastern North America, the combination of agriculture- and energy-based nitrogen losses to the environment are now 10 to 100 times greater than only a century ago.



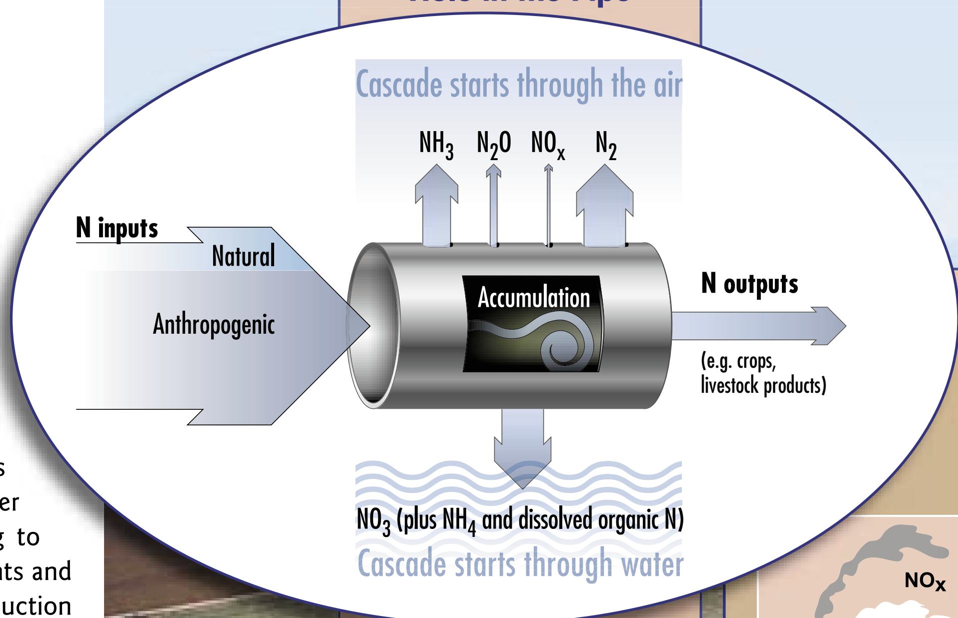
Nitrogen Deposition
Past and Present mg N/m²/yr

In 1860, the total Nr deposition to the Earth's surface was 32 million metric tons of nitrogen, mostly from natural emission sources.

By the early 1990s, total Nr deposition had increased to 100 million metric tons. The difference was entirely due to anthropogenic activities. In some regions, deposition increased 100-fold.

Adapted from Galloway et al, 2004.

Hole in the Pipe



Hole in the Pipe

Nitrogen emissions from agricultural systems to the air and water visualized by the 'hole in the pipe' model. Inputs of N occur via fertilizer and animal manure, biological N fixation and atmospheric deposition. The outputs occur via crop harvest and livestock products. The emission of both reactive and non-reactive N from the system to the environment indicates low N use efficiency.

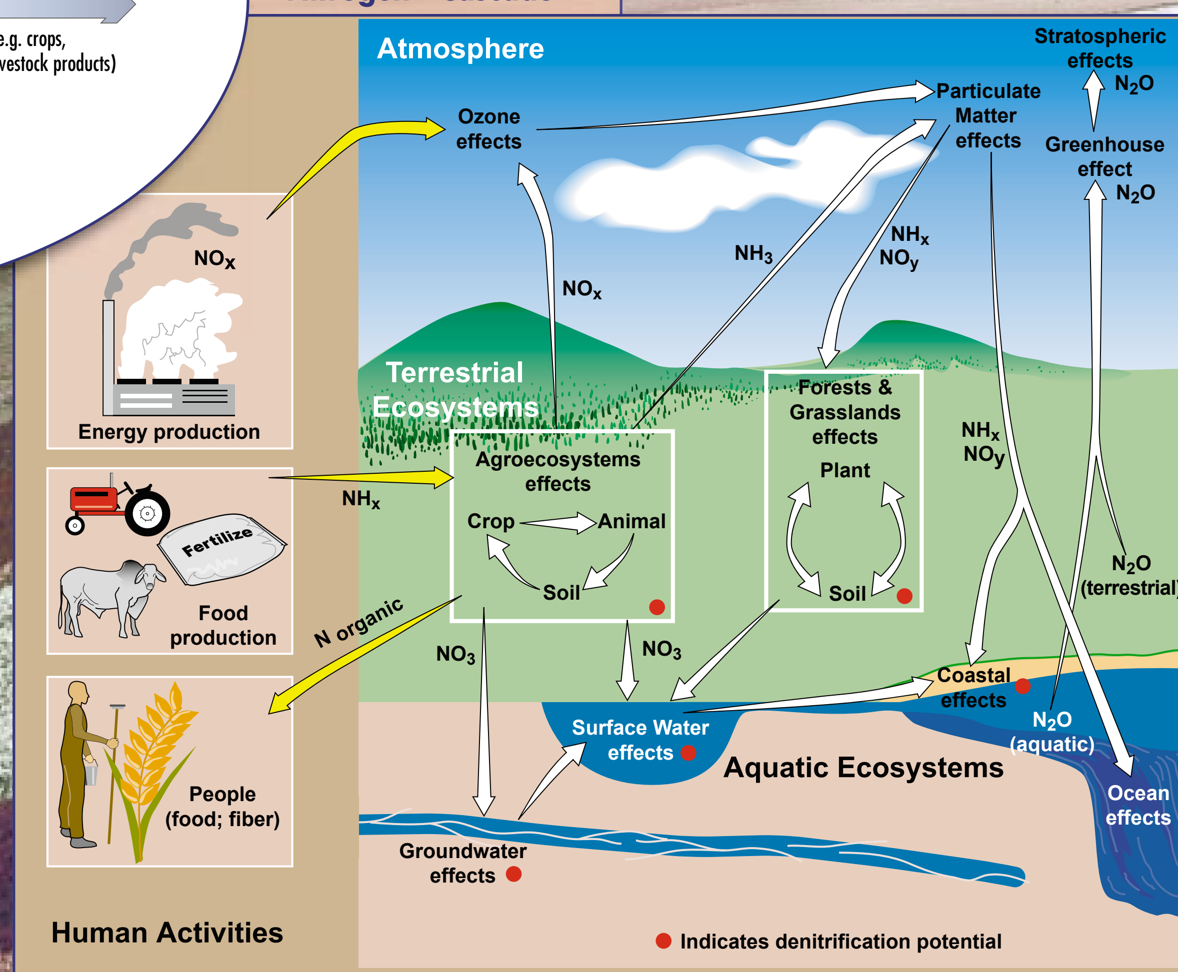
Adapted from O. Oenema et al., 2007

Nitrogen Cascade

Sequential effects that a single atom of N can have in various environmental compartments after it has been converted from a non-reactive to a reactive form.

From *GEO Yearbook 2003*, United Nations Environment Programme (UNEP), 2004.

Nitrogen Cascade



Effects of nitrogen losses to environment

Reactive N is a major contributor to photochemical smog, fine particulate pollution, ecosystem acidification and fertilization, coastal eutrophication and global warming.

For ecosystems, smog can damage crops and forests; increased fertilization and/or acidity from Nr additions causes multiple ecological changes in both terrestrial and aquatic ecosystems that can result in biodiversity shifts, favour invasive alien species, and damage the economic base of environmental systems.

Reactive N affects the global balance of several greenhouse gases, including carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Over a 100-year period, N_2O has a global warming potential 296 times larger than an equal mass of CO_2, while it also contributes to stratospheric ozone depletion.

Effects of nitrogen losses to human health

Changes in nitrogen use also affect human health. On the positive side, food produced from N fertilizers is clearly a massive public health benefit, both in terms of the amount of food produced and its average protein content. Furthermore, fertilizers will contribute to the increased production of biofuels needed for a sustainable energy production.

Nitrogen-related air pollution is linked to higher rates of cardio-pulmonary ailments and overall mortality in urban areas. There is also concern about the potential health impact of high levels of nitrate in drinking water. Finally, ecological feedbacks to excess nitrogen may inhibit crop growth, increase allergenic pollen production, and possibly increase the prevalence of several parasitic and infectious human diseases (including, but not limited to) cholera and West Nile Virus.

As human creation and use of Nr continues to rise, the net public health benefits lessen, while the negative health consequences diversify and increase.

Photo: © Yann Arthus-Bertrand/Earth From Above/UNESCO

Most important negative effects of Nr (modified from Cowling et al., 1998)

Direct and indirect effects on humans

- Respiratory disease in people caused by exposure to high concentrations of:
  - ozone
  - other photochemical oxidants
  - fine particulate aerosol
  - (on rare occasions) direct toxicity of NO_2
- Nitrate contamination of drinking water
- Increased allergenic pollen production, and several parasitic and infectious human diseases
- Blooms of toxic algae and decreased recreational use of water bodies

Direct effects on ecosystems

- Ozone damage to crops, forests, and natural ecosystems
- Acidification effects on forests, soils, ground waters, and aquatic ecosystems
- Eutrophication of freshwater and coastal ecosystems inducing hypoxia
- Nitrogen saturation of forest soils
- Biodiversity impacts on terrestrial and aquatic ecosystems
- Inducing damage by plagues and diseases

Other effects of societal importance

- Odour problems associated with animal agriculture
- Acidification effects on monuments and engineering materials
- Regional hazes that decrease visibility at scenic vistas and airports
- Accumulation of hazes in arctic regions of the globe
- Depletion of stratospheric ozone by NO_x from high-altitude aircraft
- Global climate change induced by emissions of N_2O
- Global climate induced by altered CO_2 and CH_4 exchange
- Regional climate change induced by aerosol cooling

Way forward

It is projected that Nr creation by human activities will continue to increase with time and, coupled with a loss of natural lands and a resulting decrease in natural terrestrial biological nitrogen fixation, that humans will be exerting an increasingly large control of Nr in the environment.

Opportunities to address and manage negative effects of changes in the nitrogen cycle will be enhanced by the development of sound and efficient means for exchange of information between the scientific community that studies nitrogen issues and policy-makers from local to international scales. The 2004 Nanjing Declaration on nitrogen management provides a basis for approaching such issues.

According to the Nanjing Declaration, appropriate incentives and/or policies could effect substantial increases in nitrogen efficiency with existing knowledge and technologies. A decrease in the release of Nr from food and energy production in the short term can best be realized by:

1) **Ensuring access of developing countries to technology** for the control of nitrogen losses during fossil fuel combustion, and crop and animal production.
2) **Increasing the efficiency of agricultural N use** through education, best management practices, agro-environmental measures, and incentives for adoption by farmers.
3) **Implementing emission reduction technology** and developing sustainable energy options. The rapidly growing focus on biofuels as an alternative energy source must take into account changes in N cycling that will arise from shifts towards greater integration of biofuel and feed production. Combined with other demands on agriculture, bioenergy production will require additional Nr to produce the necessary biomass. This could exacerbate existing issues related to the growth in agricultural Nr use.
4) **Performing regional assessments** of nitrogen-related issues.
5) **Developing an integrated approach** to nitrogen management and related issues.
6) **Ensuring greater access to fertilizers** in nitrogen-poor regions.

Readings

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Useful links

Biodiversity Science and Policy in UNESCO: http://www.unesco.org/mab/biodiv/biodivSC.shtml
COST Action 729: http://www.cost729.org
European Commission, Sixth Framework Research Programme: NitroEurope Integrated Project: http://www.nitroeurope.eu
European Science Foundation: Nitrogen in Europe (NinE): http://www.nine-esf.org
Global Nitrogen Enrichment (GANE) research programme: http://gane.ceh.ac.uk
International Nitrogen Initiative: http://www.initrogen.org
Island Press: http://www.islandpress.org
Scientific Committee on Problems of the Environment (SCOPE): http://www.icsu-scope.org
Tropical Soil Biology and Fertility Institute: http://www.ciat.cgiar.org/tsbf_institute/index.htm
UN Commission on Sustainable Development - Consumption and production patterns: http://www.un.org/esa/sustdev/sdissues/consumption/conprod.htm
UN-ECE Convention on Long Range Transboundary Air Pollution http://www.unece.org/env/lrtap
Woods Hole Research Center - Global Nitrogen Policy: http://www.whrc.org/policy/global_nitrogen.htm

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