

# NITROUS OXIDE EMISSION REDUCTION AND AGRICULTURE

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## Summary

Through soils, biomass burning, and animal production agriculture is responsible for approximately 77% of the anthropogenic emissions of nitrous oxide (N<sub>2</sub>O). N<sub>2</sub>O is

formed in soils by chemodenitrification and, during the microbial processes, autotrophic nitrification, heterotrophic nitrification, and denitrification.

Enhanced N<sub>2</sub>O emissions arise directly from agricultural soils as a result of application of synthetic fertilizer nitrogen (N), animal manures (urine and faeces), N derived from biological N-fixation through dinitrogen (N<sub>2</sub>)-fixing crops, crop residue returned to the field after harvest, and human sewage sludge application. Animal waste management systems also contribute N<sub>2</sub>O from waste deposition on pastures and in animal confinements. In addition to the direct N<sub>2</sub>O emissions, these inputs may lead to indirect formation of N<sub>2</sub>O after leaching or runoff of N, or following gaseous losses and deposition of nitric oxides and ammonia, and following human consumption of agricultural products and waste processing in sewage systems. Direct emissions from agricultural soils amount to 2.1 teragrams (Tg = 10<sup>12</sup> grams) N y<sup>-1</sup>, emissions from animal production total 2.1 Tg N y<sup>-1</sup>, and indirect emissions account for 2.1 Tg N y<sup>-1</sup>, giving a total agricultural input of N<sub>2</sub>O into the atmosphere of an estimated 6.3 Tg N y<sup>-1</sup>.

The large emission of N<sub>2</sub>O into the atmosphere has resulted from the need to use large amounts of fertilizer N to produce the grain and meat to feed the rapidly increasing world population, and it is expected that emissions will increase about 1.5 times between 1990 and 2020, unless steps are taken to increase the efficiency of fertilizer N. A number of management techniques have been suggested for reducing applications of fertilizer N, including matching N supply with crop demand, minimizing fallow periods, optimizing split applications, integrating animal and crop production, conserving crop residues, using controlled release fertilizers and inhibitors, and optimizing tillage, irrigation, and drainage. Using a combination of these techniques, global N<sub>2</sub>O emissions could be reduced by ~0.7 Tg N y<sup>-1</sup>.

## 1. Introduction

The trace gas nitrous oxide (N<sub>2</sub>O) plays an important role in the radiative balance of the atmosphere and it is involved in the destruction of the stratospheric ozone layer. The lifetime of N<sub>2</sub>O in the atmosphere was estimated by the Intergovernmental Panel on Climate Change (IPCC) in 1992 to be ~130 years, and the only known process for its removal is reaction with excited singlet oxygen atoms (formed by photolysis of ozone) in the stratosphere. The concentration of N<sub>2</sub>O in the atmosphere is increasing at the rate of 0.65 to 0.75 parts per billion by volume per year (ppbv y<sup>-1</sup>), which translates to an atmospheric burden increase of 3.9 (3.1–4.7) teragrams of nitrogen per year (Tg N y<sup>-1</sup>). Assuming that the stratospheric destruction of N<sub>2</sub>O is 12.3 (9–16) Tg N y<sup>-1</sup> then the total emission of N<sub>2</sub>O from the biosphere is calculated to be 16.2 (12.1–20.7) Tg N y<sup>-1</sup>. The IPCC also made some estimates of the global emissions of N<sub>2</sub>O to the atmosphere in 1995 and these are presented in Table 1.

These estimates suggest that the bulk of the emissions (~9 Tg N y<sup>-1</sup>) come from natural sources, with the oceans responsible for one-third and soils two-thirds of these emissions. Agriculture, through soils, biomass burning, and animal production, is responsible for 77% of the anthropogenic emissions (i.e. 4.4 of 5.7 Tg N; see Table 1). Agricultural soils contribute greatly to the anthropogenic emissions, so that overall soils

are the most important source of N<sub>2</sub>O.

N<sub>2</sub>O is formed in soils by chemodenitrification and, during the microbial processes, autotrophic nitrification, heterotrophic nitrification, and denitrification. Chemodenitrification is a term used to describe gaseous loss of N associated with nitrite decomposition in soils. Although nitrite is not normally present in soils at concentrations greater than 1 µg N g soil<sup>-1</sup> it does accumulate when N fertilizers, which form alkaline solutions on hydrolysis, are banded in soil. However, even though N<sub>2</sub>O has been identified as a product of nitrite decomposition in soils the amounts produced are small, and there is no evidence that significant amounts of N<sub>2</sub>O are formed as a result of chemodenitrification in soils.

Autotrophic nitrification is defined as the biological oxidation of ammonium (NH<sub>4</sub>) to nitrite and nitrate in a two-step reaction where *Nitrosomonas* is responsible for the first step and *Nitrobacter* performs the second. N<sub>2</sub>O appears to be formed by a reductive side reaction involving nitrite. Heterotrophic microorganisms can oxidize NH<sub>4</sub> to nitrite or nitrate in the presence of oxygen and an organic substrate, and they appear to be important in forest soils that are too acidic for autotrophic nitrifiers. The relative importance of heterotrophic and autotrophic organisms for the production of N<sub>2</sub>O cannot be readily determined because it is difficult to separate autotrophic and heterotrophic nitrification. In well-aerated soils, nitrification appears to be the main production mechanism for N<sub>2</sub>O, but in poorly aerated, nitrate rich soils significant emissions result from denitrification.

Source	Amount emitted (Tg N y <sup>-1</sup> )
<b>Natural</b>	
Oceans	3 (1 - 5)
Tropical soils	
Wet forests	3 (2.2 - 3.7)
Dry savannas	1 (0.5 - 2.0)
Temperate soils	
Forests	1 (0.1 - 2.0)
Grasslands	1 (0.5 - 2.0)
Sub-total	9 (4.3 -14.7)
<b>Anthropogenic</b>	
Agricultural soils	3.5 (1.8 - 5.3)
Biomass burning	0.5 (0.2 - 1.0)
Industry	1.3 (0.7 - 1.8)
Cattle and feedlots	0.4 (0.2 - 0.5)
Sub-total	5.7 (3.7 - 7.7)
<b>Total</b>	14.7(8 -22.4)

<sup>a</sup> IPCC (Intergovernmental Panel on Climate Change) (1995). Climate Change 1994:

Radiative Forcing of Climate Change and an Evaluation of the IPCC IS92 Emission Scenarios. (ed. J.T. Houghton, BA Callander and SK Varney). Cambridge: Cambridge University Press.

Table 1. Sources of atmospheric nitrous oxide <sup>a</sup>.

(Source: J.T. Houghton, L.G. Meira Filho, J. Bruce, H. Lee, B.A. Callander, E. Haites, N. Harris and K. Maskell, eds., *Radiative Forcing of Climate Change and an Evaluation of the IPCC IS92 Emission Scenarios* (Cambridge, U.K.: Cambridge University Press, 1995))

Denitrification is the dissimilatory reduction of nitrate ( $\text{NO}_3^-$ ) and nitrite ( $\text{NO}_2^-$ ) to produce nitric oxide (NO),  $\text{N}_2\text{O}$ , and dinitrogen ( $\text{N}_2$ ) by a diverse group of bacteria that synthesize a series of reductases, enabling them to utilize N oxides as electron acceptors in the absence of oxygen. The general reductive sequence is:



The most abundant denitrifiers are heterotrophs that require organic matter for metabolism. Production of  $\text{N}_2$  predominates in more anoxic sites while  $\text{N}_2\text{O}$  production is greater under more aerobic conditions. However, the ratio of  $\text{N}_2$  to  $\text{N}_2\text{O}$  emitted may also be affected by high nitrate concentrations and soil pH (low pH favors  $\text{N}_2\text{O}$  production).

Recent reviews of the literature on emission rates show that  $\text{N}_2\text{O}$  emissions from agricultural soils are generally greater and more variable than those from uncultivated land or natural ecosystems, and that more  $\text{N}_2\text{O}$  is emitted from fertilized than from unfertilized soils. Within a particular field, application of fertilizer N, animal manure, and sewerage sludge usually results in enhanced emissions of  $\text{N}_2\text{O}$ . Generally there is a large emission of  $\text{N}_2\text{O}$  immediately after the application of fertilizer lasting up to approximately six weeks. After that time the emission rate falls and fluctuates around a low value independent of the amount of fertilizer applied. Reviews of the literature have led to the conclusion that interactions between the physical, chemical, and biological variables are complex and thus  $\text{N}_2\text{O}$  fluxes are variable in time and space. Consequently, predictions of  $\text{N}_2\text{O}$  emissions associated with application of N fertilizer are not reliable. Soil management and cropping systems and variable rainfall have a greater effect on  $\text{N}_2\text{O}$  emission than does the type of fertilizer N. There is a suggestion from a number of experiments that more  $\text{N}_2\text{O}$  is emitted from organic sources than from inorganic ones, but there are insufficient comparative experiments to prove this. Therefore, it is recommended that one factor only be used for calculating the emission of  $\text{N}_2\text{O}$  from different fertilizer types:

$$\text{N}_2\text{O emitted} = 1.25\% \text{ of N applied (kg N ha}^{-1}\text{)} \quad (2)$$

This equation is based on data from long-term experiments with a variety of mineral and organic fertilizers and encompasses 90% of the direct contributions of N fertilizers to  $\text{N}_2\text{O}$  emissions.

## 2. Emission of Nitrous Oxide from Agricultural Lands

A comparison of the global emissions of N<sub>2</sub>O calculated from the increase in atmospheric concentration and the stratospheric sink (16.2 Tg N y<sup>-1</sup>) and the total sources given in Table 1 (14.7 Tg N y<sup>-1</sup>) suggest that the strength of known N<sub>2</sub>O sources is underestimated or that unidentified sinks exist. Questions as to the accuracy of the agricultural estimates were raised during the development of national inventories for N<sub>2</sub>O in agriculture and meetings of IPCC and International Global Atmospheric Chemistry (IGAC). Originally only direct N<sub>2</sub>O emissions from agricultural systems resulting from application of synthetic fertilizer were considered. The estimates used tended to underestimate total agricultural emissions as only part of the N input into crop production was considered and the animal production portion of agriculture was not included.

The United Nations Framework Convention on Climate Change requires that all parties periodically update and publish national inventories of anthropogenic emissions. In response to this mandate the IPCC, through the Organisation for Economic Co-operation and Development (OECD) and the International Energy Agency (IEA), has been coordinating the development and updating of national inventory methodologies for various greenhouse gases. The latest revision of the methodology to estimate N<sub>2</sub>O from agricultural soils was printed by OECD in 1997.

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### Biographical Sketches

**Dr. Arvin R Mosier** was born on 11 June 1945 and raised on a farm in the Arkansas River Valley near Olney Springs, Colorado. He received his B.S. in chemistry from Colorado State University in 1967, and joined the research staff of the United States Department of Agriculture, Agricultural Research Service, Nitrogen Laboratory in Fort Collins, Colorado. In 1968 he completed his M.S. in chemistry at Colorado State University, conducting research in pesticide photochemistry. He completed his Ph.D. in soil science at Colorado State University in 1974, conducting research on emission and the fate of volatile nitrogen compounds from cattle feedlots. Dr. Mosier has spent his career with the USDA-ARS-Soil-Plant-Nutrient Research Unit in Fort Collins as a research chemist and a faculty affiliate with the Colorado State University Agronomy Department.

Dr. Mosier has researched gaseous nitrogen losses to the environment from agricultural systems and investigated possible management approaches to control nitrogen losses. He has also studied the effect of land use and management on the soil-atmosphere exchange of methane and nitrous oxide. Dr. Mosier has provided international leadership in the research areas of methane and nitrous oxide production and emission from agricultural systems. His leadership has had a major impact on global nitrous oxide research, and denitrification, nitrous oxide, and methane research in Australia, Germany, India, Sweden, Thailand, and USA. He has served on advisory committees for the International Global Atmospheric Chemistry (IGAC) / International Geosphere-Biosphere Program (IGBP) activities on nitrous oxide, methane, and carbon monoxide exchange between terrestrial ecosystems and the atmosphere. His work has involved extensive collaboration with colleagues in the soil and biological sciences and resulted in

more than 150 publications, many of which are benchmarks. He serves on the editorial board of *Geoderma* and is a managing editor of *Nutrient Cycling in Agroecosystems*.

**Dr. John Raymond Freney** was born on 7 December 1928 at Millaa Millaa in Queensland, Australia. He completed his B.Sc. in chemistry and mathematics at the University of Queensland in 1949. His graduate work was undertaken on a part-time basis while fully employed by CSIRO at Armidale, New South Wales. He completed his M.Sc. in organic chemistry with the University of Queensland in 1956 and his Ph.D. in soil science at the University of New England in 1960. He started work in the Queensland Department of Agriculture and Stock in 1950 and after one year transferred to CSIRO, Division of Plant Industry. He worked at Armidale until 1961 then transferred to Canberra and worked with CSIRO there until he retired in 1993.

He pioneered work on the chemical nature of organic sulfur compounds in soils and their transformations, determined the fate of fertilizer nitrogen in different agricultural systems, elucidated the factors controlling the emission of nitrogen from plants, soils, and waters, and developed management practices to reduce gaseous emissions of nitrogen from terrestrial ecosystems. His work has involved extensive collaboration with colleagues in the field of soil science and has resulted in more than 200 publications. Dr. Freney has been a member of Advisory Committees for SCOPE projects on the global biogeochemical sulfur cycle, the interactions of the biogeochemical cycles of carbon, nitrogen, phosphorus and sulfur, the biogeochemical phosphorus cycle and is currently co-chairman for the SCOPE project on nitrogen transport and transformations. He has also been a member of the International Geosphere-Biosphere Programme (IGBP) co-ordinating panel on terrestrial biosphere-atmosphere chemistry interactions and a member of the IGBP-IGAC co-ordinating committee for the project on exchange of methane, nitrous oxide and carbon monoxide in mid- latitudes.