Phyton (Austria) Special issue: "Ntrogen emissions"	**Vol. 41**	Fasc. 3	(41)-(47)	1.11.2001

Mitigating Gaseous Nitrogen Emission from Soils: An Integrated Approach

By

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Key words: Nitrous oxide, soils, mitigation, policy.

Summary

BOECKX P., GOOSSENS A. & VAN CLEEMPUT O. 2001. Mitigating gaseous nitrogen emission from soils: An integrated approach. - Phyton (Horn, Austria) 41 (3): (41) - (47).

The actual emission rates of gaseous N compounds, such as NH_3, N_2O and NO_X are a serious constraint to sustainable development. Qualitatively, our knowledge on the most important sources and controlling factors influencing the emission of these gases is quite high. Quantitatively, however, still a lot of research needs to be done. The uncertainty of emission estimates is the result of a very important variability in time and space. Co-operation between reputed research groups is important to further upgrade our knowledge. In addition, lack of precise information and absence of palpable effects makes the society not very enthusiastic about efforts to reduce gaseous N emission from soil. Therefore, an independent, integrated assessment of reduction strategies by politicians, scientists and society should be established to assure its implementation.

Global Terrestial N-cycle

In the Earth's atmosphere N is, besides dinitrogen (N_2), also present as ammonia (NH_3), nitrous oxide (N_2O), nitric oxides (NO_X (= NO + NO_2)), nitric acid (HNO_3), organic nitrates and nitrogen containing aerosols. Most gaseous N compounds show an important interaction with the biosphere. Moreover, the biogeochemical cycling of N in terrestrial and aquatic ecosystems is rather complex. Several processes contribute to the formation of gaseous N compounds and perturbations of the N cycle via human activities have resulted in an increased production and emissionof e.g. NH_3, N_2O and NO_X. All these compounds are to a certain extent affecting the environment.

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In Fig. 1 four gaseous N compounds can be seen: N_2, NH_3, N_2O and NO_X. Dinitrogen is the most inert form of N and is only deposited in the biosphere through chemical or biological N_2 fixation. Ammonia concentrations in the atmosphere can vary in space and in time, depending on the amount and type of N present in some compartments of the biosphere. In terrestrial and aquatic environments, N_2O and NO_X are produced during nitrification and denitrification. Nitrification is the biological oxidation of NH_4^+ to nitrate (NO_3^-). Nitrous oxide and nitric oxide are by-products of this process. Denitrification is the chemical or biological reduction of NO_3^- to N_2. Nitrous oxide and NO are obligatory intermediates of this process. Thus, denitrification is a process during which fixed N can be returned to the atmosphere as N_2.

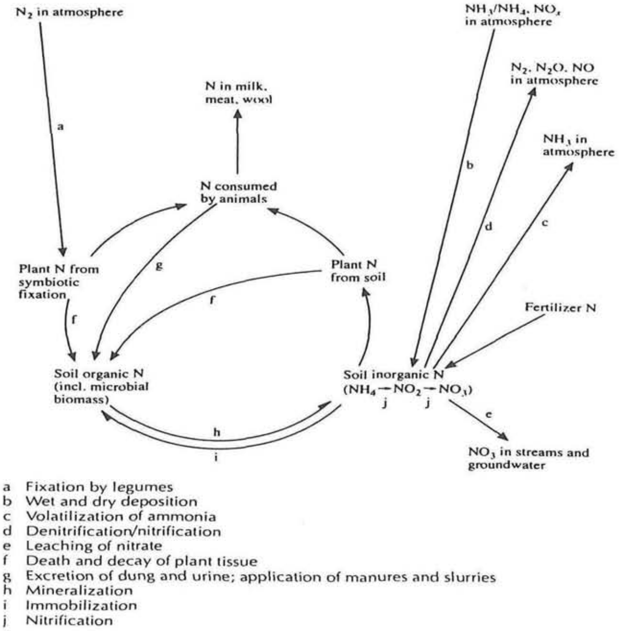

Fig. 1. The terrestrial N - cycle (WHITEHEAD 1995).

For each of the above mentioned processes estimates of global fluxes have been produced. The total terrestrial inputs of N via biological N_2 fixation (natural and agricultural) range from 139 - 170 Tg N yr^{-1} (PEOPLES & al. 1995). Biological N_2 fixation might contribute to the development of sustainable low input agricultural systems in certain parts of the (sub)tropics. On a global scale, NH_3 emission is estimated at 54 Tg NH_3-N yr^{-1}. Agriculture (animal husbandry, mineral fertilisers and crops) contributes 64 % to the annual NH_3 emission (BOUWMAN & al. 1997). Ammonia is typically transported over short distances. Deposition of emitted ammonia contributes to acidification, eutrophication and reduction of biodiversity in natural environments. Nitrous oxide is principally produced in natural and agricultural soils. Application of manure, mineral fertilisers, organic residues and land conversion result in an enhanced N_2O formation compared to natural soils. On a global scale, terrestrial ecosystems emit 11.4 Tg N_2O-N yr^{-1} (MOSIER & KROEZE 1998). This is about 70 % of the global annual emission (16.2 Tg N_2O-N yr^{-1}). Nitrous oxide is an extremely powerful greenhouse gas (global warming potential = 310 over a 100 year time period; IPCC, 1996). It contributes about 5 % to the radiative forcing due to changes in concentrations of greenhouse gases from pre-industrial times until present day (IPCC 1996). In the stratosphere, however, N_2O is oxidised and constitutes the main source of NO. Nitric oxide produced during this reaction acts as a catalyst for the destruction of stratospheric ozone and as such contributes to the so-called ozone hole. Nitric oxide emission from soils is thought to contribute 13 - 21 Tg NO-N to the global emission (24 - 54 Tg NO-N yr^{-1}) (DAVIDSON & KINGERLEE 1997, DELMAS & al. 1997). In the troposphere NO acts as a precursor for the formation of tropospheric ozone (O_3). Tropospheric ozone is responsible for photochemical smog formation, which is a substantial threat to crop yields and public health. In addition tropospheric ozone is estimated to cause about 15 % of the enhanced greenhouse effect (IPCC 1996). Nitric oxide emissions also contribute to acid deposition.

Developing Reducing Measures

At the moment several measures are investigated and discussed to reduce the emission of environmentally harmful gaseous N compounds. Qualitatively, the major sources and controlling factors of NH_3, N_2O and NO_X emission are reasonably well known, but quantitatively, there are large gaps in our knowledge. This uncertainty is due to the fact that emissions vary both in space and time. In addition, many interacting factors influence possible reduction strategies (e.g. manure incorporation reduces NH_3 volatilisation, but enhances N_2O emission). Agriculture importantly contributes to gaseous N losses. In order to minimise these losses, good agricultural practices and measures, which reduce N surpluses in agricultural systems have to be implemented. However, before mitigating strategies can be made operational correct emission inventories and scenarios should be developed. Here, the role of scientists is important. Below an example is given, which shows that incorrect input data can largely affect emission inventories and that spatial disaggregation of emission inventories could be helpful to develop or guide mitigating strategies.

Nitrous oxide inventories from agriculture can be calculated using the Revised 1996 IPCC Guidelines (HOUGHTON & al. 1997). However, VAN MOORTEL & al. 2000 found that this default methodology was largely overestimating the N_2O budget from agriculture in Belgium. If default IPCC values for crop dry matter contents and the amount of N excreted per animal type were being used instead of specific values for Belgium, the N_2O inventory was overestimated by 45 %. Another point of discussion is the accuracy of the N_2O emission factors used in this methodology. Nevertheless, using the same emission factors allows a comparison of national inventories. Such a comparison is shown in Fig. 2. Nitrous oxide emissions from agriculture in Europe (EU-15) are shown. From these data it is clear that countries with a high agricultural intensity and a high N surplus, such as Belgium, The Netherlands, Denmark and Germany, have the highest N_2O emission per ha cultivated land. Countries with a less intensive agriculture, such as northern and southern European countries, show a lower N_2O emission per ha cultivated land.

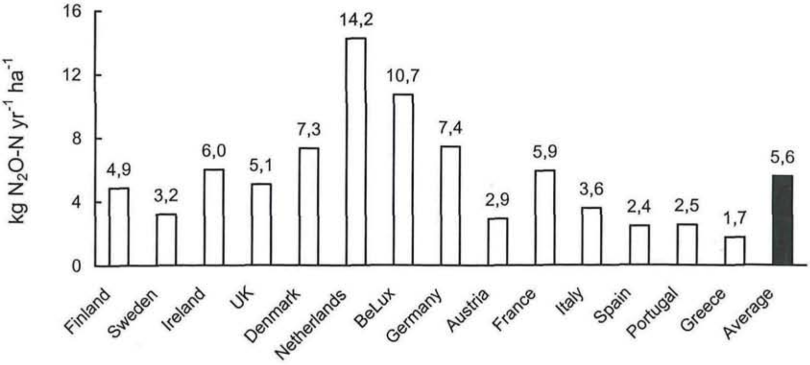

Fig. 2. N_2O emission from agriculture calculated according to the IPCC methodology (excluding the contribution of Histosols) and expressed per ha cultivated land for EU-15 countries (adapted from BOECKX & VAN CLEEMPUT 2000).

Nitrous oxide emission from agriculture may depend on the agricultural system. Therefore, spatial disaggregation of N_2O emissions from agriculture according to specific agricultural regions could be a useful tool visualising regions with high or low N_2O emissions. Spatial analysis of N_2O emissions can be very helpful to initiate advisory tools or management options reducing the N surplus of certain agricultural systems in order to control N_2O emissions. From Fig. 3 it is clear that the N_2O emission in Belgium varies per agro-pedological region. The highest emissions (13 - 14 kg N_2O-N ha^{-1} yr^{-1}) were found in regions P, Z, K and ZL, which are mainly situated in the Flemish Region (northern part of Belgium) and which are characterised by a high agricultural intensity. The average N_2O emission in regions C, LW, FF, HA and AJ is only 6.7 kg N_2O-N ha^{-1} yr^{-1}. All these regions have a more extensive form of agriculture and are predominately situated in the Walloon Region (southern part of Belgium).

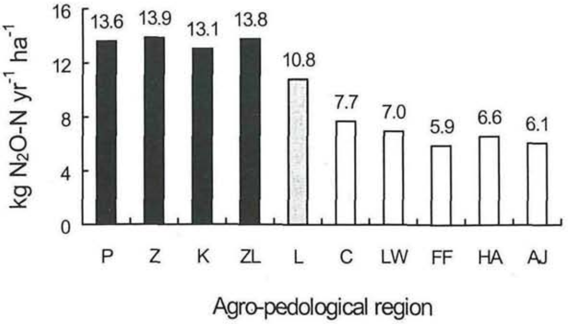

Fig. 3. N_2O emission in various agro-pedological regions in Belgium: Polders (P), Sand Region (Z), Kempen (K), Sand-Loam Region (ZL), Loam Region (L), Condroz (C), Pasture Region of Liège (LW), Fagne and Famenne (FF), Ardennes and Jura Region (AJ) and High Ardennes (HA) (adapted from BOECKX & al. 2000).

Inventory methodologies such as the IPCC guidelines could only be developed, based on the scientific expertise of several international researchers. However, improvements are still needed, e.g. by developing region-specific N_2O emission factors. Indeed, the N cycle is very variable depending on local climate, regional land use, land use changes, agricultural practices and management. Therefore, it is suggested that the next step is to produce process-oriented models to calculate N_2O inventories and to assess mitigating strategies (see further). The calculation of inventories and the formulation of mitigating measures can only become possible through a better and increasing fundamental knowledge of the underlying processes. Therefore, it is needed that scientific research stays at an innovative level to develop the necessary knowledge, which is needed to increase scientific information. Only in that way scientific knowledge can be transferred into realistic and no regret policy decisions.

Implementation of Reducing Measures: Mediation between Scientists, Policy and Society

Although our scientific knowledge is far from complete, decisions should be taken now, because there is an urgent need to implement effective reduction strategies to meet international agreements, such as the Kyoto protocol. But, possibilities for fine-tuning, adjustments, control and verification should be included. Moreover, before implementation of reduction measures (proposed by scientists and politicians) an assessment by parties concerned (e.g. farmers) and citizens should take place. Thus, in order to be effective, policy and measures have to be transparent, manageable, controllable and verifiable (OENEMA & KUIKMAN 1999). A clear cause-effect relationship of the measures must have been established (transparent) and the measures should be implemented easily and accurately (manageable). The execution of policy measures should be checked easily (controllable) and it should be possible to verify the effectiveness of the measures (verifiable). With respect to gaseous N compounds it is also recommended to use a combined approach. This implies a multi-component approach with a link to the carbon cycle as well. In this way, measures in agriculture should lead to a reduction of NH_3, N_2O, NO, NO_3^-, CH_4 and eventually give rise to an increased C sequestration in soils, plants and trees. Thus, mitigating options for gaseous N compounds (from soils) should be developed from an interdisciplinary science and be the result of an integrated assessment of the visions of scientists, politicians and society. Measures, which reduce N surpluses in agricluture, e.g. via fertilization derictives or livestock reductions in areas of intensive agriculture will have an impact on gaseous N losses, such as NH_3, N_2O, as well as on NO_3^- leaching.

The society itself is an important driving force towards a sustainable N cycle (e.g. reduced emission of gaseous N). Nitrogen use in agriculture is an important aspect of food production for human consumption. Thus, a sustainable N cycle has to be achieved through an optimisation of N resource utilisation. But, unfortunately, the society is not enough aware of its role in related environmental problems. "People do not know that eating a piece of meat contributes to the greenhouse effect. No single citizen will drive one kilometre less because of the greenhouse effect". Just because of that unawareness, e.g. climate change is not a high ranked political issue. Nevertheless, politicians, in close co-operation with scientists, should not run away from their crucial role here. Only if the public awareness is at a sufficient high level measures to improve the status of our environment can be made acceptable. Therefore scientists and policy makers should work intensively together to inform the public. Hereby, special attention should be given to the consequences of environmental damage on public health, welfare and wellbeing (MARTENS 1999), always keeping in mind an old and imperishable saying: "Premium est nocere".

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Zeitschrift/Journal: Phyton, Annales Rei Botanicae, Horn

Jahr/Year: 2001

Band/Volume: 41_3

Autor(en)/Author(s): Boeckx P., Goossens A., Van Cleemput O.

Artikel/Article: Mitigation Gaseous Nitrogen Emissions from Soils: An Integrated Approach. 41-47