

NATIONAL INSTITUTE OF PUBLIC HEALTH
AND ENVIRONMENTAL PROTECTION
BILTHOVEN
THE NETHERLANDS

Report 773004004

**Method to estimate direct nitrous oxide
emissions from agricultural soils**

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September 1994

This study was commissioned by the Air Directorate of the Directorate General for Environmental Protection of the Dutch Ministry of Housing, Physical Planning and Environment within the framework of the project "Landbouw" (project No. 773004)

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FOREWORD

This report presents the results of a literature review of measurements of nitrous oxide (N_2O) emission from fertilized fields. The aim of this analysis was to develop a simple approach for estimating the order of magnitude of N_2O emissions from agricultural lands. A number of selections from the literature data have been made to analyze the importance of factors that regulate N_2O production, including soil conditions, type of crop, fertilizer type and management. The method described in this report is a refinement of the one described in RIVM report No. 73601010, that was used for the environmental forecast MV3.

The new method presented in this study has been used in the background document on N_2O (RIVM report No. 482504001), in the global inventories of N_2O emissions from agricultural lands compiled in the framework of the RIVM-EDGAR project and the IMAGE model. It is also a contribution to the Global Emission Inventories Activity (GEIA), a project of the Global Atmospheric Chemistry Program (IGAC). The results may also be used as default estimate of N_2O emission from agricultural lands in the method for estimating national emissions that is being developed by the Intergovernmental Panel on Climate Change (IPCC).

Many researchers have been helpful by supplying reprints of articles. In particular I wish to thank Dr. Arvin Mosier (USDA-ARS) for his comments and advice during the course of this study, and Klaas van der Hoek (RIVM) for his critical review of the analysis and the text of this report.

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ABSTRACT

This analysis was based on a review of published measurements of nitrous oxide (N_2O) emission from fertilized fields. From the literature data selections were made to analyze the importance of factors that regulate N_2O production, including soil conditions, type of crop, nitrogen (N) fertilizer type and soil and crop management. Reported N_2O losses from anhydrous ammonia and organic forms of N fertilizers or combinations of organic and synthetic N fertilizers are higher than those for other types of N fertilizer. However, the management and environmental conditions represented by the set of measurement data is too limited to be used for estimating emission factors for each fertilizer type individually. The literature data are appropriate for estimating the order of magnitude of emissions. The fertilizer-induced N_2O emission is higher for measurements covering longer periods than for measurements which represent short periods. Therefore, a simple method to estimate the total annual direct N_2O emission from fertilized fields was based on those measurements covering periods of one year, resulting in the following equation: N_2O emission ($kg\ N\ ha^{-1}yr^{-1}$) = $1 + 1.25 \pm 1\%$ of the N application ($kg\ N\ ha^{-1}yr^{-1}$). The relation is independent of the type of fertilizer. Although the above regression equation includes considerable uncertainty, it may be appropriate for global analyses.

NEDERLANDSE SAMENVATTING

Deze studie is gebaseerd op een analyse van gepubliceerde metingen van de emissie van lachgas (N_2O) door bemeste landbouwgronden. Uit de literatuurgegevens zijn selecties gemaakt om de rol van verschillende factoren te analyseren, die een rol spelen bij de produktie en emissie van N_2O , zoals bodemeigenschappen en -omstandigheden, het soort gewas, het type kunstmest of organische mest, bodembeheer en gewasbehandeling. De geschatte N_2O verliezen bij gebruik van ammoniak, organische mest of combinaties van organische mest en stikstofkunstmest zijn hoger dan die veroorzaakt door andere vormen van stikstofmest. De spreiding van milieufactoren en bodem- en gewasmanagement vertegenwoordigd in de literatuurgegevens is te beperkt om de emissie voor afzonderlijke typen stikstofmest te berekenen. De gegevens zijn echter wel geschikt om de orde van grootte van de N_2O emissie te schatten. Uit de analyse is gebleken dat de N_2O verliezen die door stikstofbemesting worden geïnduceerd, groter zijn wanneer gedurende langere perioden gemeten is dan voor metingen die representatief zijn voor een korte periode. Op grond hiervan is een simpele methode voor de berekening van de N_2O emissie door bemeste bodems gebaseerd op metingen gedurende 1 jaar. Het resultaat is de volgende vergelijking: N_2O emissie ($\text{kg N ha}^{-1}\text{jaar}^{-1}$) = $1 + 1.25 \pm 1\%$ van de toegediende N ($\text{kg N ha}^{-1}\text{jaar}^{-1}$). Deze relatie is onafhankelijk van het type mest. Howel de vergelijking zeer onzeker is, kan deze methode worden gebruikt in mondiale studies.

1. INTRODUCTION

Nitrous oxide (N_2O) plays an important role in the atmospheric radiative balance and in the stratospheric ozone chemistry. A great number of major and minor sources have been identified, yet there is considerable uncertainty in the source strengths. Part of the uncertainty arises from the paucity of measurements of N_2O fluxes. Another part stems from the difficulty of extrapolating measurements of biogenic fluxes from soils and aquatic sources to larger scales, because of their extreme heterogeneity both in space and time. For abiogenic sources, such as fossil fuel combustion and industrial processes, political, economic and cultural factors are major uncertainties in making extrapolations. Khalil and Rasmussen (1992) recently presented a global N_2O budget indicating that the uncertainty for most N_2O sources amounts to at least a factor 2.

There is also considerable uncertainty in the estimates of N_2O emission from the world's cultivated fields. During recent years few new measurements of N_2O fluxes in agricultural fields have been published, despite the interest in increasing concentrations of greenhouse gases in the atmosphere. Many assessments rely on flux measurements carried out during the period 1980-1990. For example, attempts have been made to estimate the N_2O emission caused by synthetic nitrogen (N) fertilizers (Eichner, 1990) and synthetic and organic fertilizers (Bouwman, 1990) based on literature reviews. Synthesis of current knowledge resulted in an estimated annual emission from cultivated fields of 0.03 - 3 Tg $\text{N}_2\text{O-N}$ (Watson et al., 1992).

The direct efflux of N_2O from agricultural fields is possibly only part of the emission caused by N fertilization. Nitrogen may leach from the soil and form a source of N_2O fluxes from groundwater by degassing or from surface waters. Nitrogen taken up by plants may be consumed by humans or animals. Denitrification of the nitrogen in their excreta may, once in the environment, form a source of N_2O .

Many reviews have been published on the microbial processes responsible for N_2O production, nitrification and denitrification (e.g. Firestone and Davidson, 1989). The release of N_2O may be a by-product of nitrifiers that denitrify nitrite (NO_2^-) under oxygen stress (Poth and Focht, 1985). Under moist and oxygen depleted conditions denitrification is generally the major source of N_2O , and both the rate of denitrification and the conditions that influence the ratio $\text{N}_2 / \text{N}_2\text{O}$ determine the N_2O emission (Davidson, 1991). Many factors regulate nitrification and denitrification. A review of these factors is presented by Bouwman (1990). In summary they include:

- Soil moisture and temperature, regulating microbial processes;
- Soil oxygen availability, a control of denitrification; oxygen supply is determined by the soil water content and the rate of microbial respiration;
- Concentrations of NO_3^- and NH_4^+ , influencing the reaction rates; obviously the plant roots play a role here (i) by consuming the nutrients and (ii) as a source of nutrients from residues or exudates;
- Organic carbon as energy source for denitrifiers;
- Soil reaction or pH, influencing nitrification and denitrification and the ratio $\text{N}_2/\text{N}_2\text{O}$.

The method proposed by Eichner (1990) to calculate N_2O emission from different fertilizer types was adopted by the IPCC for making country estimates (OECD, 1991). The wide range of uncertainty in this estimate is, however, not appropriate in global inventories.

Another method for estimating the N_2O emission from fertilized fields was based on N application, weather conditions, soil properties, soil, crop and water management with the

complex DNDC model (Changsheng Li et al., 1992a; 1992b). Other more simple approaches are the mechanistic model developed by Mosier and Parton (1985) for Colorado grasslands, and the model relating N₂O emission to the water filled pore space (Davidson, 1991). These models describe conditions for N₂O production reasonably well. They were developed and validated for the conditions of a single site. Extrapolation of emissions should be based on validation for a wide variety of conditions. This requires soil data and daily weather data that are not available at the global scale.

The aim of this analysis is to develop an approach to estimate global direct emissions of N₂O from fertilized agricultural fields. Measurement data of N₂O emission in relation to N fertilization from various studies were collected from the literature. Section 2 briefly discusses a number of the regulating factors of N₂O production on the basis of this data set. Another important aspect that will be discussed is the length of the period covered by the flux measurements and their frequency. On the basis of this analysis and comparison with earlier estimates a method to estimate annual emission from fertilized fields will be described in section 3.

2. COMPARISON OF EXPERIMENTS

The measurement data collected from the literature presented in the Appendix include experiments in cropped and unplanted plots with different soils fertilized with different types of N fertilizers, ranging from organic fertilizers and combinations of synthetic and organic fertilizers, and measurements in unfertilized control plots. The emission of N₂O is presented as:

- The *total N₂O emission* during the period covered by the measurements.
- The *fertilizer-induced N₂O emission*, calculated as the difference in emission between the fertilized and the control plot, presented as a percentage of the fertilizer N applied. The fertilizer-induced N₂O emission ranges between 0.0% and 6.8% of the N application for 87 experiments for mineral soils in the Appendix that included a control plot.
- The total N₂O emission as a percentage of the N applied. The total N₂O emission from 180 experiments for mineral soils in the Appendix ranges between 0.0 to 7.8% of the N application.

The flux measurement technique, duration of measurements and sampling frequency is indicated for all experiments in the Appendix. Details on the techniques used can be found in the individual reports listed. Gas collection chambers on the soil surface are commonly used to quantify the N₂O flux from the soil to the atmosphere. Reviews of the theoretical and practical problems which cause variability in gas flux measurements using chambers are presented by Mosier (1989).

Several factors regulate the production, consumption and emission of N₂O. A number of these will be discussed briefly on the basis of the data in the Appendix. Another important aspect that will be discussed is the length of the period covered by the flux measurements and their frequency.

2.1. Duration of measurements

The length of the period covered by the measurements may influence the amount of N₂O stemming from fertilizers that is captured. The average fertilizer-induced N₂O emission is 0.7 ± 1.1% of the N application based on all experiments for mineral soils (Appendix). The average fertilizer-induced N₂O emission is 0.8 ± 1.2% for experiments with a duration of measurements of > 30 days, 1.1 ± 1.4% for experiments covering > 100 days, and 1.6 ± 0.4% for experiments covering > 200 days. This suggests that if measurements of N₂O fluxes from fertilized fields are extended over longer periods, the observed N₂O emission is higher. This also suggests, that it is necessary to measure fluxes during prolonged periods to account for all the fertilizer-induced emission.

2.2. Frequency of measurements

Brumme and Beese (1992) observed that N₂O flux measurements done once per week tend to overestimate the total emission estimate relative to daily observations by 20%. In many studies the frequency of measurements is once per day or once in 2 or 3 days, particularly in periods of high fluxes shortly after fertilizer application (Appendix). In some studies the measurements were done once per week. These differences in frequency of flux measurements may form another source of uncertainty.

2.3. Presence and type of crop

Many studies included fertilized but unplanted fields (Appendix). Since there is no uptake of nitrogen from the soil, denitrification and associated N₂O emission may be higher than in cropped fields. The mean fertilizer-induced N₂O emission for unplanted fields is 0.9 ± 1.5% of the N application, while the mean for fields with crops or grass is 0.4 ± 0.6%.

Ungrazed grassland plots (0.4 ± 0.7, N = 17) showed somewhat lower N₂O emission than cropped fields (0.4 ± 0.6, N = 28). Grasses have a longer growing season than crops, leading to more N uptake and less denitrification in grasslands than in cropped fields. This is not confirmed by the data, possibly because most measurements covered only the spring and summer period and not the full year.

For most experiments in the Appendix it is impossible to conclude whether differences are caused by the type of crop, the amount and type of N fertilizer or the management practices. However, in some experiments the crop or the combined effect of crop and management clearly determine the N₂O emission, i.e. wetland rice and leguminous crops.

Wetland rice in experiment 15 and 36 showed low N₂O fluxes, and the N₂O emission from dryland rice fields was somewhat higher (experiment 25). This may be caused by the low availability of oxygen, which is unfavourable for nitrification. Moreover, low oxygen availability may lead to a low N₂O / N₂ ratio in denitrification products. However, Byrnes et al. (1993) showed that drainage of wetland rice fields may give rise to significant N₂O emission. As drainage of rice fields was not considered in experiments 15 and 36, the reported N₂O emissions may be underestimated.

Fields with legumes showed high N₂O emission. As leguminous crops usually receive little or no N fertilizer, these high N₂O emissions may be attributed to N inputs from symbiotic N fixation. The only examples in the Appendix are alfalfa (2.3-4.2 kg N₂O-N ha⁻¹yr⁻¹, experiment 17), soybeans (0.34-1.97 kg N₂O-N ha⁻¹yr⁻¹, experiment 41) and clover (experiment 14). The measurements in the clover fields did not result in high fluxes, perhaps because N fertilizer added in this experiment prevented N fixation. Unfortunately the measurement period was not reported.

2.4. Crop residues

The data in the Appendix indicate that N coming from decomposition and mineralization of crop residues may also contribute to N₂O fluxes. The effect of crop residues can best be illustrated by comparing experiments in Iowa on typic Haplaqueolls (experiments 5 and 6). For both the control and the fertilizer treatment experiment 6 showed much higher N₂O emission than experiment 5. In experiment 5 maize residues were incorporated in the surface layer, while in experiment 6 soybean residues were left on the surface to decompose.

Experiment 20 included plots with rye grown as a cover crop after harvest of the previous crop. The rye crop was incorporated before sowing tobacco and resulted in lower N₂O emission than plots with manure or alfalfa residue.

2.5. Tillage

Surface application of N fertilizers to residues in plots with minimum or reduced tillage leads to high N₂O emission (experiment 20). This is consistent with experiments 8 and 13 that showed lower N₂O emission from ploughed plots cropped to winter wheat fertilized with NH₄NO₃ than unploughed, directly sown plots.

2.6. Source and amount of nitrogen

The variability in N_2O fluxes is extremely high for all N fertilizer types and all application levels (Figure 1). Fluxes ranging between 0 and 30 kg $\text{N}_2\text{O-N ha}^{-1}\text{yr}^{-1}$ were observed in plots with mineral soils. The results for the unfertilized control plots (Appendix) are also extremely variable with even net annual N_2O uptake occurring. The variability may be caused by many different factors, of which the history of fertilization and management may be important ones. For none of the fertilizer types there is a clear relation between N application and N_2O emission, but some forms of N show consistently higher N_2O emissions than other types.

Fluxes of N_2O from plots amended with combinations of organic and synthetic fertilizers are generally high. It should be noted that the literature reports listed in the Appendix presented the N in organic fertilizers as total N, including mineral nitrogen and organic nitrogen. This indicates that there is uncertainty in the amount of N applied, because part of the organic N is not directly available, while the volatilization of NH_3 after application of organic fertilizers was not accounted for. Emissions from fields fertilized with NO_3^- -based fertilizers and combinations of organic and NO_3^- fertilizers from experiment 31 were relatively high compared to results of other experiments. Measurements in experiment 31 were carried out immediately after irrigation and rainfall events, and this have caused an overestimation of both denitrification and N_2O emission extrapolated over the growing season.

Within the group of synthetic fertilizers, anhydrous ammonia induces high N_2O fluxes. This may, however, not be the result of the type of fertilizer, but merely of the mode of application (see below).

2.7. Mode of fertilizer application

Some experiments indicated an important effect of the mode of fertilizer application. Most fertilizers were broadcast onto the soil surface and incorporated by tillage. Injection is the customary method of applying anhydrous ammonia. This may produce highly alkaline soil zones of high ammonium concentration (Breitenbeck and Bremner, 1986a) that may lead to high N_2O production (Bouwman, 1990). Experiments 4, 5, 6 and 10 showed that deeper injection of anhydrous ammonia lead to higher N_2O emission than shallow injection. Another example is experiment 36 where urea drilled into the soil caused higher N_2O emission than top-dressed urea for the high N application of 180 kg N/ha.

It is difficult to explain why deeper injection resulted in higher N_2O emission. The N loss by NH_3 volatilization from applied anhydrous ammonia is probably lower for deep than for shallow injection. However, if the ammonia is injected deeper, the transport of the N_2O formed is over a longer distance, which increases possibilities for further N_2O reduction.

2.8. Timing of fertilizer application

The set of data does not include sufficient experiments studying the effect of timing of fertilizer application. Application in periods when the crop actually needs nutrients will reduce N losses by denitrification and leaching, thereby also reducing N_2O losses (Mosier, 1993).

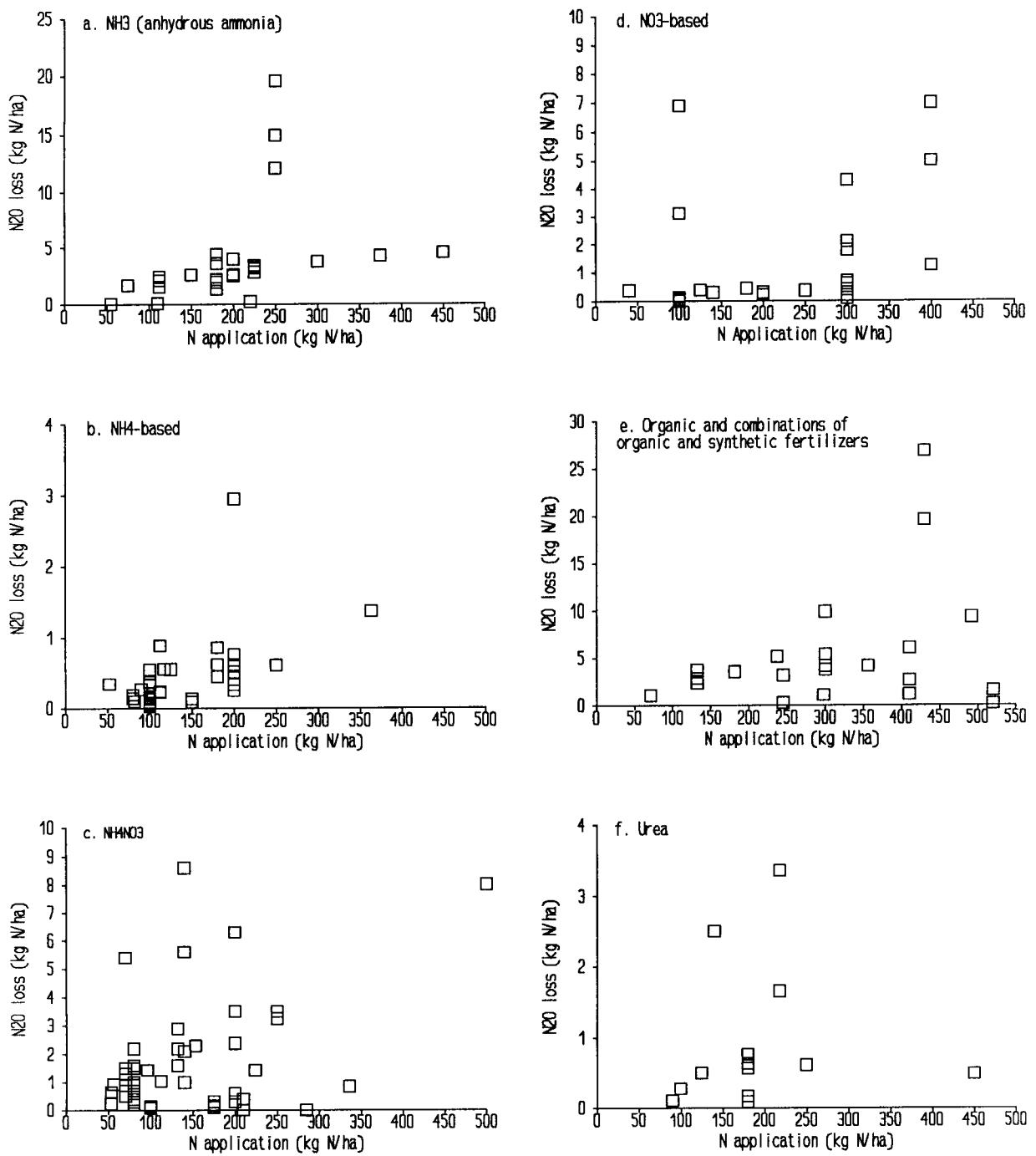


Figure 1a-f. Relation between N fertilizer application and N₂O emission from mineral soils for experiments listed in the Appendix, independent of the period covered by the measurements, presented for (a) anhydrous ammonia (NH₃); (b) ammonium (NH₄)-based fertilizers; (c) ammonium nitrate (NH₄NO₃); (d) nitrate (NO₃)-based fertilizers; (e) organic fertilizers and combinations of organic and synthetic fertilizers; (f) urea.

2.9. Soil type and properties

In experiments 4 and 6 different soils were included to measure the effect of different N fertilizers on N₂O emission. Unfortunately the authors of the report did not explain the

differences. A possible explanation may be the soil texture. In experiments 6 and 8 similar soils with different textures were included. The heavy textured soils showed higher N₂O emission than the soil with lighter texture. In contrast, in experiment 4 the light textured soils showed higher emissions than heavier textured soils.

Drained organic soils showed high N₂O emission of up to 100 kg N₂O-N ha⁻¹yr⁻¹ (experiments 17 and 43). Although the fields studied were not fertilized, the mineralization of the organic soil material is a significant source of N. Terry et al. (1981) estimated that mineralization of nitrogen may amount to up to 1300 kg N ha⁻¹yr⁻¹ (see Appendix). The observed N₂O emission from these soils constitutes a fraction of < 1 to > 10% of N mineralization (Appendix).

Another soil property that may affect N₂O emission is the soil reaction or pH. The pH may affect nitrification, denitrification and the N₂O reduction. Generally it is thought that N₂O reduction is inhibited at low pH (various references quoted in Bouwman, 1990; Bouwman et al., 1993). Plots with identical soils of different pH established in 1962 gave no measurable differences in N₂O emission (experiment 20). This may be due to adaptation of denitrifiers to soil pH (Parkin et al., 1985).

2.10. Soil drainage

Experiment 11 concentrated on drainage of a poorly drained soil with stagnant water (stagnogley). Draining the soil caused a decrease in the N₂O emission. For all experiments the soil was classified as well drained, poorly drained or moderately well drained, based on data given in the reports or on the soil taxonomic class or soil description. For example, Paleudalfs are considered well drained, while the name Calciaquolls suggests hydromorphic properties and poor drainage. However, there was no clear relation found between soil drainage and N₂O emission for the experiments listed.

3. METHOD TO ESTIMATE DIRECT N₂O EMISSION FROM FERTILIZED FIELDS

The method presented by Eichner (1990) accounts for the fertilizer-induced emission, i.e. the emission from a fertilized plot minus that from a control plot, determined during the measurement period. Eichner (1990) calculated the fertilizer-induced N₂O emission as a percentage of N fertilizer applied specified for a number of fertilizer types (Table 1). There are a number of uncertainties in this method:

- The data sets used by Eichner (1990) and in this study represent only a limited number of climatic, soil and management conditions. For example, Eichner (1990) based the median and range of N₂O emission induced by anhydrous NH₃, on only a few experiments, mostly carried out in Iowa (experiments 3-7). The highest fertilizer-induced N₂O emission (6.8%, experiment 6) was observed in fields where soybean residues were left on the surface to decompose. This may not be representative of worldwide practices in fields where anhydrous ammonia is applied.
- Addition of observations to the dataset of Eichner (1990) can result in changes in the calculated average N₂O losses caused by fertilization. This study includes 14 measurements for anhydrous ammonia that were not reviewed by Eichner (1990), causing a 40% lower fertilizer-induced emission (Table 1). This has important consequences for the estimated emission from the application of anhydrous ammonia, which contributes about 45% to the global N₂O emission from fertilizers based on Eichner's method. The greatest difference is found for urea, where the N₂O emission resulting from this study exceeds the estimate of Eichner (1990) by a factor of 3 by 7 additional measurements.
- The concept of the fertilizer-induced N₂O emission does not yield an estimate of the *total* annual emission. Most measurements listed in the Appendix cover the crop season or shorter periods. Most of the N₂O is usually released during a period of a month after fertilizer application, after which emissions decline to a "background" level (Breitenbeck and Bremner, 1986). This is consistent with most of the literature reports in the Appendix. Although the background emission may be low, the contribution to the annual flux may not be negligible. Moreover, it is uncertain whether this background emission level is influenced by the fertilization and soil management during previous years. As the observed N₂O emission from fertilized lands in the Appendix is significantly higher for longer measurement periods than for shorter measurement periods, the background emission should be included in estimates of the annual emission from fertilized lands.

A simple method is proposed here to calculate the *total annual* N₂O emission from fertilized fields, independent of crop, management, soil conditions and fertilizer type. As noted above the length of the measurement period seems to be important to determine the total of N₂O emission. Figure 1 shows the relation between N-fertilizer application and N₂O emission for all experiments on mineral soils in the Appendix. Clearly, there is no correlation between N application level and N₂O emission if the duration of measurements is not taken into account. For experiments with a duration of N₂O flux measurements of a full year, the correlation is much better. Data presented in Figure 2 for cropped fields and ungrazed grass plots include a variety of different fertilizers (including synthetic, organic and combinations of organic and synthetic N fertilizers), weather conditions and soils. The results from experiment 2 were excluded, because of reported abnormal low precipitation. The experiments for leguminous crops (experiment 17 and 41) were also excluded because the input from N fixation was not reported.

Table 1. Range, average and median fertilizer-induced N_2O emission† reported by Eichner (1990), and the average and standard deviation from this study, for different types of N fertilizer

Type	N‡	Eichner (1990)		This study		
		Average	Range	N‡	Average	S.D.§
Anhydrous ammonia	9	2.70	0.86-6.84	23	1.57	1.64
Ammonium nitrate	8	0.44	0.04-1.71	10	0.30	0.30
Salts of ammonium	17	0.11¶	0.02-0.90	20	0.12	0.09
urea	6	0.11	0.07-0.18	14	0.31	0.55
Salts of nitrate	13	0.07	0.001-0.50	16	0.18	0.44
Organic / combinations of organic and synthetic fertilizers				5	1.49	0.54

† The fertilizer-induced emission is calculated as emission from the fertilized plot minus that from the control plot, presented as % of N fertilizer application.

‡ N = number of experiments

§ S.D. = standard deviation

¶ The average fertilizer-induced emission presented in Eichner (1990) is 0.25%. This was recalculated with corrected data from Seiler and Conrad (1981) that were by mistake multiplied by a factor of 10 in the data tables compiled by Eichner (1990).

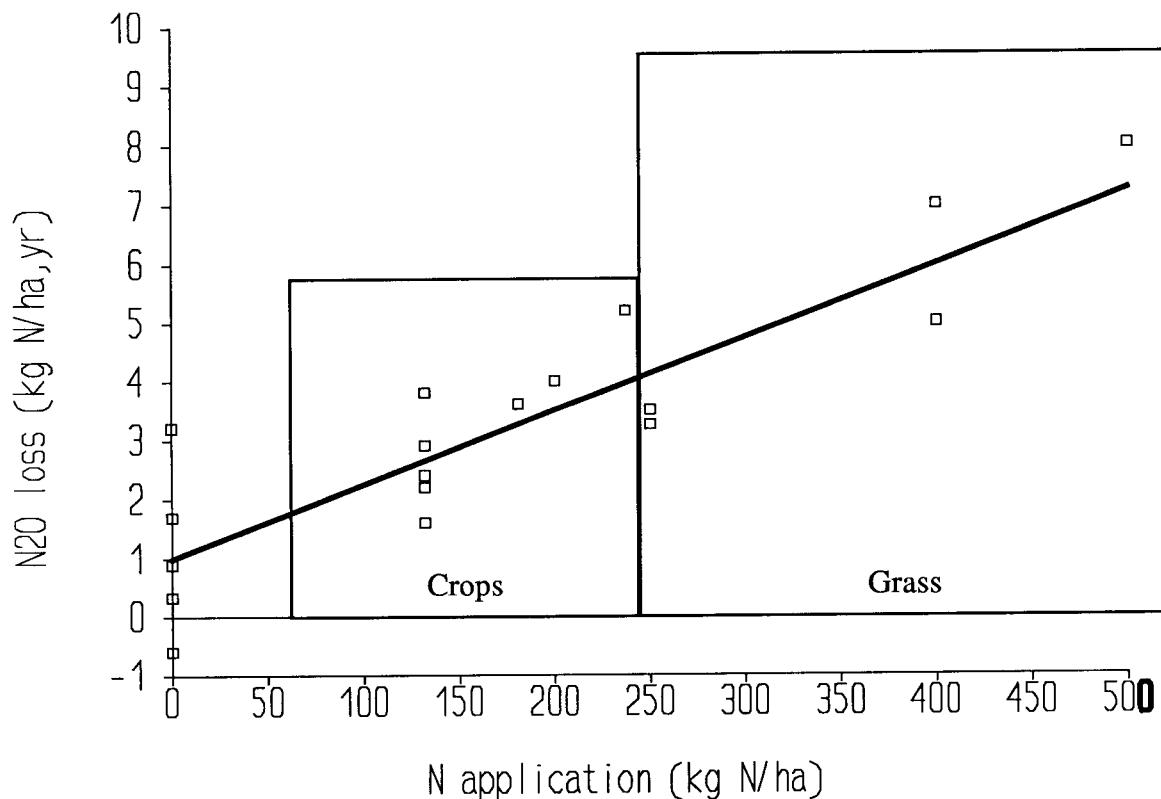


Figure 2. Relation between N fertilizer application and N_2O emission for experiments on plots with mineral soils with a coverage of measurements of 1 year and for N application rates < 500 kg N/ha yr⁻¹, excluding results for experiment 2 and measurements for leguminous crops. The boxes indicate measurements in cropped fields and those in ungrazed grasslands.

Least squares fitting of the data in Figure 2 to a linear function resulted in equation (1) with r^2 of 0.8:

$$N_2O\text{-flux (kg N ha}^{-1}\text{yr}^{-1}) = 1 + 0.0125 * N \text{ application} \quad (1)$$

This relationship was based on 20 different measurements only, and its global applicability is highly uncertain. The *background* emission of 1 kg N₂O-N ha⁻¹yr⁻¹ was based on only 5 measurements for unfertilized plots, with a range of emissions of -0.6 to + 3.2 kg N₂O-N ha⁻¹yr⁻¹ (experiment 30 and 19, respectively). It is, however, consistent with the average of the 33 measurements covering more than 100 days in unfertilized control plots of 1.2 ± 1.1 kg N ha⁻¹.

The *fertilizer-induced N₂O emission* of 1.25% is close to the calculated 1.1% (± 1.4) fertilizer-induced N₂O emission based on 43 experiments with a duration of measurements of > 100 days where a control plot was included. The 1.25% fertilizer-induced emission is also consistent with the estimate of 1% of Mosier (1993), and with the 0.5-2% N₂O emission from fertilizers estimated by Bolle et al. (1986).

4. DISCUSSION AND CONCLUSIONS

Although the individual factors that control N₂O production are known, it is impossible to describe their interaction under field conditions on the basis of the data in the Appendix. The processes of nitrification and denitrification and the controls of the reduction of N₂O to N₂ have their specific optimum conditions. These conditions may change from one year to another, and the importance of the different N₂O producing processes may also change as a consequence. The variability in the data is caused by a variety of factors related to management, such as timing of N additions, timing and frequency of irrigation or precipitation, presence or absence of crops, type of crop, history, mode and timing of fertilizer application, and soil management. It is also caused by factors such as local rainfall and temperature that are not manageable.

Byrnes et al. (1990) concluded that N₂O emissions may be more closely related to soil properties than to the N source applied. The comparison in Table 1 suggests that there may be differences in N₂O emission caused by the fertilizer type. However, the addition of a few measurements can drastically change the calculated emission factor for a fertilizer type, as was shown for e.g. anhydrous ammonia. Therefore, the set of data presented in the Appendix is too limited to calculate the N₂O emission specific for each fertilizer type, and it is not likely that in the coming years sufficient new data will be generated. However, the available data are adequate to estimate the order of magnitude of emissions.

A simple approach was developed, based on a background emission of 1 kg N₂O-N ha⁻¹yr⁻¹ plus a fertilizer-induced N₂O emission of 1.25% of the N application. This method applies to all fertilizer types, and may not be adequate to estimate emissions for local conditions or specific crops. The range of uncertainty for the fertilizer-induced N₂O emission is 0.25 - 2.25% based on the full set of data, but excluding the extremes (A.R. Mosier, 1994, personal communication).

The method may be adequate for global analyses. Assuming that the global N fertilizer use in 1990 of 80 Tg N yr⁻¹ (FAO, 1991) is applied exclusively to arable fields and that no organic fertilizers are used, the background emission calculated for the global arable land area of 1440x10⁶ ha is 1.4 x 10¹² g N₂O-N yr⁻¹ and the fertilizer-induced emission is 1 Tg N₂O-N yr⁻¹.

This estimate does not include N₂O emissions from leguminous crops. These crops usually receive little or no N fertilizer. The N₂O emissions from fields with leguminous crops may be considerable. These high N₂O emissions may be attributed to N inputs from symbiotic N fixation. The global area of leguminous crops is 145 Mha (FAO, 1991), about 10% of the total arable land. This area does not include legumes grown as green manures not reported by the FAO (1991), and legumes in grasslands and N fixing grass species. The N inputs from legumes to agricultural systems may be of the same order of magnitude as global synthetic N fertilizer use (Duxbury et al., 1993), indicating the potential importance for the N₂O cycle.

The above estimate for arable lands does not include N₂O emissions from grasslands and animal excreta. A global inventory of N₂O for this source was made on the basis of this study by Bouwman et al. (in prep.), and included in the EDGAR database and the IMAGE model.

This report discusses direct atmospheric emission of N₂O. Leaching of N from fertilizer and animal excreta may lead to N₂O emission from groundwater, freshwater systems and coastal marine waters. This aspect is being studied in the framework of the EDGAR project as a contribution to the Global Emission Inventories Activity (GEIA), a project of the Global Atmospheric Chemistry Program (IGAC).

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APPENDIX

Ref.†	Location	Soil classification	Texture/other properties	Drainage§	Crop/treatment	Fertilizer type¶	N-App. rate	N ₂ O loss of exp.	Length of exp. (kg N/ha)	Mc-tied #	Frequency††	Fertilizer induced N ₂ O loss (% of N-app.)‡‡	Remarks	
													I	II
MINERAL SOILS														
1	Reading, UK	leamy sand	w	unplanted			NO ₃	200	0.30	135	c-	d	0.2	weed free
1	Reading, UK	sandy loam	w	unplanted			NO ₃	200	0.22	135	c-	d	0.1	weed free
2	Texas, USA	glossarenic Paleudalfs	sandy loam, 1.7 %C	w	grass		NH ₄	117	0.56	63	c-	d/w	0.5	intensive management
2	Texas, USA	glossarenic Paleudalfs	sandy loam, 1.7 %C	w	grass		NH ₄	82	0.10	63	c-	d/w	0.1	intensive management
2	Texas, USA	glossarenic Paleudalfs	sandy loam, 1.7 %C	w	grass		NH ₄	0	0.13	105	c-	d/w	0.1	intensive management
2	Texas, USA	glossarenic Paleudalfs	sandy loam, 1.7 %C	w	grass		NH ₄	112	0.23	63	c-	d/w	0.2	intensive management
2	Texas, USA	glossarenic Paleudalfs	sandy loam, 1.7 %C	w	grass		NH ₄	52	0.35	63	c-	d/w	0.7	intensive management; also presented in Hutchinson & Brans (1992)
2	Texas, USA	glossarenic Paleudalfs	sandy loam, 1.7 %C	w	grass		NH ₄	0	0.30	63	c-	d/w	0.2	low management
2	Texas, USA	glossarenic Paleudalfs	sandy loam, 1.7 %C	w	grass		NH ₄	0	0.07	63	c-	d/w	0.2	low management
2	Texas, USA	glossarenic Paleudalfs	sandy loam, 1.7 %C	w	grass		NH ₄	0	0.08	105	c-	d/w	0.2	low management
2	Texas, USA	glossarenic Paleudalfs	sandy loam, 1.7 %C	w	grass		NH ₄	112	0.24	63	c-	d/w	0.2	low management; also presented in Hutchinson & Brans (1992)
2	Texas, USA	glossarenic Paleudalfs	sandy loam, 1.7 %C	w	grass		NH ₄	0	0.20	63	c-	d/w	0.4	intensive management; sum 365 days
2	Texas, USA	glossarenic Paleudalfs	sandy loam, 1.7 %C	w	grass		NH ₄	363	1.37	365	c-	d/w	0.8	low management; sum 365 days
2	Texas, USA	typic Calcisaprols	sandy loam, 1.7 %C	w	grass		NH ₄	112	0.89	365	c-	d/w	0.8	low management
3	Iowa, USA	typic Calcisaprols	clay loam, 4.9% C	p	unplanted		NH ₄	0	0.33	96	c-	3-7 d	0.4	
3	Iowa, USA	typic Calcisaprols	clay loam, 4.9% C	p	unplanted		urea	125	0.50	96	c-	3-7 d	0.1	
3	Iowa, USA	typic Calcisaprols	clay loam, 4.9% C	p	unplanted		urea	250	0.62	96	c-	3-7 d	0.1	
3	Iowa, USA	typic Calcisaprols	clay loam, 4.9% C	p	unplanted		NH ₄	125	0.56	96	c-	3-7 d	0.2	
3	Iowa, USA	typic Calcisaprols	clay loam, 4.9% C	p	unplanted		NH ₄	250	0.61	96	c-	3-7 d	0.1	
3	Iowa, USA	typic Calcisaprols	clay loam, 4.9% C	p	unplanted		NO ₃	125	0.38	96	c-	3-7 d	0.3	
3	Iowa, USA	typic Calcisaprols	clay loam, 4.9% C	p	unplanted		NO ₃	250	0.36	96	c-	3-7 d	0.1	
4	Iowa, USA	typic Haplaphagniols	loam, 2.5%C, pH 7.7	p	unplanted		NH ₄	0	0.65	140	c-	3-7 d	2.1	AA injected at 20 cm
4	Iowa, USA	typic Haplaphagniols	loam, 2.5%C, pH 7.7	p	unplanted		NH ₄ (eq. ammonia)	180	4.40	140	c-	3-7 d	2.1	AA injected at 20 cm
4	Iowa, USA	typic Haplaphagniols	loam, 2.5%C, pH 7.7	p	unplanted		NO ₃	180	0.86	140	c-	3-7 d	0.1	0.5
4	Iowa, USA	typic Haplaphagniols	loam, 2.5%C, pH 7.7	p	unplanted		urea	180	0.77	140	c-	3-7 d	0.1	0.4
4	Iowa, USA	typic Calcisaprols	silty clay loam, 4.9% C, pH 7.9	p	unplanted		NH ₄	0	0.38	140	c-	3-7 d	0.9	AA injected at 20 cm
4	Iowa, USA	typic Calcisaprols	silty clay loam, 4.9% C, pH 7.9	p	unplanted		NH ₄	180	1.92	140	c-	3-7 d	0.9	AA injected at 20 cm
4	Iowa, USA	typic Calcisaprols	silty clay loam, 4.9% C, pH 7.9	p	unplanted		NH ₄ (eq. ammonia)	180	0.45	140	c-	3-7 d	0.0	0.3
4	Iowa, USA	typic Calcisaprols	silty clay loam, 4.9% C, pH 7.9	p	unplanted		urea	180	0.57	140	c-	3-7 d	0.1	0.3
4	Iowa, USA	typic Calcisaprols	silty clay loam, 4.9% C, pH 7.9	p	unplanted		NO ₃	180	0.44	140	c-	3-7 d	0.1	0.2
4	Iowa, USA	typic Haplaphagniols	silty clay loam, 2.7%C, pH 6.9	p	unplanted		NH ₄	0	0.51	140	c-	3-7 d	0.9	AA injected at 20 cm
4	Iowa, USA	typic Haplaphagniols	silty clay loam, 2.7%C, pH 6.9	p	unplanted		NH ₄	180	2.17	140	c-	3-7 d	0.9	AA injected at 20 cm
4	Iowa, USA	typic Haplaphagniols	silty clay loam, 2.7%C, pH 6.9	p	unplanted		NH ₄ (eq. ammonia)	180	0.62	140	c-	3-7 d	0.1	0.3
4	Iowa, USA	typic Haplaphagniols	silty clay loam, 2.7%C, pH 6.9	p	unplanted		urea	180	0.64	140	c-	3-7 d	0.1	0.4
5	Iowa, USA	typic Haplaphagniols	clay loam, 3.8% C, pH 6.9	p	unplanted; maize residues incorporated		NH ₃	0	0.45	116	c-	3-7 d	1.6	AA injected at 20 cm
5	Iowa, USA	typic Haplaphagniols	clay loam, 3.8% C, pH 6.9	p	unplanted; maize residues incorporated		NH ₃	75	1.67	116	c-	3-7 d	1.4	AA injected at 20 cm
5	Iowa, USA	typic Haplaphagniols	clay loam, 3.8% C, pH 6.9	p	unplanted; maize residues incorporated		NH ₃	150	2.58	116	c-	3-7 d	1.2	AA injected at 20 cm
5	Iowa, USA	typic Haplaphagniols	clay loam, 3.8% C, pH 6.9	p	unplanted; maize residues incorporated		NH ₃	225	3.17	116	c-	3-7 d	1.4	AA injected at 20 cm
5	Iowa, USA	typic Haplaphagniols	clay loam, 3.8% C, pH 6.9	p	unplanted; maize residues incorporated		NH ₃	300	3.75	116	c-	3-7 d	1.3	AA injected at 20 cm

APPENDIX

Ref. [†]	Location	Soil classification [‡]	Texture/other properties	Drainage [§]	Crop/treatment	Fertilizer type [¶]	N-App [¶]	N ₂ O loss of exp. [¶]	Length of exp. ^(days)	Me-thd #	Frequency [¶]	Period induced N ₂ O loss (% of N-App) [¶]	Remarks	
MINERAL SOILS														
5	Iowa, USA	typic Hapludolls	clay loam; 3.8% C, pH 6.9	P	unplanted; maize residues incorporated	NH ₃	375	4.26	116	c-	3-7 d	1.0	1.1	AA injected at 20 cm
5	Iowa, USA	typic Hapludolls	clay loam; 3.8% C, pH 6.9	P	unplanted; maize residues incorporated	NH ₃	450	4.54	116	c-	3-7 d	0.9	1.0	AA injected at 20 cm
5	Iowa, USA	typic Hapludolls	clay loam; 3.8% C, pH 6.9	P	unplanted; maize residues incorporated	NH ₃	0	0.71	156	c-	3-7 d			
5	Iowa, USA	typic Hapludolls	clay loam; 3.8% C, pH 6.9	P	unplanted; maize residues incorporated	NH ₃	112	1.52	156	c-	3-7 d	0.7	1.4	AA injected at 10 cm
5	Iowa, USA	typic Hapludolls	clay loam; 3.8% C, pH 6.9	P	unplanted; maize residues incorporated	NH ₃	112	2.10	156	c-	3-7 d	1.2	1.9	AA injected at 20 cm
5	Iowa, USA	typic Hapludolls	clay loam; 3.8% C, pH 6.9	P	unplanted; maize residues incorporated	NH ₃	112	2.39	156	c-	3-7 d	1.5	2.1	AA injected at 30 cm
5	Iowa, USA	typic Hapludolls	clay loam; 3.8% C, pH 6.9	P	unplanted; maize residues incorporated	NH ₃	112	2.82	156	c-	3-7 d	0.9	1.3	AA injected at 10 cm
5	Iowa, USA	typic Hapludolls	clay loam; 3.8% C, pH 6.9	P	unplanted; maize residues incorporated	NH ₃	225	3.25	156	c-	3-7 d	1.1	1.4	AA injected at 20 cm
5	Iowa, USA	typic Hapludolls	clay loam; 3.8% C, pH 6.9	P	unplanted; maize residues incorporated	NH ₃	225	3.44	156	c-	3-7 d	1.2	1.5	AA injected at 30 cm
5	Iowa, USA	typic Hapludolls	clay loam; 3.8% C, pH 6.9	P	unplanted; soybean plants left to decompose	NH ₃	0	1.70	139	c-	w			
6	Iowa, USA	typic Calcicraepts	silty clay loam; 4.6% C, pH 7.9	P	unplanted; soybean plants left to decompose	NH ₃	250	15.00	139	c-	w	5.3	6.0	AA injected at 20 cm
6	Iowa, USA	typic Calcicraepts	silty clay loam; 4.6% C, pH 7.9	P	unplanted; soybean plants left to decompose	NH ₃	0	2.50	139	c-	w	6.8	7.8	AA injected at 20 cm
6	Iowa, USA	typic Hapludolls	clay loam; 2.7% C, pH 6.9	P	unplanted; soybean plants left to decompose	NH ₃	250	19.60	139	c-	w			
6	Iowa, USA	typic Hapludolls	clay loam; 2.58% C, pH 7.7	P	unplanted; soybean plants left to decompose	NH ₃	0	2.00	139	c-	w			
6	Iowa, USA	typic Hapludolls	clay loam; 2.58% C, pH 7.7	P	unplanted; soybean plants left to decompose	NH ₃	250	12.10	139	c-	w	4.0	4.8	AA injected at 20 cm
6	Iowa, USA	typic Hapludolls	clay loam; 3.7% C, pH 6.8	P	unplanted; maize residues incorporated	NH ₃	0	0.62	355	c-	3-7 d			
7	Iowa, USA	typic Hapludolls	clay loam; 3.7% C, pH 6.8	P	unplanted; maize residues incorporated	NH ₃	180	3.62	355	c-	3-7 d	1.7	2.0	AA injected at 18 cm in fall
7	Iowa, USA	typic Hapludolls	clay loam; 3.7% C, pH 6.8	P	unplanted; maize residues incorporated	NH ₃	0	0.43	167	c-	3-7 d			
7	Iowa, USA	typic Hapludolls	clay loam; 3.7% C, pH 6.8	P	unplanted; maize residues incorporated	NH ₃	180	1.37	167	c-	3-7 d	0.5	0.8	AA injected at 18 cm in spring
8	Oxon, UK	typic Haplaquepts	clay, 3.2-3.9% C	P	wheat, winter, ploughed	NH ₄ NO ₃	70	0.90	212	c-	w			
8	Oxon, UK	typic Haplaquepts	clay, 3.2-3.9% C	P	wheat, winter, direct drilled	NH ₄ NO ₃	70	5.40	212	c-	w			
8	Oxon, UK	typic Haplaquepts	clay, 3.2-3.9% C	P	oilseed rape, ploughed	NH ₄ NO ₃	140	5.60	212	c-	w			
8	Oxon, UK	typic Haplaquepts	clay, 3.2-3.9% C	P	oilseed rape, direct drilled	NH ₄ NO ₃	140	8.60	212	c-	w			
8	Oxon, UK	typic Haplaquepts	clay loam; 2-2.1% C	P	wheat, winter, ploughed	NH ₄ NO ₃	70	0.50	212	c-	w	0.7	0.7	Nov.'77-June '78
8	Oxon, UK	typic Haplaquepts	clay loam; 2-2.1% C	P	wheat, winter, direct drilled	NH ₄ NO ₃	70	1.50	212	c-	w	2.1	2.1	Nov.'77-June '78
8	Oxon, UK	typic Haplaquepts	clay loam; 2-2.1% C	P	oilseed rape, ploughed	NH ₄ NO ₃	140	1.00	212	c-	w	0.7	0.7	Nov.'78-June '79
8	Oxon, UK	typic Haplaquepts	clay loam; 2-2.1% C	P	oilseed rape, direct drilled	NH ₄ NO ₃	140	2.10	212	c-	w	1.5	1.5	168/13/56 mature NH ₄ NO ₃ /area;
9	Madison, USA	typic Hapludalfs	w	maize	organic/NH ₄ NO ₃ /area	237	5.20	365	c-	7-30 d	2.1	2.2	168/13/56 mature NH ₄ NO ₃ /area;	
9	Madison, USA	typic Hapludalfs	w	maize	organic/NH ₄ NO ₃	181	3.60	365	c-	7-30 d	1.8	2.0	prev. maize residues incorporated	
9	Madison, USA	typic Hapludalfs	w	grass	0	0.34	365	c-	7-30 d	1.8				
10	Washington, USA	ulic Hapluderrals	w	unplanted	0	0.03	35	c-	2 d					
10	Washington, USA	ulic Hapluderrals	silt loam	w	unplanted	NH ₃	55	0.05	35	c-	2 d	0.0	0.1	AA injected at 15 cm
10	Washington, USA	ulic Hapluderrals	silt loam	w	unplanted	NH ₃	110	0.10	35	c-	2 d	0.1	0.1	AA injected at 15 cm
10	Washington, USA	ulic Hapluderrals	silt loam	w	wheat, winter, direct drilled	NH ₄ NO ₃	220	0.23	35	c-	2 d	0.1	0.1	AA injected at 15 cm
11	Oxon, UK	typic Haplaquepts	clay, undrained	P	wheat, winter, direct drilled	NH ₄ NO ₃	53	0.65	30	c 1	w			
11	Oxon, UK	typic Haplaquepts	clay, undrained	P	wheat, winter, direct drilled	NO ₃	0	0.07	28	c 1	w			
11	Oxon, UK	typic Haplaquepts	clay, undrained	P	wheat, winter, direct drilled	NO ₃	100	3.12	31	c 1	w			
11	Oxon, UK	typic Haplaquepts	clay, undrained	P	wheat, winter, direct drilled	NO ₃	0	0.07	28	c 1	w			
11	Oxon, UK	typic Haplaquepts	clay, drained	m	wheat, winter, direct drilled	NO ₃	96	1.44	30	c 1	w			
11	Oxon, UK	typic Haplaquepts	clay, drained	m	wheat, winter, direct drilled	NO ₃	53	0.22	31	c 1	w			
														24 hour cont. measurement per 2 days

APPENDIX

Ref.†	Location	Soil classification‡	Texture/other properties	Drainage§	Crop/treatment	Fertilizer type¶	N-App. rate	N ₂ O loss of exp.	Length of exp. (days)	Me-thod #	Frequency††	Fertilizer induced N ₂ O loss (% of N-app.)††	Remarks
MINERAL SOILS													
11	Oxon, UK	typic Haplaquepts	clay, drained	m	wheat, winter, direct drilled	NH ₄ NO ₃	0	1.49	31	c1	w	1.5	
11	Oxon, UK	typic Haplaquepts	clay, drained	m	wheat, winter, direct drilled	NH ₄ NO ₃	0.077	30	c1	w	1.5		
12	Oxon, UK	typic Haplaquepts	clay, undrained	p	wheat, winter, direct drilled	NH ₄ NO ₃	153	2.30	57	c1	2-3 d	1.6	
13	Oxon, UK	typic Haplaquepts	clay, 3.7% C	p	wheat, winter, ploughed	NH ₄ NO ₃	70	1.10	242	c1	w	1.9	
13	Oxon, UK	typic Haplaquepts	clay, 3.7% C	p	wheat, winter, direct drilled	NH ₄ NO ₃	70	1.30	242	c1	w	1.9	
13	Oxon, UK	typic Haplaquepts	clay, 3.7% C	p	grass	NH ₄ NO ₃	210	0.40	242	c1	w	0.2	
14	Mainz, Germany	loess, parentendina	sandy clay loam	w	grass	NO ₃	100	0.07	c-	d	0.1		
14	Mainz, Germany	loess, parentendina	sandy clay loam	w	grass	NH ₄	100	0.05	c-	d	0.1		
14	Mainz, Germany	loess, brown soil	sandy loam	w	unplanted (beet field, plants removed)	NO ₃	100	0.02	c-	d	0.0		
14	Mainz, Germany	loess, brown soil	sandy loam	w	unplanted (beet field, plants removed)	NH ₄	100	0.15	c-	d	0.2		
14	Mainz, Germany	loess, brown soil	sandy loam	w	unplanted (beet field, plants removed)	NO ₃	100	0.22	c-	d	0.2		
14	Mainz, Germany	loess	sandy clay loam	w	grass	NH ₄	100	0.01	c-	d	0.0		
14	Mainz, Germany	loess	sandy clay loam	w	grass	NO ₃	100	0.03	c-	d	0.0		
14	Mainz, Germany	loess	sandy clay loam	w	grass	NH ₄	100	0.07	c-	d	0.1		
14	Mainz, Germany	loess	sandy clay loam	w	grass	NO ₃	100	0.02	c-	d	0.1		
14	Mainz, Germany	loess	sandy clay loam	w	grass	NH ₄	100	0.08	c-	d	0.1		
14	Mainz, Germany	loess	sandy loam	w	grass	NO ₃	100	0.07	c-	d	0.1		
14	Mainz, Germany	loess	sandy loam	w	grass	NH ₄	100	0.38	c-	d	0.4		
14	Mainz, Germany	loess	sandy loam	w	grass	NO ₃	100	0.00	c-	d	0.0		
14	Mainz, Germany	loess	sandy loam	w	clover	NH ₄	100	0.07	c-	d	0.1		
14	Mainz, Germany	loess	sandy loam	w	clover	NO ₃	100	0.02	c-	d	0.0		
14	Mainz, Germany	loess	sandy loam	w	grass	NH ₄	100	0.07	c-	d	0.1		
14	Mainz, Germany	loess	sandy loam	w	grass	NO ₃	100	0.08	c-	d	0.1		
14	Mainz, Germany	loess	sandy loam	w	rice, wetland	NH ₄	100	0.07	c-	d	0.1		
15	Australia	clay	silt loam, 1% C, pH 6.9	w	maize	NO ₃	0	0.30	85	c1	o-	cont	1.0
16	New York, USA	glossoboritic Hapludalfs	silt loam, 1% C, pH 6.9	w	maize	NO ₃	140	2.50	85	c1	d	0.0	0.2
16	New York, USA	glossoboritic Hapludalfs	silt loam, 1% C, pH 6.9	w	maize	urea	140	2.40	365	c1	d	1.6	1.8
16	New York, USA	glossoboritic Hapludalfs	silt loam, 1% C, pH 6.9	w	maize	organic/NH ₄ NO ₃	132	2.40	365	c-	d	0.0	1.8
17	New York, USA	glossoboritic Hapludalfs	silt loam	w	maize	organic/NH ₄ NO ₃	132	2.90	365	c-	d	0.0	2.2
17	New York, USA	glossoboritic Hapludalfs	silt loam	w	maize	organic/NH ₄ NO ₃	132	3.80	365	c-	d	0.1	2.9
17	New York, USA	glossoboritic Hapludalfs	silt loam	w	timothy weeds	0	0.90	365	c-	d	0.0	1.8	
17	New York, USA	glossoboritic Hapludalfs	silt loam	w	timothy weeds	NH ₄ NO ₃ /urea	0	1.70	365	c-	d	0.0	1.8
17	New York, USA	glossoboritic Hapludalfs	silt loam	w	maize	NH ₄ NO ₃ /urea	132	1.60	365	c-	d	1.2	1.979/80
17	New York, USA	glossoboritic Hapludalfs	silt loam	w	maize	NH ₄ NO ₃ /urea	132	2.90	365	c-	d	2.2	1.980/81
17	New York, USA	glossoboritic Hapludalfs	silt loam	w	maize	NH ₄ NO ₃ /urea	132	2.20	365	c-	d	1.7	1.980/81
17	New York, USA	glossoboritic Hapludalfs	silt loam	w	alfalfa	0	2.30	365	c-	d	0.0	1.980/81	
17	New York, USA	glossoboritic Hapludalfs	silt loam	w	alfalfa	organic	1230	3.25	314	c-	d	0.3	1.978-1979
18	Edinburgh, UK	stagnogley, 4.1% C	sandy loam over clay loam	p	grass	0	0.45	273	8	d/w	0.3	1.979-1980	
18	Edinburgh, UK	stagnogley, 4.1% C	sandy loam over clay loam	p	grass	NO ₃	400	1.25	273	8	d/w	0.3	1.979-1980
18	Edinburgh, UK	stagnogley, 4.1% C	sandy loam over clay loam	p	grass	organic	298	1.10	273	8	d/w	0.4	1.979-1980
18	Edinburgh, UK	stagnogley, 4.1% C	sandy loam over clay loam	p	grass	NO ₃	100	6.90	314	8	d/w	6.9	1.978-1979
18	Edinburgh, UK	stagnogley, 4.1% C	sandy loam over clay loam	p	grass	NO ₃	700	13.40	365	o2	2-3 d/w	1.9	
19	Edinburgh, UK	stagnogley, 4.1% C	sandy loam over clay loam	p	grass	organic	700	3.30	365	o2	2-3 d/w	0.5	
19	Edinburgh, UK	stagnogley, 4.1% C	sandy loam over clay loam	p	grass	0	3.20	365	o2	2-3 d/w	0.2		

APPENDIX

Ref.†	Location	Soil classification‡	Texture/other properties	Drainage§	Crop/treatment	Fertilizer type¶	N-Appl. rate (kg N/ha)	N ₂ O loss exp. (days)	Method #	Frequency††	Fertilizer induced N ₂ O loss (% of N-appl.)††	Remarks
										I	II	
MINERAL SOILS												
20	Wisconsin, USA	typic Argiudolls	silt loam; pH 4.7; 2.16% C	w	tobacco	NH ₄ NO ₃ /straw	80	0.70	253	c-	w	0.9
20	Wisconsin, USA	typic Argiudolls	silt loam; pH 4.7; 2.27% C	w	tobacco	NH ₄ NO ₃ /straw	80	0.30	190	c-	w	0.4
20	Wisconsin, USA	typic Argiudolls	silt loam; pH 4.7; 2.31% C	w	tobacco	organic/NH ₄ NO ₃	245	0.30	190	c-	w	0.1
20	Wisconsin, USA	typic Argiudolls	silt loam; pH 4.7; 2.72% C	w	tobacco	organic/NH ₄ NO ₃	410	2.70	252	c-	w	0.7
20	Wisconsin, USA	typic Argiudolls	silt loam; pH 6.7; 1.61% C	w	tobacco	NH ₄ NO ₃	80	1.00	210	c-	w	1.3
20	Wisconsin, USA	typic Argiudolls	silt loam; pH 5.1; 1.56% C	w	tobacco	NH ₄ NO ₃	80	0.90	210	c-	w	1.1
20	Wisconsin, USA	typic Argiudolls	silt loam; pH 4.7; 1.56% C	w	tobacco	NH ₄ NO ₃	80	1.50	206	c-	w	1.9
20	Wisconsin, USA	typic Argiudolls	silt loam; pH 4.7; 2.16% C	w	tobacco	NH ₄ NO ₃ /straw	80	2.20	249	c-	w	2.8
20	Wisconsin, USA	typic Argiudolls	silt loam; pH 4.7; 2.27% C	w	tobacco	NH ₄ NO ₃ /straw	80	1.60	202	c-	w	2.0
20	Wisconsin, USA	typic Argiudolls	silt loam; pH 4.7; 2.31% C	w	tobacco	organic/NH ₄ NO ₃	245	3.20	202	c-	w	1.3
20	Wisconsin, USA	typic Argiudolls	silt loam; pH 4.7; 2.72% C	w	tobacco	organic/NH ₄ NO ₃	410	6.10	257	c-	w	1.5
20	Wisconsin, USA	typic Argiudolls	silt loam; pH 5.8; 2.72% C	w	barley	organic/NH ₄ NO ₃	520	1.60	215	c-	w	0.3
20	Wisconsin, USA	typic Argiudolls	silt loam; pH 6.8; 1.74% C	w	maize	NH ₄ NO ₃	200	6.30	190	c-	w	3.2
20	Wisconsin, USA	typic Argiudolls	silt loam; pH 6.8; 1.74% C	w	maize	NH ₄ NO ₃	200	3.50	190	c-	w	1.8
20	Wisconsin, USA	typic Argiudolls	silt loam; pH 6.7; 1.56% C	w	vegetables	NH ₄ NO ₃	80	0.20	160	c-	w	0.3
20	Wisconsin, USA	typic Argiudolls	silt loam; pH 5.1; 1.56% C	w	vegetables	NH ₄ NO ₃	80	0.20	160	c-	w	0.3
20	Wisconsin, USA	typic Argiudolls	silt loam; pH 4.7; 1.56% C	w	vegetables	NH ₄ NO ₃	80	0.40	160	c-	w	0.5
20	Wisconsin, USA	typic Argiudolls	silt loam; pH 4.7; 2.72% C	w	barley	organic/NH ₄ NO ₃	410	1.20	160	c-	w	0.3
20	Wisconsin, USA	typic Argiudolls	silt loam; pH 5.8; 2.72% C	w	barley	organic/NH ₄ NO ₃	520	0.20	152	c-	w	0.0
20	Wisconsin, USA	typic Argiudolls	silt loam; pH 6.8; 1.81% C	w	maize	NH ₄ NO ₃	200	0.30	157	c-	w	0.2
20	Wisconsin, USA	typic Argiudolls	silt loam; pH 6.8; 1.74% C	w	maize	NH ₄ NO ₃	200	0.60	157	c-	w	0.3
21	Colorado, USA	aridic Argiustoll	clay (monmorillonitic)	w	maize	NH ₃	200	2.60	128	c-/m	w	1.3
21	Colorado, USA	aridic Argiustoll	clay (monmorillonitic)	w	maize	NH ₃	200	4.00	365	c-/m	w	2.0
22	Ontario, Canada	gray brown Luvisol	sandy loam	w	maize	NH ₄ NO ₃	0	0.10	80	c-	w	Estimated from Figure 1, p. 434
22	Ontario, Canada	gray brown Luvisol	sandy loam	w	maize	NH ₄ NO ₃	336	0.85	80	c-	w	About 3 measurements/month
23	Korosu, Japan	alluvial soil	rape	w	maize	NH ₄	150	0.09	38	c-	2 h	Fig. 4 (p. 24) shows 2 h intervals of measurement
											0.1	

APPENDIX

Ref.†	Location	Soil classification‡	Texture/other properties	Drainage§	Crop/treatment	Fertilizer type¶	N Appl. rate	N ₂ O loss of exp.	Length of exp. (days)	Me-thod #	Frequency††	Fertilizer induced N ₂ O loss (% of N-appl.)‡‡	Remarks	
										I	II			
MINERAL SOILS														
23	Konan, Japan	alluvial soil andeols	w	wheat		NH ₄	80	0.14	186	c-	2 h	0.2		
23	Tsukuba, Japan	andeols	w	wheat		NH ₄	80	0.19	186	c-	2 h	0.2		
23	Tsukuba, Japan	andeols	w	rape		NH ₄	100	0.34	56	c-	2 h	0.3		
23	Tsukuba, Japan	andeols	w	rape		NH ₄	150	0.14	38	c-	2 h	0.1		
23	Tsukuba, Japan	andeols	w	carrot		NH ₄	200	0.52	116	c-	2 h	0.3		
23	Konan, Japan	alluvial soil	w	carrot		NH ₄	200	0.62	116	c-	2 h	0.3		
23	Konan, Japan	alluvial soil	w	rice, dryland		NH ₄	100	0.33	120	c-	2 h	0.3		
23	Tsukuba, Japan	andeols	w	rice, dryland		NH ₄	100	0.55	120	c-	2 h	0.6		
23	Mito, Japan	andeols	w	rice, dryland		NH ₄	90	0.27	139	c-	2 h	0.3		
24	Tsukuba, Japan	gray lowland soil, 2.5% C	p	carrot		NH ₄	200	0.25	116	c-	3-10 d	0.1		
24	Tsukuba, Japan	gray lowland soil, 2.5% C	p	carrot		NH ₄	200	0.60	116	c-	3-10 d	0.3		
24	Tsukuba, Japan	gray lowland soil, 2.5% C	p	carrot		NH ₄	0	0.08	116	c-	3-10 d	0.3		
24	Tsukuba, Japan	gray lowland soil, 2.5% C	p	carrot		NH ₄	200	0.34	116	c-	3-10 d	0.1		
25	Colorado, USA	aridic Argiustolls	w	maize		NH ₃ organic (N-mineralized)	200	2.50	123	c-m	1.3			
26	Colorado, USA	ustic Torriorthents	w	barley		NH ₃ organic (N-mineralized)	336	4.19	153	c-	3 d/w	1.0		
26	Colorado, USA	ustic Torriorthents	w	barley		NH ₃ organic (N-mineralized)	71	1.09	153	c-	3 d/w	0.8		
26	Colorado, USA	ustic Torriorthents	w	barley		NH ₃ organic (N-mineralized)	0	0.82	153	c-	3 d/w	0.5		
26	Colorado, USA	ustic Torriorthents	w	barley		NH ₄ NO ₃	224	1.43	153	c-	3 d/w	0.4		
26	Colorado, USA	ustic Torriorthents	w	barley		NH ₄ NO ₃	112	1.04	153	c-	3 d/w	0.9		
26	Colorado, USA	ustic Torriorthents	w	barley		NH ₄ NO ₃	56	0.93	153	c-	3 d/w	0.7		
26	Colorado, USA	ustic Torriorthents	w	barley		NH ₄ NO ₃	0	0.52	153	c-	3 d/w	0.7		
27	Colorado, USA	aridic Argiustolls	w	maize		NH ₄	0	2.23	20	c 2-4 p/d3 p/w	irrigated maize	1.5		
27	Colorado, USA	aridic Argiustolls	w	maize		NH ₄	200	2.95	120	c 2-4 p/d3 p/w	irrigated barley	0.4		
27	Colorado, USA	aridic Argiustolls	w	barley		NH ₄	0	0.45	86	c 2-4 p/d3 p/w	irrigated barley	0.4		
27	Colorado, USA	aridic Argiustolls	w	barley		NH ₄	200	0.76	86	c 2-4 p/d3 p/w	irrigated barley	0.4		
28	California, USA	typic Xerorthents	w	unplanted		NO ₃ /organic	300	9.90	16	c 2	unknown amount of N from organic fert; controlled soil moisture; summer exp.	3.3		
28	California, USA	typic Xerorthents	w	unplanted		NO ₃ /organic	300	5.40	16	c 2	d/w	1.8		
28	California, USA	typic Xerorthents	loam	loam	w	unplanted (ryegrass 4 months before exp.)	NO ₃	300	4.30	16	c 2	d/w	1.4	
28	California, USA	typic Xerorthents	loam	loam	w	unplanted (ryegrass 4 months before exp.)	NO ₃	300	1.80	16	c 2	d/w	0.6	
28	California, USA	typic Xerorthents	loam	loam	w	unplanted	NO ₃	300	2.10	16	c 2	d/w	0.7	
28	California, USA	typic Xerorthents	loam	loam	w	unplanted	NO ₃	300	0.60	16	c 2	d/w	0.2	
28	California, USA	typic Xerorthents	loam	loam	w	unplanted	NO ₃ /organic	300	4.20	16	c 2	d/w	1.4	

APPENDIX

Ref.†	Location	Soil classification	Texture/other properties	Drainage‡	Crop/treatment	Fertilizer type¶	N Appl. rate (kg N/ha)	N ₂ O loss of exp. (days)	Length of exp.	Method #	Frequency††	Fertilizer induced N ₂ O loss (% of N-appl.)‡‡	Remarks
MINERAL SOILS													
28	California, USA	typic Xerorthents	loam	w	unplanted					c 2	d/w		1.3
28	California, USA	typic Xerorthents	loam	w	unplanted (regress 4 months before exp.)	NO ₃	300	0.70	16	c 2	d/w	0.2	unknown amount of N from organic fert.; controlled soil moisture; winter exp.
28	California, USA	typic Xerorthents	loam	w	unplanted (regress 4 months before exp.)	NO ₃	300	0.10	16	c 2	d/w	0.0	controlled soil moisture; winter exp.
28	California, USA	typic Xerorthents	loam	w	unplanted	NO ₃	300	0.40	16	c 2	d/w	0.1	controlled soil moisture; winter exp.
28	California, USA	typic Xerorthents	loam	w	unplanted	NO ₃	300	0.20	16	c 2	d/w	0.1	controlled soil moisture; winter exp.
29	Berkshire, UK	Ochrequals	loam over clay; 3.5 % C	p	grass	NH ₄ NO ₃	250	3.25	365	o-	d3 p/w	1.3	
30	Berkshire, UK	Ochrequals	loam over clay; 3.5 % C	p	grass		0	-0.60	365	o 1	2-3 p/w.		
30	Berkshire, UK	Ochrequals	loam over clay; 3.5 % C	p	grass	NH ₄ NO ₃	500	8.00	365	o 1	2-3 p/w.	1.6	
30	Berkshire, UK	Ochrequals	loam over clay; 3.5 % C	p	grass	NH ₄ NO ₃	250	3.50	365	o 1	2-3 p/w.	1.4	
31	California, USA	pacific Hapluxerolls	fine loamy	w	vegetables	NO ₃	620	41.80	210	o 1	d2-3 d	6.7	lettuce-celery, irrigated
31	California, USA	pacific Hapluxerolls	fine loamy	w	vegetables	NO ₃	620	20.20	210	o 1	d2-3 d	3.3	lettuce-celery, irrigated
31	California, USA	pacific Hapluxerolls	fine loamy	w	vegetables	NO ₃	620	26.40	210	o 1	d2-3 d	4.3	lettuce-celery, irrigated
31	California, USA	pacific Hapluxerolls	fine loamy	w	vegetables	organic/NO ₃	430	19.60	210	o 1	d2-3 d	4.6	144/286 organic/NO ₃ ; artichokes, irrigated
31	California, USA	pacific Hapluxerolls	fine loamy	w	vegetables	organic/NO ₃	430	26.90	210	o 1	d2-3 d	6.3	144/286 organic/NO ₃ ; artichokes, irrigated
31	California, USA	pacific Hapluxerolls	fine loamy	w	vegetables	NO ₃	680	26.80	210	o 1	d2-3 d	3.9	cauliflower, irrigated
31	California, USA	pacific Hapluxerolls	fine loamy	w	vegetables	NO ₃	680	29.20	210	o 1	d2-3 d	4.3	cauliflower, irrigated
32	California, USA	pacific Hapluxerolls	fine loamy	w	vegetables	NH ₄ /area/NH ₃	335	7.68	123	o 1	d/w	2.3	celery, irrigated; 12-18% of denitrification of 51.2 kg N/ha as N ₂ O (p.117)
33	Mainz, Germany	loess loam	sandy 1-clay loam, 0.8% C, pH 7.4	w	grass	NO ₃	0	0.02	49	c-	d	0.05	0.1
33	Mainz, Germany	loess loam	sandy 1-clay loam, 0.8% C, pH 7.4	w	grass	NH ₄	100	0.07	49	c-	d	0.07	0.1
33	Mainz, Germany	loess loam	sandy 1-clay loam, 0.8% C, pH 7.4	w	grass		0	0.13	71	c-	d		
33	Mainz, Germany	colian sand	sand	w	woods	NO ₃	100	0.14	71	c-	d	0.01	0.1
33	Mainz, Germany	colian sand	sand	w	woods	NH ₄	100	0.22	71	c-	d	0.09	0.2
33	Mainz, Germany	colian sand	sand	w	woods		0	0.02	32	c-	d		
33	Mainz, Germany	loess	sandy loam, 2-2.6% C	w	grass	NO ₃	100	0.03	32	c-	d	0.01	authors refer to crop as "meadow"
33	Mainz, Germany	loess	sandy loam, 2-2.6% C	w	grass	NH ₄	100	0.05	32	c-	d	0.03	authors refer to crop as "meadow"
33	Mainz, Germany	loess	sandy loam, 2-2.6% C	w	grass		0	0.04	72	c-	d		estimated from Figure 2, p.165
34	Mainz, Germany	colian sand	sand	w	weeds	NH ₄	100	0.13	72	c-	2d/m	0.1	0.1
34	Mainz, Germany	colian sand	sand	w	weeds	NO ₃	100	0.05	72	c-	2d/m	0.0	0.1
34	Mainz, Germany	colian sand	sand	w	weeds	NH ₄ NO ₃	100	0.09	72	c-	2d/m	0.1	0.1
35	Andalucia, Spain	loamy sand	loamy sand	w	grass	NH ₄ NO ₃	100	0.00	10	c-	d	0.1	estimated from Figure 2, p.165
35	Andalucia, Spain	loamy sand	loamy sand	w	unplanted, soybean residues incorporated		0	0.10	28	c-	d	0.1	estimated from reported % N ₂ O loss; plot had received additional 75 kg N earlier in the year estimated from 15x10 ⁻⁶ M ₂ O-N loss/m ² h. §

APPENDIX

Ref.†	Location	Soil classification	Texture/other properties	Drainage§	Crop/treatment	Fertilizer type¶	N-App. rate (kg N/ha)	N_2O length loss of exp. (days)	Method #	Frequency††	Fertilizer induced N_2O loss (% of N-appl.)††	Remarks
									I	II		
MINERAL SOILS												
35	Andalucia, Spain	loamy sand	w	unplanted, soybean residues incorporated	NH_4NO_3	urea	100	0.14	28	c-	0.0	0.1
35	Andalucia, Spain	loamy sand	w	unplanted, soybean residues incorporated	NH_4NO_3	urea	90	0.07	105	c-	w	estimated from reported 0.04 % N_2O loss from NH_4NO_3
36	Louisiana, USA	typic Albaqualfs	silt loam; 0.7% C; pH 6	p	rice, wetland	urea	90	0.11	105	c-	w	0.1
36	Louisiana, USA	typic Albaqualfs	silt loam; 0.7% C; pH 6	p	rice, wetland	urea	180	0.17	105	c-	w	0.1
36	Louisiana, USA	typic Albaqualfs	silt loam; 0.7% C; pH 6	p	rice, wetland	urea	90	0.11	105	c-	w	0.1
36	Louisiana, USA	typic Albaqualfs	silt loam; 0.7% C; pH 6	p	rice, wetland	urea	180	0.09	105	c-	w	0.1
36	Louisiana, USA	typic Albaqualfs	silt loam; 0.7% C; pH 6	p	rice, wetland	NO_3^-	400	7.00	365	c-	2 p.d/w	1.8
37	UK	clay loam, 4% C	w	grass	NO_3^-	urea	400	5.00	365	c-	2 p.d/w	1.3
37	UK	silt loam, 2.3% C	w	grass	NO_3^-	urea	0	0.90	365	c-	2 p.d/w	mean of reported emission of 4.0-6.0 kg N/ha
37	UK	silt loam, 2.3% C	w	grass	NH_4NO_3	organic	200	2.38	100	o-	h	0.9
38	Denmark	sandy loam, 1.9% C, pH 5.3	w	grass	NH_4NO_3	492	9.35	100	o-	h	0.9	1.2
38	Denmark	sandy loam, 1.9% C, pH 5.3	w	grass	NH_4NO_3	492	9.35	100	o-	h	1.8	1.9
38	Denmark	sandy loam, 1.9% C, pH 5.3	w	grass	NH_4NO_3	0	0.67	100	o-	h	0.9	mean of reported emission of 0.8-1.0 kg N/ha
39	Scotland	loam; pH 6.6; 4.4% C	w	barley, winter, ploughed	NH_4NO_3	210	0.01	8	c-	d	0.0	0.0
39	Scotland	loam; pH 6.6; 4.4% C	w	barley, winter, ploughed	NH_4NO_3	285	0.01	8	c-	nk	0.0	0.0
39	Scotland	loam; pH 6.6; 4.4% C	w	barley, winter, direct drilled	NH_4NO_3	210	0.01	8	c-	nk	0.0	0.0
39	Scotland	loam; pH 6.6; 4.4% C	w	barley, winter, direct drilled	NH_4NO_3	285	0.01	8	c-	nk	0.0	0.0
39	Scotland	loam; pH 6.5; 3.3% C	w	barley, winter, ploughed	NH_4NO_3	210	0.01	8	c-	nk	0.0	0.0
39	Scotland	loam; pH 6.5; 3.3% C	w	barley, winter, ploughed	NH_4NO_3	285	0.00	8	c-	nk	0.0	0.0
39	Scotland	loam; pH 6.5; 3.3% C	w	barley, winter, direct drilled	NH_4NO_3	210	0.01	8	c-	nk	0.0	0.0
39	Scotland	loam; pH 6.5; 3.3% C	w	barley, winter, direct drilled	NH_4NO_3	285	0.01	8	c-	nk	0.0	0.0
40	Colorado, USA	Arctic Argiustolls	w	maize	NH_4NO_3	0	0.12	97	c-	3 p.w	1.5	1.5
40	Colorado, USA	Arctic Argiustolls	w	maize	urea	218	3.36	97	c-	3 p.w	1.5	irrigated maize
40	Colorado, USA	Arctic Argiustolls	w	maize	urea	0	0.11	97	c-	3 p.w	0.8	irrigated maize
40	Colorado, USA	Arctic Argiustolls	w	maize	urea	218	1.65	97	c-	3 p.w	0.7	irrigated maize
41	Iowa, USA	silty clay loam, 5.4% C, pH 7.9	w	soybeans	0	0.34	365	c-	3d/21d			
41	Iowa, USA	clay loam, 1.1% C, pH 7.2	w	soybeans	0	0.65	365	c-	3d/21d			
41	Iowa, USA	clay loam, 1.1% C, pH 7.2	w	soybeans	0	1.35	365	c-	3d/21d			
41	Iowa, USA	clay loam, 1.1% C, pH 7.2	w	soybeans	0	1.05	365	c-	3d/21d			
41	Iowa, USA	sandy loam, 1.3% C, pH 6.7	w	soybeans	0	1.97	365	c-	3d/21d			
41	Iowa, USA	loam, 2.9% C, pH 6.9	w	soybeans	0	1.87	365	c-	3d/21d			
41	Iowa, USA	loam, 2.5% C, pH 6.5	w	soybeans	0	0.09	46	nk	nk	0.1	0.2	
42	New York, USA	typic Calcicaquolls	w	wheat	NH_4NO_3	175	0.30	46	nk	nk	0.0	0.1
42	New York, USA	typic Calcicaquolls	w	wheat	NH_4NO_3	175	0.16	46	nk	nk	0.0	0.1
42	New York, USA	typic Haplaqueolls	w	grass	NH_4NO_3	0.14	62	c-	3d	0.1	0.1	0.1
44	Colorado, USA	utricolic Haplargids	w	fine sandy loam	NH_4NO_3	450	0.49	62	c-	3d	0.1	0.1
44	Colorado, USA	utricolic Haplargids	w	fine sandy loam	NH_4NO_3	0	0.1	62	c-	3d	0.1	0.1

APPENDIX

Ref.†	Location	Soil classification	Texture/other properties	Drainage‡	Crop/treatment	Fertilizer type¶	N Appl. rate	N_2O loss of exp.	Length of exp. (days)	Method #	Frequency††	Fertilizer induced N_2O loss I (%) N-appl.)††	Fertilizer induced N_2O loss II (%) N-appl.)††	Remarks
ORGANIC SOILS														
17	Florida, USA	organic	w	onions										
17	Florida, USA	organic	w	onions										
17	Florida, USA	organic	w	maize										
17	Florida, USA	organic	w	maize										
17	Florida, USA	organic	w	sugarcane										
17	Florida, USA	organic	w	sugarcane										
17	Florida, USA	organic	w	grass										
17	Florida, USA	organic	w	grass										
17	Florida, USA	organic	w	unplanted										
17	Florida, USA	organic	w	unplanted										
43	Florida, USA	euic lithic Medisapristis	organic	p	unplanted									
43	Florida, USA	euic lithic Medisapristis	organic	p	grass									
43	Florida, USA	euic lithic Medisapristis	organic	p	sugarcane									

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† 1 = Armstrong (1983); 2 = Brams et al. (1990); 3 = Breitenbeck et al. (1980); 4 = Breitenbeck & Bremner (1986a); 5 = Breitenbeck & Bremner (1986b); 6 = Bremner et al. (1981a); 7 = Bremner et al. (1981b); 8 = Burford et al. (1981); 9 = Cates & Keeney (1987); 10 = Cochran et al. (1980); 11 = Colbourne & Harper (1987); 12 = Colbourne et al. (1984a); 13 = Colbourne et al. (1984b); 14 = Conrad et al. (1983); 15 = Denmead et al. (1979); 16 = Duxbury & McConaughay (1986); 17 = Duxbury et al. (1982); 18 = Eggington & Smith (1986); 19 = Eggington & Smith (1986); 20 = Goodroad et al. (1984); 21 = Hutchinson & Mosier (1979); 22 = McKenney et al. (1980); 23 = Minami (1987); 24 = Minami (1990); 25 = Mosier & Hutchinson (1981); 26 = Mosier et al. (1982); 27 = Mosier et al. (1986); 28 = Rolston et al. (1978); 29 = Ryden (1981); 30 = Ryden & Lund (1980); 31 = Ryden et al. (1979); 32 = Ryden et al. (1981); 33 = Seiler & Conrad (1981); 34 = Conrad & Seiler (1980); 35 = Slemer et al. (1984); 36 = Smith et al. (1982); 37 = Webster & Dowdell (1982); 38 = Christensen (1983); 39 = Arah et al. (1991); 40 = Bronson et al. (1992); 41 = Bremner et al. (1980); 42 = Duxbury (personal communication), quoted in Eichner (1990); 43 = Terry et al. (1981).

‡ Reported soil classification according to USDA (1975) or general description.

§ w = well drained; m = moderately well drained; p = poorly drained.

¶ NH_3 = anhydrous ammonia; NH_4NO_3 = salts of ammonia; NO_3 = salts of nitrate; organic = various forms of organic fertilizers.

c = closed chamber method; o = open chamber method; g = soil N_2O gradient method; m = micrometeorological method; - = only N_2O measured; 1 = N_2 and N_2O measured (C_2H_2 inhibition); 2 = ^{15}N labelling.

†† d = once per day, w = once per week, m = once per month, 3-7 d = once per 3-7 days, 2 p.d or 2 p.w = twice per day/week, cont = continuous, d/w or other combinations indicate higher frequency at high and lower frequency at low flux rates.

†† I = flux from fertilized plot minus flux from unfertilized control plot, presented as % of N-application.

II = flux from fertilized plot presented as % of N-application.