RIVM report 680125003/2007
MNP report 500080003/2007

Direct and indirect nitrous oxide emissions from agricultural soils, 1990 - 2003

Background document on the calculation method for the Dutch National Inventory Report

K.W. Van Der Hoek, M.W. Van Schijndel[1]
and P.J. Kuikman[2]

[1]Netherlands Environmental Assessment Agency (MNP)
[2]Alterra

Contact:
K.W. Van Der Hoek
Laboratory for Environmental Monitoring (LVM)
Klaas.van.der.Hoek@rivm.nl

M.W. Van Schijndel
Agriculture and Rural Areas Team (LDL)
Marian.van.Schijndel@mnp.nl

This investigation has been performed by order and for the account of SenterNovem, within the framework of project 1331-04-02-02-005/4700007562 and 0377-04-01-06-003/4700008403.

RIVM, P.O. Box 1, 3720 BA Bilthoven, telephone: 31 - 30 - 274 91 11; telefax: 31 - 30 - 274 29 71

Abstract

Direct and indirect nitrous oxide emissions from agricultural soils, 1990 - 2003
Background document on the calculation method for the Dutch National Inventory Report

Since 2005 the Dutch method to calculate the nitrous oxide emissions from agricultural soils has fully complied with the Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidelines. In order to meet the commitments of the Convention on Climate Change and the Kyoto Protocol, nitrous oxide emissions have to be reported annually in the Dutch National Inventory Report (NIR). Countries are encouraged to use country-specific data rather than the default values provided by the IPCC. This report describes the calculation schemes and data sources used for nitrous oxide emissions from agricultural soils in the Netherlands.

The nitrous oxide emissions, which contribute to the greenhouse effect, occur due to nitrification and denitrification processes. They include direct emissions from agricultural soils due to the application of animal manure and fertilizer nitrogen and the manure production in the meadow. Also included are indirect emissions resulting from the subsequent leaching of nitrate to ground water and surface waters, and from deposition of ammonia that had volatilized as a result of agricultural activities. Before 2005 indirect emissions in the Netherlands were calculated using a method that did not compare well with IPCC definitions and categories. The elaborate explanation here should facilitate reviewing by experts. Finally, the report also presents an overview of the nitrous oxide emissions from agricultural soils and the underlying data used in the 1990 - 2003 period.

Key words: nitrous oxide, greenhouse gases, emissions, animal manure, fertilizer, Kyoto Protocol, climate change, IPCC, agricultural soil, nitrification, denitrification

Rapport in het kort

Directe en indirecte lachgas emissies uit de landbouwbodem, 1990 - 2003
Achtergronddocument van de berekeningsmethode voor het Nederlandse National Inventory Report

Sinds 2005 berekent Nederland de uitstoot van lachgas uit landbouwbodems volgens de richtlijnen van het Intergovernmental Panel on Climate Change (IPCC). Dit rapport beschrijft deze gegevens op toegankelijke wijze.

De uitstoot van lachgas, dat bijdraagt aan het broeikaseffect, is het gevolg van nitrificatie- en denitrificatieprocessen. De lachgasemissies bestaan uit directe en indirecte emissies uit landbouwbodems. De directe emissies komen voort uit dierlijke mest en kunstmest die op landbouwbodems is toegediend en uit dierlijke mest die in de weide is geproduceerd. De indirecte lachgasemissies ontstaan nadat nitraat uit mest naar het grond- en oppervlaktewater is uitgespoeld. Een andere bron van indirecte lachgasemissies is ammoniak dat vrijkomt uit mest en neerslaat op de bodem. In voorgaande jaren werden indirecte emissies op een andere manier berekend, die niet goed aansloot bij de definities en categorieën van het IPCC.

In het Kyotoprotocol is afgesproken dat Nederland jaarlijks rapporteert over de broeikasgasemissies in het National Inventory Report (NIR). Landen worden daarbij aangemoedigd landspecifieke gegevens te gebruiken in plaats van de standaarddata die het IPCC aanbiedt. Nederland heeft aan dat verzoek gehoor gegeven.

Het rapport geeft een beschrijving van de rekenregels van het IPCC en de databronnen die Nederland heeft gebruikt om de uitstoot van lachgas uit de landbouwbodem te rapporteren. De uitvoerige toelichting hierbij maakt deze werkwijze toegankelijk voor experts. Het rapport omvat ten slotte een overzicht van de officieel geregistreerde lachgasemissies uit de landbouwbodem en van alle onderliggende data tussen 1990 en 2003.

Trefwoorden: lachgas, broeikasgas, emissies, dierlijke mest, kunstmest, Kyoto protocol, klimaatverandering, IPCC, landbouwbodem, nitrificatie, denitrificatie

Contents

Summary

The countries that have ratified the Kyoto Protocol are obliged to provide an annual National Inventory Report (NIR) on the relevant greenhouse gas (GHG) emissions. To facilitate the production of national emission inventories, the Intergovernmental Panel on Climate Change (IPCC) has issued Good Practice Guidelines. At the same time the IPCC encourages countries to use country-specific methods and data if these give a more realistic picture of the emission of greenhouse gases. However, if a country uses country-specific methods and data, it has to provide a transparent description of the emission calculation method and data sources used.

This report describes the calculation schemes and data sources used in the Netherlands for direct and indirect nitrous oxide emissions from agricultural soils, due to nitrification and denitrification processes.

- *Direct* emissions result from the application of animal manure and fertilizer to agricultural soils, from manure production in the meadow, from crop residues left in the field, from biological nitrogen fixation by crops and from cultivation of organic soils (histosols).
- *Indirect* emissions are the result of the subsequent leaching of nitrate from agricultural soils to ground water and surface waters. Deposition of ammonia that had been volatilized as a result of agricultural activities contributes to indirect emissions of nitrous oxide.

The Netherlands is characterised by a high animal density and a high fertilizer consumption, which makes available a considerable amount of statistical data on animal manure and fertilizer to comply with environmental protection and manure legislation. The Dutch recommendations for fertilizer use also take into account the nitrogen release from crop residues left in the field, from biological nitrogen fixing crops and from cultivated organic soils (histosols) with a lowered ground water table. The availability of these data in the Netherlands means that country- and year-specific animal manure and fertilizer data can be used as well as country-specific data on crop residues and organic soils. In facilitating expert reviewing, this report presents the Dutch approach and also provides an overview of the Dutch data used for the calculations.

This report not only provides the calculation schemes but also presents an overview of direct and indirect nitrous oxide emissions from agricultural soils and all underlying data used in the 1990 – 2003 period.

1. Introduction

The United Nations Framework Convention on Climate Change (UNFCCC), aimed at stabilizing emissions of greenhouse gases to levels that prevent a negative impact of human activities on climate was agreed on in Rio de Janeiro in 1992. The convention has been ratified by the Netherlands and came into force in March 1994. One of the commitments for Parties under the Convention is to develop, publish and regularly update national emission inventories of greenhouse gases.

The awareness that further steps were needed led in 1997 to the Kyoto Protocol, in which Annex 1 Parties agreed to reduce greenhouse gas emissions by some 5% in the 2008 - 2012 period relative to 1990. Reduction commitments differ per country. The agreements reached in Kyoto and, subsequently, in the European Union, have resulted in a 6% emission reduction commitment for the Netherlands. This target pertains to the most important greenhouse gases: carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and a number of fluorinated (F) gases.

The Netherlands has implemented a series of policies and measures to achieve a reduction in greenhouse gas emissions. Emissions and emission reductions have to be monitored, registered and reported in compliance with international (IPCC) standards.

The monitoring process in the Netherlands

The Netherlands has, for many years, had a system for the registration and reporting of relevant emissions to air, water and soil. This system, the Pollutant Emission Register (PER), was implemented under the responsibility of the Ministry of Housing, Spatial Planning and the Environment (VROM). Since April 2004, the Netherlands Environmental Assessment Agency (MNP in Dutch) has coordinated the PER on behalf of the Ministry. The MNP acts as the interface between science and policy. It assesses the quality of the environment for people and ecosystems so as to advise national and international policy makers.

Several institutes are involved in the process of compiling the national greenhouse gas inventory. Actual data collection and elaboration is done by institutes such as CBS, MNP, RIVM, LEI and TNO[1] on the basis of the annual environmental reports from companies, questionnaires and studies. Agricultural data are collected and reported by LEI (Agricultural Economics Research Institute) and CBS (Statistics Netherlands). MNP calculates the methane and nitrous oxide emissions on the basis of the annual agricultural census data.

In December 2005 SenterNovem was designated by law as the National Inventory Entity. In addition to co-ordinating the establishment of a National System for monitoring greenhouse gas emissions, the tasks of SenterNovem include the overall co-ordination of (improved) quality control and quality assurance activities as part of the National System and co-ordination of the support/response to the UNFCCC review process. In this context, SenterNovem was involved in the development of monitoring protocols for greenhouse gas emissions and also commissioned this background document.

[1] TNO = Netherlands Organisation for Applied Scientific Research

The Monitoring Improvement Programme

The Kyoto Protocol under the UNFCCC requires Parties to implement a national system for greenhouse gas emissions. This is a programme implemented in the Netherlands under the responsibility of the Ministry of VROM (Environment), which has led to the establishment of the Dutch National System. This system was in place by the end of 2005. Practical co-ordination of this programme was assigned to SenterNovem.

The most important projects in this programme included:

- Adaptation of the monitoring procedures (where needed) to new international requirements, with methods, instructions, working processes, tasks and responsibilities described in protocols. Where necessary, agreements with sectors and institutes were made on adapting the present methods to comply with new international standards.
- Updating and elaborating the quality assurance and control process of greenhouse gas monitoring.
- Improving the uncertainty assessment and management in emission data. Many data necessarily imply estimates or rough assessments; the climate convention requires an assessment of related uncertainties.
- Studies into more accurate and detailed emission factors and/or methodologies.

The background document

This report, the result of a study carried out as part of the improvement programme, provides background information for two agricultural protocols available via www.greenhousegases.nl These include:

- nitrous oxide emissions from agricultural soils: direct emissions and emissions from 'animal production' (this is the IPCC term for production of animal manure while grazing in the meadow).
- indirect nitrous oxide emissions from agricultural soils.

The report also provides an overview of emissions and underlying statistical data used.

After a brief overview of the agricultural nitrogen flow in the Netherlands in Chapter 2, the two subsequent chapters describe the Dutch procedures for calculating *direct* and *indirect* nitrous oxide emissions from agricultural soils. Nitrous oxide emissions from animal production (grazing animals) are included in direct emissions. These two chapters may be read independently. The last chapter of the report (Chapter 5) reflects briefly on several topics that might be put on the research agenda.

This background document was originally intended for NIR 2005, covering the 1990 – 2003 period (Klein Goldewijk et al., 2005). Because of a delay in preparation, however, it was decided to include new insights used for NIR 2006. In this way the report serves as a background document for NIR 2006. This meant including the methodology for the full 1990 – 2004 period, but presenting data for the 1990 – 2003 period, data being in conformity with the NIR 2006 (Brandes et al., 2006).

2. Agricultural nitrogen flow in the Netherlands

The Netherlands, with a total agricultural area of 2,000,000 hectare, is characterized by a high animal density and a high level of fertilizer use. Amidst other European countries it ranks highest with respect to nitrogen loading per hectare of agricultural land. Table 2.1 presents the figures for all EU15 Member States for the year 2000. The high use of fertilizer on grassland is one of the reasons that the Netherlands uses about 2.4 times more fertilizer nitrogen per hectare than the average figure of 73 kg per hectare for the EU15. The high animal density in the Netherlands is responsible for a four times higher manure nitrogen production per hectare than the EU15 average figure of 66 kg per hectare of agricultural area.

Table 2.1 Fertilizer use and animal manure production in de EU15 Member States in 2000.

	Agricultural area 10^3 hectare	Nitrogen fertilizer 10^6 kg N	Animal manure 10^6 kg N	Nitrogen fertilizer Kg N/ha	Animal manure Kg N/ha	Nitrogen fert + animal manure Kg N/ha
Austria	3,407	117	164	34	48	83
Belgium	1,396	157	327	112	234	346
Denmark	2,641	246	270	93	102	195
Finland	2,209	166	112	75	51	126
France	29,796	2,314	1,961	78	66	143
Germany	17,067	2,014	1,346	118	79	197
Greece	3,901	257	408	66	105	170
Ireland	4,418	399	457	90	103	194
Italy	15,189	717	935	47	62	109
Luxemburg	135			0	0	0
The Netherlands	1,969	339	528	172	268	440
Portugal	3,907	140	165	36	42	78
Spain	25,386	1,264	837	50	33	83
Sweden	2,974	189	159	64	54	117
UK	15,722	1,202	919	76	58	135
EU15 states	130,117	9,522	8.590	73	66	139

Source: agricultural areas: Eurostat; fertilizer and manure data: EEA, 2006

Some basic data for the Netherlands are presented in Table 2.2. Both the nitrogen fertilizer consumption and the nitrogen excretion by animals decreased by approximately 30% in the 1990 – 2003 period. This is the result of the Dutch manure policy to reduce the load of nitrogen and phosphorus to agricultural soils in order to minimize nitrate and phosphate leaching to ground water and surface water.

The nitrogen excretion through animal husbandry in the Netherlands is split up in excretion in the animal house and excretion in the meadow.

In the 1990 – 2003 period the amount of nitrogen excreted in animal houses decreased from 493 to 376 million kg; this corresponds to a decrease of 24%. During manure storage in the animal house and in the storage facilities outside the animal house, ammonia is emitted to the air. A small part of the stored amount of manure which is available for land spreading is exported abroad (<5%). Land spreading also gives rise to ammonia volatilization, resulting in a lower net nitrogen flow to the soil. Between 1990 and 2003 the net flow of nitrogen in stored animal manure to soil decreased from 315 to 281 million kg, a decrease of 11%. Apparently the 24% decrease of total nitrogen excretion effectuated by the Dutch manure policy is not fully reflected in the 11% decrease of the net nitrogen flow to soil. Reason is that the Dutch manure policy is partly counteracted by the Dutch ammonia policy aimed at reducing ammonia emissions from animal houses, animal manure storages outside the animal houses and ammonia emissions during manure application. Low ammonia emissions from manure go along with conservation of a relatively higher amount of nitrogen in the animal manure. In 1990 almost all animal manure was applied on the surface and in subsequent years low emission techniques like shallow (sod) injection on grasslands and direct incorporation on arable lands were introduced and made obligatory.

In the 1990 – 2003 period the nitrogen excretion in the meadow is nearly halved, because the period that cattle stay in the meadow for grazing has decreased. This is done in order to increase both the cost-effectiveness of milk production and the efficiency of manure application as an effect of the Dutch manure policy.

Table 2.2 Agricultural nitrogen flow in the Netherlands, with amounts given in 10^6 kg N.

	1990	1995	2000	2003	Change 2003 - 1990
Nitrogen fertilizer consumption	412.0	406.0	339.0	291.0	- 29%
of which ammonium fertilizer	3.6	11.2	6.5	40.1	+ 1023%
NH_3-N emission during application	11.1	10.6	9.2	11.1	- 1%
Net fertilizer to soil	400.9	395.4	329.8	279.9	- 30%
Nitrogen excretion by animals	663.8	656.9	528.1	470.7	- 29%
Nitrogen excretion in animals houses	493.0	500.4	415.0	375.7	- 24%
of which in solid form	61.9	71.2	76.9	59.6	- 4%
of which in liquid form	431.2	429.3	338.0	316.1	- 27%
NH_3-N emission in animal houses	73.5	73.8	60.7	48.7	- 34%
Net available manure for application	419.5	426.6	354.3	327.0	- 22%
Nitrogen in manure exported abroad	6.4	22.1	14.7	12.0	+ 88%
NH_3-N emission during application	98.2	51.4	36.8	33.8	- 66%
Net animal manure to soil	314.9	353.1	302.7	281.2	- 11%
Nitrogen excretion in meadow	170.8	156.5	113.1	95.0	- 44%
NH_3-N emission in meadow	13.0	11.9	8.5	7.1	- 45%
Net animal manure to soil	157.8	144.6	104.6	87.9	- 44%
Nitrogen fixation in arable crops	7.8	4.9	4.7	5.2	- 34%
Nitrogen in crop residues left in field	36.4	34.9	34.1	34.5	- 5%
Nitrogen in sewage sludge on agric. land	5.0	1.5	1.5	1.6	- 68%
Total agricultural NH_3-N emission	195.8	147.7	115.2	100.6	- 49%
Total agricultural NH_3 emission	237.8	179.3	139.9	122.2	- 49%

3. *Direct* N_2O (nitrous oxide) emissions from agricultural soils

This chapter focuses on *direct* nitrous oxide emissions from agricultural soils (IPCC source category 4D1). Animal production (IPCC source category 4D2) is also included in this chapter. Direct emissions are linked to direct nitrogen additions to the agricultural soils like nitrogen fertilizer and animal manure.

Indirect nitrous oxide emissions are linked to the leaching of nitrate from the upper soil and to the deposition of NO_x and NH_3 emitted during manure management, and fertilizer and manure application. Chapter 4 deals with the indirect emissions.

3.1 Contribution of agricultural *direct* N_2O emissions to total Dutch GHG emissions

Total Dutch greenhouse gas emissions were about 215 * 10^9 kg CO_2 equivalent in 2003 (Brandes et al., 2006). Roughly 10% is N_2O based and the share of agriculture in N_2O is roughly 50% (Table 3.1). Direct soil emissions (including animal production emissions) comprise 50 to 60% of agricultural soil emissions. Manure management comprises the nitrous oxide emissions from animal houses. These emissions are discussed in another background document (Van der Hoek and Van Schijndel, 2006) and associated protocol (VROM, 2005c). The protocol is also available via www.greenhousegases.nl.

Table 3.1 Relevance of agricultural nitrous oxide emissions in the Netherlands.

	IPCC category	Units	1990	1995	2000	2003
Total GHG emissions		10^9 kg CO_2 equivalents	213.0	225.1	214.4	215.7
Total N_2O emissions		10^9 kg CO_2 equivalents	21.22	22.39	19.87	17.37
Total N_2O emissions		10^6 kg N_2O	68.45	72.24	64.09	56.05
Total agricultural emissions		10^6 kg N_2O	37.05	40.80	34.52	30.41
Manure management	4B	10^6 kg N_2O	2.24	2.49	2.51	2.06
Agricultural soils	4D1	10^6 kg N_2O	14.91	19.86	17.44	15.64
Animal production	4D2	10^6 kg N_2O	4.22	3.86	2.71	2.28
Direct soil emissions	4D1 + 4D2	10^6 kg N_2O	19.13	23.72	20.15	17.92
Indirect soil emissions	4D3	10^6 kg N_2O	15.68	14.59	11.86	10.42

Source: Brandes et al., 2006

3.2 Scientific background of *direct* N_2O emissions from agricultural soils

Nitrogen is involved in many important soil processes. Nitrogen added to the soil can be in mineral form (ammonium or nitrate) like synthetic fertilizers, in organic form like compost and sewage sludge or it can be in both forms like in animal manure. The mineral nitrogen (e.g. ammonium) is readily transformed into nitrate. The organic nitrogen decomposition is a slower process, but will also end up as mineral nitrogen. In the soil, mineral nitrogen is incorporated into soil organic matter and at the same time soil organic matter is decomposed.

Free ammonium and nitrate can be taken up by crops and nitrate is also susceptible to leaching. Nitrate can also be denitrified to nitrogen gas.

Nitrous oxide can be produced as a by-product during nitrification and denitrification processes. Nitrification is an aerobic process which oxidizes ammonium into nitrate and denitrification is an anaerobic process which denitrifies nitrate into nitrogen gas. When the conditions are insufficiently aerobic (nitrification) or insufficiently anaerobic (denitrification) nitrous oxide is likely to be formed.

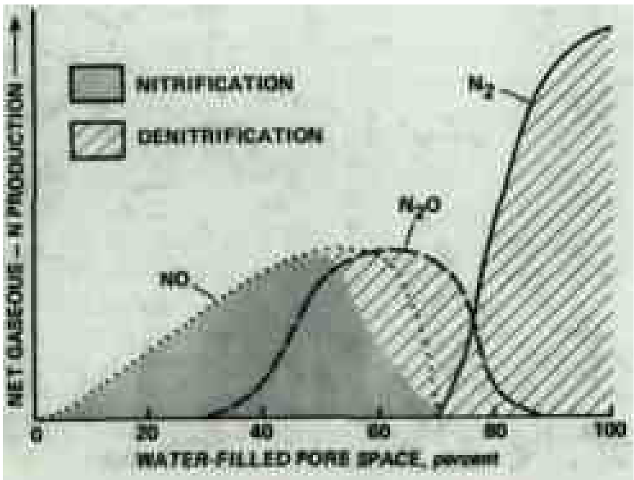

Figure 3.1 Effect of water-filled pore space on nitrification and denitrification (Davidson et al., 2000).

The water-filled pore space (WFPS) concept is very useful in understanding when suboptimal conditions prevail. WFPS is the percentage of total soil pores occupied by water. Optimal water contents for nitrification range between 30% and 70% WFPS. At the upper end of this range oxygen transfer can be limited and nitrous oxide can be produced. Above 60% WFPS denitrification will take place and because there is no absolute anaerobic situation, nitrous oxide can be produced as a by-product. With higher WFPS levels the anaerobic situation is more guaranteed and the production of nitrous oxide will decrease. Nitric oxide (NO) can be produced too during nitrification and denitrification (Firestone and Davidson, 1989; Davidson et al., 2000). Nitric oxide, however, is not discussed in this report, because it is not a greenhouse gas.

There are three levels of regulating the nitrous oxide emissions leaving the soil:

1. The amount of ammonium and nitrate in the soil.
2. The conversion rate of ammonium and nitrate into nitrous oxide.
3. The conversion rate of nitrous oxide into nitrogen gas before it leaves the soil.

This regulation is also known as the *hole in pipe* concept (Figure 3.2). Ammonium enters the first pipe (= nitrification) and leaves it as nitrate, whereas holes in this pipe represent the escape of nitric and nitrous oxides. Nitrate enters the second pipe (= denitrification) and nitrogen gas (N_2) is leaving and holes in this pipe represent the escape of nitric and nitrous oxides as well as the entrance of nitric and nitrous oxides produced elsewhere. The nitrogen flow into the pipes and/or total nitrogen output via crop products is the first level of regulation and the holes in the pipes represent the second and third levels (Firestone and Davidson, 1989; Davidson et al., 2000).

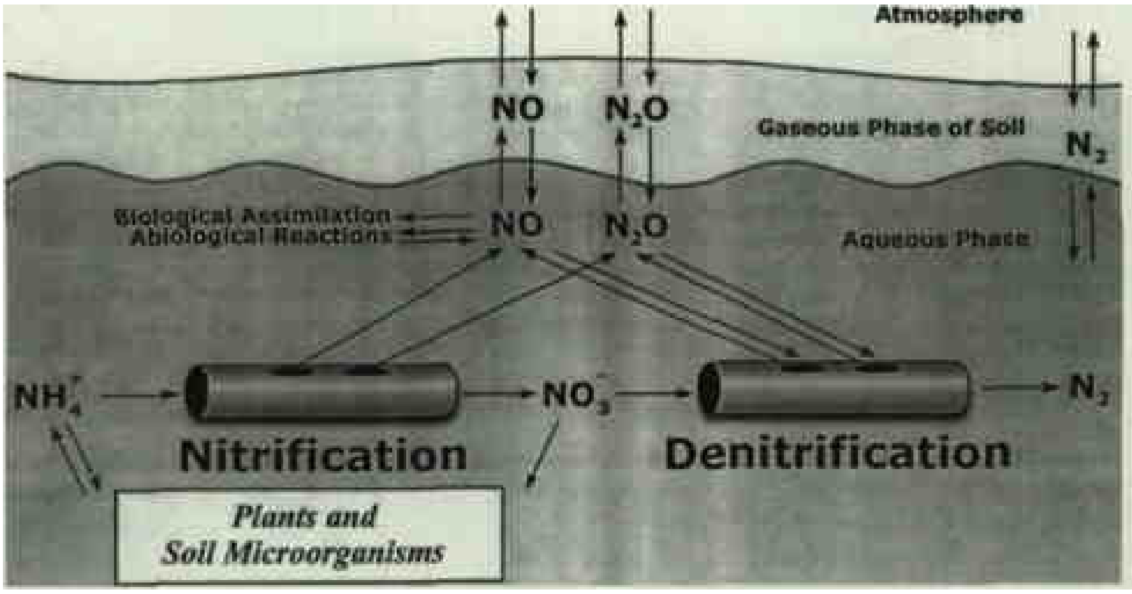

Figure 3.2 Hole in pipe concept (Davidson et al., 2000).

Blocking one or more of these holes in the pipe (without decreasing the total input and/or total output via crops) usually leads to increased fluxes from other holes. The extent of the changes in the fluxes depends on the local circumstances.

Detailed information on emission factors for nitrous oxide emissions for different nitrogen sources and different soil types will be presented in section 3.5.

3.3 Method of calculating *direct* N_2O emissions from agricultural soils

Until 2004 the direct nitrous oxide emissions from agricultural soils were calculated for most sources as described in the IPCC Guidelines (1997, 2001). Country-specific activity data for nitrogen fertilizer, animal manure and ammonia volatilization were used as well as country-specific emission factors (Kroeze, 1994). Later on, the calculation methods were summarized in Spakman et al. (1997, 2003).
In 2005 the calculation method was adjusted by including crop residues and the cultivation of organic soils (histosols) as two new sources and removing the source background emissions for a better compliance with IPCC source definitions. Other minor adjustments are found in the calculation method for biological nitrogen fixing crops and for animal grazing (= animal production), and in the introduction of two different emission factors for two types of nitrogen fertilizers.

This section gives a full description of the calculation methods as they are now in use in the Netherlands and also provides background information for the following agricultural protocol, which is available via www.greenhousegases.nl:

- Nitrous oxide emissions from agricultural soils: direct emissions and emissions from animal production (VROM, 2005a).

The IPCC Guidelines methodology for the calculation of direct nitrous oxide emissions from agricultural soils is based on an emission factor per kg N in the source, see Equation (1).

$$\text{Total } N_2O \text{ Emission} = \sum 44/28 * \text{N amount in source}_i * \text{Emission factor per kg N in source}_i \quad (1)$$

The factor 44/28 is used for converting N_2O-N into N_2O

According to the IPCC Guidelines the net amount of nitrogen in every source has to be taken into account (IPCC, 1997, p 4.93 and IPCC, 2001, p 4.56). This means that the corresponding ammonia nitrogen emissions have to be subtracted.

The following seven sources are taken into account:

IPCC category 4D1
- synthetic fertilizer applied to agricultural soils
- animal manure applied to agricultural soils
- sewage sludge applied to agricultural soils[2]
- biological nitrogen fixation by crops
- crop residues
- cultivation of organic soils (histosols)

IPCC category 4D2
- animal manure during grazing (= animal production)

The following two soil types are taken into account: mineral soils and organic soils. Organic soils (= histosols) are soils containing an organic rich surface layer at least 40 cm in thickness, with a minimum of 20% organic matter if the clay content is low, and a minimum of 30% organic matter where the clay content exceeds 50% (IPCC, 2001, page 4.53; Kuikman et al., 2005).

3.4 Relevant statistical data necessary for calculating *direct* N_2O emissions from agricultural soils

The Netherlands are characterized by a high animal density. As a consequence of manure and ammonia policy, a lot of statistical data for animal manure and ammonia emissions is available. Therefore the Netherlands use country- and year-specific values for nitrogen excretion per animal and for ammonia emissions.

This section provides information about the statistical data (= activity data) necessary to calculate the direct nitrous oxide emissions from the seven nitrogen sources mentioned in section 3.3. The nitrogen sources are described in the same sequence as in section 3.3, and for every nitrogen source the appropriate subdivision of mineral soils and organic soils is given. The IPCC methodology is based on the net supply of nitrogen, and gives default figures for ammonia emissions. Country- and year-specific values for ammonia emissions are used in the Dutch calculations.

[2] This source has been included in the latest submission of the National Inventory Report (NIR2006), which will be published this year. It was not yet included in the NIR2005.

● Synthetic fertilizer (IPCC category 4D1)

Net synthetic nitrogen fertilizer to soil = A – B

A = amount of applied nitrogen fertilizer, specified into ammonium fertilizer (without nitrate) and other nitrogenous fertilizer, which, every year is recorded by LEI (Dutch Agricultural Economics Research Institute) and reported in Landbouwcijfers (Agricultural Data); figures also available on the internet via www.lei.wur.nl (see also Appendix 1).

B = ammonia emissions associated with fertilizer application are taken from the annual emission inventories from PER (Pollutant Emission Register). The calculation method for these ammonia emissions is described in full detail in Van der Hoek (1994, 2002). Emission data are available via www.mnp.nl, click through to Environmental Data Compendium (http://www.mnp.nl/mnc/index-en.html) (see also Appendix 1). The country-specific ammonia emissions for nitrogen fertilizer application are much lower than the IPCC default values of 10%.

It is assumed that 90% of the fertilizer is used on mineral soils and 10% on organic soils. These figures reflect the subdivision of the Dutch agricultural soils into mineral soils and organic soils (Kroeze, 1994). Very recently the area of organic soils was calculated at 223,000 hectare, which is about 11% of the total Dutch agricultural area (Kuikman et al., 2005).

● Animal manure applied to agricultural soils (IPCC category 4D1)

Net animal manure nitrogen application to soil = A – B – C – D – E

A = total nitrogen excretion by the animals as calculated by the WUM (Working Group on Uniform Data for Animal Excretion) on an annual basis for all animal categories except horses and ponies. The first WUM reports describe in detail the methodology (WUM, 1994a, b and c); for subsequent years an annual publication is available (Van Eerdt, 1995a, b, 1996, 1997, 1998, 1999, Van Eerdt et al., 2003, Van Bruggen, 2003, 2004, 2005).

Data on annual nitrogen excretion for horses and ponies are taken from the Belgian manure legislation (VLM, 2000). It is assumed that 70% of the annual manure production of horses and ponies is produced in the animal house and 30% in the meadow (Van der Hoek and Van Schijndel, 2006).

The nitrogen excretion per animal type is collected in Appendix 3 and the number of animals in the Netherlands is presented in Appendix 2. Combining Appendices 2 and 3 results in total nitrogen excretion by the animals; national totals are presented in Appendix 1.

B = total nitrogen excretion in the meadow, calculated by the WUM, see under entry A.

C = ammonia emissions from animal houses and manure storage facilities outside the animal houses, taken from the annual emission inventories from PER (Pollutant Emission Register). The calculation method for these ammonia emissions is described in full detail in Van der Hoek (1994, 2002). Emission data are available via www.mnp.nl and then go to Environmental Data Compendium (http://www.mnp.nl/mnc/index-en.html) (see also Appendix 1).

Ammonia emissions from horses and ponies are not yet accounted for by PER, but will be in the near future. Instead we used an average emission factor for the housing period of 3.6 kg NH_3 per animal per year. This value is derived from the emission factors for horses and ponies used in the Dutch ammonia legislation (RAV, 2005). The average emission factor is calculated by multiplying the share of the numbers per animal type in the total population of horses and ponies times the emission factor per animal type: 16/36 * 5.0 (horses over 3 year) + 8/36 * 2.1 (horses under 3 year) + 9/36 * 3.1 (ponies over 3 year) + 3/36 * 1.3 (ponies under 3 year) = 3.6 kg NH_3.

D = animal manure exported abroad, taken from the annual emission inventories from PER (Pollutant Emission Register). Data are available via www.mnp.nl, click through to the Environmental Data Compendium (http://www.mnp.nl/mnc/index-en.html) (see also Appendix 1).

E = ammonia emissions during application of animal manure, taken from the annual emission inventories from PER (Pollutant Emission Register). The calculation method for these ammonia emissions is described in full detail in Van der Hoek (1994, 2002). Emission data are available via www.mnp.nl and, click through to Environmental Data Compendium (http://www.mnp.nl/mnc/index-en.html) (see also Appendix 1).
Ammonia emissions during application of manure from horses and ponies are not accounted for by PER, making entry E a little underestimated.

The ammonia policy implied that from 1990 onwards surface spreading of animal manure was gradually replaced by shallow (sod) injection on grassland and by direct incorporation on arable land. The implementation of low emission application techniques took place in the 1990 – 1995 period, see Table 3.2 (Van der Hoek, 2002).

Table 3.2 Implementation of low emission application techniques for animal manure in the Netherlands (in % of total applied animal manure).

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Surface spreading	100	92	32	30	18	5	5	5	5	0
Low emission techniques	0	8	68	70	82	95	95	95	95	100

Source: Van der Hoek, 2002

The country-specific ammonia emissions from animal housing, manure storage outside the animal houses, manure application and manure during grazing (defined as % of total nitrogen excretion) decreased from approximately 28% in 1990 to approximately 19% in 2003. The IPCC default value is 20%. The Dutch figures have the advantage that they are year specific and therefore reflect the effects of the Dutch ammonia emissions policy.

It is assumed that 87% of the animal manure is used on mineral soils and 13% on organic soils. These figures reflect the subdivision of the Dutch agricultural soils into mineral soils and organic soils (Kroeze, 1994). Very recently the area of organic soils was calculated at 223,000 hectare, which is about 11% of the total Dutch agricultural area (Kuikman et al., 2005). The net nitrogen mineralization in cultivated organic soils with a low ground water table implies a saving on nitrogen fertilizer, and explains why the figure of 10% for synthetic nitrogen fertilizer is lower than the figure of 13% for animal manure on organic soils.

● Sewage sludge applied to agricultural soils (IPCC category 4D1)

Net sewage sludge to soil = A – B

A = amount of applied sewage sludge taken from the annual emission inventories from PER (Pollutant Emission Register). The quantities are low and available via www.mnp.nl, click through to Environmental Data Compendium (http://www.mnp.nl/mnc/index-en.html) (see also Appendix 1).

B = ammonia emissions associated with sewage sludge application, not accounted for by PER. The mineral nitrogen content of sewage sludge is very low and therefore the ammonia emissions using land spreading are negligible. It is assumed that all sewage sludge is applied on mineral soils.

● Biological nitrogen fixation by crops (IPCC category 4D1)

In line with the IPCC Guidelines biological nitrogen fixation is calculated only for arable and horticultural crops. The following crops[3] are considered in the Netherlands (the amount of country-specific fixated nitrogen per hectare is in brackets) (Mineralen Boekhouding, 1993):

Arable crops:

- Lucerne (422 kg N per hectare)
- Green peas (dry to harvest) and bump cherry, marrow fats and peas, kidney beans, peas (green to harvest) (164 kg N per hectare)
- Broad and field beans (325 kg N per hectare)

Horticultural crops:

- Tribe broad beans (green to harvest), stick broad beans (75 kg N per hectare)
- Broad beans (164 kg N per hectare).

Total areas grown with these crops are taken from the annual agricultural census. Arable and horticultural crops are assumed to be only grown on mineral soils. These data are reported in Landbouwcijfers (Agricultural Data), issued by LEI (Dutch Agricultural Economics Research Institute) and CBS (Statistics Netherlands) and included in Appendix 4. These data are also available on the internet www.cbs.nl (select Statline).

---

[3] These crops have the following Dutch names:

Akkerbouw gewassen

- Luzerne (422 kg N per hectare)
- Groene erwten (droog te oogsten) en schokkers, kapucijners en grauwe erwten, bruine bonen, erwten (groen te oogsten) (164 kg N per hectare)
- Veldbonen (325 kg N per hectare)

Tuinbouwgewassen

- Stambonen (groen te oogsten), pronk-/sla-/stokbonen (75 kg N per hectare)
- Tuinbonen (164 kg N per hectare)

● Crop residues (IPCC category 4D1)

In line with the IPCC Guidelines only crop residues from arable and horticultural crops are taken into account. The Netherlands consider all arable and horticulture crops which are part of the annual agricultural census.

Also in line with IPCC Guidelines only above-ground parts of crops are considered as a source for N_2O emission. The long history of fertilizer research in the Netherlands enables the use of country-specific values for the nitrogen content in the above-ground parts of the crop residues. As these crops are harvested in mature state, fixed amounts of nitrogen are used for the different crop residues (Appendix 4 in Velthof and Kuikman, 2000). A correction has been made for the part of the residues that are leaving the field, for instance, straw from cereals and stems from fodder maize (personal communication of W. Van Dijk (Applied Plant Research, PPO in Dutch). This information is included for all crop types in Appendix 5.

Total areas grown with arable and horticultural crops are taken from the annual agricultural census. These data are reported in Landbouwcijfers (Agricultural Data) issued by LEI (Dutch Agricultural Economics Research Institute) and CBS (Statistics Netherlands). This data are included in Appendix 6 and on the internet www.cbs.nl (select Statline).

The nitrogen release from incorporated crop residues is also accounted for in the Dutch Guidelines for fertilization of arable crops (Van Dijk, 2003). It is assumed that arable and horticultural crops are only grown on mineral soils.

● Cultivation of organic soils (histosols) (IPCC category 4D1)

Recently, the 1970 Dutch soil survey was actualized for organic soils. The area of cultivated organic soils was calculated at 223,000 hectare in the year 2003. The decrease in the organic soil area since the 1970 survey mainly took place in the early 1980s, due to the policy of lowering water tables in that period. Therefore it is reasonable to use the area of 223,000 hectare for the full 1990 – 2003 period (Kuikman et al., 2005).

Measurements of the decline of surface levels in organic soils areas were carried out in the Netherlands on a long-term basis. Combining these decline rates with carbon oxidation rates and C/N ratios of the organic soil layers that had disappeared results in an annual release of 235 kg nitrogen per hectare of cultivated organic soils with lowered water tables (Kuikman et al., 2005).

The nitrogen release from cultivated organic soils with lowered water tables is also accounted for in the Dutch Guidelines for fertilization of grasslands (Anonymous, 2005).

● Animal manure during grazing (= animal production) (IPCC cat 4D2)

Net animal manure nitrogen to soil by grazing = A – B – C

A = total nitrogen excretion by the animals, calculated by the WUM (Werkgroep Uniformering Mestcijfers, Working Group on Uniform Data for Animal Excretion) on an annual basis for all animal categories except horses and ponies. The first WUM reports describe in detail the methodology (WUM, 1994a, b and c) and an annual publication is available for subsequent years (Van Eerdt, 1995a, b, 1996, 1997, 1998, 1999, Van Eerdt et al., 2003, Van Bruggen, 2003, 2004, 2005).

Data on annual nitrogen excretion for horses and ponies are taken from the Belgian manure legislation (VLM, 2000). It is assumed that 70% of the annual manure production of horses and ponies is produced in the animal house and 30% in the meadow (Van der Hoek and Van Schijndel, 2006). The nitrogen excretion per animal type is collected in Appendix 3 and the number of animals in the Netherlands is presented in Appendix 2. Combining Appendices 2 and 3 results in the total nitrogen excretion by the animals; the national totals are presented in Appendix 1.

B = total nitrogen excretion in animal houses, is calculated by the WUM, see under entry A.

C = ammonia emissions during grazing are taken from the annual emission inventories from PER (Pollutant Emission Register). The calculation method for these ammonia emissions is described in full detail in Van der Hoek (1994, 2002). Emission data are available via www.mnp.nl, click through to the Environmental Data Compendium (http://www.mnp.nl/mnc/index-en.html) (see also Appendix 1).
Ammonia emissions from horses and ponies during grazing are not accounted for by PER. As the contribution of horses and ponies to the total nitrogen excreted in the meadow is small, ranging from 0.6% in 1990 to 2.0% in 2003, this omission is negligible.

The Netherlands emission inventory differentiates between the nitrogen in faeces and urine with respect to the emission factor for nitrous oxide emissions (see section 3.5). The shares of nitrogen in faeces and urine of grazing cattle are dependent on the nitrogen content of grass. The shares of nitrogen in faeces and urine were assumed to be 30/70 in the 1990 – 1999 period and 35/65 in 2000 and onwards (Valk et al., 2002).

In contrast with the application of nitrogen fertilizer and animal manure to agricultural soils, no distinction is made between mineral soils and organic soils in the case of animal manure during grazing. This item is discussed in more detail in section 3.5.

3.5 Emission factors for *direct* N_2O emissions from agricultural soils

Until recently the emission factors for direct nitrous oxide emissions from agricultural soils originated mainly in Dutch research (Kroeze, 1994). In this research the Netherlands distinguishes different emission factors for mineral soils and organic soils.

In 2005 the emission factors were reviewed and partly refined on the basis of data on N_2O emissions collected from research projects carried out under the ROB-Agro Programme[4] (Kuikman et al., 2006). This review confirmed the use of some of the emission factors from the past (e.g. a doubling of the emission factor for organic soils compared to mineral soils for the application of nitrogen from fertilizer and manure). Measurements showed that after correction for a specific emission factor for cultivation of organic soils, the latter still have higher nitrous oxide emissions than mineral soils (Velthof et al., 1996).

[4] ROB-Agro (Reductieplan Overige Broeikasgassen) is a program coordinated by SenterNovem and involves research in the field of reduction of non-CO_2 greenhouse gases. More information is available on the website www.robklimaat.nl

Therefore, most emission factors now in use in the Netherlands are the same as the ones used in the past (see Table 3.3 for these emission factors, along with the IPCC default values). The only difference is the refinement of the emission factor for synthetic fertilizer.

The emission factors for the seven nitrogen sources are described here in the same sequence as in section 3.3.

Table 3.3 Emission factors for direct N_2O emission from soils, expressed as kg N_2O-N per kg N supplied.

Source	Default IPCC	Mineral soils	Organic soils	Reference
Nitrogen fertilizer	0.0125			
Ammonium fertilizer		0.005	0.01	4
Other fertilizers		0.01	0.02	1,4
Animal manure application	0.0125			
Surface spreading		0.01	0.02	1
Incorporation into soil		0.02	0.02	1
Sewage sludge	0.0125	0.01		2
Biological nitrogen fixation crops	0.0125	0.01		1
Crop residues	0.0125	0.01		2
Cultivation of organic soils (histosols)			0.02	2,3
Animal manure during grazing	0.02			
Faeces		0.01	0.01	1
Urine		0.02	0.02	1

References 1 = Kroeze, 1994; 2 = this publication; 3 = Kuikman et al., 2005; 4 = Kuikman et al., 2006.

● Synthetic fertilizer (IPCC category 4D1)

The values of the emission factors for mineral (0.01) and organic soils (0.02) originated mainly in Dutch research in the early 1990s (Kroeze, 1994). More recent research showed that ammonium fertilizer (without nitrate) had lower nitrous oxide emissions on grassland in springtime especially during wet periods (Velthof et al., 1997). Therefore it has been decided to refine the emission factor for fertilizer application by using a 50% lower emission factor for ammonium fertilizer (without nitrate). These findings were confirmed by research carried out by Stehfest and Bouwman (2006) and by the review of Kuikman et al. (2006).

● Animal manure applied to agricultural soils (IPCC category 4D1)

The values of the emission factors for surface spreading and incorporation into the soil on mineral (0.01 and 0.02, respectively) and organic soils (0.02 and 0.02, respectively) originate mainly in Dutch research in the early 1990s (Kroeze, 1994). The higher value for incorporation is explained by two mechanisms. Incorporation of animal manure into the soil produces less ammonia emission and hence more reactive nitrogen enters the soil. Furthermore, the animal manure is more concentrated (e.g. hot spots) in comparison with surface spreading and hence the process conditions for nitrification and denitrification can be more suboptimal. A recent review of the literature showed that in most experiments with simultaneous surface spreading and incorporation the latter produces higher nitrous oxide emissions. It was, however, not possible to derive a new emission factor for incorporation or shallow (sod) injection (Kuikman et al., 2006). Therefore it was decided not to change the existing emission factors.

● Sewage sludge applied to agricultural soils (IPCC category 4D1)
Dutch research in the early 1990s did not pay attention to the application of sewage sludge on agricultural soils (Kroeze, 1994). However, later on sewage sludge was mentioned as a source to take into account (IPCC, 1997; 2001). There are no arguments that these emission factors should be any different than the emission factors for application of nitrogen fertilizer or animal manure on agricultural soils.

● Biological nitrogen fixation by crops (IPCC category 4D1)
The value of the emission factor for mineral (0.01) soils originates mainly in Dutch research in the early 1990s (Kroeze, 1994). There are no new Dutch measurements available so there is no reason to change this value. A recent Canadian study revealed that nitrous oxide emissions of biological nitrogen fixation crops are very low and hardly exceed the background emissions from agricultural soils. As most of the nitrous oxide emissions arise from the roots, the authors propose to remove the biological nitrogen fixation crops as such from the IPCC inventory. Instead of reporting nitrous oxide emissions under biological nitrogen fixation crops, the amount of nitrogen should be added to the crop residues (Rochette and Janzen, 2005).

● Crop residues (IPCC category 4D1)
Nitrous oxide emissions from crop residues were not explicitly discussed in the study by Kroeze (1994). It was decided to use the emission factor 0.01 for mineral soils, because nitrogen losses from crop residues are comparable with application of nitrogen fertilizer and animal manure to mineral soils. A Dutch laboratory incubation study with crop residues showed that most crop residues had an emission factor less than 0.01. Only sprouts, mustard, and broccoli had higher emission factors on sandy soils, ranging from 0.03 to 0.06 (Velthof et al., 2002).

● Cultivation of organic soils (histosols) (IPCC category 4D1)
Nitrous oxide emissions from cultivation of organic soils were not explicitly discussed in the study by Kroeze (1994). However, the anthropogenic biogenic emissions (so-called background emissions) from (organic) soils in Kroeze (1994) are implicitly comparable to the N_2O emissions from the cultivation of organic soils.

The nitrogen which is mineralized in cultivated organic soils with low water tables is subject to the same nitrification and denitrification processes as the nitrogen from fertilizer and animal manure applied to organic soils. Therefore it is reasonable to use the emission factor of 0.02 for the mineralized nitrogen in organic soils with a low water table (Kuikman et al., 2005).

Combining the annual release of 235 kg nitrogen (see section 3.4) per hectare cultivated organic soils with an emission factor of 0.02 (see Table 3.3) results in a nitrous oxide emission of 4.7 kg N_2O-N per hectare of cultivated organic soils. This country-specific value is lower than the default IPCC value of 8 kg N_2O-N per hectare of cultivated organic soils.

● Animal manure during grazing (= animal production) (IPCC cat 4D2)
The values of the emission factors for faeces (0.01) and urine (0.02) originate mainly in Dutch research in the early 1990s (Kroeze, 1994). The emission factor for urine is higher than for faeces because the ratio mineral nitrogen/total nitrogen is higher in urine than in faeces, leading to faster nitrification and denitrification in urine-affected spots. Furthermore, urine penetrates faster into the soil than faeces, which enhances the lack of sufficient oxygen in the soil for the nitrification process. Together with the higher mineral nitrogen ratio in urine, it is clear that urine creates a higher potential for suboptimal conditions for nitrification and denitrification than faeces. Finally, there are no new Dutch measurements available so there is no reason to change both of these emission factors.

● Comparison to IPCC default emission factors
To compare the country-specific emission factors with the IPCC defaults, implied emission factors have to be calculated on the same source level. The implied emission factors for nitrogen fertilizer (0.0102 – 0.0110), animal manure application (0.0113 – 0.0200) and animal manure during grazing (0.0165 – 0.0170) are presented in Table 3.4 of section 3.6. For nitrogen fertilizer and animal manure during grazing the country-specific implied emission factors are approximately 15 to 20% lower than the IPCC value. The implied emission factor is approximately 60% higher for application of animal manure after 1995 (this means almost 100% incorporation into soil).

3.6 Overview of *direct* N_2O emissions from agricultural soils 1990 - 2003

An overview of the direct nitrous oxide emissions for the different nitrogen sources is presented in Table 3.4. The total direct nitrous oxide emissions from agricultural soils increased in the 1990 -1995 period and steadily decreased in more recent years.

It should be noted that the direct nitrous oxide emissions increased in the 1990 – 1995 period and decreased after 1995. The increase is explained by the gradual implementation of low ammonia emission techniques for application of animal manure. These techniques have a higher emission factor for nitrous oxide than the original technique of surface spreading. The effects of decreasing amounts of nitrogen in fertilizer and animal manure become visible after 1995.

The implied emission factor is often used as a check on the correctness and completeness of the calculations. The implied emission factor is simply calculated by dividing the total emission by the total size of the source. For nitrogen fertilizer, animal manure application, and animal manure during grazing the implied emission factors are presented in Table 3.4. These sources are chosen because of the two types of activity data for each source (two types of nitrogen fertilizer, two animal manure application techniques and the presence of faeces and urine in animal manure during grazing) and the fact that emission factors are dependent on soil type (mineral soils or organic soils). It appears that the calculated implied emission factors are consistent with the assumptions and differentiations in the three sources. At the same time the implied emission factors present an overall average emission factor, which can be easily compared with the default IPCC emission factors (see also Table 3.3 and discussion at the beginning of section 3.5).

The total direct nitrous oxide emissions from agricultural soils for the Netherlands in the year 2000 are estimated at 20.15 * 10^6 kg. This corresponds with 10.2 kg N_2O per hectare agricultural soil. The total direct nitrous oxide emissions from agricultural soils for the EU15 Member States was estimated at 443.9* 10^6 kg in the year 2000, corresponding with 3.4 kg N_2O per hectare of agricultural soil (EEA, 2006).

The amount of nitrogen in fertilizer and animal manure in the Netherlands is on average roughly three times higher than that in the EU15 Member States: 440 kg N per hectare versus 139 kg N per hectare, see Table 2.1. However, a more detailed analysis of all data sets will be necessary before a linear relationship between N_2O emission and nitrogen input can be concluded.

Table 3.4 Overview of direct nitrous oxide emissions from agricultural soils during the 1990 – 2003 period.

	Cat	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Nitrous oxide emissions															
Nitrogen fertilizer	4D1	6.90	6.66	6.54	6.51	6.19	6.74	6.45	6.67	6.69	6.36	5.65	4.89	4.65	4.51
Animal manure application	4D1	5.59	5.90	8.87	9.62	9.96	10.82	10.56	10.33	10.46	10.25	9.51	9.53	9.04	8.84
Sewage sludge application	4D1	0.08	0.08	0.09	0.06	0.04	0.02	0.03	0.02	0.02	0.01	0.02	0.02	0.03	0.03
Biological nitrogen fixation crops	4D1	0.12	0.11	0.10	0.09	0.08	0.08	0.08	0.07	0.07	0.08	0.07	0.08	0.07	0.08
Crop residues	4D1	0.57	0.59	0.58	0.56	0.55	0.55	0.54	0.53	0.54	0.56	0.54	0.53	0.56	0.54
Cultivation of org soils (histosols)	4D1	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
Total emissions category 4D1		14.91	14.99	17.82	18.50	18.47	19.86	19.31	19.26	19.42	18.91	17.44	16.70	15.99	15.64
Animal manure during grazing	4D2	4.22	4.70	4.48	4.12	3.79	3.86	4.04	3.73	3.20	2.95	2.71	2.77	2.27	2.28
Total direct emissions as N_2O		19.13	19.69	22.30	22.62	22.27	23.72	23.35	23.00	22.62	21.86	20.15	19.47	18.26	17.92
Activity data*															
Nitrogen fertilizer	4D1	400.9	388.9	381.2	379.8	361.9	395.4	378.9	390.6	392.4	373.0	329.8	289.4	282.4	279.9
Animal manure application	4D1	314.9	313.1	327.7	352.2	343.8	353.1	344.7	337.0	341.2	326.2	302.7	303.2	287.6	281.2
Animal manure during grazing	4D2	157.8	175.9	167.6	154.3	142.0	144.6	151.1	139.7	119.7	110.4	104.6	106.9	87.5	87.9
Implied emission factors															
Nitrogen fertilizer	4D1	0.0110	0.0109	0.0109	0.0109	0.0109	0.0108	0.0108	0.0109	0.0109	0.0108	0.0109	0.0108	0.0105	0.0102
Animal manure application	4D1	0.0113	0.0120	0.0172	0.0174	0.0184	0.0195	0.0195	0.0195	0.0195	0.0200	0.0200	0.0200	0.0200	0.0200
Animal manure during grazing	4D2	0.0170	0.0170	0.0170	0.0170	0.0170	0.0170	0.0170	0.0170	0.0170	0.0170	0.0165	0.0165	0.0165	0.0165

Values of nitrous oxide emissions and activity data are given as 10^6 kg N_2O per year, implied emission factors as kg N_2O-N per kg applied N

* Activity data are presented as net data, meaning that ammonia emissions are subtracted.

4. *Indirect* N_2O (nitrous oxide) emissions from agricultural soils

This chapter focuses on *indirect* nitrous oxide emissions from agricultural soils (IPCC source category 4D3). Direct emissions are linked to direct nitrogen inputs to the agricultural soils like nitrogen fertilizer and animal manure. Indirect emissions are linked to the leaching of nitrate from the upper soil and to the deposition of NO_x and NH_3.
Direct nitrous oxide emissions are discussed in Chapter 3.

4.1 Contribution of agricultural *indirect* N_2O emissions to total Dutch GHG emissions

Total Dutch greenhouse gas emissions were about 215 * 10^9 kg CO_2 equivalent in 2003 (Brandes et al., 2006). Roughly 10% is N_2O-based and the share of agriculture in N_2O is roughly 50% (Table 4.1). Indirect soil emissions comprise roughly 40% of agricultural N_2O emissions. Direct soil emissions are discussed in Chapter 3. Manure management comprises the nitrous oxide emissions from animal houses, which are discussed in another background document (Van der Hoek and Van Schijndel, 2006) and associated protocol (VROM, 2005c). The protocol is also available via www.greenhousegases.nl.

Table 4.1 Relevance of agricultural nitrous oxide emissions in the Netherlands.

	IPCC category	Units	1990	1995	2000	2003
Total GHG emissions		10^9 kg CO_2 equivalents	213.0	225.1	214.4	215.7
Total N_2O emissions		10^9 kg CO_2 equivalents	21.22	22.39	19.87	17.37
Total N_2O emissions		10^6 kg N_2O	68.45	72.24	64.09	56.05
Total agricultural emissions		10^6 kg N_2O	37.05	40.80	34.52	30.41
Manure management	4B	10^6 kg N_2O	2.24	2.49	2.51	2.06
Direct soil emissions	4D1 + 4D2	10^6 kg N_2O	19.13	23.72	20.15	17.92
Indirect soil emissions	4D3	10^6 kg N_2O	15.68	14.59	11.86	10.42

Source: Brandes et al., 2006

4.2 Scientific background of *indirect* N_2O emissions from agricultural soils

Indirect nitrous oxide emissions are connected with nitrate that is no longer available for agricultural plant uptake (usually 100 cm or more below the surface of soils) or with ammonium after volatilization and deposition elsewhere. This process usually leads to nitrogen loadings to ground water and surface waters or to deposition of nitrogen compounds on soil and surface waters.

In the root zone of a soil, ammonium is normally taken up by the crop or converted into nitrate, and only nitrate is susceptible for leaching. In the ground water flow and also in the receiving water bodies, denitrification can occur with simultaneous production of nitrous oxide. Runoff to surface waters and nitrogen deposition on soil and surface waters may also contain ammonium, which is readily converted to nitrate and is subsequently eventually denitrified.

4.3 Method of calculating *indirect* N_2O emissions from agricultural soils

Until 2004 the indirect nitrous oxide emissions were calculated with a method - later summarized in Spakman et al. (1997, 2003) - that was not comparable to the IPCC method (Kroeze, 1994).
In 2005 the IPCC method was adopted to calculate the indirect emissions. IPCC default values for emission factors and for the leaching fraction are used here in combination with country-specific activity data on nitrogen manure and fertilizer application and on ammonia volatilization.

This section gives a full description of the calculation methods as they are now in use in the Netherlands and also provides background information for the following agricultural protocol, available via www.greenhousegases.nl:

- Indirect nitrous oxide emissions from agricultural soils (VROM, 2005b).

The IPCC Guidelines methodology for calculation of indirect nitrous oxide emissions from agricultural soils is based on an emission factor per kg N in the applied nitrogen.

$$\text{Total } N_2O \text{ Emission} = \sum 44/28 * \text{N amount in source}_i * \text{Emission factor per kg N in source}_i \quad (2)$$

The factor 44/28 is used for converting N_2O-N into N_2O.

The IPCC Guidelines distinguish five nitrogen sources for indirect N_2O emissions:

1. Atmospheric deposition of NO_x and NH_3
2. Leaching and runoff of nitrogen that is applied to agricultural soils.
3. Discharge of human sewage into rivers and estuaries.
4. Formation of N_2O in the atmosphere from NH_3 emissions.
5. Discharge of effluents from food processing and other operations to surface waters.

The calculation methods for the first and second sources are as follow.

• Atmospheric deposition of NO_x and NH_3

The IPCC Guidelines explain that the calculations should be based on the emissions of NO_x and NH_3 originating from nitrogen fertilizers and animal manure in the Netherlands and not on the deposition of NO_x and NH_3 on Dutch territory (IPCC, 2001, page 4.67).

NO_x emissions from fertilizer and animal manure application are not accounted for in the Dutch annual emission inventories from PER (Pollutant Emission Register). However, this emission source was included for the NIR 2005 calculations on the basis of the assumption that NO_x emissions are equal to 15% of the ammonia emissions in the Netherlands (based on De Vries et al., 2003). During the critical review of this emission source during the preparations for the NIR 2006 the magnitude of this source was found to be uncertain. Therefore it was decided to leave out this emission source.

● Leaching and runoff of nitrogen that is applied to agricultural soils
A modified equation (3) is used, with the term $FRAC_{leach}$ indicating which percentage the nitrogen in the source is leached into the ground water.

Total N_2O Emission = 44/28 * N amount in source * $FRAC_{leach}$ * Emission factor per kg N leached (3)

The factor 44/28 is used for converting N_2O-N into N_2O.

The last three nitrogen sources are not included in the agricultural emission inventory.

- Discharge of human sewage into rivers and estuaries is discussed in the Waste sector (CRF category 6B).
- Formation of N_2O in the atmosphere from NH_3 emissions is lacking in the IPCC calculation method.
- Discharge of effluents from food processing and other operations to surface waters is discussed in the Waste sector (CRF category 6B).

4.4 Relevant statistical data necessary for calculating *indirect* N_2O emissions from agricultural soils

This section provides information about the data that are necessary to calculate the indirect nitrous oxide emissions (see also equations 2 and 3).

● Atmospheric deposition of nitrogen
As described in section 4.3, calculation of nitrous oxide emissions after atmospheric deposition of nitrogen has to be based on the emission of the nitrogen compounds and not on its deposition on Dutch territory.

Ammonia emissions from fertilizer application and agricultural activities (animal houses, manure storage facilities outside the animal houses, manure application and grazing) are taken from the annual emission inventories from PER (Pollutant Emission Register). The calculation method for these ammonia emissions is described in full detail in Van der Hoek (1994, 2002). Emission data are available via www.mnp.nl, then click through to the Environmental Data Compendium (http://www.mnp.nl/mnc/index-en.html (see also Appendix 1).

Ammonia emissions from horses and ponies are not yet accounted for by PER. Instead, we used an average emission factor for the housing period of 3.6 kg NH_3 per animal per year. The value of this factor is derived from the emission factors for horses and ponies used in the Dutch ammonia legislation (RAV, 2005). The average emission factor is calculated by multiplying the share of the numbers per animal type in the total population of horses and ponies times the emission factor per animal type: 16/36 * 5.0 (horses over 3 year) + 8/36 * 2.1 (horses under 3 year) + 9/36 * 3.1 (ponies over 3 year) + 3/36 * 1.3 (ponies under 3 year) = 3.6 kg NH_3. The number of horses and ponies is taken from the Dutch annual census (see Appendix 2).
Ammonia emissions during application of manure from horses and ponies are not accounted for by PER, indicating that this entry is a little underestimated.

Ammonia emissions from horses and ponies during grazing are not accounted for by PER. The small contribution of horses and ponies (ranging from 0.6% in 1990 to 2.0% in 2003 for the total nitrogen excreted in the meadow) makes this omission negligible.

● Nitrogen leaching and runoff

The IPCC Guidelines clearly indicate that the nitrogen supply with fertilizer and animal manure to the soil should **not** be corrected for their ammonia emissions. This reflects the methods' assumption that such nitrogen is subject to leaching after redeposition to soil (IPCC, 2001, note 25 on page 4.71).

Only subtraction of animal manure exported abroad is justified. The Dutch inventory focuses on the nitrogen input by application of synthetic fertilizer and animal manure (including animal manure production during grazing) to the Dutch agricultural soils. The application of sewage sludge to agricultural soils is not taken into account. However, the mineral nitrogen content of sewage sludge is very low and therefore this omission is negligible.

Fertilizer and animal manure to soil = A + B – C

A = amount of applied nitrogen fertilizer, recorded every year by LEI (Dutch Agricultural Economics Research Institute) and reported in Landbouwcijfers (Agricultural Data); figures are also available on the internet via www.lei.wur.nl (see also Appendix 1).

B = total nitrogen excretion by the animals as calculated by the WUM (Working Group on Uniform Data for Animal Excretion) on an annual basis for all animal categories except horses and ponies. The first WUM reports describe in detail the methodology (WUM, 1994a, b and c), while an annual publication is available for subsequent years (Van Eerdt, 1995a, b, 1996, 1997, 1998, 1999, Van Eerdt et al., 2003, Van Bruggen, 2003, 2004, 2005).
Data on annual nitrogen excretion for horses and ponies are taken from the Belgian manure legislation (VLM, 2000).

The nitrogen excretion per animal type is collected in Appendix 3 and the number of animals in the Netherlands is presented in Appendix 2. Combining Appendices 2 and 3 results in the total nitrogen excretion by the animals, with the national totals presented in Appendix 1.

C = amount of animal manure exported abroad, taken from the annual emission inventories from PER (Pollutant Emission Register). Data are available via www.mnp.nl and then go to Environmental Data Compendium (http://www.mnp.nl/mnc/index-en.html) (see also Appendix 1).

4.5 Emission factors for *indirect* N_2O emissions from agricultural soils

The following emission factors are used in the Dutch calculations.

● Atmospheric deposition of nitrogen

The IPCC default emission factor 0.01 kg N_2O-N per kg emitted NH_3.

● Nitrogen leaching and runoff

The IPCC default values for $FRAC_{leach}$ (= 0.30) and for the nitrous oxide emission factor (0.025 kg N_2O-N per kg N leached).

More information about the background of these default values is available (Seitzinger and Kroeze, 1998; Mosier et al., 1998; Nevison, 2000; Denier van der Gon et al., 2004). The Netherlands does not use country-specific values for $FRAC_{leach}$ and the corresponding emission factor. This is because of a lack of coherent data at the time (see also Chapter 5).

4.6 Overview of *indirect* N_2O emissions from agricultural soils 1990 - 2003

An overview of the indirect nitrous oxide emissions for the two nitrogen sources is presented in Table 4.2. The total indirect nitrous oxide emissions from agricultural soils decreased from 15.68 to 10.42 * 10^6 kg N_2O in the 1990 – 2003 period. This decline is observed for both atmospheric deposition of nitrogen and for leaching and runoff and corresponds with the decrease in ammonia emissions and nitrogen load to the soil, respectively.

Table 4.2 Overview of indirect nitrous oxide emissions from agricultural soils during the 1990-2003 period.

	Cat	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Atmospheric deposition of nitrogen	4D3														
NH_3 emission expressed as NH_3		237.8	245.5	214.0	217.6	194.3	179.3	178.7	176.0	159.9	154.3	139.9	131.0	126.5	122.2
NH_3 emission expressed as NH_3-N		195.8	202.2	176.3	179.2	160.0	147.7	147.1	145.0	131.7	127.0	115.2	107.8	104.2	100.6
N_2O emission expressed as N_2O-N		1.96	2.02	1.76	1.79	1.60	1.48	1.47	1.45	1.32	1.27	1.15	1.08	1.04	1.01
N_2O emission expressed as N_2O		3.08	3.18	2.77	2.82	2.51	2.32	2.31	2.28	2.07	2.00	1.81	1.69	1.64	1.58
Nitrogen leaching and runoff	4D3														
Nitrogen fertilizer consumption		412.0	400.1	391.8	389.9	371.6	406.0	389.0	401.0	402.9	383.3	339.0	298.0	292.0	291.0
Total nitrogen excretion – export		657.4	680.0	661.0	675.6	636.1	634.8	632.8	611.3	582.1	553.3	513.4	509.3	469.7	458.7
Total N supply to soil		1069.4	1080.1	1052.8	1065.5	1007.7	1040.8	1021.8	1012.3	985.0	936.6	852.4	807.3	761.7	749.7
Total N supply * FRACleach		320.8	324.0	315.8	319.7	302.3	312.3	306.6	303.7	295.5	281.0	255.7	242.2	228.5	224.9
N_2O emission expressed as N_2O-N		8.02	8.10	7.90	7.99	7.56	7.81	7.66	7.59	7.39	7.02	6.39	6.05	5.71	5.62
N_2O emission expressed as N_2O		12.60	12.73	12.41	12.56	11.88	12.27	12.04	11.93	11.61	11.04	10.05	9.51	8.98	8.84
Total indirect emissions as N_2O	4D3	15.68	15.91	15.18	15.37	14.39	14.59	14.36	14.21	13.68	13.03	11.86	11.21	10.61	10.42

Values of nitrous oxide emissions and activity data are given as 10^6 kg per year.

5. Reflection and recommendations

The calculation methods now in use by the Netherlands are described in full in Chapters 3 and 4. During the preparation of these chapters we encountered a wealth of scientific information on direct and indirect nitrous oxide emissions from agricultural soils from countries all over the world. The information includes measurements on plot and field scale, compilation of databases of measurements, modelling approaches, statistical analyses, process-oriented research and emission inventories.

The topics described below are relevant for the Dutch situation and might be put on the research agenda.

● Shallow injection and incorporation of animal manure

We have spent considerable time to find scientific evidence for the effect of shallow (sod) injection and arable land incorporation of animal manure on nitrous oxide emissions. Not only in the Netherlands, but also in a number of countries like Canada, the UK, and Sweden were measurements done on this effect (see, for example, Rodhe et al., 2006). Only a few experiments with a low ammonia emission application technique were done with a simultaneous surface application of animal manure (the so-called reference situation). For most of the experiments with a local reference situation, the low ammonia emission technique resulted in an enhanced nitrous oxide emission. However, sometimes there was no difference. A critical evaluation showed that the soil water status and the mineral nitrogen content of the animal manure had a paramount impact. Studying the reported experiments in more detail could reveal more insight into the parameters primarily responsible for nitrous oxide emissions. It is, however, very difficult to extrapolate a national emission factor from a few experiments. It is even more complicated considering that important parameters like rain fall precipitation and soil water status vary from year to year.

● Use of models to predict nitrous oxide emissions

Carbon and nitrogen processes in the soil are coupled so much research is dedicated to models for soil organic matter in order to predict nitrate leaching and nitrous oxide emissions. A quick scan showed that only the USA is using such a model for the direct nitrous oxide emissions from agricultural soils (Lokupitiya and Paustian, 2006; Del Grosso et al., 2006). Germany and the UK report studies which show that such soil organic matter models can be used (Butterbach-Bahl et al., 2004; Brown et al., 2002).

● Country-specific emission factors for leaching

In the case of nitrogen supply to the agricultural soils, the magnitude of the indirect nitrous oxide emissions is dependent on the amount of nitrate leaching to the ground water and surface water (= $FRAC_{leach}$) and the associated emission factor. The IPCC default value for $FRAC_{leach}$ is 0.30, which is also used by the Netherlands. With a fixed default value it is not possible to visualize the effect of measures aimed at decreasing the leaching rate.

In principle the $FRAC_{leach}$ is a function of:
- soil type like sand, clay and organic soils,
- ground water level,
- application level of synthetic nitrogen fertilizer and animal manure,
- time of the year when animal manure is applied, in autumn there is more leaching than in spring or summer,
- grazing intensity of grassland.

Several countries use country specific $FRAC_{leach}$ values.

- On the basis of experiments New Zealand has lowered its $FRAC_{leach}$ from 0.15 as used in previous years to a factor of 0.07 and recalculated the full 1990 – 2003 period with this factor (De Klein and Ledgard, 2005; Thomas et al., 2005).
- Canada and Finland both use a factor of 0.15 (Boehm et al., 2004; Monni et al., 2006).
- Switzerland calculates the indirect emissions with a factor of 0.20 (Leifeld and Fuhrer, 2005).
- Denmark uses a year-specific $FRAC_{leach}$ based on models. The value for the $FRAC_{leach}$ in the middle of the 1990s was 0.39 and the factor 0.34 was used for the years 2002 – 2004. This decrease is explained by a ban on animal manure application after harvest (NERI, 2006).

In the Netherlands the integrated modelling system STONE is used for the calculation of nutrient emissions from agriculture. Nutrient emissions include the leaching of nitrate to ground and surface waters (De Willigen et al., 2003; Wolf et al., 2003). In principle an averaged Dutch value for $FRAC_{leach}$ could be generated by STONE.

However, direct and indirect N_2O emissions in the Netherlands partially originate from the same soils and sources. In the Netherlands no experimental data are available to evaluate the value of the emission factor for indirect emissions. For this reason the default IPCC emission factor for indirect emissions is used. A recent Dutch desk study states that a transparent future estimation methodology should acknowledge this by harmonizing emission factors according to ecosystem and may even integrate the separate direct and indirect N_2O estimation methodologies (Denier van der Gon et al., 2004).

● Better understanding of biological processes

We conclude this chapter with the words of our Canadian colleagues: we should improve our understanding of biological processes rather than compiling more measurements. If we understand processes better than we do now, we will be able to generalize and use calculation models that represent local and regional conditions better than default emission factor methodologies. We may also be able to understand experimental results and observations more adequately. Certainly, a closer examination of processes in conjunction with ongoing measurements is required (Helgason et al., 2005). This is also true for the Dutch situation and a combined effort of measurements and modelling will improve the quality of the estimates of the emission factors used and nitrogen flows.

References

Anonymous, 2005. Adviesbasis bemesting grasland en voedergewassen. Commissie Bemesting Grasland en Voedergewassen. Praktijkonderzoek Veehouderij, Lelystad.
Boehm, M., B. Junkins, R. Desjardins, S. Kulshreshtha, and W. Lindwall, 2004. Sink potential of Canadian agricultural soils. Climatic Change 65, 297-314.
Brandes, L.J., G.E.M. Alkemade, P.G. Ruyssenaars, H.H.J. Vreuls, P.W.H.G. Coenen, 2006. Greenhouse gas emissions in the Netherlands 1990-2004. National Inventory Report 2006. MNP report 500080001. MNP, Bilthoven.
Brown, L., B. Syed, S.C. Jarvis, R.W. Sneath, V.R. Phillips, K.W.T. Goulding, and C. Li, 2002. Development and application of a mechanistic model to estimate emission of nitrous oxide from UK agriculture. Atmospheric Environment 36, 917-928.
Butterbach-Bahl, K., M. Kesik, P. Miehle, H. Papen, and C. Li, 2004. Quantifying the regional source strength of N-trace gases across agricultural and forest ecosystems with process based models. Plant and Soil 260, 311-329.
CBS, Statline, Landbouwtellingen. CBS, Voorburg / Heerlen, www.cbs.nl.
CBS, Statline, Mestproductie. CBS, Voorburg / Heerlen, www.cbs.nl.
Davidson, E.A., M. Keller, H.E. Erickson, L.V. Verchot, and E. Veldkamp, 2000. Testing a conceptual model of soil emissions of nitrous and nitric oxides. BioScience 50, 667-680.
De Klein, C.A.M., and S.F. Ledgard, 2005. Nitrous oxide emissions from New Zealand agriculture – key sources and mitigation strategies. Nutrient Cycling in Agroecosystems 72, 77-85.
Del Grosso, S.J., W.J. Parton, A.R. Mosier, M.K. Walsh, D.S. Ojima, and P.E. Thornton, 2006. DAYCENT National-scale simulations of nitrous oxide emissions from cropped soils in the United States. Journal of Environmental Quality 35, 1451-1460.
Denier van der Gon, H.A.C., A. Bleeker, T. Ligthart, J.H. Duijzer, P.J. Kuikman, J.W. van Groenigen, W. Hamminga, C. Kroeze, H.P.J. de Wilde and A. Hensen, 2004. Indirect nitrous oxide emissions from the Netherlands: source strength, methodologies, uncertainties and potential for mitigation. TNO report R 2004/275. TNO, Apeldoorn, pp. 43.
De Vries, W., J. Kros, O. Oenema and J. de Klein, 2003. Uncertainties in the fate of nitrogen II: A quantitative assessment of the uncertainties in major nitrogen fluxes in the Netherlands. Nutrient Cycling in Agroecosystems 66, 71-102.
De Willigen, P., P. Cleij, H.P. Oosterom, and C.G.J. Schotten, 2003. Lot van het stikstofoverschot. Analyse van STONE-berekeningen die zijn uitgevoerd in het kader van Evaluatie Meststoffenwet 2002. Alterra rapport 732. Alterra, Wageningen.
EEA, 2006. Annual European Community greenhouse gas inventory 1990 – 2004 and inventory report 2006. EEA Technical Report No 6/2006. EEA, Copenhagen, Denmark.
Environmental Data Compendium, Netherlands Environmental Assessment Agency http://www.mnp.nl/mnc/index-en.html
Firestone, M.K, and E.A. Davidson, 1989. Microbiological basis of NO and N_2O production and consumption in soil, page 7-21. In M.O. Andreae and D.S. Schimel (ed.) Exchange of trace gases between terrestrial ecosystems and the atmosphere. John Wiley & Sons, Inc., New York.
Helgason, B.L., H.H. Janzen, M.H. Chantigny, C.F. Drury, B.H. Ellert, E.G. Gregorich, R.L. Lemke, E. Pattey, P. Rochette, and C. Wagner-Riddle, 2005. Toward improved coefficients for predicting direct N_2O emissions from soil in Canadian agroecosystems. Nutrient Cycling in Agroecosystems 72, 87-99.

IPCC, 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Emission Inventories. Three volumes: Reference manual, Reporting Guidelines and Workbook. IPCC/OECD/IEA. IPCC WG1 Technical Support Unit, Hadley Centre, Meteorological Office, Bracknell, UK.

IPCC, 2001. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, IPCC-TSU NGGIP, Japan.

Klein Goldewijk, K., J.G.J. Olivier, J.A.H.W. Peters, P.W.H.G. Coenen, H.H.J. Vreuls, 2005. Greenhouse Gas Emissions in the Netherlands 1990-2003. National Inventory Report 2005. RIVM report 773201009. RIVM, Bilthoven.

Kroeze, C., 1994. Nitrous oxide. Emission inventory and options for control in the Netherlands. RIVM report 773001004. RIVM, Bilthoven.

Kuikman, P.J., J.J.H. van den Akker, F. de Vries, 2005. Lachgasemissie uit organische landbouwbodems. Alterra rapport 1035-2. Alterra, Wageningen.

Kuikman, P.J., K.W. van der Hoek, A. Smit, K. Zwart, 2006. Update of emission factors for direct emissions of nitrous oxide from agricultural soils on the basis of measurements in the Netherlands. Alterra rapport 1217. Alterra, Wageningen.

Leifeld, J., J. Fuhrer, 2005. Greenhouse gas emissions from Swiss agriculture since 1990: implications for environmental policies to mitigate global warming. Environmental Science and Policy 8, 410-417.

Lokupitiya, E., and K. Paustian, 2006. Agricultural soil greenhouse gas emissions: a review of national inventory methods. Journal of Environmental Quality 35, 1413-1427.

Mineralen Boekhouding, 1993. Kiezen uit gehalten. Forfaitaire gehalten voor de Mineralenboekhouding 1994. Mineralen Boekhouding.

Monni, S., P. Perälä, and K. Regina, 2006. Uncertainty in agricultural CH_4 and N_2O emissions from Finland - possibilities to increase accuracy in emission estimates. Mitigation and Adaptation Strategies for Global Change, in press.

Mosier, A.R., C. Kroeze, C. Nevison, O. Oenema, S. Seitzinger, O. van Cleemput, 1998. Closing the global N_2O budget: nitrous oxide emissions through the agricultural nitrogen cycle. Nutrient Cycling in Agroecosystems 52, 225-248.

NERI, 2006. Denmark's National Inventory Report 2006. Technical Report No. 589, NERI, Roskilde, Denmark.

Nevison, C., 2000. Review of the IPCC methodology for estimating nitrous oxide emissions associated with agricultural leaching and runoff. Chemosphere – Global Change Science 2, 493-500.

RAV, 2005. Wijziging Regeling Ammoniak en Veehouderij. Staatscourant 13 juli 2005, nr 133 pag 17 and correction in Staatscourant 10 augustus 2005, nr 153 pag 9.

Rochette, P., and H.H. Janzen, 2005. Towards a revised coefficient for estimating N_2O emissions from legumes. Nutrient Cycling in Agroecosystems 73, 171-179.

Rodhe, L., M. Pell, and S. Yamulki, 2006. Nitrous oxide, methane and ammonia emissions following slurry spreading on grassland. Soil use and management, 22, 229-237.

Seitzinger, S.P. and C. Kroeze, 1998. Global distribution of nitrous oxide production and N inputs in freshwater and coastal marine ecosystems. Global Biogeochemical Cycles 12, 93-113.

Spakman, J., M.M.J. van Loon, R.J.K. van der Auweraert, D.J. Gielen, J.G.J. Olivier, E.A. Zonneveld, 1997. Methode voor de berekening van broeikasgasemissies. Publicatiereeks Emissieregistratie 37. Ministerie van VROM, Den Haag.

Spakman, J., M.M.J. van Loon, R.J.K. van der Auweraert, D.J. Gielen, J.G.J Olivier, and E.A. Zonneveld, 2003. Method for calculating greenhouse gas emissions. Report Emission Registration no. 37b, March 2003. VROM-HIMH, The Hague. Electronic update of original report No. 37 of July 1997. Electronic version only; in Dutch and English available at website: www.greenhousegases.nl

Stehfest, E. and A.F. Bouwman, 2006. N_2O and NO emission from agricultural fields and soils under natural vegetation: summarizing available measurement data and modeling of global annual emissions. Nutrient Cycling in Agroecosystems 74, 207-228.

Thomas, S.M., S.F. Ledgard, and G.S. Francis, 2005. Improving estimates of nitrate leaching for quantifying New Zealands's indirect nitrous oxide emissions. Nutrient Cycling in Agroecosystems 73, 213-226.

Valk, H., A.M. van Vuuren, A.C. Beynen, 2002. Effect of grassland fertilizer on urinary and fecal concentrations of nitrogen and phosphorus in grass-fed dairy cows. In: H. Valk, 2002. Nitrogen and phosphorus supply of dairy cows. PhD Thesis RU Utrecht.

Van Bruggen, C., 2003. Dierlijke mest en mineralen 2001, www.cbs.nl

Van Bruggen, C., 2004. Dierlijke mest en mineralen 2002, www.cbs.nl

Van Bruggen, C., 2005. Dierlijke mest en mineralen 2003, www.cbs.nl

Van der Hoek, K.W., 1994. Berekeningsmethodiek ammoniakemissie in Nederland voor de jaren 1990, 1991 en 1992. RIVM rapport 773004003. RIVM, Bilthoven.

Van der Hoek, K.W., 2002. Uitgangspunten voor de mest- en ammoniakberekeningen 1999 tot en met 2001 zoals gebruikt in de Milieubalans 2001 en 2002, inclusief dataset landbouwemissies 1980-2001. RIVM rapport 773004013. RIVM, Bilthoven.

Van der Hoek, K.W., and M.W. van Schijndel, 2006. Methane and nitrous oxide emissions from animal manure management, 1990 - 2003. Background document on the calculation method for the Dutch National Inventory Report. RIVM report 680125002, MNP report 500080002. RIVM, Bilthoven.

Van Dijk, W., 2003. Adviesbasis voor de bemesting van akkerbouw- en vollegrondsgroentengewassen. Praktijkonderzoek Plant & Omgeving, Lelystad.

Van Eerdt, M.M., 1995a. Mestproductie, mineralenuitscheiding en mineralen in de mest, 1993. Kwartaalbericht Milieustatistieken 1995/2, p. 4-11. CBS, Voorburg/Heerlen.

Van Eerdt M.M., 1995b. Mestproductie, mineralenuitscheiding en mineralen in de mest, 1994. Kwartaalbericht Milieustatistieken 1995/4, p. 11-21. CBS, Voorburg/Heerlen.

Van Eerdt M.M., 1996. Mestproductie en mineralenuitscheiding, 1995. Kwartaalbericht Milieustatistieken 1996/4, p. 20-28. CBS, Voorburg/Heerlen.

Van Eerdt M.M., 1997. Mestproductie en mineralenuitscheiding, 1996. Kwartaalbericht Milieustatistieken 1997/4, p. 28-38. CBS, Voorburg/Heerlen.

Van Eerdt M.M., 1998. Mestproductie en mineralenuitscheiding, 1997. Kwartaalbericht Milieustatistieken 1998/4, p. 41-46. CBS, Voorburg/Heerlen.

Van Eerdt M.M., 1999. Mestproductie en mineralenuitscheiding, 1998. Kwartaalbericht Milieustatistieken, 1999/4, p. 27-31. CBS, Voorburg/Heerlen.

Van Eerdt M.M., T. Heijstraten, A.K.H. Wit, 2003. Dierlijke mest en mineralen, 1998-2001*. http://www.cbs.nl/nl/publicaties/artikelen/milieu-en-bodemgebruik/milieu/mest/dierlijke-mest-mineralen.htm

Velthof, G.L., A.B. Brader, and O. Oenema, 1996. Seasonal variations in nitrous oxide losses from managed grasslands in the Netherlands. Plant and Soil 181, 263-274.

Velthof, G.L., O. Oenema, R. Postma and M.L. van Beusichem, 1997. Effects of type and amount of applied nitrogen fertilizer on nitrous fluxes from intensively managed grassland. Nutrient Cycling in Agroecosystems 46, 257-267.

Velthof, G.L. and P.J. Kuikman, 2000. Beperking van lachgasemissie uit gewasresten. Een systeemanalyse. Alterra rapport 114.3. Alterra, Wageningen.

Velthof, G.L., P.J. Kuikman and O. Oenema, 2002. Nitrous oxide emission from soils amended with crop residues. Nutrient Cycling in Agroecosystems 62, 249-261.

VLM, 2000. Mestgids, wegwijs in het Vlaamse mestbeleid. Vlaamse Landmaatschappij, Brussel.

VROM, 2005a. Protocol 5434, Direct nitrous oxide emissions from agricultural soils, 22 December 2005 (in Dutch), www.greenhousegases.nl

VROM, 2005b. Protocol 5433, Indirect nitrous oxide emissions from agricultural soils, 22 December 2005 (in Dutch), www.greenhousegases.nl

VROM, 2005c. Protocol 5429, Nitrous oxide emissions from manure management, 22 December 2005 (in Dutch), www.greenhousegases.nl

Wolf, J., A.H.W. Beusen, P. Groenendijk, T. Kroon, R. Roetter, H. van Zeijts, 2003. The integrated modeling system STONE for calculating nutrient emissions from agriculture in the Netherlands. Environmental Modelling & Software 18, 597-617.

WUM, 1994a. Uniformering berekening mest en mineralen. Standaardcijfers rundvee, schapen en geiten, 1990 t/m 1992. Werkgroep Uniformering berekening mest- en mineralencijfers (redactie M.M. van Eerdt). CBS, IKC-Veehouderij, LAMI, LEI-DLO, RIVM en SLM.

WUM, 1994b. Uniformering berekening mest en mineralen. Standaardcijfers varkens, 1990 t/m 1992. Werkgroep Uniformering berekening mest- en mineralencijfers (redactie M.M. van Eerdt). CBS, IKC-Veehouderij, LAMI, LEI-DLO, RIVM en SLM.

WUM, 1994c. Uniformering berekening mest en mineralen. Standaardcijfers pluimvee, konijnen en pelsdieren, 1990 t/m 1992. Werkgroep Uniformering berekening mest- en mineralencijfers (redactie M.M. van Eerdt). CBS, IKC-Veehouderij, LAMI, LEI-DLO, RIVM en SLM.

Appendix 1. Basic data on agricultural nitrogen in the Netherlands 1990 – 2003

All amounts are given in 10^6 kg N.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Nitrogen fertilizer consumption	412.0	400.1	391.8	389.9	371.6	406.0	389.0	401.0	402.9	383.3	339.0	298.0	292.0	291.0
of which ammonium fertilizer	3.6	7.1	5.4	6.4	7.9	11.2	11.2	10.0	10.8	10.8	6.5	13.3	27.8	40.1
NH_3-N emission during application	11.1	11.2	10.6	10.1	9.7	10.6	10.1	10.4	10.5	10.3	9.2	8.6	9.6	11.1
Net fertilizer to soil	400.9	388.9	381.2	379.8	361.9	395.4	378.9	390.6	392.4	373.0	329.8	289.4	282.4	279.9
Nitrogen excretion by animals	663.8	686.8	672.2	690.6	657.3	656.9	645.8	622.3	591.9	566.2	528.1	527.3	489.4	470.7
Nitrogen excretion in animal houses	493.0	497.7	491.9	523.6	503.6	500.4	482.5	470.5	461.4	446.5	415.0	411.8	395.0	375.7
of which in solid form	61.9	67.6	73.0	71.9	67.9	71.2	70.9	70.4	77.7	80.8	76.9	73.0	76.2	59.6
of which in liquid form	431.2	430.2	418.9	451.8	435.8	429.3	411.6	400.1	383.7	365.8	338.0	338.8	318.7	316.1
NH_3-N emission in animal houses	73.5	75.6	75.3	78.2	75.5	73.8	70.9	67.7	63.8	65.7	60.7	52.9	52.1	48.7
Net available manure for application	419.5	422.1	416.6	445.4	428.1	426.6	411.6	402.8	397.6	380.8	354.3	358.9	342.9	327.0
Nitrogen in manure exported abroad	6.4	6.8	11.2	15.0	21.2	22.1	13.0	11.0	9.8	12.9	14.7	18.0	19.7	11.6
NH_3-N emission during application	98.2	102.1	77.7	78.2	63.2	51.4	53.9	54.8	46.6	41.7	36.8	37.7	35.6	33.8
Net animal manure to soil	314.9	313.1	327.7	352.2	343.8	353.1	344.7	337.0	341.2	326.2	302.7	303.2	287.6	281.2
Nitrogen excretion in meadow	170.8	189.1	180.3	167.0	153.7	156.5	163.3	151.8	130.5	119.7	113.1	115.5	94.4	95.0
NH_3-N emission in meadow	13.0	13.2	12.7	12.7	11.7	11.9	12.2	12.1	10.8	9.3	8.5	8.6	6.9	7.1
Net animal manure to soil	157.8	175.9	167.6	154.3	142.0	144.6	151.1	139.7	119.7	110.4	104.6	106.9	87.5	87.9
Biological nitrogen fixation	7.8	6.8	6.2	5.7	5.3	4.9	4.9	4.7	4.7	5.0	4.7	5.1	4.7	5.2
Nitrogen in crop residues left in field	36.4	37.4	36.8	35.9	35.1	34.9	34.7	33.8	34.1	35.8	34.1	33.8	35.4	34.5
Nitrogen in sewage sludge on agric. land	5.0	5.0	5.7	3.8	2.5	1.5	1.6	1.2	1.0	0.9	1.5	1.4	1.6	1.6
Total agricultural NH_3-N emission	195.8	202.2	176.3	179.2	160.0	147.7	147.1	145.0	131.7	127.0	115.2	107.8	104.2	100.6
Total agricultural NH_3 emission	237.8	245.5	214.0	217.6	194.3	179.3	178.7	176.0	159.9	154.3	139.9	131.0	126.5	122.2

The presented figures related to nitrogen excretion are higher than published by PER because PER does not include horses and ponies

Appendix 2. Animal numbers in the Netherlands 1990 - 2003

Animal category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Cattle for breeding														
Female young stock under 1 yr	752,658	760,636	720,342	687,326	687,442	696,063	703,237	651,019	615,834	596,635	562,563	552,595	529,127	503,703
Male young stock under 1 yr	53,229	59,044	53,905	49,753	47,841	44,163	57,182	46,785	41,830	37,653	37,440	88,001	44,692	31,213
Female young stock, 1-2 yr	734,078	754,860	748,325	696,243	678,960	682,888	679,796	684,011	639,875	607,670	594,100	559,089	551,716	528,133
Male young stock, 1-2 yr	34,635	37,628	39,297	31,957	33,034	33,118	37,203	31,632	27,586	25,331	26,328	26,819	31,543	19,650
Female young stock, 2 yr and over	145,648	152,994	144,542	139,866	123,924	124,970	125,153	137,880	117,120	106,348	104,633	106,908	96,781	89,162
Cows in milk and in calf	1,877,684	1,852,165	1,775,259	1,746,733	1,697,868	1,707,875	1,664,648	1,590,571	1,610,630	1,588,489	1,504,097	1,539,180	1,485,531	1,477,766
Bulls for service 2 yr and over	8,762	9,899	8,547	8,551	7,975	8,674	9,229	8,198	8,141	10,278	10,410	10,982	14,132	11,755
Cattle for fattening														
Meat calves, for rosé veal production	28,876	39,784	51,018	62,996	77,226	85,803	100,394	100,948	101,267	118,397	145,828	150,950	152,033	171,501
Meat calves, for white veal production	572,709	581,834	586,713	593,214	612,290	583,516	577,196	603,171	609,724	634,257	636,907	556,780	561,300	560,027
Female young stock < 1 yr	53,021	65,551	61,436	63,009	63,144	57,218	55,575	47,669	42,362	45,977	41,300	42,911	38,887	38,016
Male young stock (incl. young bullocks) < 1 yr	255,375	275,383	244,178	233,479	226,539	188,193	147,553	137,053	115,106	97,465	83,447	76,861	62,988	59,682
Female young stock, 1-2 yr	56,934	70,367	76,980	78,906	70,340	66,653	60,061	54,137	50,169	46,462	44,807	42,950	42,337	44,081
Male young stock (incl. young bullocks), 1-2 yr	178,257	198,533	199,261	186,821	179,714	169,546	139,452	142,050	130,080	112,198	88,669	82,234	68,759	53,705
Female young stock, 2 yr and over	42,555	51,515	50,843	49,859	50,791	48,365	37,084	22,345	20,208	17,528	16,917	18,097	16,228	16,595
Male young stock (incl. young bullocks) ≥ 2 yr	12,073	12,503	13,253	11,596	12,161	10,969	11,170	8,664	7,790	8,421	9,397	12,668	11,368	10,197
Suckling cows (incl. fattening/grazing ≥ 2 yr)	119,529	139,375	145,708	156,459	146,462	146,181	146,384	144,502	145,362	152,581	163,397	160,802	150,972	144,004

The Agricultural Census provides the numbers of rosé veal calves from 1995. The rosé veal breeding farming started in the second half of the 1980s. In 1995 the share of rosé veal calves was 12.8% of the total number of veal calves. It is assumed that over the period from 1987 to 1995 the share of rosé veal calves annually increased by 1.6%. Therefore, the share for 1990 was calculated to be 4.8%.

Continued. Appendix 2

Animal category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Ruminants, not cattle														
Sheep (ewes)	789,691	858,779	876,293	874,674	794,317	770,730	784,976	719,190	693,897	715,776	681,441	647,668	589,315	592,806
Goats (mothers)	37,472	43,706	38,123	34,607	37,554	43,231	55,251	61,448	71,152	85,764	98,077	115,573	142,879	157,848
Horses	49,931	55,438	62,231	65,089	68,333	70,101	73,397	75,468	76,639	76,619	78,892	77,587	79,084	83,002
Ponies	19,661	21,278	24,021	26,639	28,990	29,903	33,308	36,868	36,969	38,547	39,352	42,899	42,383	43,290
Pigs														
Piglets	5,190,749	4,465,911	5,270,428	5,672,918	5,599,760	5,596,117	5,626,233	5,996,140	5,094,466	5,238,755	5,102,434	5,418,427	4,744,505	4,541,673
Fattening pigs	7,025,102	7,040,888	7,144,732	7,525,935	7,270,868	7,123,923	7,094,533	7,432,558	6,591,246	6,774,085	6,504,540	6,216,252	5,591,044	5,367,450
Gilts not yet in pig	385,502	396,132	398,868	392,432	367,675	357,520	375,251	393,745	421,101	343,620	339,570	312,990	282,510	289,355
Sows	1,272,215	1,272,559	1,307,710	1,334,880	1,293,910	1,287,224	1,292,402	1,318,003	1,293,619	1,171,016	1,129,174	1,071,504	1,007,154	950,449
Young boars*	13,893	14,312	12,901	13,061	10,530	11,382	8,623	18,759	19,343	7,057	6,917	7,405	6,625	5,487
Boars for service	27,587	26,812	25,763	25,219	22,268	21,297	21,631	29,859	26,091	32,284	35,182	15,072	15,839	14,681
Poultry														
Broilers	41,172,110	41,639,370	46,524,971	45,780,901	43,055,802	43,827,286	44,142,119	44,986,833	48,537,027	53,246,552	50,936,625	50,127,029	54,660,302	39,319,158
Broilers parents < 18 weeks	2,882,250	3,088,160	3,007,100	3,003,660	3,166,090	3,065,170	2,688,180	3,090,370	3,482,870	3,254,710	3,644,120	2,932,780	2,553,650	2,328,749
Broilers parents ≥ 18 weeks	4,389,830	4,359,760	4,837,300	4,900,600	4,811,560	4,506,840	5,032,380	4,951,550	5,237,950	5,804,260	5,397,520	4,548,120	4,949,320	3,723,907
Laying hens < 18 weeks, L**	7,339,708	7,230,010	7,821,924	6,635,699	6,258,132	4,889,555	5,381,525	5,713,747	2,646,390	2,760,770	2,865,850	2,722,013	1,527,888	896,730
Laying hens < 18 weeks, S**	3,781,062	3,724,550	4,029,476	3,418,391	4,172,088	4,000,545	4,403,066	4,674,884	7,939,170	8,282,310	8,597,550	8,166,038	8,658,032	6,001,196
Laying hens ≥ 18 weeks, L**	19,919,466	20,132,292	19,882,788	19,307,928	15,218,915	12,294,122	12,513,392	12,469,090	6,786,734	6,911,947	7,166,060	7,004,301	3,731,346	2.672,492
Laying hens ≥ 18 weeks, S**	13,279,644	13,421,528	13,255,192	12,871,952	15,218,915	16,977,598	17,280,398	17,219,220	24,062,056	24,505,993	25,406,940	24,833,429	24,971,314	17,885,137
Ducks for slaughter	1,085,510	1,151,710	1,035,968	843,875	756,128	868,965	861,064	906,225	970,279	1,076,737	958,466	866,945	852,420	655,259
Turkeys for slaughter	1,003,350	1,184,920	1,310,348	1,257,402	1,252,965	1,175,527	1,205,705	1,218,055	1,461,973	1,386,608	1,543,830	1,523,250	1,450,590	796,032
Turkeys parents < 7 months	28,550	31,050	29,700	45,650	18,050	13,930	27,000	102,800	20,600	38,600	-	-	-	-
Turkeys parents ≥ 7 months	20,460	20,160	24,110	19,610	23,890	17,290	17,150	36,220	17,650	13,200	-	-	-	-
Rabbits (mother animals)***	105,246	105,246	105,249	89,373	73,719	64,234	61,492	64,372	61,323	54,666	52,252	49,386	50,391	44,634
Minks (mother animals)***	543,969	543,969	563,054	465,735	476,337	456,104	485,357	525,088	565,564	575,830	584,806	611,368	617,472	613,296
Foxes (mother animals)***	10,029	10,029	7,933	7,320	7,079	7,102	6,748	6,744	7,644	5,290	3,816	4,648	4,851	4,179

* = not yet in service
** = L = liquid manure, S = solid manure
*** = no figures available in 1990, for consistency in time series figures for 1991 are used for 1990

Appendix 3. Nitrogen excretion per animal type 1990 - 2003

Values are given in kg nitrogen per animal per year.

Animal category		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Nitrogen excretion in animal houses															
Cattle for breeding															
Female young stock under 1 yr	L	29.2	31.5	31.1	31.6	32.8	32.5	30.5	34.0	29.6	28.2	27.0	26.9	25.6	23.4
Male young stock under 1 yr	L	29.3	31.7	31.2	31.6	32.8	32.5	30.4	33.8	29.5	39.9	38.9	39.1	38.4	39.1
Female young stock, 1-2 yr	L	45.2	49.2	48.3	48.9	51.5	50.4	47.2	53.7	48.4	46.9	44.9	44.8	42.2	43.6
Male young stock, 1-2 yr	L	90.7	99.1	97.1	98.2	103.8	101.3	94.7	108.5	105.8	101.1	96.7	96.6	90.6	92.2
Female young stock, 2 yr and over	L	45.0	49.1	48.2	48.8	51.4	50.3	47.1	53.7	48.4	46.8	44.8	44.8	42.2	43.6
Cows in milk and in calf	L	89.0	87.1	81.2	94.4	94.7	96.5	94.2	92.6	97.1	93.1	91.6	94.0	99.6	103.7
Bulls for service 2 yr and over	L	90.7	99.1	97.1	98.2	103.8	101.3	94.7	108.5	105.8	101.1	96.7	96.6	90.6	92.2
Cattle for fattening															
Meat calves, for rosé veal production	L	29.9	29.9	29.9	29.9	29.9	29.9	30.3	28.8	28.7	35.6	35.3	36.1	31.0	31.3
Meat calves, for white veal production	L	10.6	10.6	10.6	10.6	10.6	11.6	11.4	10.3	11.6	10.9	11.9	11.9	12.1	12.2
Female young stock < 1 yr	L	29.0	31.3	30.9	31.3	32.5	32.3	30.2	33.6	29.2	27.8	26.6	26.5	25.3	23.2
Male young stock (incl. young bullocks) < 1 yr	L	24.9	23.3	21.9	28.6	30.4	29.5	28.4	28.0	27.3	27.6	27.3	28.2	27.0	27.4
Female young stock, 1-2 yr	L	45.0	49.0	48.2	48.7	51.2	50.2	46.9	53.2	48.0	46.5	44.5	44.4	41.9	43.3
Male young stock (incl. young bullocks), 1-2 yr	L	52.8	48.8	48.1	88.6	71.5	64.6	63.4	58.8	58.0	58.5	56.8	59.7	57.4	57.8
Female young stock, 2 yr and over	L	45.2	49.2	48.4	48.9	51.4	50.4	47.1	53.5	48.1	46.5	44.5	44.4	41.8	43.3
Male young stock (incl. young bullocks) ≥ 2 yr	L	52.8	48.8	48.1	88.6	71.5	64.6	63.4	58.8	58.0	58.5	56.8	59.7	57.4	57.8
Suckling cows (incl. fattening/grazing ≥ 2 yr)	S	42.4	46.4	45.6	46.2	48.4	47.7	44.5	50.5	48.5	41.4	41.0	40.9	41.2	40.5
Nitrogen excretion in meadow															
Cattle for breeding															
Female young stock under 1 yr	M	13.4	12.9	11.9	12.7	12.5	12.6	13.2	13.1	15.2	13.4	13.9	13.8	13.8	17.8
Male young stock under 1 yr	M	13.4	13.0	11.9	12.7	12.5	12.6	13.1	13.0	15.1					
Female young stock, 1-2 yr	M	46.9	45.1	41.5	44.1	43.9	43.5	45.9	45.7	41.8	36.4	37.9	37.8	37.5	36.1
Male young stock, 1-2 yr															
Female young stock, 2 yr and over	M	46.9	45.1	41.5	44.1	43.9	43.5	45.9	45.7	41.8	36.4	37.9	37.8	37.5	36.1
Cows in milk and in calf	M	46.6	55.7	56.7	48.8	44.9	46.8	49.6	46.9	36.9	37.4	34.6	37.0	26.4	27.4
Bulls for service 2 yr and over															
Cattle for fattening															
Meat calves, for rosé veal production															
Meat calves, for white veal production															
Female young stock < 1 yr	M	13.3	12.8	11.8	12.6	12.4	12.5	13.0	12.9	15.0	13.2	13.7	13.6	13.6	17.7
Male young stock (incl. young bullocks) < 1 yr															
Female young stock, 1-2 yr	M	46.9	45.1	41.5	44.1	43.9	43.5	45.9	45.7	41.8	36.4	37.9	37.8	37.5	36.1
Male young stock (incl. young bullocks), 1-2 yr															
Female young stock, 2 yr and over	M	46.9	45.1	41.5	44.1	43.9	43.5	45.9	45.7	41.8	36.4	37.9	37.8	37.5	36.1
Male young stock (incl. young bullocks) ≥ 2 yr															
Suckling cows (incl. fattening/grazing ≥ 2 yr)	M	68.3	65.4	60.1	64.1	63.6	63.1	66.7	66.4	62.8	53.4	54.0	54.1	52.4	51.4

Continued. Appendix 3

Values are given in kg nitrogen per animal per year.

Animal category		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Nitrogen excretion in animal houses															
Ruminants, not cattle															
Sheep (ewes)	S	3.9	4.0	3.8	4.0	4.2	4.0	3.9	4.4	4.4	3.9	3.9	3.9	3.7	3.7
Goats (mother animals)	S	19.9	20.9	20.3	21.1	21.6	21.5	20.6	22.0	22.4	19.4	19.4	20.6	20.1	20.1
Horses	S	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
Ponies	S	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
Pigs															
Piglets															
Fattening pigs	L	14.3	13.7	14.4	14.5	14.9	14.5	14.3	13.0	13.8	13.3	12.1	12.1	11.7	11.9
Gilts not yet in pig	L	14.0	14.1	14.0	13.7	13.6	14.4	13.9	13.8	13.4	13.9	14.0	13.1	13.2	14.2
Sows	L	33.8	30.9	31.8	31.9	30.1	31.4	31.3	29.9	29.9	30.6	30.3	31.0	30.0	29.9
Young boars not yet in service	L	14.0	14.1	14.0	13.7	13.6	14.4	13.9	13.8	13.4	13.9	14.0	13.1	13.2	14.2
Boars for service	L	25.0	24.5	25.4	24.6	23.0	24.6	23.7	22.8	22.4	22.4	22.6	23.5	23.3	23.8
Poultry															
Broilers	S	0.61	0.64	0.64	0.62	0.57	0.63	0.61	0.59	0.57	0.57	0.54	0.52	0.54	0.53
Broilers parent animals under 18 weeks	S	0.56	0.57	0.62	0.57	0.56	0.55	0.52	0.56	0.51	0.44	0.42	0.35	0.35	0.32
Broilers parent animals 18 weeks and over	S	1.32	1.41	1.47	1.54	1.40	1.42	1.42	1.30	1.30	1.28	1.21	1.11	1.09	1.05
Laying hens under 18 weeks, liquid manure	L	0.38	0.39	0.43	0.39	0.38	0.36	0.34	0.36	0.33	0.33	0.31	0.30	0.30	0.30
Laying hens under 18 weeks, solid manure	S	0.38	0.39	0.43	0.39	0.38	0.36	0.34	0.36	0.33	0.33	0.31	0.30	0.30	0.30
Laying hens 18 weeks and over, liquid manure	L	0.75	0.82	0.87	0.91	0.81	0.81	0.80	0.70	0.69	0.71	0.67	0.68	0.67	0.70
Laying hens 18 weeks and over, solid manure	S	0.75	0.82	0.87	0.91	0.81	0.81	0.80	0.70	0.69	0.71	0.67	0.68	0.67	0.70
Ducks for slaughter	S	1.12	1.12	1.12	1.12	1.12	1.09	1.09	1.09	1.09	1.00	0.99	0.95	0.95	0.90
Turkeys for slaughter	S	1.98	1.98	1.98	2.08	2.08	1.97	1.97	1.97	1.97	1.84	1.85	1.70	1.68	1.76
Turkeys parent animals under 7 months	S	2.38	2.38	2.38	2.38	2.38	2.78	2.52	2.52	2.52	2.52	-	-	-	-
Turkeys parent animals 7 months and over	S	3.17	3.17	3.17	3.17	3.17	3.04	3.04	3.04	3.04	3.04	-	-	-	-
Rabbits (mother animals)*	S	8.70	8.70	8.70	8.70	8.70	8.10	8.10	8.10	8.1	7.9	7.6	7.6	7.7	7.8
Minks (mother animals)*	S	4.08	4.08	4.08	4.08	4.08	4.08	3.50	3.50	3.5	4.2	3.5	3.3	3.0	2.9
Foxes (mother animals)*	S	13.90	13.90	13.90	13.90	13.90	13.90	9.00	9.00	9.0	9.9	8.3	7.7	7.0	6.6
Nitrogen excretion in meadow															
Ruminants, not cattle															
Sheep (ewes)	M	21.1	20.7	19.7	20.2	20.3	20.3	21.9	21.0	21.6	18.8	19.5	19.1	18.9	18.8
Goats (mother animals)															
Horses	M	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Ponies	M	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0

L and S refer to liquid and solid manure production in animal houses, M refers to manure produced in the meadow

* Figures for 1990 and 1991 are not available; the 1992 figures are used in order to develop a consistent time series for emission calculation.
Source: WUM and VLM (horses and ponies)

Appendix 4. Biological nitrogen fixation and area of crops involved 1990 – 2003

Areas are given in hectare, biological nitrogen fixation in 10^6 kg N.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Areas for crop production														
Arable crops														
Lucerne	5,960	5,686	6,075	6,566	6,425	5,836	5,675	6,055	6,252	6,408	6,616	7,114	5,981	6,259
Green peas (dry to harvest), bump cherry	10,908	6,887	4,420	2,221	1,394	691	827	674	727	862	752	801	1,138	2,075
Marrow fats and peas	794	638	917	953	891	367	764	486	424	638	388	700	632	766
Kidney beans	3,730	4,099	2,673	2,348	2,039	2,221	2,856	2,033	1,956	1,935	1,126	1,514	1,556	2,304
Peas (green to harvest)	7,667	7,635	7,579	6,628	6,931	7,131	6,170	4,395	4,554	6,085	5,867	5,535	6,278	6,033
Broad and field beans	3,169	2,032	1,670	1,274	802	532	664	1,008	774	648	679	703	522	592
Horticultural crops														
Tribe broad beans (green to harvest)	3,695	4,588	4,926	4,198	4,654	4,678	4,478	4,576	4,812	4,840	3,627	3,668	3,810	4,145
Broad beans	1,178	1,249	1,101	879	922	877	959	1,269	932	781	694	779	969	1,113
Stick broad beans	225	177	164	192	166	0	0	0	0	0	0	0	0	0
Areas for total crops	37,326	32,991	29,525	25,259	24,224	22,333	22,393	20,496	20,431	22,197	19,749	20,814	20,886	23,287
Biological nitrogen fixation														
Arable crops	7.33	6.22	5.66	5.18	4.82	4.34	4.35	4.13	4.15	4.48	4.35	4.63	4.27	4.67
Horticultural crops	0.51	0.66	0.59	0.49	0.53	0.51	0.51	0.58	0.53	0.51	0.40	0.42	0.47	0.52
Total crops	7.85	6.88	6.25	5.67	5.35	4.86	4.87	4.71	4.68	4.98	4.75	5.05	4.73	5.18

Dutch translation of crop names are given in footnote 2 in section 3.4

Appendix 5. Crop residues: data per type of crop

English name	Dutch name	Crop residue Kg N/hectare	Part that Remains in field
Arable crops			
Winter wheat	Wintertarwe	28	0.1
Spring wheat	Zomertarwe	28	0.1
Winter barley	Wintergerst	19	0.1
Spring barley	Zomergerst	19	0.1
Rye	Rogge	16	0.1
Oats	Haver	19	0.1
Triticale	Triticale	24	0.1
Green peas and bump cherry	Groene erwten en schokkers	74	1.0
Peas (green to harvest)	Erwten (groen te oogsten)	194	1.0
Marrow fats	Kapucijners	74	1.0
Kidney beans	Bruine bonen	74	1.0
Broad and field beans	Veldbonen	16	1.0
Seed for grass production	Graszaad	28	1.0
Rape	Koolzaad	42	1.0
Caraway	Karwijzaad (actueel jaar)	37	1.0
Oilseed poppy	Blauwmaanzaad	20	1.0
Flax	Vlas	23	1.0
Evening primrose	Teunisbloem	40	1.0
Seed potatoes on sand/org soils	Pootaardappelen op zand of veen	26	1.0
Seed potatoes on clay	Pootaardappelen op klei	26	1.0
Ware potatoes on sand/org soils	Consumptieaardappelen op zand of veen	26	1.0
Ware potatoes on clay	Consumptieaardappelen op klei	26	1.0
Industrial potatoes	Zetmeelaardappelen, totaal	26	1.0
Sugar beets	Oppervlakte suikerbieten	174	1.0
Fodder beets	Oppervlakte voederbieten	92	1.0
Lucerne	Luzerne	23	1.0
Fodder maize	Snijmaïs	22	0.1
Green manure	Groenbemestingsgewassen	80	1.0
Grain maize	Korrelmais	70	1.0
Corn-cob mix	Corn-cob-mix	70	1.0

Continued. Appendix 5

English name	Dutch name	Crop residue Kg N/hectare	Part that Remains in field
Chicory	Cichorei	40	1.0
Hemp	Hennep	40	1.0
Onions	Uien	4	1.0
Remaining arable crops	Overige akkerbouwgewassen	40	1.0
Horticultural crops			
Strawberries	Aardbeien	23	1.0
Endives	Andijvie	78	1.0
Asparagus	Asperges	24	1.0
Gherkins	Augurken	78	1.0
Winter cabbage	Bewaarkool	206	1.0
Cauliflower	Bloemkool	89	1.0
Broccoli	Broccoli	89	1.0
Headed cabbage	Sluitkool	206	1.0
Celeriac	Knolselderij	78	1.0
Garden beet	Kroten	78	1.0
Lettuce	Sla	25	1.0
Leeks	Prei	62	1.0
Salsify and scorzonera	Schorseneren	78	1.0
Spinach	Spinazie	62	1.0
Brussels sprouts	Spruitkool	206	1.0
Tribe broad beans	Stambonen	61	1.0
Stick broad beans	Stokbonen	61	1.0
Broad beans	Tuinbonen	13	1.0
Carrot	Was- en bospeen	99	1.0
Winter carrot	Winterpeen	99	1.0
Chicory carrot	Witlofwortel	78	1.0
Remaining horticultural crops	Overige groenten	78	1.0

Sources: see text on Biological nitrogen fixation crops in section 3.4

Appendix 6. Crop residues: area of crops involved 1990 – 2003

Areas are given in hectare, total nitrogen in crop residues in 10^6 kg N.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Areas for arable crops														
Winter wheat	135,104	115,201	116,697	99,819	98,559	125,599	134,122	124,985	128,276	61,638	120,510	95,791	113,190	105,879
Spring wheat	5,499	8,033	10,195	18,214	23,028	9,813	7,485	12,526	11,038	41,142	16,176	28,931	22,659	24,066
Winter barley	9,941	7,126	6,040	4,398	2,502	3,100	2,673	2,626	3,075	1,980	3,635	3,236	2,660	3,101
Spring barley	30,447	34,791	28,052	35,657	41,169	32,480	32,811	39,329	36,658	56,313	43,537	63,525	54,280	51,924
Rye	8,604	6,997	6,207	7,432	5,603	8,175	6,893	4,980	6,330	2,652	5,961	3,568	3,567	3,535
Oats	3,401	3,324	3,646	5,153	5,518	2,914	1,909	1,955	2,066	2,518	2,404	2,556	2,462	2,527
Triticale	0	2,978	2,367	1,904	1,622	2,579	3,270	2,933	4,429	1,835	6,646	4,808	5,006	4,246
Green peas and bump cherry	10,908	6,887	4,420	2,221	1,394	691	827	674	730	862	752	801	1,138	2,075
Peas (green to harvest)	7,667	7,635	7,579	6,628	6,931	7,131	6,170	4,395	4,589	6,085	5,867	5,534	6,278	6,033
Marrow fats	794	638	917	953	891	367	764	486	424	638	388	700	632	766
Kidney beans	3,730	4,099	2,673	2,348	2,039	2,221	2,856	2,033	1,956	1,935	1,126	1,514	1,556	2,304
Broad and field beans	3,169	2,032	1,670	1,274	802	532	664	1,008	755	648	679	703	522	592
Seed for grass production	26,314	27,957	26,863	27,098	19,755	21,893	21,302	23,882	28,418	21,299	21,960	19,743	17,918	21,599
Rape	8,415	7,070	4,234	2,350	1,424	1,493	878	579	873	1,319	854	707	481	963
Caraway	342	142	141	125	328	1,211	613	236	190	113	138	163	176	183
Oilseed poppy	264	374	108	1,030	3,393	1,411	332	592	1,199	1,452	588	798	368	436
Flax	5,535	4,408	4,727	3,758	4,651	4,407	3,874	4,253	3,498	3,753	4,379	4,755	4,096	4,553
Evening primrose	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Seed potatoes on sand/org soils	5,486	6,004	6,425	5,460	4,754	5,361	6,531	6,459	6,603	6,400	7,096	6,079	4,871	3,855
Seed potatoes on clay	30,101	33,152	34,816	32,963	32,269	32,438	32,206	33,533	33,345	34,614	34,706	33,332	34,088	35,437
Ware potatoes on sand/org soils	16,025	16,420	17,742	14,412	14,401	18,451	20,842	17,327	21,710	24,423	25,632	21,000	26,480	22,062
Ware potatoes on clay	60,869	61,353	63,632	60,229	59,448	61,706	62,764	60,169	62,681	61,842	61,809	54,909	50,733	48,496
Industrial potatoes	62,838	62,650	64,710	62,854	60,154	61,345	62,881	62,414	56,962	52,526	50,958	48,614	48,986	48,794
Sugar beets	124,995	123,316	120,736	116,685	114,509	116,081	116,574	114,066	113,032	119,748	110,998	109,126	108,894	102,787
Fodder beets	3,023	2,817	2,573	2,157	2,066	1,576	1,357	1,166	1,158	991	891	800	731	637
Lucerne	5,960	5,686	6,075	6,566	6,425	5,836	5,675	6,055	6,257	6,408	6,616	7,114	5,981	6,259
Fodder maize	201,811	202,014	217,525	228,683	228,508	219,217	222,872	231,985	219,940	230,746	205,321	203,874	214,403	216,897
Green manure	7,282	12,125	13,368	15,746	16,397	12,248	5,621	2,284	2,347	2,932	2,615	3,453	24,253	24,090
Grain maize	0	11,165	7,790	10,819	11,624	9,005	10,872	12,682	13,698	16,036	20,298	27,173	23,694	24,547
Corn-cob-mix	0	3,237	2,583	3,767	5,236	5,005	5,644	5,416	5,761	5,970	7,219	7,672	6,690	7,067

Continued. Appendix 6

Areas are given in hectare, total nitrogen in crop residues in 10^6 kg N.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Chicory	0	0	0	0	0	0	0	4,222	4,196	4,471	4,756	4,845	4,313	4,792
Hemp	0	0	0	0	0	0	0	1,249	1,083	1,150	792	981	2,079	1,461
Onions	12,828	13,773	14,183	13,578	15,504	16,082	16,674	15,566	18,349	19,682	19,979	20,465	21,101	23,243
Remaining arable crops	8,084	3,120	5,966	7,233	5,399	5,982	9,262	6,691	8,451	8,101	10,883	10,272	9,795	8,768
Areas for horticultural crops														
Strawberries	1,867	1,720	1,761	1,768	1,949	1,763	1,595	1,817	1,968	1,863	1,746	1,721	1,734	1,915
Endives	234	250	248	292	272	276	239	228	260	268	252	262	330	355
Asparagus	2,663	2,641	2,749	2,584	2,389	2,324	2,281	2,243	2,304	2,219	2,084	2,117	2,173	2,423
Gherkins	257	278	146	67	89	0	0	0	0	0	0	0	0	0
Winter cabbage	1,576	1,669	1,768	1,930	1,743	1,784	1,812	1,783	1,765	1,727	1,528	1,388	1,471	1,571
Cauliflower	2,368	2,581	2,722	2,820	2,622	2,430	2,351	2,174	2,250	2,287	2,160	2,175	2,269	2,326
Broccoli	0	0	0	0	0	534	589	618	769	865	846	1,064	1,099	1,165
Headed cabbage	1,002	1,223	1,285	1,269	1,015	1,139	1,234	1,202	1,176	1,219	1,016	1,012	1,149	1,119
Celeriac	1,363	1,344	1,423	1,237	1,208	1,414	1,566	1,448	1,534	1,601	1,285	1,396	1,363	1,327
Garden beet	0	0	0	0	0	353	282	334	408	462	290	360	379	334
Lettuce	955	992	999	1,247	1,004	1,042	1,081	963	935	1,060	1,090	1,082	1,151	1,361
Leeks	2,873	3,552	4,119	3,934	4,250	3,854	3,642	3,746	3,641	3,724	3,184	3,226	3,319	3,241
Salsify and scorzonera	1,395	1,352	1,658	1,687	1,585	1,480	1,608	1,646	1,839	1,601	1,138	1,104	1,169	1,339
Spinach	1,153	945	922	907	881	965	954	1,062	1,195	1,331	1,208	1,164	1,190	1,036
Brussels sprouts	4,803	5,058	5,820	5,728	5,041	4,388	4,235	4,197	4,622	5,207	4,834	4,394	3,890	4,232
Tribe broad beans	3,695	4,588	4,926	4,198	4,654	4,678	4,478	4,576	4,852	4,840	3,627	3,668	3,810	4,145
Stick broad beans	225	177	164	192	166	0	0	0	0	0	0	0	0	0
Broad beans	1,178	1,249	1,101	879	922	877	959	1,269	935	781	694	779	969	1,113
Carrot	3,030	3,127	3,236	3,015	3,225	3,274	3,197	2,981	2,934	3,160	2,985	3,012	2,910	2,830
Winter carrot	2,951	3,932	3,585	3,929	4,296	4,675	4,404	4,197	4,822	5,753	4,729	4,837	4,981	5,439
Chicory carrot	5,919	5,991	4,842	5,161	4,519	3,889	4,020	4,615	4,242	4,759	4,199	3,767	3,692	3,566
Remaining horticultural crops	2,774	3,072	3,286	3,487	3,412	2,867	2,549	3,552	3,858	3,468	3,171	3,072	5,634	4,887
Total area arable crops	799,434	796,524	804,659	801,513	796,300	796,352	807,221	808,756	810,078	802,221	806,169	797,542	824,080	813,976
Total area horticultural crops	42,279	45,743	46,762	46,329	45,243	44,005	43,076	44,652	46,307	48,195	42,067	41,599	44,683	45,725
Total area arable + horticulture	841,713	842,267	851,421	847,842	841,543	840,356	850,297	853,408	856,385	850,415	848,236	839,141	868,763	859,701
Total N in crops res. arable	32.53	33.14	32.40	31.47	30.91	30.84	30.66	29.68	29.85	31.29	30.14	29.90	31.33	30.34
Total N in crops res. horticulture	3.89	4.24	4.42	4.42	4.20	4.08	4.00	4.07	4.27	4.53	3.98	3.87	4.05	4.15
Total N in crop residues	36.42	37.37	36.82	35.89	35.11	34.92	34.67	33.75	34.13	35.82	34.12	33.76	35.38	34.48