Protocol
4D: N_2O from agricultural soil: indirect emissions

IPCC Category:	4D3
NFR Code:	Not applicable
NOSE Code:	Not applicable
NACE Code 2008	011, 012, 014 and 015

Foreword
Under the Kyoto Protocol, the Netherlands is required to set up and maintain a national system to monitor its greenhouse gas emissions. One of the elements of this system is a transparent and verifiable description of the methods and processes used in this monitoring system. These methods must meet international guideline criteria, which have been defined by the United Nations (UN) and the European Union (EU).

The Netherlands meets the aforementioned requirement, for example, by defining a series of Monitoring Protocols, which describe the methods and work processes used to determine greenhouse gas emissions and the amounts of carbon sinks available. Protocols have been written for about 40 greenhouse gas sources or sinks. This document describes the protocol for one of these sources or sinks.

The protocols have been compiled in close collaboration with experts from various sectors of society in the Netherlands, particularly experts from the Emissions Registration (ER). The ER is a collaborative group that includes institutions such as CBS, WUR, RIVM and PBL. Until 31 December 2009 this was coordinated by PBL (Planbureau for the Leefomgeving, or the Netherlands Environmental Assessment Agency), but on 1 January 2010 this coordination task was taken over by RIVM (the Netherlands institute for public health and the environment). Other institutions that have contributed to the protocols include NL Agency; Ministry of Agriculture, Nature and Food Quality; and the Ministry of VROM (Housing, Spatial Planning and the Environment).

1 Scope and significance of emission sources/activities

1.1 Scope and definition
This protocol describes the methodology and working processes for determining the indirect N_2O (laughing gas) emissions from the soil, as a result of agricultural activities in the Netherlands (IPCC category 4D3). This concerns the SBI codes 011 and 012 (arable farming and horticulture), 014 (animal husbandry and breeding) and 015 (arable farming and/or horticulture in combination with animal husbandry and breeding).

The IPCC Guidelines (1997) and the IPCC Good Practice Guidance (2001) give separate estimates of the direct and indirect emissions of laughing gas from the agricultural sector. *Direct* emissions occur in the agricultural system, primarily as a result of the application of fertilisers and animal manure. *Indirect* emissions of laughing gas concern the formation of N_2O in soils and aquatic systems as a result of nitrogen losses from the soil to air and water.

The IPCC differentiates between two sources of indirect laughing gas emissions.

- Indirect laughing gas emissions after atmospheric depositions of nitrogen compounds that have evaporated in the form of ammonia and nitrogen oxides from stables and manure storage, grazing and from fertiliser and animal manure use.
- Indirect laughing gas emissions from aquatic systems through nitrogen (especially nitrate) leaching and runoff from agricultural soils. Nitrate undergoes denitrification in groundwater or surface water, which creates laughing gas.

1.2 Significance and influences

1.2.1 Contribution to total national emissions

Indirect N_2O emissions from the soil contribute about 1% to the Netherlands annual greenhouse gas emissions.

1.2.2 Developments that infuence emissions

Since 1990 indirect emissions of laughing gas have shown a decreasing trend. This fall is the result of reduced ammonia depositions and reduced nitrogen supply to the soil via fertilisers and animal manure, which in turn is the result of the Dutch Government’s fertiliser and ammonia policy (Brandes et al., 2007).

2 Method, emission factors and activity data

2.1 Calculation method

Indirect laughing gas emissions from agricultural soils are calculated by multiplying the amount of nitrogen per supply source by the default IPCC emission factor. The total N_2O emission of all supply sources is then calculated by adding up the N_2O emissions per supply source. Detailed information can be found in the Background Document (Van der Hoek et al., 2007).

$$N_2O \text{ emission (in kg } N_2O) = \sum E_i * EF_i * 44/28$$

E_i	: amount of N for the defined supply source (i)
EF_i	: emission factor for the defined supply source (i), in kg N_2O-N/kg N in supply source.
44/28	: conversion factor from N_2O-N to N_2O

The aforementioned formula differentiates between the following supply sources for agricultural soils.

1. Deposition of ammonia released during manure production and storage, and after application of artificial/animal fertiliser to agricultural soil
2. Leaching and runoff of nitrogen from application of artificial/animal fertiliser to agricultural soil.

Comparison to the IPCC Guidelines and Good Practice Guidance (GPG)

The aforementioned method is very similar to the IPCC method as described in the GPG (IPCC, 2001, p. 4.67). However, one difference is that the IPCC method also includes deposition of NO_x in the calculation. To date, the Netherlands has collated no data within the ER framework on NO_x emissions as a result of the application of artificial/animal fertilisers.

The IPCC also differentiates between two other supply sources.

- N_2O formation in the atmosphere from ammonia emissions.
  The IPCC has no calculation method for this source, therefore the laughing gas emissions created by ammonia in the atmosphere are not included here.
- Discharging effluent from sewage treatment plants into surface water.
  The laughing gas emissions created from discharging effluent into surface water are not included in the agricultural sector, but in the CRF (Common Reporting Format, Category 6B).

Determining the extent of the various supply sources is carried out using country-specific data at tier 2 level. The N_2O emissions are determined via a tier 1 analysis. Default IPCC emission factors are used.

Additional information on the emission factors is included in Section 2.2 of this protocol.

2.2 Emission factors

With respect to *leaching and runoff of the nitrogen added to the soil*, the emission factor concerns that part of the nitrogen that is leaching and running off, the so-called $FRAC_{leach}$. Here too, a fixed (IPCC default) value is used.

The total indirect laughing gas emissions from agricultural soils is calculated by multiplying the amount of nitrogen per supply source by the following emission factors and then aggregating this over all supply sources (Van der Hoek et al., 2007).

Table 1. $FRAC_{leach}$ and laughing gas emission factors for indirect laughing gas emissions from agricultural soil (Van der Hoek et al., 2007).

Supply source	**Factor**
Depositions of NO_x and ammonia	
- laughing gas emission factor	0.01 kg N_2O–N per kg N supply
Leaching and runoff from agricultural soil	
- $FRAC_{leach}$	0.30 kg N per kg N to soil
- laughing gas emission factor	0.025 kg N_2O–N per kg N rinsed off/out

The following section provides additional information on the emission factors used.

Depositions of NO_x and ammonia in the soil
The lack of measurement data in the Netherlands means that default emission factors were chosen when calculating the indirect emissions from laughing gas (Denier van der Gon *et al*., 2004; Van der Hoek *et al.*, 2007).

Leaching and runoff of nitrogen added to the soil
The following calculation rule has to be used to calculate the laughing gas emissions for this supply source.

$$N_2O \text{ emission} = E * FRAC_{leach} * EF * 44/28$$

E	: amount of N in the supply source (kg)
$FRAC_{leach}$	: fraction of the nitrogen that is leaching and running off
EF	: emission factor in kg N_2O-N/kg N in supply source
44/28	: conversion factor from N_2O-N to N_2O

The amount of nitrogen refers to the total amount of fertiliser and the total amount of animal manure, minus the amount exported to other countries. Both the emission factor and the value of the $FRAC_{leach}$ are IPCC default factors. Further background information on the IPCC values for $FRAC_{leach}$ (0.30) and the laughing gas emission factor (0.025) can be found in Seitzinger and Kroeze (1998) and Mosier et al. (1998). Further information concerning the calculations for nitrogen leaching and runoff can be obtained from the Background Document (Van der Hoek *et al*., 2007).

2.3 Activity data

Depositions of NO_x and ammonia on the soil
Although the term 'deposition' is used here, it appears from the IPCC guidelines that this refers not to ammonia depositions by the agricultural sector in the Netherlands, but means the total ammonia emissions in the Netherlands by the agricultural sector. This primarily concerns the total depositions of all ammonia emitted by the Netherlands agricultural sector, whatever the geographical location of these depositions (thus also outside the country's borders).

The extent of the ammonia emission from fertiliser and animal manure (stables, manure storage, manure application and grazing) is all part of the annual calculations within the framework of the Emission Registration. The LEI (Dutch agricultural economic institute) performs these calculations based on the methodology described in Van der Hoek (1994, 2002). Ammonia emissions are published in the Environmental data compendium (http://www.planbureauvoordeleefomgeving.nl).

Leaching and runoff of nitrogen added to the soil
The IPCC Guidelines and Good Practice Guidance clearly indicate that the gross supply refers to nitrogen in fertiliser and animal manure, thus without deducting ammonia evaporation from stables, manure storage, grazing and use of manure. The reason for this is that the leaching and runoff is then the result of (subsequents) depositions of NH_3 and NO_x which are included immediately and do not need to be determined separately. Any manure that is net exported (export – import) to other countries is deducted from the above.

The annual figures showing the amount of nitrogen produced in animal manure are yearly calculated by the Working group for Uniform calculations of Manure and mineral figures (WUM) and published via www.cbs.nl. This applies to both stable manure and meadow manure. The nitrogen in exported manure is determined annually by CBS (published via www.cbs.nl).

All the aforementioned flows of fertiliser and animal manure are included in the annual calculations under the framework of the Emissions Registration. The results are published annually by both the CBS/Statline and Environmental data compendium, and are available from www.cbs.nl and (http://www.planbureauvoordeleefomgeving.nl) respectively.

The default IPCC value of 30% is used for the part of the nitrogen in the soil that is leaching and running off (i.e. the $FRAC_{leach}$ in the IPCC definitions) and then becomes a source of indirect N_2O emissions. The reason for this is that, at the end of 2005, it appeared that further study is required to make the available country-specific data suitable for use in calculations that follow the IPCC definitions.

3 Working processes

Process for estimating (t-1)

If preliminary figures are required at any point, the following process is used to estimate the figure for t-1. The preliminary data for the work package leader are calculated by extrapolating them from the previous years' figures, based on prognoses for the developments in the most important activity data (taken from CBS (Statistics Netherlands) or other statistical sources).

When calculating indirect N_2O emissions from agricultural soils, the data on nitrogen added to agricultural soils and air (NH_3-N) are corrected to take account of changes in animal numbers in (t-1). See also the process for final determination (t-2).

INPUT	PROCESS	OUTPUT	BY WHOM
Preliminary data work package leader (t-1)	Include t-1 data in ER database	ER-db with (t-1) data	Work package leader non-CO_2 ER working group for agriculture and land use
ER-db with (t-1) data	Check emission figures: compare with previous years (trend), modify if required and document everything	ER-db (t-1) with any modified figures	ER working group for agriculture and land use

Process for final determination of (t-2)

The final emission figures (as described in this protocol) are calculated using the following process.

INPUT	PROCESS	OUTPUT	BY WHOM
Gross extent of nitrogen supply Agricultural soil: • Total fertiliser-N use (via LEI/CBS) • Total N-excretion in animal manure (via WUM/CBS) with deduction of N- excretion for manure export (CBS/Statline) **(A)** ***Fracleach*** IPCC default factor (Denier van der Gon et al., 2004 and Van der Hoek et al., 2007) **(B)**	Calculating extent of nitrogen leaching and runoff: **(A) x (B)**	Extent of nitrogen leaching and runoff in Excel spreadsheet **(C)**	Work package leader non-CO_2 ER working group for agriculture and land use

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INPUT	PROCESS	OUTPUT	BY WHOM
N_2O-emission factor leaching and runoff (IPCC default) **(D)**	Calculation of N2O emissions from leaching and runoff (Cx D)	N2O emissions leaching and runoff in Excel spreadsheet **(E)**	Work package leader non-CO2 ER working group for agriculture and land use
Extent of total ammonia-N depositions ***Extent of total NH3-N emission agriculture*** Total NH3-N emission agriculture (via CBS Statline and PBL Environmental data Compendium) **(F)** N_2O emission factor - deposition (IPCC default) (Denier van der Gon et al., 2005; Van der Hoek et al., 2007) **(G)**	Calculating N_2O emission depositions **(F x G)** (Van der Hoek et al., 2007)	N_2O emissions depositions in Excel spreadsheet **(H)**	Work package leader non-CO2 ER working group for agriculture and land use
(E) + (H)	First validation of emission figures via trend analysis and expert judgement	Validated emission figures in Excel spreadsheet (=Final data Work package leader (t-2)) **(I)**	Work package leader non-CO_2 ER working group for agriculture and land use
Final data Work package leader (t-2) **(I)**	Include (t-2) data in ER database	ER-db with (t-2) data **(J)**	Work package leader non-CO_2 ER working group for agriculture and land use
ER-db with (t-2) data **(J)**	Check, and trend analysis of air emissions: explain deviations or modify figures	Final defined emission figures (t-2) **(K)**	ER working group for agriculture and land use

4 Uncertainty and quality

4.1 Estimating uncertainties

A Tier-1 uncertainty analysis is implemented every year before the NIR is submitted by the ER, based on the greenhouse gas inventory and in compliance with IPCC guidelines. The assumptions used and the results thereof are described in a background report to the NIR. In addition to this, where included in the QA/QC programme for the relevant period, extra analyses are implemented regularly in specific situations, which include any updating of the Tier-2 uncertainty analyses. The Tier-2 uncertainty assessment was last updated in 2006. This assessment showed that a Tier-1 uncertainty assessment is sufficiently reliable and that Tier-2 uncertainty assessments need only be implemented at periodic intervals of around 5 years, unless a major change in an important source is sufficient to require earlier reassessment.

- Source-specific uncertainty
The uncertainty estimate $_{total}$ concerns the root of the sum of uncertainty in the data sources used (AD_{onz}) in the square and the uncertainty of the emission factor (EF_{onz}) in the square. The extent of the total uncertainty is here primarily determined by the greatest AD or EF uncertainty.

$$\text{Uncertainty estimate}_{total} = \sqrt{EF_{onz.}^{\;2} + AD_{onz.}^{\;2}}$$

The uncertainty estimates concerning the data sources (AD) and emission factors (EF) used, and the total uncertainty estimate, are listed in the following table.

IPCC	Category	Gas	AD onz.	EF onz.	Uncertainty estimates tot
4D3	Indirect N_2O emissions from nitrogen used in agriculture	N2O	50	200	206

4.2 Quality assurance and quality control (QA/QC)

The ER work package leaders check that:
1. the basic data are well documented and adopted (check for typing errors, use of the correct unit sizes and correct conversion);
2. the calculations have been implemented correctly;
3. assumptions are consistent, also whether specific parameters (e.g. activity data) are used consistently;
4. complete and consistent data sets have been supplied.

Any actions that result from these checks are noted on an ‘action list’. Before defining the data, supervisors check whether the relevant actions on this list, plus the QC checks, have all been completed. Defining the data is carried out by the WEM (working group on emissions monitoring), and confirmed in writing via an e-mail from the institute representatives to the ER project leader at PBL.

The work package leaders fill out a new documentation sheet when adding new data. For reasons of efficiency a minimum level has been set for obligatory documentation, i.e. 5% changes at target group level, and 0.5% at levels concerning the national total. These documentation sheets form part of the trend analysis, as well as the eventual definition of the data set.

The ER work package leaders communicate by e-mail regarding these QC checks, results and actions. They send a printed copy to the ER secretary, who keeps a logbook and compiles these e-mails into an ‘action list’. This shows explicitly that the required checks and corrections have been carried out.

4.3 Verification

In order to check the quality of the emission figures for the sources in this protocol, general QA/QC procedures have been followed that are in line with the IPCC guidelines. These are described further in the QAQC programme used by the National System, and the annual working plans published by the ER.

- Sector-specific QC
No additional specific verification procedures are implemented for the sources defined in this protocol.

4.4 Possibilities for improvement compared to the current calculation method

4.4.1 History

At the beginning of the 1990s, a country-specific calculation of indirect laughing gas emissions was implemented (Kroeze, 1994), which was based on the preliminary IPCC protocol. This was later summarised into a description of the methodology (Spakman et al, 1997). At the beginning of 2005, the method of calculating indirect laughing gas emissions was revised and brought into line with the IPCC Guidelines and Good Practice Guidance (Van der Hoek et al., 2007). This also fits in with the conclusions in Denier van der Gon et al. (2004), which recommends initially using the default IPCC method, due to the lack of country-specific data.

In the old calculation method, a so-called increased background emission was calculated, which was partially based on laughing gas emissions from the animal manure used in the past. An N_2O emission from surface water was also reported as a fixed value, including CRF category 7 (Other). Around 75% of these emissions were attributable to agriculture.

The main modification in the current protocol is that the increased background emission and the percentage from agriculture in the fixed value for N_2O emission from surface water have been replaced by the indirect emission of laughing gas through leaching and runoff of agricultural soils. In addition, the laughing gas emissions resulting from the depositions of ammonia are also taken into account. At the beginning of 2005 the calculations also included NO_x emissions as a source of depositions. The NO_x emissions resulting from the use of artificial/animal fertilisers are not (yet) included in the annual calculations under the ER framework. Therefore the extent of these NO_x emissions was based on De Vries *et al*., 2003. However, as with the final determination of the calculation methods under the framework of the Kyoto Protocol (end 2005), this was cancelled because apparently this estimate was very uncertain. The figure used covered only one year, and this year was not even representative for other years with respect to differences in implementing the various manure application techniques (Van der Hoek *et al*., 2007).

A consistent timeseries is now available. Fur-covered animals have been added for the years 1990 and 1991, and for cattle (1990-1994) the meat calves have been split into meat calves (rosé veal) and meat calves (white veal) (the same as with following years). The timeseries is now also complete because horses and ponies are included.

Another modification concerns the activity data used for nitrogen in used animal manure and in meadow manure, as well as for manure exports (see protocol 4D: N_2O, Agricultural soil: direct emissions and grazing emissions).

This is partially the result of a change in activity data used for N_2O emissions arising from manure storage (see protocol 4B N_2O on Manure Management). From 2005 onwards the WUM figures form the basis for nitrogen excretions per manure management system (see also Section 2.3), although activity data were previously taken from that used in ammonia calculations. These activity data are also based on WUM nitrogen excretion factors and lead to roughly the same amounts for total nitrogen excretion, but the distribution differs between stable manure and meadow manure. Compared to the WUM figures when calculating ammonia, the indoor nitrogen excretions are generally somewhat higher and the outdoor (meadow) nitrogen excretions are somewhat lower. This results from the different starting points used when calculating ammonia emissions. Since the WUM figures concerning nitrogen excretions (both indoors and outdoors) form the basis for the ammonia calculations, it has been decided that this information should also form the basis for the N_2O calculations (rather than use possibly modified data, such as that used for ammonia calculations).

In addition, from 2005 onwards the data on exported manure are taken from the CBS statistics, although previously the activity data were taken from the figures used for ammonia calculations. This also led to a modification in the total amount of manure used.

The N-excretion figures for all animal categories have been recalculated in 2009. The previous method did not take account of feed losses, and the feed intake by dairy cattle was underestimated. The N-excretions are calculated on the basis of feed intake.

Figures for horses and ponies (from 1990 onwards) have also been recalculated in 2009. Before this date the N-excretion factors used did not differentiate between horses and ponies [Van der Hoek *et al*., 2006]. However, from the NIR 2009 onwards, the N-excretion factors for horses and ponies are calculated via the same method used to calculate all other animal categories. The N-excretion factors are available from 2006 onwards. The figures for 2006 are also used for all preceding years.

4.4.2 Future

A default figure of 30% (of the added nitrogen) is used for nitrogen that is leached and runoff from agricultural soil ($FRAC_{leach} = 0.30$). This means that a relatively large amount of nitrogen leaves the root zone and therefore, theoretically, could cause higher nitrate levels in the top groundwater levels than those usually detected. Developing country-specific data for the $FRAC_{leach}$ (and also any associated emission factor) leads to a better approach to the practical situation in the Netherlands.

When calculating the amounts of nitrogen that are associated with *leaching of nitrogen that has been applied to the soil*, manure removed for processing and (co)-digestion can, in future, be deducted from these amounts. As a result (in the future), processed or digested manure can be used on agricultural soils, but this nitrogen must be included as a supply source. Information on the extent of this new subcategory is required before an accurate calculation can be made.

The supply source *sewage sludge* is not included in the calculation of indirect N_2O emissions from agricultural soil. According to the IPCC Guidelines, this source must also form part of the calculations. However, this is a very small source. One question that also needs to be answered is whether other sources of nitrogen in agricultural soils (in addition to artificial/animal fertilisers) also need to be included in these calculations, e.g. crop residues, N-fixing crops and histosols. The IPCC Guidelines make no mention of these.

The supply source of NO_x depositions as a result of application of artificial fertilisers and animal manure are not included in calculations of indirect N_2O emissions from agricultural soils. There are no monitoring data available, because this supply source is not included in the annual calculations for the ER.

5 Remaining aspects

5.1 Point source criteria
Not applicable

5.2 Substance profiles
Not applicable

5.3 Regionalisation
Not applicable

5.4 Time-based variations in source strength
Not applicable

6 References and additional information

6.1 References

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6.2 Additional information

Not applicable