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# Effects of measures on nitrous oxide emissions from agriculture

Using INITIATOR and IPCC methods

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# Effects of measures on nitrous oxide emissions from agriculture

Using INITIATOR and IPCC methods

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## Abstract

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The mandatory national reporting of nitrous oxide (N<sub>2</sub>O) emissions under the UN Climate Change Convention is usually done with the IPCC inventory approach using default emission factors for N<sub>2</sub>O emissions from different sources. Although simple and transparent, the drawback is that emissions will change with management and these effects cannot be included. Here we compare results of calculated national N<sub>2</sub>O emissions with the model INITIATOR and IPCC methods for the year 2000 before and after inclusion of various measures. Although results on a national basis appear to be quite comparable (within 20%), deviations can be large for peat soils and INITIATOR calculates larger reductions in N<sub>2</sub>O emissions from various emission reduction measures than the IPCC methods. This is logical since changes in the efficiency of use of nitrogen is not included in the IPCC factors. To adequately account for these impacts, the standard IPCC methodology should be updated.

Keywords: nitrous oxides, emissions, IPCC, Kyoto protocol, agriculture, management

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# Summary

The mandatory national reporting of nitrous oxide ( $\text{N}_2\text{O}$ ) emissions under the UN Climate Change Convention is usually done with the IPCC inventory approach, using various default emission factors for  $\text{N}_2\text{O}$  emissions from different sources. The standard IPCC emission factor approach is simple, transparent and can be used by the wide range of people who have responsibility for inventory reporting. One of the problems is, however, that emissions will change with management and these effects cannot be included. One of the approaches to bridge this gap and improve the standard IPCC emission factor approach is to use relatively simple models, such as INITIATOR. This model calculates N inputs and N losses both to the atmosphere, distinguishing ammonia ( $\text{NH}_3$ ), nitrous oxide ( $\text{N}_2\text{O}$ ), nitrogen oxides ( $\text{NO}_x$ ) and di nitrogen ( $\text{N}_2$ ), and to water, distinguishing between nitrate ( $\text{NO}_3$ ) and ammonium ( $\text{NH}_4$ ), on a regionally explicit basis.

Here we compare results of calculated  $\text{N}_2\text{O}$  emissions on the basis of INITIATOR and two IPCC methods in terms of an inventory of national emissions and with respect to the effects of measures on those emissions. The first IPCC approach is the one used by the Netherlands in their official estimation of greenhouse gas emissions in a national inventory report and the second one is the current formal IPCC methodology including default emissions factors. In order to compare the  $\text{N}_2\text{O}$  emissions, calculated with INITIATOR, with those derived by IPCC methods, the latter methods are included in the model, implying that the same activity data are used in all approaches.

The total  $\text{N}_2\text{O}$  fluxes calculated by the two IPCC methods and by INITIATOR on a national basis appeared to be quite comparable (within 20%). Relatively large deviations, however, occurred for peat soils, where both IPCC methods assume a constant  $\text{N}_2\text{O}$  emission by mineralisation ( $4.7$  or  $8 \text{ kg} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ ) whereas INITIATOR calculates the  $\text{N}_2\text{O}$  emission as a function of the ground water level, influencing the mineralisation, nitrification and denitrification rates. The uncertainties calculated with both methods is large and ranges between 50-70% of the average estimate, implying a large overlap in the calculated range of both methods.

Results of impacts of various measures to reduce inputs and emissions of nitrogen to atmosphere, soil and water on  $\text{N}_2\text{O}$  emissions, as calculated by the three methods, showed that INITIATOR calculates larger reductions in  $\text{N}_2\text{O}$  emissions from various emission reduction measures than the two IPCC methods. This is logical since the IPCC methods only respond to changes in activity data affecting the N inputs, whereas INITIATOR also includes changes in the efficiency of the use of nitrogen, an effect is not included in the IPCC factors. To adequately account for these impacts, the standard IPCC methodology should be updated by using factors that account for management differences.



# 1 Introduction

Nitrous oxide ( $\text{N}_2\text{O}$ ) is a powerful greenhouse gas and is formed during biogenic transformations in soil. The mandatory national reporting under the UN Climate Change Convention is usually done with the IPCC inventory approach using various default emission factors for  $\text{N}_2\text{O}$  emissions from different sources. In agricultural ecosystems, the main source is emission in response to nitrogen inputs by fertilizer and manure. The IPCC Guidelines suggest three different tier methodologies with increasing detail and precision: tier 1 as a simple methodology with default emission factors, tier 2 as a country specific methodology with measured emission factors for specific conditions and sources and tier 3 for efforts including budget and process models. Tier 2 or tier 3 methodologies for a country may be (i) relatively simple process based ecosystem model approaches, focusing on annual GHG emission estimates in response to agricultural management (tier 2) and (ii) detailed ecosystem model approaches that include seasonal dynamics and hydrological aspects at short time scale (tier 3). Depending on the availability of statistical information and models, guidelines on reporting will enable countries to choose their level of detail going from simple tier 1 to detailed tier 3 reporting. The IPCC emission factor approach, using standard tier 1 or updated tier 2 emission factors is simple, transparent and can be used by the wide range of people who have responsibility for inventory reporting. The problems in connection with  $\text{N}_2\text{O}$  emissions are, amongst others, that emissions will change with management, climate/ weather and soil type and hence emission factors will change as well. At present only few of the emission factors depend on these factors (an example is the differentiation between organic soils and mineral soils as discussed in Section 2).

Complex dynamic process models (tier 3), such as DNDC (Li et al., 1992; Li et al., 1994), do not necessarily have these disadvantages and they can also be used to estimate the effect of different management practices and climatic differences on  $\text{N}_2\text{O}$  emissions. That is true as long as the impact of management and climate is adequately recognized and parameterized in the model, requiring monitoring of both aspects. The advantage of the DNDC model is further that it has been extensively tested and shows reasonable agreement between measurements and model results for many different ecosystems (e.g. Li, 2000; Stange et al., 2000; Brown et al., 2001; Smith et al., 2002; Li et al., 2004; Kesik et al., 2005). The disadvantage of such a model is the extensive data requirement, specifically with regards to agricultural management and soil parameters. Even though the model has been applied on a national and even continental scale (Li et al., 1996; Brown et al., 2001; Butterbach-Bahl et al., 2001; Kesik et al., 2005; Pathak et al., 2005), there is a trade-off between model complexity and data availability, thus making the results on this scale highly uncertain. It is therefore important to develop a methodology that helps to bridge the generic approach using default IPCC emission factors (tier 1) and the sophisticated approach using complex process oriented biogeochemical models (tier 3).

One of the approaches to bridge this gap and improve the standard IPCC emission factor approach is to use relatively simple models, such as INITIATOR (De Vries et al., 2003) or its follow up version INTITIATOR2 (De Vries et al., 2005), being an intermediate approach (Tier 2) between a simple default emission factor approach (Tier 1) and a complex dynamic process model (DNDC) approach (Tier 3). The INITIATOR model calculates N fluxes on a regionally explicit basis, including calculated emissions of  $\text{N}_2\text{O}$ . The model can be used on a country scale since the data requirements are modest and region specific estimates can be made for most parameters. The INITIATOR model also allows to evaluate more management measures. Effective management of emissions of nitrous oxide follows three principles: structural, technical or management measures. The first two change the activity or area whereas the latter changes the efficiency of use of nitrogen and this effect is not included in the IPCC factors.

In this study, we compare results on N<sub>2</sub>O emissions in the Netherlands on the basis of the INITIATOR model and the IPCC approach, while accounting for the uncertainties in both approaches. Furthermore, we evaluated the impacts of various measures on the calculated N<sub>2</sub>O emissions in the Netherlands by both methods, focusing on measures that aim to reduce ammonia emissions.

With respect to the IPCC methodology, a distinction was made between the calculations applied by: The Netherlands in their official estimation of greenhouse gas emissions and the national inventory report (Van der Maas et al., 2010). The formal most recent IPCC method (IPCC, 2006a), being an update of the method introduced by Mosier (1998a).

The methods mainly differ in their categorization of N<sub>2</sub>O fluxes and the parameterization of these fluxes. In order to compare the N<sub>2</sub>O emissions, calculated with INITIATOR, with those derived by IPCC methods, the latter methods are included in the model using INITIATOR codes for the abbreviation of N<sub>2</sub>O and N fluxes.

A short overview of both IPCC methods and INITIATOR and their parameterization is given in Chapter 2, including a scaling approach for INITIATOR to derive the N<sub>2</sub>O fluxes from inputs of grazing animals, animal manure, fertilizers, deposition, fixation and net mineralisation separately. A comparison of the results by the two IPCC methods and INITIATOR is given in Chapter 3, including an overview of the N<sub>2</sub>O fluxes on a national scale as induced by the various N inputs mentioned above, the uncertainties in those results and an evaluation of effects of measures on those emissions. Chapter 4 presents the conclusions of this study.

## **2 Calculation of nitrous oxide emissions with IPCC methods and INITIATOR**

Both the IPCC methods and INITIATOR assess the N<sub>2</sub>O emissions due to anthropogenic inputs, while neglecting natural N<sub>2</sub>O emissions. Natural N<sub>2</sub>O emissions are estimated in the order of 0.3-0.5 kg N.ha<sup>-1</sup>.yr<sup>-1</sup> (Kroeze, 1994). Kroeze (1994) included this source to calculate the total annual input of nitrous oxide from the biosphere into the atmosphere and compare the calculated input with the observed changes in nitrous oxide concentration in the atmosphere. However, for an intercomparison with of INITIATOR results with IPCC estimates, such an inclusion is not necessary. In this chapter, we first describe the standard IPCC method and the one used in the Netherlands and the approach used in INITIATOR (Section 2.1). We then summarize the approach used to assess uncertainties in the N<sub>2</sub>O emissions by both approaches (Section 2.2) followed by an overview of the measures, and their parameterization in both IPCC methods and INITIATOR, that were applied to assess effects on N<sub>2</sub>O emissions by those methods (Section 2.3).

### **2.1 IPCC methods and INITIATOR approach**

#### **2.1.1 Introduction**

IPCC Guideline development for agricultural emissions started in the mid-1990s (IPCC, 1997; Mosier et al., 1998b; Kroeze et al., 1999) and was updated in 2006 (IPCC, 2006b; De Klein et al., 2007). The IPCC method as used in the Netherlands for their national inventory report (NIR) is described in Van de Maas et al. (2010). This method is further referred to as NIR 2010. In the IPCC approach, a distinction is made in N<sub>2</sub>O emissions due to livestock housing, direct emissions due to soil inputs by manure and fertiliser application, biological fixation, crop residues, grazing animals and mineralisation in peat soils and indirect emissions due to N deposition and N leaching. Unlike, the IPCC methods, INITIATOR calculates N<sub>2</sub>O emissions as a function of nitrification and denitrification fluxes, which in turn are a function of the net N input (all N inputs corrected for N uptake and NH<sub>3</sub> emission), as described by De Vries et al. (2003). A comparison of the various approaches is given in Table 1. The main difference between the IPCC methods and INITIATOR is that the N<sub>2</sub>O emission from the soil is related to the N input in both IPCC methods and to the N that remains in the soil after N uptake in INITIATOR.

**Table 1**

A comparison of terms included in the IPCC methods and in INITIATOR (De Vries et al., 2003) and the allocation of N<sub>2</sub>O emission sources to different categories.

N <sub>2</sub> O emission source	Allocation to categories	
	IPCC (2006a)/ NIR 2010	INITIATOR
<b>Manure storage</b>	Livestock	Housing
<b>Manure application</b>	Direct	(De)nitrification soil
<b>Grazing</b>	Direct	(De)nitrification soil
<b>Fertiliser</b>	Direct	(De)nitrification soil
<b>Crop residues</b>	Direct	Not explicitly included
<b>Fixation</b>	Direct <sup>1</sup>	Denitrification soil
<b>Mineralisation peat soils</b>	Direct	Denitrification soil
<b>Deposition<sup>1</sup></b>	Indirect	Denitrification soil
<b>Leaching/runoff</b>	Indirect	(De)nitrification ground and surface water

<sup>1)</sup> Not included in the formal IPCC method

<sup>2)</sup> It is important to note that N<sub>2</sub>O emission due to atmospheric deposition in the IPCC methods (NIR, 2010 and IPCC, 2006a) is related to the N emissions (IPCC reporting method) and in INITIATOR to the N deposition.

## 2.1.2 Assessment of N<sub>2</sub>O emissions by IPCC

### Overall approach

Mosier et al. (1998a) were the first to present the methodology that was excepted by IPCC to form the standard and default methodology according to which countries are required to report on their national emissions inventory under the climate agreement to the UNFCCC. Since then, various updates have been made and the most recent approach is the one described in the guidelines of 2006 (IPCC, 2006a). Both in IPCC (2006a) and in the adapted Dutch approach (Van der Maas et al., 2010), total N<sub>2</sub>O emission from agriculture is calculated according to:

$$N_2O_{em,tot} = N_2O_{em,livestock} + N_2O_{em,direct} + N_2O_{em,indirect} \quad (1)$$

where:

$N_2O_{em,livestock}$  = N<sub>2</sub>O emissions due to animal housing (kg N.ha<sup>-1</sup>.yr<sup>-1</sup>)

$N_2O_{em,direct}$  = N<sub>2</sub>O emissions due to soil inputs by manure and fertiliser application, biological fixation, crop residues, grazing animals and mineralisation in peat soils (kg N.ha<sup>-1</sup>.yr<sup>-1</sup>)

$N_2O_{em,indirect}$  = N<sub>2</sub>O emissions due to N deposition and N leaching (kg N.ha<sup>-1</sup>.yr<sup>-1</sup>)

In the IPCC approach, the N<sub>2</sub>O emissions due to livestock are calculated as a fraction of the N excretion, depending on the housing or manure storage system. The direct N<sub>2</sub>O soil emissions induced by N inputs in managed 'agricultural' land are calculated as a fraction of the N input with N<sub>2</sub>O emission factors (in % of the N input) depending on the kind of N input, i.e. synthetic N fertiliser, organic N fertiliser (e.g. animal manure, compost, sewage sludge), crop residues, N fixation, N mineralisation and urine and dung N by grazing animals. In the IPCC approach, the N<sub>2</sub>O emissions due to N deposition are calculated as so-called indirect emissions, being 1% of the N volatilized from managed soils. Similarly, indirect emissions due to N leaching are calculated, assuming a certain leaching fraction of the net N input. In this intercomparison, all activity data are assumed equal and are based on the INITIATOR data or calculations for N inputs, N deposition and N leaching. The differences in direct and indirect emissions calculated by INITIATOR and the IPCC methods (both the Dutch approach and the formal IPCC method) thus only differ in emission fractions or functions and not in activity data. Below, the details of the calculations used are presented.

## N<sub>2</sub>O emissions from livestock

N<sub>2</sub>O emission due to excretion from livestock, stored in housing and manure management systems, is calculated as:

$$N_{2O_{em,h}} = frN_{2O_{em,h}} \cdot N_{ex} \quad (2)$$

where

$$\begin{aligned} N_{2O_{em,h}} &= N_{2O} \text{ emission induced by housing (manure storage) (kg N.ha}^{-1} \cdot \text{yr}^{-1}) \\ frN_{2O_{em,h}} &= N_{2O} \text{ emission fraction from excreted manure in housing (manure storage) systems (-)} \\ N_{ex} &= N \text{ excretion (kg N.ha}^{-1} \cdot \text{yr}^{-1}) \end{aligned}$$

The N<sub>2</sub>O emission fractions vary as a function of the animal housing system. For liquid systems (used for pigs) the value differs from the one used for solid storage (used for cows and poultry), as shown in Table 2 for both the Dutch NIR 2010 (Van der Maas et al., 2010) method and standard IPCC (2006a) method.

## Direct N<sub>2</sub>O emissions

Direct N<sub>2</sub>O emissions are calculated according to:

$$N_{2O_{em,direct}} = N_{2O_{em,am}} + N_{2O_{em,g}} + N_{2O_{em,f}} + N_{2O_{em,cr}} + N_{2O_{em,fix}} + N_{2O_{em,mi}} \quad (3)$$

where

$$\begin{aligned} N_{2O_{em,am}} &= N_{2O} \text{ emission due to manure application (kg N.ha}^{-1} \cdot \text{yr}^{-1}) \\ N_{2O_{em,g}} &= N_{2O} \text{ emission due to input of faeces and urine by grazing animals (kg N.ha}^{-1} \cdot \text{yr}^{-1}) \\ N_{2O_{em,f}} &= N_{2O} \text{ emission due to fertiliser (kg N.ha}^{-1} \cdot \text{yr}^{-1}) \\ N_{2O_{em,cr}} &= N_{2O} \text{ emission due to crop residues (kg N.ha}^{-1} \cdot \text{yr}^{-1}) \\ N_{2O_{em,fix}} &= N_{2O} \text{ emission due to biological fixation (kg N.ha}^{-1} \cdot \text{yr}^{-1}) \\ N_{2O_{em,min}} &= N_{2O} \text{ emission due to mineralisation of organic soils (kg N.ha}^{-1} \cdot \text{yr}^{-1}) \end{aligned}$$

N<sub>2</sub>O emission fluxes due to input by animal manure, grazing, fertiliser and biological fixation are calculated according to:

$$N_{2O_{em,am}} = frN_{2O_{em,am}} \cdot N_{in,am} \quad (4)$$

$$N_{2O_{em,g}} = frN_{2O_{em,g}} \cdot N_{in,g} \quad (5)$$

$$N_{2O_{em,f}} = frN_{2O_{em,f}} \cdot N_{in,f} \quad (6)$$

$$N_{2O_{em,fix}} = frN_{2O_{em,fix}} \cdot N_{fix} \quad (7)$$

The various N<sub>2</sub>O emission fractions as used by NIR 2010 and IPCC (2006a) are given in Table 1. Table 1 shows that different fractions are used for the N<sub>2</sub>O emission induced by urine input (2%) and faeces input (1%) in the NIR 2010 method, whereas the IPCC (2006a) method distinguishes between excretions in the field by cattle, pig and poultry (2%) and by sheep and other animals (1%). The N input by urine and faeces is calculated in INITIATOR assuming that 60% of the total N input by grazing is urine and 40% is faeces (see Kroeze, 1994). The N input by excretions in the field calculated by INITIATOR shows further that 88% of the total N input by grazing is faeces/urine by cattle, pig and poultry and 12% by sheep and other animals. N<sub>2</sub>O emissions due to urine and faeces input or due to input by different cattle sources can now be calculated by distinguishing the different N<sub>2</sub>O emission fractions according to:

$$N_{2O_{em,g}} = frN_{2O_{em,g,ur}} \cdot N_{in,ur} + frN_{2O_{em,g,fae}} \cdot N_{in,fae} \quad (8)$$

$$N_{2O_{em,g}} = frN_{2O_{em,g,cattle}} \cdot N_{in,cattle} + frN_{2O_{em,g,sheep}} \cdot N_{in,sheep} \quad (9)$$

In the NIR method, distinction is also made between (i) application method for manure (included in the GIAB database used by INITIATOR), (iii) ammonium or nitrate input in case of chemical fertilizer and (iv) soil type, i.e. organic soils versus mineral soils (see Table 1). In the Netherlands, ammonium nitrate is the dominant fertilizer (CBS, FAO) and therefore we assumed that 50% of the incoming fertilizer is  $\text{NH}_4$  and the other 50% is nitrate.

$\text{N}_2\text{O}$  emission due to N input by crop residues in arable land, including maize land, is calculated as:

$$\text{N}_2\text{O}_{\text{em,cr}} = \text{frN}_2\text{O}_{\text{em,cr}} \cdot \text{N}_{\text{up}} / \text{N}_{\text{index}} \quad (10)$$

The N index stand for the ratio of nitrogen in the N removed from the field by harvesting and the N remaining in crop residues. The ratio  $\text{N}_{\text{up}} / \text{N}_{\text{index}}$  in Eq. (16) thus equals the N remaining in crop residues. For non N fixing crops, Mosier et al. (1998a) used a fixed N index of 0.9. This index is based on the assumption that the total crop biomass is twice as high as the edible crop biomass and that 45% of the nitrogen is removed from the field with the harvest, because of slightly different N contents in the edible and non-edible parts of the crop. For crops in the Netherlands, this N index seems, however, far too low. On the basis of N index data in a literature review by Velthof and Kuikman (2000) and the estimated land areas of those crops, the average  $\text{N}_{\text{index}}$  for arable land is 2.27. For maize, the  $\text{N}_{\text{index}}$  is even much higher, being equal to 4.91. For grassland, there are no real crop residues to be included in the calculation.

The  $\text{N}_2\text{O}$  emissions due to mineralisation of organic soils, mainly caused by drainage of those soils, are given as input data depending on land use as shown in Table 2. The  $\text{N}_2\text{O}$  emission due to mineralisation of peat soils,  $\text{N}_2\text{O}_{\text{em,min}}$ , is estimated at 8 kg  $\text{N}_2\text{O-N} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$  for temperate regions by IPCC, being almost twice as much as the total value used by NIR 2010 (see Table 2).

### Indirect $\text{N}_2\text{O}$ emissions

Indirect  $\text{N}_2\text{O}$  emissions are calculated as:

$$\text{N}_2\text{O}_{\text{em,indirect}} = \text{N}_2\text{O}_{\text{em,dep}} + \text{N}_2\text{O}_{\text{em,le}} \quad (11)$$

where

$\text{N}_2\text{O}_{\text{em,dep}}$  =  $\text{N}_2\text{O}$  emission due to atmospheric deposition (kg  $\text{N} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ )

$\text{N}_2\text{O}_{\text{em,le}}$  =  $\text{N}_2\text{O}$  emission due to leaching/runoff to ground- and surface water (kg  $\text{N} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ )

The various terms are calculated as:

$$\text{N}_2\text{O}_{\text{dep}} = \text{frN}_2\text{O}_{\text{em,dep}} \cdot (\text{NH}_{3,\text{em}} + \text{NO}_{\text{x,em}}) \quad (12)$$

$$\text{N}_2\text{O}_{\text{em,le}} = \text{frN}_2\text{O}_{\text{em,le}} \cdot \text{N}_{\text{le}} \quad (13)$$

It is important to note that the  $\text{N}_2\text{O}$  emission due to atmospheric deposition is related to the N ( $\text{NH}_3$  and  $\text{NO}_x$ ) emissions in IPCC and not to the deposition, by assuming that this amount is ultimately deposited, although partly not in our own country (IPCC reporting method). In the intercomparison between INITIATOR and IPCC, we used, however, the N deposition in both cases to assess the  $\text{N}_2\text{O}$  emissions. Values used for  $\text{frN}_2\text{O}_{\text{em,dep}}$  and  $\text{frN}_2\text{O}_{\text{em,le}}$  in the Netherlands (Van der Maas et al., 2010) and by the formal IPCC approach (IPCC, 2006a) are given in Table 1.

Multiplication of the total  $\text{N}_2\text{O-N}$  fluxes in Table 1 with the respective land areas directly gives the national current background  $\text{N}_2\text{O-N}$  emissions ( $\text{GgN} \cdot \text{yr}^{-1}$ ), being the sum of natural (background) and land use induced  $\text{N}_2\text{O}$  emissions. These emissions include the nitrous oxide formed from fertilization and management of crop residues in the past 200 years and is considered to be constant.



### 2.1.3 Assessment of N<sub>2</sub>O emissions by INITIATOR

Total N<sub>2</sub>O emission is calculated in INITIATOR as (De Vries et al., 2003):

$$N_2O_{em,tot} = N_2O_{em,h} + N_2O_{em,s} + N_2O_{em,le} \quad (14)$$

where:

$$\begin{aligned} N_2O_{em,h} &= N_2O \text{ emission due to animal housing (kg N.ha}^{-1}\text{.yr}^{-1}) \\ N_2O_{em,s} &= N_2O \text{ emission from soil due to N inputs (kg N.ha}^{-1}\text{.yr}^{-1}) \\ N_2O_{em,le} &= N_2O \text{ emission due to N leaching and runoff to ground and surface water (kg N.ha}^{-1}\text{.yr}^{-1}) \end{aligned}$$

N<sub>2</sub>O emission due to housing is comparable to Eq. (2). The N<sub>2</sub>O emission fractions, however, differ and are related to a large number of different housing systems.

#### N<sub>2</sub>O emissions from soil due to N inputs

N<sub>2</sub>O emissions are due to nitrification, followed by denitrification of N inputs by animal manure and fertiliser application, grazing animals, fixation, atmospheric deposition and net mineralisation in peat, corrected for N emissions and N uptake according to:

$$N_2O_{em,s} = N_2O_{em,ni,s} + N_2O_{em,de,s} \quad (15)$$

$$N_2O_{em,ni,s} = frN_2O_{em,ni} \cdot N_{ni,s} \quad (16)$$

$$N_2O_{em,de,s} = frN_2O_{em,de} \cdot N_{de,s} \quad (17)$$

with:

$$N_{ni,s} = frN_{ni,s} \cdot (N_{in,am} + N_{in,g} + N_{in,f} + N_{fix} + N_{dep} + N_{mi,s} - N_{em,a} - N_{up}) \quad (18)$$

$$N_{de,s} = frN_{de,s} \cdot N_{ni,s} \quad (19)$$

where:

$$\begin{aligned} N_2O_{em,ni,s} &= N_2O \text{ emission from soil due to nitrification (kg N.ha}^{-1}\text{.yr}^{-1}) \\ N_2O_{em,de,s} &= N_2O \text{ emission from soil due to denitrification (kg N.ha}^{-1}\text{.yr}^{-1}) \end{aligned}$$

Combination of Eq. (16)-(20) leads to:

$$N_2O_{em,s} = frN_2O_{em,s} \cdot (N_{in,net} - N_{up}) \quad (20)$$

with:

$$frN_2O_{em,s} = frN_{ni,s} \cdot (frN_2O_{em,ni} + frN_{de,s} \cdot frN_2O_{em,de}) \quad (21)$$

$$N_{in,net} = N_{in,am} + N_{in,g} + N_{in,f} + N_{fix} + N_{dep} + N_{mi,s} - N_{em,a} \quad (22)$$

Unlike the IPCC methods, the fraction  $frN_2O_{em,s}$  varies in as a function of soil type and groundwater level which all influence the nitrification and denitrification fractions ( $frN_{ni,s}$  and  $frN_{de,s}$ ) and the N<sub>2</sub>O emission fractions related to these processes ( $frN_2O_{em,ni}$  and  $frN_2O_{em,de}$ ).

Allocation of the N<sub>2</sub>O emissions to the various inputs is possible by scaling according to (compare Eq. (4)-(7)):

$$N_2O_{em,am} = N_2O_{em,s} \cdot \left( \frac{N_{in,am} - N_{em,am}}{N_{in,net}} \right) \quad (23)$$

$$N_2O_{em,g} = N_2O_{em,s} \cdot \left( \frac{N_{in,g} - N_{em,g}}{N_{in,net}} \right) \quad (24)$$

$$N_2O_{em,f} = N_2O_{em,s} \cdot \left( \frac{N_{in,f} - N_{em,f}}{N_{in,net}} \right) \quad (25)$$

$$N_2O_{em,fix} = N_2O_{em,s} \cdot \frac{N_{fix}}{N_{in,net}} \quad (26)$$

$$N_2O_{em,dep} = N_2O_{em,s} \cdot \frac{N_{dep}}{N_{in,net}} \quad (27)$$

$$N_2O_{em,mi} = N_2O_{em,s} \cdot \frac{N_{mi,s}}{N_{in,net}} \quad (28)$$

Another difference between the IPCC methods and INITIATOR is that  $N_2O$  emissions related to N mineralisation in peat soils vary as a function of ground water level, influencing the mineralisation rate and the various fractions influencing  $frN_2O_{em,s}$  (See Eq. 22).

### **$N_2O$ emission from ground water and surface water by leaching and runoff**

In the two IPCC methods, the  $N_2O$  emission from ground water and surface water is calculated as a fraction of the leaching and runoff to these compartments, with the N leaching (excess N input) calculated as a fraction of the N input by fertiliser and animal manure, using a default value of 0.3. In INITIATOR, however, the excess is calculated as:

$$N_{le} = N_{ex} - N_{in,net} - N_{up} - N_{de,s} \quad (29)$$

with  $N_{in,net}$  being the net N input, as defined before (Eq. 23).

In our comparison, we used this INITIATOR calculation for N leaching both as input for INITIATOR and for the two IPCC methods, to allow a strict intercomparison between the methods.

The denitrification in the various compartments is calculated separately in INITIATOR, according to:

$$N_2O_{em,le} = N_2O_{em,gw} + N_2O_{em,de} + N_2O_{em,sw} \quad (30)$$

with:

$$N_2O_{em,gw} = frN_2O_{de} \cdot fr_{de,gw} \cdot (1 - fr_{ro}) \cdot (N_{ni,s} - N_{de,s}) \quad (31)$$

$$N_2O_{em,di} = frN_2O_{ni} \cdot fr_{ro} \cdot (N_{in,net} - N_{up} - N_{ni,s}) + frN_2O_{de} \cdot fr_{de,di} \cdot fr_{ro} \cdot N_{le} \quad (32)$$

$$N_2O_{em,sw} = frN_2O_{de} \cdot fr_{de,sw} \cdot fr_{ret} \cdot (fr_{ro} \cdot N_{le} - N_{de,di} + N_{dep}) \quad (33)$$

where:

$fr_{ro}$  = runoff fraction in soil (-)  
 $fr_{ret}$  = retention fraction in surface waters(-)

This set of equations does not allow a single description of  $N_2O$  emission from leaching as a function of N leaching.

## 2.2 Model parameterization

### IPCC emission fractions

The standard IPCC emission percentages used in the tier 1 approach are 1% except for manure inputs by grazing cattle, pig and poultry (2%), while N fixation is neglected (see Table 2).

**Table 2**

*Range in N<sub>2</sub>O emission fractions due to different N inputs, as used in the Netherlands and the standard IPCC method*

Type of input	Differentiation	Range in frN <sub>2</sub> O <sub>em</sub> (%)	
		NIR2010	IPCC2006
<b>Excretion (housing)</b>	Liquid	0.1 <sup>1)</sup> (0.0 - 0.2) <sup>8)</sup>	0.5 <sup>4)</sup> (0.25 - 1.0) <sup>9)</sup>
	Solid	2.0 <sup>1)</sup> (1.0 - 4.0) <sup>8)</sup>	0.5 <sup>4)</sup> (0.25 - 1.0) <sup>9)</sup>
<b>Manure application</b>	Surface application on organic soils	2.0 <sup>2)</sup> (0.6 - 3.4) <sup>8)</sup>	1.0 (0.3 - 3.0) <sup>5)</sup>
	Surface application on mineral soils	1.0 <sup>2)</sup> (0.4 - 1.6) <sup>8)</sup>	1.0 (0.3 - 3.0) <sup>5)</sup>
	Low - ammonia emission application on all soils <sup>2)</sup>	2.0 <sup>2)</sup> (0.6 - 3.4) <sup>8)</sup>	1.0 (0.3 - 3.0) <sup>5)</sup>
<b>Grazing</b>	Urine	2.0 <sup>2)</sup> (0.6 - 3.4) <sup>8)</sup>	-
	Faeces	1.0 <sup>2)</sup> (0.4 - 1.6) <sup>8)</sup>	-
	Cattle, Pig and Poultry	-	2.0 (0.7 - 6) <sup>5)</sup>
<b>Fertiliser</b>	Sheep and other animals	-	1.0 (0.3 - 3.0) <sup>5)</sup>
	Ammonium on organic soils	1.0 <sup>2)</sup> (0.4 - 1.6) <sup>8)</sup>	1.0 (0.3 - 3.0) <sup>5)</sup>
	Ammonium on mineral soils	0.5 <sup>2)</sup> (0.2 - 0.8) <sup>8)</sup>	1.0 (0.3 - 3.0) <sup>5)</sup>
	Nitrate on organic soils	2.0 <sup>2)</sup> (0.6 - 3.4) <sup>8)</sup>	1.0 (0.3 - 3.0) <sup>5)</sup>
	Nitrate on mineral soils	1.0 <sup>2)</sup> (0.4 - 1.6) <sup>8)</sup>	1.0 (0.3 - 3.0) <sup>5)</sup>
<b>Crop residues</b>	-	1.0 <sup>2)</sup> (0.4 - 1.6) <sup>8)</sup>	1.0 (0.3 - 3.0) <sup>5)</sup>
<b>Fixation</b>	-	1.0 <sup>2)</sup> (0.4 - 1.6) <sup>8)</sup>	-
<b>Deposition (emission)</b>	-	1.0 (0.0 - 3.0) <sup>3)</sup>	1.0 (0.2 - 5.0) <sup>5)</sup>
<b>Leaching (excess)</b>	-	2.5 <sup>3)</sup> (0.0 - 7.5) <sup>3)</sup>	0.75 (0.5 - 2.5) <sup>5)</sup>

<sup>1)</sup> See: [http://www.broeikasgassen.nl/documents/4B\\_N2O\\_manure\\_NIR2010.pdf](http://www.broeikasgassen.nl/documents/4B_N2O_manure_NIR2010.pdf)

<sup>2)</sup> See: [http://www.broeikasgassen.nl/documents/4D\\_N2O\\_agricultural\\_soil\\_direct\\_NIR2010.pdf](http://www.broeikasgassen.nl/documents/4D_N2O_agricultural_soil_direct_NIR2010.pdf)

<sup>3)</sup> See: [http://www.broeikasgassen.nl/documents/4D\\_N2O\\_agricultural\\_soil\\_indirect\\_NIR2010.pdf](http://www.broeikasgassen.nl/documents/4D_N2O_agricultural_soil_indirect_NIR2010.pdf)

<sup>4)</sup> IPCC2006 Guidelines, see: [http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4\\_Volume4/V4\\_10\\_Ch10\\_Livestock.pdf](http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf)

<sup>5)</sup> IPCC2006 Guidelines, see: [http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4\\_Volume4/V4\\_11\\_Ch11\\_N2O&CO2.pdf](http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf)

<sup>6)</sup> In the IPCC2006 biological nitrogen fixation as a direct source of N<sub>2</sub>O is removed, because of the lack of evidence of significant emissions arising from the fixation process

<sup>7)</sup> In the IPCC2006 the overall value for the emission factor for leached N (EF5) has been changed from 2.5 to 0.75% leached/ in runoff water. Consisting of an emission factor for: groundwater and surface drainage of 0.25% mineral N (mainly nitrate) leached; rivers of 0.25% in the water and for estuaries 0.25%

<sup>8)</sup> The uncertainty in the N<sub>2</sub>O emission factors for manure management, based on expert judgments, was estimated to be 100% (Olivier et al, 2009), and 60% for the direct N<sub>2</sub>O emissions from agricultural soils [http://www.broeikasgassen.nl/documents/4D\\_N2O\\_agricultural\\_soil\\_direct\\_NIR2010.pdf](http://www.broeikasgassen.nl/documents/4D_N2O_agricultural_soil_direct_NIR2010.pdf)

<sup>9)</sup> There are large uncertainties associated with the default emission factors for this source category (-50% to +100%) (IPCC, 2006)

Furthermore, a fixed emission is used for N<sub>2</sub>O emission (in kg N.ha<sup>-1</sup>.yr<sup>-1</sup>) due to N mineralisation from organic soils (see Table 3). In the NIR method, more distinction is made between various sources, distinguishing e.g. between: (i) urine input and faeces input of grazing animals, (ii) application method for manure, (iii) ammonium or nitrate input in case of fertilizer soil and (iv) soil type, i.e. organic soils versus mineral soils (see Table 2).

**Table 3**

*Mineralisation induced N<sub>2</sub>O emissions from organic soils as a function of land use according to the NIR (2000) and IPCC (2006a).*

Land use	N <sub>2</sub> O <sub>em</sub> (kg N.ha.yr <sup>-1</sup> )	
	NIR 2010	IPCC (2006a)
<b>Temperate organic crop and grassland soils</b>	4.7 (1.9 - 7.5) <sup>1)</sup>	8 (2 - 24) <sup>2)</sup>
<b>Temperate organic nutrient rich forest soils</b>	-	0.6 (0.16 - 2.4) <sup>2)</sup>
<b>Temperate organic nutrient poor forest soils</b>	-	0.1 (0.02 - 0.3) <sup>2)</sup>

<sup>1)</sup> See: [http://www.broeikasgassen.nl/documents/4D\\_N2O\\_agricultural\\_soil\\_direct\\_NIR2010.pdf](http://www.broeikasgassen.nl/documents/4D_N2O_agricultural_soil_direct_NIR2010.pdf)

<sup>2)</sup> IPCC2006 Guidelines, see:

[http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4\\_Volume4/V4\\_11\\_Ch11\\_N2O&CO2.pdf](http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf)

During the development of these IPCC Guidelines, the uncertainties in N<sub>2</sub>O emissions were an important issue, since uncertainty estimates are an essential element of a complete GHG inventory of emissions and it helps to prioritize national efforts to reduce GHG emissions. The uncertainty of inventories in N<sub>2</sub>O emissions from agricultural soils is the source with the largest uncertainty in GHG emissions. These uncertainties are caused by uncertainties related to the emission factors and activity data and are amongst others due to natural variability in space and time, lack of coverage of measurements and temporal and spatial aggregation errors. In the IPCC 2006 guidelines the uncertainty range of the 1% EF is 0.3 - 3.0% (Table 2). The uncertainty in the NIR 2010 method is also given in this table.

### INITIATOR parameters

Information on the parameterization of the various fractions is given in De Vries et al. (2003). Important are the uncertainties in nitrification and denitrification fractions, which are both a function of soil type, land use and ground water level class, as shown in Table 4 and Table 5 for agricultural and non-agricultural soils, respectively. The most uncertain fractions in this approach are the N<sub>2</sub>O emission fractions related nitrification ( $frN_{2O_{em,ni}}$ ) and denitrification ( $frN_{2O_{em,de}}$ ), which do affect the N<sub>2</sub>O emissions in all parts of the considered system. The range used for those fractions is given in Table 6. Sources for the variation are e.g. Martikainen and De Boer (1993), Skiba et al. (1993), Smith and Chalk (1980). Actually, the ranges are even much larger and evidence exists that  $frN_{2O_{em,ni}}$  increases when the soil becomes more wet (and nitrification itself is more limited) whereas  $frN_{2O_{em,de}}$  increases when the soil becomes more dry (and denitrification itself is more limited). In the calculations for this report, we used the average values of the given ranges for all parameters in Table 4, 5 and 6.

**Table 4**

Ranges in nitrification and denitrification parameters used in the simulations for agricultural soils.

Soil type	Wetness class	Nitrification fraction; $fr_{ni}$		Denitrification fraction; $fr_{de}$			
		Grassland	maize/ arable	grassland	maize/ arable	ground water	Ditches
<b>Sand</b>	Dry <sup>1)</sup>	0.98 - 1.00	0.98 - 1.00	0.30 - 0.60	0.20 - 0.50	0.10 - 0.50	0.00 - 0.80
	Moist <sup>2)</sup>	0.95 - 1.00	0.95 - 1.00	0.40 - 0.80	0.30 - 0.70	0.20 - 0.70	0.10 - 0.90
	Wet <sup>3)</sup>	0.90 - 0.95	0.90 - 0.95	0.60 - 0.95	0.50 - 0.95	0.50 - 0.90	0.50 - 0.95
<b>Loess</b>	Dry	0.98 - 1.00	0.98 - 1.00	0.50 - 0.70	0.30 - 0.60	0.10 - 0.85	0.10 - 0.85
	Moist	0.95 - 1.00	0.95 - 1.00	0.60 - 0.85	0.40 - 0.80	0.30 - 0.90	0.30 - 0.90
	Wet	0.90 - 0.95	0.90 - 0.95	0.70 - 0.95	0.60 - 0.95	0.50 - 0.95	0.50 - 0.95
<b>Clay</b>	Dry	0.95 - 1.00	0.95 - 1.00	0.60 - 0.90	0.50 - 0.90	0.30 - 0.90	0.30 - 0.90
	Moist	0.90 - 1.00	0.90 - 1.00	0.70 - 0.95	0.60 - 0.90	0.50 - 0.95	0.50 - 0.95
	Wet	0.85 - 0.95	0.85 - 0.95	0.80 - 0.98	0.80 - 0.98	0.80 - 0.95	0.80 - 0.95
<b>Peat</b>	Dry	0.90 - 1.00	0.90 - 1.00	0.80 - 0.95	0.60 - 0.90	0.90 - 1.00	0.80 - 0.95
	Moist	0.85 - 0.95	0.90 - 1.00	0.80 - 0.95	0.70 - 0.95	0.90 - 1.00	0.80 - 0.95
	Wet	0.80 - 0.90	0.80 - 0.95	0.90 - 0.98	0.90 - 0.98	0.90 - 1.00	0.90 - 0.98

<sup>1)</sup> Dry is related to a MHW level of >80 cm; <sup>2)</sup> Moist is related to a MHW level between 40 and 80 cm

<sup>3)</sup> Wet is related to a MHW level below 40 cm.

**Table 5**

Ranges in N transformation parameters used in the simulation for non-agricultural soils.

Soil type	Water table class	(De)nitrification	
		$fr_{ni}$ <sup>1)</sup>	$fr_{de,s}$ <sup>2)</sup>
<b>Sand<sup>1)</sup></b>	Dry	0.90 - 1.00	0.0 - 0.2
	Moist	0.75 - 0.95	0.1 - 0.3
	Wet	0.70 - 0.90	0.4 - 0.5
	Very wet	0.30 - 0.50	0.5 - 0.7
	Extremely wet	0.10 - 0.30	0.7 - 0.9
<b>Loess</b>	Dry	0.95 - 1.00	0.1 - 0.3
	Moist	0.90 - 1.00	0.2 - 0.4
	Wet	0.90 - 1.00	0.4 - 0.6
	Very wet	0.20 - 0.60	0.6 - 0.8
	Extremely wet	0.10 - 0.50	0.8 - 1.0
<b>Clay</b>	Dry	0.95 - 1.00	0.4 - 0.8
	Moist	0.90 - 1.00	0.5 - 0.9
	Wet	0.90 - 1.00	0.8 - 1.0
	Very wet	0.70 - 0.90	0.9 - 1.0
	Extremely wet	0.50 - 0.80	0.9 - 1.0
<b>Peat</b>	Dry	0.95 - 1.00	0.7 - 1.0
	Moist	0.90 - 1.00	0.8 - 1.0
	Wet	0.80 - 1.00	0.9 - 1.0
	Very wet	0.40 - 0.90	0.9 - 1.0
	Extremely wet	0.30 - 0.70	0.9 - 1.0

<sup>1)</sup> Nitrification fractions ( $fr_{ni}$ ) in calcareous sandy soils were set slightly higher i.e. 0.4-0.6 for extremely wet soils, 0.8-1.0 for wet soils, 0.9-1.0 for moist soils and 0.95-1.0 for dry soils

<sup>2)</sup> The denitrification fractions in ground water and in ditches were assumed equal to the soil ( $fr_{de,s}$ )

**Table 6**

Ranges in  $N_2O$  emissions fractions due to nitrification and denitrification used in the simulation.

Soil type	N <sub>2</sub> O emissions fractions	
	frN <sub>2</sub> O <sub>em,ni</sub>	frN <sub>2</sub> O <sub>em,de</sub>
Sand/ loess/ clay	0.005 - 0.02	0.01 - 0.06
Peat	0.01 - 0.03	0.02 - 0.12

## 2.3 Applied mitigation measures and their parameterization

Measures that were evaluated include current Dutch policies combined with additional measures: (i) emission reduction from poultry and pig housing system by using air scrubbers, (ii) low-emission cattle housing, (iii) low protein feeding, (iv) more restrictive animal manure application and (v) conversion towards organic cattle farms. A description of the measures with its parameterization is given in Table 7. A brief explanation of the parameterisation is given below. For details we refer to Gies et al. (2008) and Kros et al. (2010)

**Table 7**

Description and parameterisation of the evaluated measures for emission reductions.

Measure	Description	Parameterisation
1	Air scrubbers for pigs/poultry	Reduction of NH <sub>3</sub> emission from stables and manure storages by 70% compared to current practice in pigs and poultry stables.
	Low-emission stables for cattle	Reduction of NH <sub>3</sub> emission from stables and manure storages by 40% compared to current dairy cattle stables.
2	Reduced protein feed for cattle combined with reduced N application by manure and fertilizer	Reducing the N excretion factor by 18%. Reducing the mineral N content in manure by 25% Reducing N application by animal manure to 170 kg N on arable land and 250 kg N on grassland. Apply N fertilizer according to the use requirements in the national manure and fertilizer law of 2006.
	Maximum manure application rate	Apply no more animal manure than 170 kg N ha <sup>-1</sup> (EU Nitrate Directive). Although the EU nitrate directive is only valid for the defined Nitrate Vulnerable Zones, we applied this measure for all regions. Currently for some countries, e.g. the Netherlands, a derogation exists, but we did not take that into account, since this derogation is meant to be temporarily. When the sum of amount of applied manure and manure by grazing exceeds 170 kg N ha <sup>-1</sup> , the remaining manure is removed from the system. We adjusted the fertilizer amount depending on the crop demand, which may result in higher fertilizer gifts.
4	Apply cover crops in arable land	Reduce the N input with 40 kg N for arable land by assuming that this amount is released during the growing season by the mineralization of the residues of a cover crop sown in a previous year.
5	Optimal drainage	Increasing water level for dry mineral soils (excludes peat soils) to a ground water level that is optimal for growth.
6	Restoration of histosols	Restoration of histosols may lead to reduced N (and C) mineralisation and by a change in N <sub>2</sub> O emission. In Initiator a linear relation between the mean summer groundwater level and the C mineralization is used, as presented in De Vries et al. (2010), while using average values for groundwater level per land use type on peat throughout the Netherlands. For this measure we used a generic elevation of the mean summer groundwater level for arable land and grassland to 10 cm and refrain from fertilizer application for these areas.
7	All measures together	

As a reference situation for all measures we assumed a full implementation of the current NH<sub>3</sub> policy for animal husbandry in the Netherlands, implying full implementation of low emission stables according to the Ammonia and Livestock Farming Regulation for intensive animal husbandry (mainly pigs and poultry) VROM (VROM, 2005) and the IPPC directive (IPPC directive 96/61/EG) (EC, 1996). Both measures focus on ammonia emissions from intensive livestock farming (mainly pigs and poultry) and should be implemented before 2010 (Van Horne et al., 2006), but the date was recently extended to 2013. Since it is likely that relatively small farms will not invest in low emission stables, farms smaller than 40 livestock units (LSU) were closed, while relocating the animals to large farms (> 70 LSU). Formally, also dairy cattle farms are affected by the regulation (VROM, 2005). However, the maximum allowable emission, set to 9.5 kg NH<sub>3</sub> per head, is equal to the emission of a practice dairy farm with average grazing regime (pers. comm. S. Bokma, ASG, part of Wageningen UR) (Kuipers and Mandersloot, 1999) and consequently, we limited the regulation to large pig and poultry farms. The introduction of *Air scrubbers* for pigs and poultry farms (2) is aiming at an additional reduction of ammonia from animal housing systems. The ammonia removal effectiveness for air scrubbers is ranging from 70 to 95% (Melse et al., 2009). In this study we assumed air scrubbers with an ammonia removal effectiveness of 70% that was applied after the implementation of measure 1. Since the current policy on low emission housing systems is limited to pigs and poultry farms, a measure on *Low-emission stables for cattle* (3) was included for cattle. At the moment, cattle housing systems with substantial lower ammonia emission are not available. A lot of effort is, however, put into the development of adapted housing systems, with e.g. rubber closed raster floors and mechanical ventilation. This effort may result in a reduction of the ammonia emission of 40% compared to current practice stables (pers. comm. Nico Ogink). The use of *Reduced protein feed for cattle* (4) aims to enhance the N efficiency in all livestock categories by dietary changes, e.g. by the partial replacement of grass by maize for cattle and multiphase feeding for pigs and poultry. A 20% reduction in estimated N excretion to urine and faeces was achieved by reducing the protein content of the concentrate (Nielsen et al., 2003). In our study we assumed a slightly lower reduction, 18% based on Schröder et al. (2005). With respect to *Low-emission application* (5), we assumed that the current practice of trailing shoe application is replaced by sod incorporation for grass land with an emission fraction of 10%. With the conversion towards *Organic cattle farms* (6) we assumed a complete shift towards organic farming by refraining from application of chemical fertilizer for all cattle farms in the 10 km zone.

All measures were applied one at the time and as all measures together. Since there can be an interaction, the effect of a combination of two or more measures cannot always be derived from the sum of the effects.





### 3 Comparison of nitrous oxide emissions calculated with the IPCC methods and INITIATOR

#### 3.1 Differences in N<sub>2</sub>O emissions for the year 2000

Results obtained on annual N<sub>2</sub>O fluxes (Gg N.yr<sup>-1</sup>) by the various approaches for the base year 2000 are presented in Table 8. Table 8 also includes information on N inputs by the different N sources (mainly N inputs by animal manure and fertiliser and also by deposition, fixation, grazing animals and mineralisation from peat soils). The difference between the two IPCC methods is mainly due to a different parameterization (see Table 1 and 2) and partly because the N<sub>2</sub>O emission by crop residues is not included in INITIATOR (also implicitly by N mineralization) while N<sub>2</sub>O emission by N fixation is not include in the IPCC (2006a) method.

**Table 8**

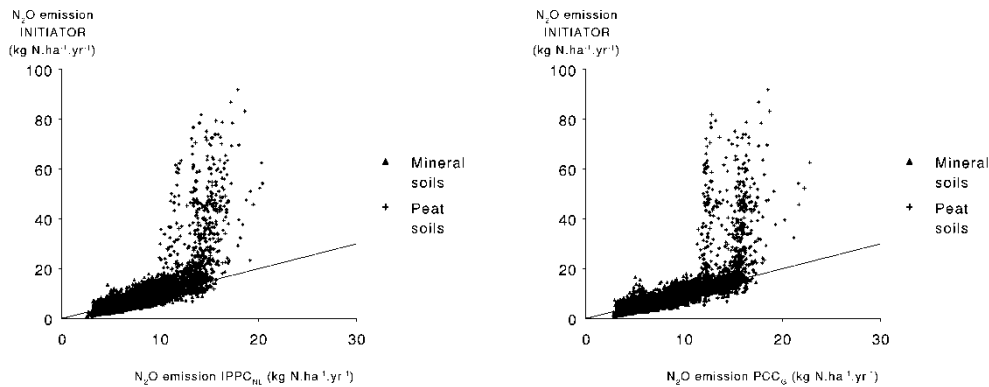
*A comparison of annual N<sub>2</sub>O fluxes for the Netherlands with the IPCC methods used in the Netherlands (IPCC<sub>NL</sub>: NIR, 2010) and in general (IPCC<sub>G</sub>: IPCC (2006a) and by INITIATOR (De Vries et al., 2003) using N inputs for the year 2000.*

Source	N fluxes (Gg N.yr <sup>-1</sup> )	N <sub>2</sub> O fluxes (Gg N.yr <sup>-1</sup> ) <sup>1</sup>		
		NIR 2010	IPCC 2006	INITIATOR
<b>Manure excretion</b>	427	1.8	2.7	1.7
<b>Manure application</b>	314	3.6	3.1	4.7
<b>Grazing</b>	108	1.7	2.0	1.8
<b>Fertiliser</b>	305	2.7	3.1	5.0
<b>Fixation</b>	18	0.2	-	0.3
<b>Deposition/Emission</b>	103	1.3	1.3	1.8
<b>Crop residues</b>	46	0.5	0.5	-
<b>Mineralisation peat soils</b>	111	1.5	2.6	4.7
<b>Leaching/runoff</b>	102	2.6	0.8	2.7
<b>Total</b>		15.4	15.8	22.8

The difference between the total N<sub>2</sub>O emission appears to be very small on a national scale for two IPCC methods, but there is a clear difference in the contribution of N sources to the emission. In the NIR 2010 method, the contribution of manure excretion and mineralisation of peat soils is much less than in the IPCC 2006 method, whereas the indirect N<sub>2</sub>O emissions due to N leaching/runoff are much larger. The overall N<sub>2</sub>O emission by INITIATOR is about 30% larger and the allocation to the various sources suggest that this is mainly due to a larger emission from applied fertilizer and manure and from N mineralized in peat soils (see also further).

A comparison of the total N<sub>2</sub>O fluxes calculated by the two IPCC methods and by INITIATOR for all STONE plot is given in Figure 1. Results show that relatively large deviations do occur for peat soils, where both IPCC methods assume a constant N<sub>2</sub>O emission by mineralisation (4.7-8 kg.ha<sup>-1</sup>.yr<sup>-1</sup>) whereas INITIATOR calculates

the N<sub>2</sub>O emission as a function of the ground water level, influencing the mineralisation, nitrification and denitrification rates.



**Figure 1**

*A comparison of annual N<sub>2</sub>O fluxes for the Netherlands with the IPCC methods by Kroeze (1994) and Mosier et al. (1998a) and by INITIATOR (De Vries et al., 2003) using N inputs for the year 2000 for the different plots included in the calculation, using the most recent schematization*

## 3.2 Difference in future N<sub>2</sub>O emissions in response to various measures

An overview of the impact of various measures to reduce inputs and emissions of nitrogen to atmosphere, soil and water on N<sub>2</sub>O emissions, as calculated by the three methods is given in Table 9. Details on the various N fluxes, as given in Table 8 for the reference situation, are presented in Annex 1.

**Table 9**

*A comparison of annual N<sub>2</sub>O fluxes for the Netherlands calculated with the IPCC methods by NIR 2010 and IPCC (2006) and by INITIATOR for various scenarios either reducing N inputs or NH<sub>3</sub> emissions starting with the year 2000 (0 = reference situation).*

Number	Measure	N <sub>2</sub> O fluxes (Gg N.yr <sup>-1</sup> )		
		NIR 2010	IPCC 2006	INITIATOR
0	Reference situation 2000	15.4	15.8	22.8
1	Air scrubbers/low emission stables	15.3	15.7	23.4
2	Reduced protein feed for cattle combined with reduced N application by manure and fertilizer	12.5	12.9	18.6
3	Maximum manure application rate	12.9	13.3	18.9
4	Apply cover crops in arable land	14.3	14.8	20.6
5	Optimal drainage	15.5	16.1	23.6
6	Restoration of histosols combined with zero N fertilizer application	14.4	15.2	17.1
7	All measures	10.1	11.1	11.3

The results show that INITIATOR calculates in general larger reductions in N<sub>2</sub>O emissions from the various measures (51% when all measures are carried out) than the two IPCC methods (34% by NIR and 30% by IPCC 2006). The results show that measures that lead to a reduction in the N input ( the measures 2-4 and 6) also cause a reduction in N<sub>2</sub>O emissions. Apart from the restoration of histosols (Measure 6), all other N input reduction measures lead to a similar percentage reduction in N<sub>2</sub>O emission by all models, i.e. between: (i) 18-

19% for reduced protein feed for cattle (measure 2), 16-17% for maximum N manure application rate (measure 3) and (iii) 7-10% for application of cover crops (measure 4), with the highest values calculated by INITIATOR. The restoration of histosols combined with reduced N application, however, reduces the N<sub>2</sub>O emission by INITIATOR by 25%, whereas the N<sub>2</sub>O emission by the two IPCC methods is reduced by 4-6 % only. This large difference is due to the neglect of the effect of a change in ground water level by the IPCC methods, whereas this causes a large reduction in N mineralization and thereby on the N<sub>2</sub>O emissions calculated by INITIATOR (Compare Table A1.6 and Table A1.0 in Annex 1). Measure 2 that is focused on a reduction of NH<sub>3</sub> emissions, by use of air scrubbers or low emission stables, leads to an increased N input to the soil by manure application, but this is partly compensated by a reduced N fertilizer input (Compare Table A1.1 and Table A1.0 in Annex 1). In the IPCC methods, however, the N deposition also reduces largely since all NH<sub>3</sub> that is emitted is assumed to come back again (either on agricultural or non- agricultural soils) and this leads to a reduction in indirect N<sub>2</sub>O emissions, implying that the overall effect of NH<sub>3</sub> reduction in the IPCC methods is a small reduction in N<sub>2</sub>O emissions. In INITIATOR, the reduction in N deposition is less as it only accounts for the effect on agricultural soils and here NH<sub>3</sub> reduction leads to increased N<sub>2</sub>O emission (pollution swapping). Finally, optimal drainage also causes a reduced N<sub>2</sub>O emission according to the IPCC methods as it increases growth uptake and thereby reduces N leaching/runoff and the related indirect emissions. In INITIATOR, however, optimal drainage not only reduces N uptake but it also affects the processes of nitrification and denitrification, ultimately leading to higher N<sub>2</sub>O emissions. The results thus show that measures focused on a reduction in N inputs leads to comparable reductions by the various approaches but a decrease in NH<sub>3</sub> emissions and an increase in N use efficiency (optimal drainage) leads to pollution swapping when using INITIATOR as it includes processes not included explicitly in the IPCC methods. For more insight on the effect of various fluxes, we refer to Annex 1 again.



## 4 Discussion and conclusions

From this study we can conclude that:

- A comparison of the total N<sub>2</sub>O fluxes calculated by the two IPCC methods and by INITIATOR on a national basis the results appear to be quite comparable (within 30%). Relatively large deviations, however, occur for peat soils.
- Results of impacts of various measures to reduce inputs of nitrogen (reduced protein feed combined with reduced N application, maximum N manure application rate, apply cover crops) show that INITIATOR calculates comparable reductions in N<sub>2</sub>O emissions as the two IPCC methods.
- The results further show that measures focused on a decrease in NH<sub>3</sub> emissions lead to pollution swapping when using INITIATOR as it includes processes not included explicitly in the IPCC methods.
- Similarly, measures focused on a change towards optimal hydrology (implying an increase in N use efficiency due to optimal drainage and restoration of histosols) lead to much larger impacts when using INITIATOR compared to the IPCC methods.
- Changes in the nitrogen use efficiency and in hydrology on N<sub>2</sub>O emissions are not included in the IPCC factors. To adequately account for these impacts, the standard IPCC methodology should be updated by a method such as used in INITIATOR.

It should be stressed that the uncertainties calculated with both methods is large. Insight in those uncertainties can be obtained by using the ranges in parameter values for both the IPCC methods, as given in Table 2 and 3 and the INITIATOR model, as given in Table 4, 5 and 6. An indication of the widest possible range due to these ranges is to use systematically the lower and upper boundaries for these parameters. Results thus obtained for the two methods for the year 2000 lead to uncertainties that are about 60-90%, leading to overlapping ranges of national N<sub>2</sub>O emissions estimates by the IPCC methods and INITIATOR, but this is likely to be an overestimate. A more systematic assessment requires a complete uncertainty analysis were all uncertain parameters are varied at the same time and taking their cross correlations and spatial correlation into account. This can be achieved by performing a Monte Carlo simulation were it is assumed that the uncertainty of the parameters can be characterised by their distribution functions and their correlations and performing simulations with a randomly selected sets of parameter values from the distribution functions while taking their mutual correlations into account (see e.g. De Vries et al., 2003). However, such an analysis goes beyond the scope of this report.



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# Annex 1 Comparison of annual N<sub>2</sub>O fluxes for the Netherlands with the IPCC methods as used in the Netherlands and the default value and by INITIATOR after various reduction measures

**Table A1.0**

*Comparison of annual N<sub>2</sub>O fluxes for the Netherlands for the reference situation for the year 2000.*

N <sub>2</sub> O emission source	N <sub>2</sub> O fluxes (Gg N.yr <sup>-1</sup> )		
	NIR 2010	IPCC 2006	INITIATOR
Manure storage	1.8	2.7	1.7
Manure application	3.6	3.1	4.7
Grazing	1.7	2.0	1.8
Fertiliser	2.7	3.1	5.0
Fixation	0.2	-	0.3
Deposition	1.3	1.3	1.8
Crop residues	0.5	0.5	-
Mineralisation peat soils	1.5	2.6	4.7
Leaching/runoff	2.6	0.8	2.7
Total	15.4	15.8	22.8

**Table A1.1**

*Comparison of annual N<sub>2</sub>O fluxes for the Netherlands after inclusion of measure 1: Air scrubbers/low emission stables.*

	N <sub>2</sub> O fluxes (Gg N.yr <sup>-1</sup> )		
	NIR 2010	IPCC 2006	INITIATOR
Manure storage	1.8	2.7	1.7
Manure application	4.0	3.4	5.3
Grazing	1.7	2.0	1.9
Fertiliser	2.5	2.9	4.8
Fixation	0.2	-	0.3
Deposition	1.0	1.0	1.7
Crop residues	0.5	0.5	-
Mineralisation peat soils	1.5	2.6	4.8
Leaching/runoff	2.6	0.8	2.8
Total	15.3	15.7	23.4

**Table A1.2***Comparison of annual N<sub>2</sub>O fluxes for the Netherlands after inclusion of measure 2: Reduced protein feed for cattle.*

N <sub>2</sub> O emission source	N <sub>2</sub> O fluxes (Gg N.yr <sup>-1</sup> )		
	NIR 2010	IPCC 2006	INITIATOR
Manure storage	1.1	1.7	1.7
Manure application	2.5	2.1	2.7
Grazing	1.1	1.3	1
Fertiliser	2.9	3.3	4.7
Fixation	0.2	-	0.3
Deposition	1	1	1.5
Crop residues	0.5	0.5	-
Mineralisation peat soils	1.5	2.6	4.6
Leaching/runoff	2.1	0.6	2.1
Total	12.5	12.9	18.6

**Table A1.3***Comparison of annual N<sub>2</sub>O fluxes for the Netherlands after inclusion of measure 3: Maximum manure application rate.*

N <sub>2</sub> O emission source	N <sub>2</sub> O fluxes (Gg N.yr <sup>-1</sup> )		
	NIR 2010	IPCC 2006	INITIATOR
Manure storage	1.2	1.8	1.7
Manure application	2.5	2.2	2.8
Grazing	1.0	1.2	0.9
Fertiliser	3.1	3.6	4.9
Fixation	0.2	-	0.3
Deposition	1.1	1.1	1.6
Crop residues	0.5	0.5	-
Mineralisation peat soils	1.5	2.6	4.5
Leaching/runoff	2.1	0.6	2.2
Total	12.9	13.3	18.9

**Table A1.4***Comparison of annual N<sub>2</sub>O fluxes for the Netherlands after inclusion of measure 4: Apply cover crops in arable land.*

N <sub>2</sub> O emission source	N <sub>2</sub> O fluxes (Gg N.yr <sup>-1</sup> )		
	NIR 2010	IPCC 2006	INITIATOR
Manure storage	1.8	2.7	1.7
Manure application	3.6	3.1	4.4
Grazing	1.7	2.0	1.8
Fertiliser	2.0	2.3	3.5
Fixation	0.2	-	0.3
Deposition	1.2	1.2	1.7
Crop residues	0.5	0.5	-
Mineralisation peat soils	1.5	2.6	4.7
Leaching/runoff	2.2	0.6	2.4
Total	14.3	14.8	20.6

**Table A1.5***Comparison of annual N<sub>2</sub>O fluxes for the Netherlands after inclusion of measure 5: Optimal drainage.*

N <sub>2</sub> O emission source	N <sub>2</sub> O fluxes (Gg N.yr <sup>-1</sup> )		
	NIR 2010	IPCC 2006	INITIATOR
Manure storage	1.8	2.7	1.7
Manure application	3.5	3.1	5.0
Grazing	1.7	2.0	1.7
Fertiliser	2.9	3.3	5.3
Fixation	0.2	-	0.3
Deposition	1.3	1.3	1.9
Crop residues	0.5	0.5	-
Mineralisation peat soils	1.5	2.6	4.7
Leaching/runoff	2.5	0.7	3.0
Total	15.5	16.1	23.6

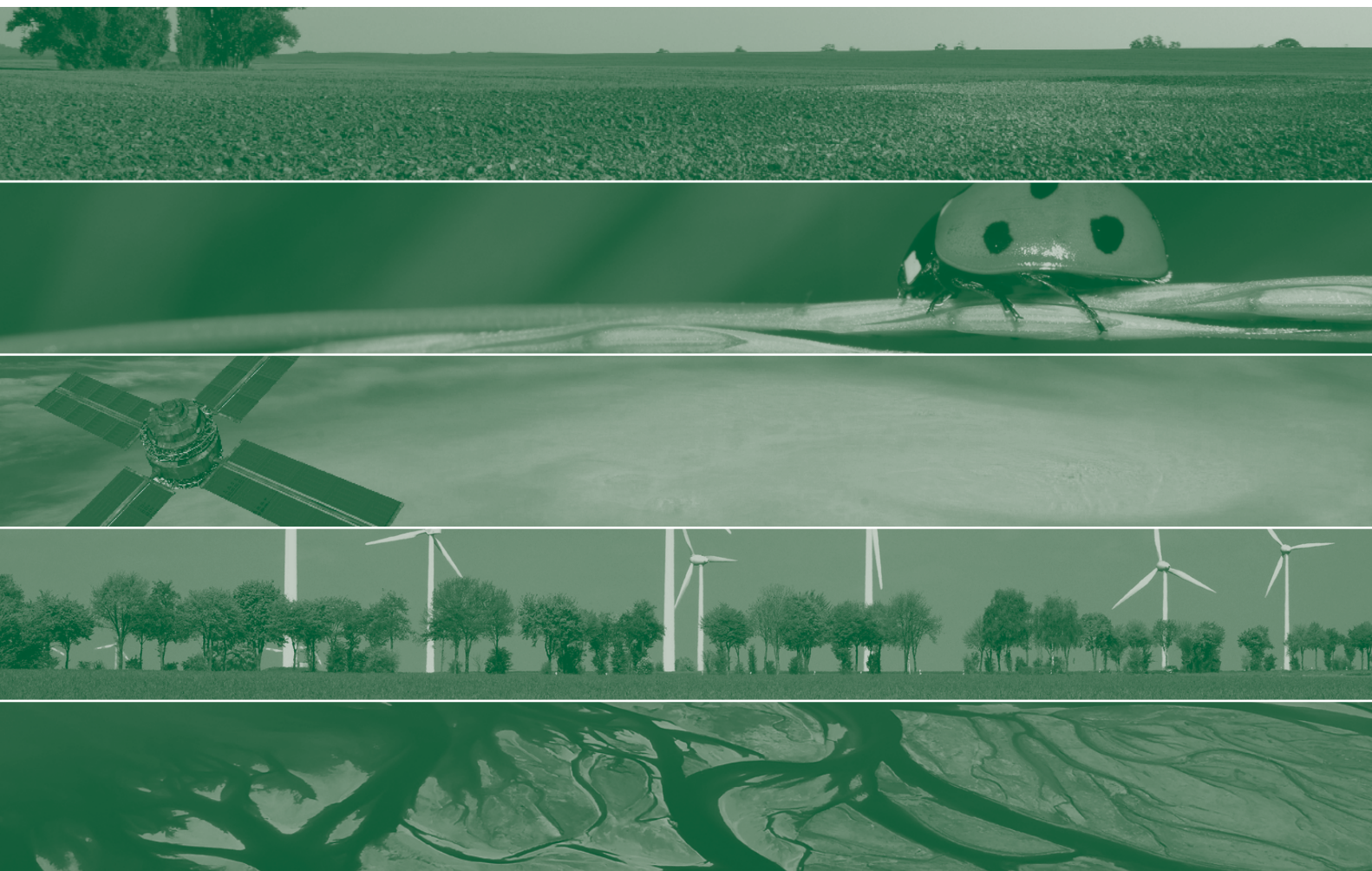
**Table A1.6***Comparison of annual N<sub>2</sub>O fluxes for the Netherlands after inclusion of measure 6: Restoration of histosols.*

N <sub>2</sub> O emission source	N <sub>2</sub> O fluxes (Gg N.yr <sup>-1</sup> )		
	NIR 2010	IPCC 2006	INITIATOR
Manure storage	1.8	2.7	1.7
Manure application	3.6	3.1	3.9
Grazing	1.7	2.0	1.4
Fertiliser	1.9	2.5	3.4
Fixation	0.2	-	0.3
Deposition	1.2	1.2	1.6
Crop residues	0.5	0.5	-
Mineralisation peat soils	1.5	2.6	2.7
Leaching/runoff	2.4	0.7	2.1
Total	14.4	15.5	17.1

**Table A1.7***Comparison of annual N<sub>2</sub>O fluxes for the Netherlands after inclusion of all measures.*

N <sub>2</sub> O emission source	N <sub>2</sub> O fluxes (Gg N.yr <sup>-1</sup> )		
	NIR 2010	IPCC 2006	INITIATOR
Manure storage	1.1	1.6	1.7
Manure application	2.5	2.2	1.7
Grazing	1.1	1.3	0.3
Fertiliser	1.5	2.1	2.1
Fixation	0.2	-	0.2
Deposition	0.7	0.7	1.1
Crop residues	0.5	0.5	-
Mineralisation peat soils	1.5	2.6	2.9
Leaching/runoff	1.3	0.4	1.3
Total	10.1	11.1	11.3





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