



# Life cycle analysis of horticultural products:

## Memo on Nitrogen and phosphorus emissions modelling

Anton Kool, Hans Blonk (Blonk Consultants)

### Introduction

This memo has been prepared to address the modelling of pesticides emissions from fertilisers. This is in the context of the development of a methodology for calculating the environmental footprints of horticultural products, the HortiFootprint category rules (HFCR, see Helmes et al., 2020). The goal of the HFCR is to provide a harmonised methodology after which consistent life cycle assessment (LCA) studies can be performed for the European horticultural sector. The development of the methodology is following as much as possible the most recent guidance for developing product environmental category rules (PEFCR) published by the European Commission (Zampori and Pant, 2019).

The development of the HFCR was initiated by Royal FloraHolland, Fresh Produce Centre and Wageningen Economic Research, with co-financing from the Dutch Fund for Horticulture & Propagation Materials, ABN AMRO Bank N.V., the Dutch sector organisation for greenhouse horticulture (Glastuinbouw Nederland), MPS, Rabobank, Foundation Benefits of Nature and in co-production with experts from Blonk Consultants and PRé Sustainability.

At the start of the project, several topics were identified where additional guidance was needed for the horticulture sector as well as the guidance currently available in the PEF. The following methodological challenges were identified:

- modelling nitrogen and phosphorus emissions;
- modelling pesticides emissions;
- handling multifunctionality of combined heat and power systems used during cultivation;
- modelling of capital goods.

This memo is one of the four memos, elaborating on methodological challenges.

This memo describes a proposal on how to measure and/or calculate nitrogen and phosphorous (N and P) emissions in the HortiFootprint category rules (HFCR, Helmes et al., 2020) aligned to the LCA standard. The main idea is to introduce a preference level approach that defines the favoured order of indicating emissions depending on the data that can be made available by farms.

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The preference levels consist of:

1. Direct measurement
2. Preferred modelling
3. Default HFCR modelling

Direct measurement of the emissions is the most accurate method to indicate the emissions provided that the measurement complies with given conditions. The preferred modelling is based on calculation rules derived from existing models, whereas some principles are applied to select the most relevant model/method. These principles are:

- The calculation rule must be freely available from a model. Some models are not transparent in the use of calculation rules.
- The calculation rule should not be too complex; in other words data needed should be available on a level of regular management of a farmer/grower. This means that if data is needed on the basis of very frequent measurement (for instance on a daily basis), information is needed on parameters that are not in the scope of regular management (for instance carbon content of the soil), or a large amount/high density of data on the farm level is needed (for instance 10 soil samples per ha) the model is considered too complex to be used for the purpose of this HFCR (Helmes et al., 2020).
- The model must be representative on a global level.

The default modelling must be applied if the measurement and the preferred modelling cannot be performed. So, the most important criteria for the default modelling is that it should be applicable even if only minor information on cultivation is known.

Besides this, the background of this HFCR implies that comparability is more important than precision<sup>1</sup>. In other words, at the preferred modelling only one method is used, instead of several regional models, although this might imply less accurate results for certain regions. This means that at the default HFCR modelling the IPCC TIER 1 is preferred above the IPCC TIER 2 approach, because the TIER 1 approach results in a comparable approach for each situation, whereas choosing the IPCC TIER 2 approach the method will differ between countries which results in less comparable results.

The choice depends on data availability and the cultivation methods. We make a distinction between four types of cultivation:

- Open field soilless<sup>2</sup>
- Open field in soil
- Protected soilless
- Protected in soil

Most of the cultivation of fruits, vegetables, flowers and ornamental plants takes place in open field systems in the soil. The area of protected cultivation is growing rapidly, however.

In this memo, N and P emissions are calculated from N and P inputs as, among others, synthetic fertiliser, manure and other organic fertilisers. The step before, how much N and P inputs should be allocated to a specific crop in the case of a rotation scheme is described in a separate chapter in the HFCR (see Helmes et al., 2020, section 6.1.5).

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<sup>1</sup> The use of the default approach, although allowing comparability, may not extend to specific country or region as no country-specific emission factors are applied. This is acknowledged as a limitation of the HFCR approach as only comparability of applied N is possible.

<sup>2</sup> We assume a situation where the soil is completely covered by a material that prevents precipitation flowing to the soil and cultivation takes place in a substrate on top of this material.

## Nitrogen emissions

### Nitrate emissions

Nitrate emissions to groundwater and surface water originate from nitrogen surplus of external inputs from, for instance, fertiliser, nitrogen fixation, crop residues or deposition. For nitrate emissions the following methods are proposed (Table 1), which are explained in the following sections. In the preferred method, a distinction is made between run-off and emissions to groundwater. The ILCD impact methodology for marine eutrophication allows for making a distinction between N to soil and nitrate to fresh water. Groundwater is not an emission compartment as such and also the human toxicological effects of nitrate in groundwater are not considered. We propose to consider both run-off and emissions to groundwater as a direct emission of nitrate to fresh water. Both emission pathways are separated in the emissions flows so that later on, when LCA methodology develops and separate impact factors become available, this can be applied easily.

**Table 1** Measurement and modelling options for nitrate emissions

Preference level	Open field Soilless	Open field in soil	Protected soilless	Protected in soil
Measurement	Measured nitrate emissions, if closed recirculation and measurements of nitrate concentration and volume of discharged water available	Not applicable	Measured nitrate emissions, if closed recirculation and measurements of nitrate concentration and volume of discharged water available	Not applicable
Preferred modelling		Run-off and leaching compliant to Miterra <sup>3</sup> .		Run-off and leaching compliant to Miterra
Default modelling	Based on IPCC, Tier 1	Based on IPCC, Tier 1	Based on IPCC, Tier 1	Based on IPCC, Tier 1

### Direct measurements for soilless systems

The preferred option to determine nitrate leaching is by measuring nitrate emissions to ground and/or surface water. Nitrate emission measurements are only representative/accurate in completely closed water systems which are applied in soilless systems. In these systems all discharged water is monitored on nitrate content. In that case, the nitrate emissions are calculated as volume discharged water times the measured nitrate concentration. This implies that for cultivations in the soil, regardless of whether it is protected, measurements of nitrate emissions are not applicable.

In the Netherlands it is mandatory that for cultivation in greenhouses on substrate the annual amount of discharged water (to surface water or a sewage system) and nitrate concentration is measured and reported to the authorities

([www.glastuinbouwwaterproof.nl/content/0Grondgebonden/Registratie/doc/Meet-\\_\\_registratie-en\\_rapportageverplichtingen.pdf](http://www.glastuinbouwwaterproof.nl/content/0Grondgebonden/Registratie/doc/Meet-__registratie-en_rapportageverplichtingen.pdf)). This annual measured and reported quantity for nitrate in discharged water should be taken as nitrate emission. If it can be proved that the water recirculation system is closed, and no water is discharged at all, the nitrate leaching can be taken as zero. This zero discharge of water must be confirmed by the relevant legal authority (in the Netherlands this is the water board or in Dutch, 'waterschap').

In soilless systems where the water system is not closed and/or discharged water is not monitored for nitrate content this method is not applicable and the next preferred method (preferred modelling) has to be considered (see next section).

<sup>3</sup> 'Miterra-Europe is a deterministic and static model which calculates N and P balances, emissions of NH<sub>3</sub>, N<sub>2</sub>O, NO<sub>x</sub> and CH<sub>4</sub> to the atmosphere, and leaching of N to groundwater and surface waters. The model was developed to assess the effects and interactions of policies and measures in agriculture, including structural measures, on those fluxes' (Velthof et al., 2009).

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NB: Waste water processing is designed to reduce the nitrate and ammonia emissions to the environment. In the Netherlands around 83% of the incoming N is released to the atmosphere (mostly N<sub>2</sub> and small fraction of N<sub>2</sub>O) and 17% remains in the sewage sludge which can be incinerated or otherwise treated. It is important to have accurate waste water treatment processing in the secondary LCA database that supports the HFCR for horticulture.

### **Preferred modelling for cultivation in soil: run-off and leaching**

Several models for assessing nitrate losses are available, such as DNDC from the University of New Hampshire USA (Anonymous, 2017), DayCent used by US EPA and US DA in the National Greenhouse Gas Inventory (Necpalova et al., 2015), STICS from the Environment and Agronomy Division of INRA (Brisson et al. 2002) and CERES-EGC from INRA AgroParisTech Environment and Arable Crops Research Unit (CERES-EGC, 2018), Miterra-Europe (Velthof et al., 2007, 2009) and SALCA-NO<sub>3</sub> in Switzerland (Richner et al., 2014).

Applying the criteria for the preferred modelling of nitrate as stated earlier, the preferred modelling of nitrate emissions is based on the Miterra-Europe model (Velthof et al., 2007, 2009). This model has a proven track record in European studies (Velthof et al., 2014; Leip et al., 2014; Oenema et al., 2009; De Vries et al., 2011), and data needed for calculation of nitrate emissions should be easily available on the farm level.

Two pathways for nitrate losses can be distinguished: run-off to surface water and leaching to groundwater (which indirectly can leach to surface water).

## **Run-off**

The fraction of nitrogen applied with manure and fertiliser that is emitted by run-off is determined by precipitation surplus, soil characteristics and the slope, and conform to the Miterra-Europe model (Velthof et al., 2007, 2009).

Formula 1:  $N_{runoff} = N_{fert + org} * LF_{surface\ run-off}$

Where:

$N_{runoff}$  = the amount of N emitted as nitrate by run-off to surface water

$LF_{surface\ run-off}$  = fraction of N applied with synthetic and organic fertiliser emitted as nitrate by run-off

The leaching fraction due to run-off of applied nitrogen ( $LF_{surface\ run-off}$ ) is calculated from a maximal surface run-off and a set of reduction factors:

Formula 2:  $LF_{surface\ run-off} = LF_{surface\ run-off,max} * f_{lu} * \text{minimum of } (f_p, f_{rc}, f_s)$

Where:

$LF_{surface\ run-off,max}$  = maximum run-off fraction for different slope categories

$f_{lu}$  = reduction factor land use: arable land 1.0, grassland 0.25

$f_p$  = reduction factor precipitation

$f_{rc}$  = reduction factor depth to rock

$f_s$  = reduction factor soil type

Horticulture production systems are always classified as arable land (reduction factor 1), so this parameter can be neglected.

The values for the other parameters are listed in Table 2.

**Table 2** The values for the parameters to calculate the run-off fraction of N applied (Velthof et al., 2007, 2009)

Parameter		value
LF <sub>surface run-off, max</sub>	Slope 0 to 8%	10%
	Slope 8-15%	20%
	Slope 15-25%	35%
	Slope > 25%	50%
F <sub>p</sub>	Precipitation surplus > 300 mm	1
	Precipitation surplus 100-300 mm	0.75
	Precipitation surplus 50-100 mm	0.50
	Precipitation surplus < 50 mm	0.25
F <sub>s</sub>	Mineral soils, clay content > 60%	1
	Mineral soils, clay content 35-60%	0.9
	Mineral soils, clay content 18-34%	0.75
	Mineral soils, clay content <18%	0.25
	Peat soils	0.25
F <sub>rc</sub>	Depth soil to rock ≤ 25 cm	1
	Depth soil to rock > 25 cm	0.8

## Leaching to groundwater

The amount of nitrate leached to groundwater is calculated as a fraction of the nitrogen surplus in the soil. N-deposition is also included in the N-surplus in the soil but is considered a 'background input' for which the farmer is not directly accountable, although good farming practice is to take the deposition into account in the planning of fertilisation. Therefore, a correction is included, based on the share of deposition in the total N input.

$$\text{Formula 3: } N_{\text{leaching}} = \text{soil N-surplus} * LF * (1 - (N_{\text{dep}} / (N_{\text{fert}} + N_{\text{org}} + N_{\text{fix}} + N_{\text{dep}})))$$

Where:

$N_{\text{leaching}}$  = the amount of N (Kg N/yr) emitted as nitrate leaching to groundwater

Soil N-surplus = surplus amount of N applied to soil Kg N/yr, see Formula 4

LF = fraction of soil N-surplus emitted as nitrate leaching to groundwater, see Formula 5

$N_{\text{fert}}$  = annual amount of synthetic fertiliser nitrogen applied, Kg N/yr

$N_{\text{org}}$  = annual amount of organic nitrogen (compost, animal manure, sewage sludge and other organic nitrogen) applied, Kg N/yr

$N_{\text{fix}}$  = annual amount of nitrogen input from N-fixation in crop, Kg N/yr

$N_{\text{dep}}$  = annual amount of nitrogen input from N-deposition, Kg N/yr

$(1 - (N_{\text{dep}} / (N_{\text{fert}} + N_{\text{org}} + N_{\text{fix}} + N_{\text{dep}})))$  = correction factor for the share of N-deposition in total N input

The nitrogen surplus in the soil is calculated as the difference of N-inputs and N-outputs of the soil-plant system. External N-inputs entering this system are considered: N-inputs from synthetic fertiliser and organic manure, N-fixation and deposition. Nitrogen in crop residues are no external inputs and considered as internal N-flows. The N-outputs are the nitrogen in harvested crop and co-products, gaseous losses ( $\text{NH}_3$ ,  $\text{N}_2\text{O}$ ,  $\text{NO}_x$ ) and N lost by run-off (Miterrà: (Lesschen, 2018; Velthof et al., 2007; Velthof et al., 2009)).

The amount fixed by pulses and soya bean (*Glycine max* L.) is assumed to be equal to the amount of N in the harvested products.

$$\text{Formula 4: } \text{Soil N-surplus} = N_{\text{fert}} + N_{\text{org}} + N_{\text{fix}} + N_{\text{dep}} - N_{\text{harv}} - \text{NH}_3 - \text{N}_2\text{O} - \text{NO}_x - N_{\text{runoff}}$$

Where:

Soil N-surplus = annual N-surplus in the soil, available for nitrate leaching, Kg N/yr

$N_{\text{fert}}$  = annual amount of synthetic fertiliser nitrogen applied, Kg N/yr

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$N_{org}$  = annual amount of organic nitrogen (compost, animal manure, sewage sludge and other organic nitrogen) applied, Kg N/yr

$N_{fix}$  = annual amount of nitrogen input from N-fixation in crop, Kg N/yr.

In accordance with Miterra, N-fixation can be assumed to be equal to the amount of nitrogen in the harvested products. This assumption is acceptable in situations where no or small amounts of extra N is applied by fertilisers. Some N-fixating crops (like beans) may receive such high N-inputs with fertilisers (synthetic or organic) that N-fixation will be much lower or even stopped. Therefore, an additional rule is applied that in the case where N input with synthetic and organic fertiliser equals or exceeds the N removal by harvested crop, N-fixation is set to 0.

$N_{dep}$  = annual amount of nitrogen input from N-deposition, Kg N/yr. The amount of N-deposition can be based on country-specific data.

$N_{harv}$  = amount of nitrogen in harvested crop (main and co-products), Kg N/yr. The amount of N in the harvested crop can be calculated as N-content (kg/tonne product) times the amount of product harvested (Kg). For the harvested product specific data has to be used, for N-content specific data can be used and if those are not available, the defaults as listed in Annex B must be used.

$NH_3$  = amount of N- $NH_3$  from synthetic and organic fertiliser applied, Kg N- $NH_3$ /yr; see methodology in the section 'Ammonia volatilisation'.

$N_2O$  = amount of N- $N_2O$  from N applied with synthetic and organic fertiliser, deposition and fixation, Kg N- $N_2O$  /yr; see methodology in the section 'Nitrous oxide direct'.

$NO_x$  = amount of N- $NO_x$  from N applied with synthetic and organic fertiliser, deposition and fixation, Kg N-  $NO_x$  /yr; see methodology in the section 'Nitrous oxide direct'.

$N_{runoff}$  = the amount of N emitted as nitrate by run-off to surface water; see Formula 1, Kg N/yr.

The fraction of the soil N-surplus emitted as nitrate leaching is determined by soil characteristics, precipitation surplus, temperature and rooting depth (Miterra: Velthof et al., 2007, 2009).

Formula 5:  $LF = LF_{soil\ type, max} \times f_{lu} \times \text{minimum of } (f_p, f_r, f_t, f_c)$

Where:

$LF_{soil\ type, max}$  = maximum leaching fraction for soil types

$f_{lu}$  = reduction factor land use: arable land 1.0, grassland 0.36

$f_p$  = reduction factor precipitation

$f_r$  = reduction factor rooting depth

$f_t$  = reduction factor temperature

$f_c$  = reduction factor soil organic C content

As in horticulture production systems, the land use can always be classified as arable land (reduction factor 1) so this parameter can be neglected.

The values for the other parameters are listed in Table 3.



**Table 3** The values for the parameters to calculate the leaching fraction of the N-surplus in the soil (Velthof et al., 2007, 2009)

Parameter		Value
LF <sub>soil type, max</sub>	Sandy soils	100%
	Loamy soils	75%
	Clay soils	50%
	Peat soils	25%
F <sub>p, sand and loam</sub>	Precipitation surplus > 300 mm	1
	Precipitation surplus 100–299 mm	0.75
	Precipitation surplus 50–99 mm	0.50
	Precipitation surplus < 50 mm	0.25
F <sub>p, clay and peat</sub>	Precipitation surplus > 300 mm	0.50
	Precipitation surplus 100–300 mm	1
	Precipitation surplus 50–299 mm	0.75
	Precipitation surplus < 50 mm	0.25
F <sub>r</sub>	Rooting depth < 40 cm	1
	Rooting depth > 60 cm	0.75
F <sub>t</sub>	Temperature < 5° C av. annual temp	1
	Temperature 5–15° C	0.75
	Temperature > 15° C	0.50
F <sub>c</sub>	Soil organic C content < 1%	1
	Soil organic C content 1–2%	0.90
	Soil organic C content 2–5%	0.75
	Soil organic C content > 5%	0.50

### Default HFCR modelling

Nitrate emissions are calculated according to the IPCC 2006 Guideline (IPCC, 2006) whereas 30% of the applied nitrogen is emitted as nitrate. The applied nitrogen is the sum of nitrogen applied with synthetic fertiliser, organic fertiliser (compost, animal manure, sewage sludge and other organic nitrogen additions to the soil), crop residues and nitrogen mineralised in organic soils or associated with land use change.

The fraction leached is 30% for situations where soil/substrate water-holding capacity is exceeded, as a result of an excess of rainfall compared to potential evaporation or where irrigation (excluding drip irrigation) is employed. For dry circumstances where evaporation exceeds rainfall or irrigation the IPCC 2006 Guideline (IPCC, 2006) prescribes a leaching fraction of 0%, so no leaching takes place at all. This is, however, not in line with the preferred modelling where the reduction factor for a situation with a negative precipitation surplus is still more than 0% (25%, see Table 3). Therefore, in this methodology the fraction leached is set at a minimum of 25% for those situations where it can be proved that rainfall or irrigation (including drip) irrigation is not exceeding evaporation on a yearly basis.

$$\text{Formula 6: } NO_3 = \text{Fra}_{\text{leach}} * (N_{\text{fert}} + N_{\text{org}} + N_{\text{cr}} + N_{\text{min}}) * 62/14$$

Where:

NO<sub>3</sub> = annual amount of nitrate emissions from leaching and run-off of N additions, kg NO<sub>3</sub> /yr

Fra<sub>leach</sub> = fraction of added nitrogen that is emitted as nitrate through leaching and run-off.

As stated above, this fraction is 30% for situations where soil/substrate water-holding capacity is exceeded, as a result of an excess of rainfall compared to potential evaporation or where irrigation (excluding drip irrigation) is employed. In dry circumstances where evaporation exceeds rainfall or irrigation this fraction is 25%. Only when it can be proved that rainfall or irrigation (including drip) irrigation is not exceeding evaporation on a yearly basis, can the fraction be taken as 25%.

N<sub>fert</sub> = annual amount of synthetic fertiliser nitrogen applied to soils or substrate, Kg N/yr

$N_{org}$  = annual amount of organic nitrogen (compost, animal manure, sewage sludge and other organic nitrogen) applied to soils or substrate, Kg N/yr

$N_{cr}$  = annual amount of nitrogen in crop residues (above and below ground).

The amount of crop residues and N content can be based on specific data and if not available, this can be based on defaults (see Annex A). In soilless systems, crop residues are negligible or not relevant because the living crop is sold together with the substrate (pot plants) or after the cultivation period the crop is either removed together with substrate or the crop remains growing on the substrate for the next production cycle (strawberries on substrate).

$N_{min}$  = annual amount of N mineralised in mineral soils associated with loss of soil C from soil organic matter as a result of changes to land use or management and N mineralised from organic soils/substrates. The latter implies that N mineralised from oxidation of organic matter in peat used as substrate should also be taken into account.

62/14 = Conversion factor of N-NO<sub>3</sub> to NO<sub>3</sub>

## Ammonia volatilisation

The main source for ammonia emissions in horticulture systems is via application of nitrogen in synthetic and organic fertiliser (animal manure, compost, sewage sludge etc.). Other sources of ammonia volatilisation as standing crops and crop residues are recognised but modelling these emissions as a robust and usable methodology covering various cultivation systems in different regions is not yet possible (EEA, 2016). Nevertheless, in some situations these sources are modelled and included in inventories, as for instance ammonia volatilisation from crop residues in the Netherlands which is included as source in the National Inventory (Vonk et al., 2018). In this methodology, ammonia volatilisation from N-application through synthetic and organic fertiliser is being considered.

**Table 4** Measurement and modelling options for ammonia volatilization

	Open field soilless	Open field in soil	Protected soilless s	Protected in soil
Preferred modelling	Modelled NH <sub>3</sub> volatilisation from fertiliser use	Modelled NH <sub>3</sub> volatilisation from fertiliser use	Modelled NH <sub>3</sub> volatilisation from fertiliser use	Modelled NH <sub>3</sub> volatilisation from fertiliser use
Default HFCR modelling	Based on IPCC, Tier 1	Based on IPCC, Tier 1	Based on IPCC, Tier 1	Based on IPCC, Tier 1

### Preferred modelling

Based on an extensive literature research, (Bouwman, et al., 2002) ammonia volatilisation is described as a function of fertiliser type, application method, soil characteristics (pH and CEC) and climate (average temperature).

Formula 7:  $EF_{NH_3} = Exp^{(crop + fertiliser + application + soil\ pH + soil\ CEC + climate)}$

Where:

$EF_{NH_3}$  = emission factor NH<sub>3</sub>, the % of N applied which is emitted as ammonia  
*crop + fertiliser + application + soil pH + soil CEC + climate* = values for the respective parameters, listed in Table 5.

Synthetic N-fertilisers solely based on nitrate do not have any volatilisation at application (EEA, 2016).



**Table 5** The parameters to calculate the ammonia emission factor according to Bouwman et al. (2002)

Parameter		Value
crop type	Upland	-0.045
	Grass	-0.158
	Flooded	0
fertiliser	Ammonium sulfate (AS)	0.429
	Urea	0.666
	Ammonium nitrate (AN)	-0.35
	Calcium ammonium nitrate (CAN)	-1.064
	Anhydrous ammonia (AA)	-1.151
	Other straight N	-0.507
	Nitrogen solutions	-0.748
	Ammonium phosphates (mono-ammonium and diammonium phosphate)	0.065
	Other compound NP	0.0014
	Compound NK	-1.585
	Compound NPK	0.014
application	Ammonium bicarbonate	0.387
	Animal manure	0.995
	Broadcast	-1.305
	Broadcast to floodwater	-1.305
	Incorporated	-1.895
	Solution	-1.292
	Broadcast and then flooded	-1.844
	Incorporated and then flooded	-1.844
	Broadcast to floodwater at panicle initiation	-2.465
	soil pH	< 5.5
5.5 > pH ≤ 7.3		-0.933
7.3 > pH ≤ 8.5		-0.608
> 8.5		0
soil CEC	≤ 16	0.088
in cmol/kg	16 < CEC ≤ 24	0.012
	24 < CEC ≤ 32	0.163
	> 32	0
Climate	Temperate < 20 °C	-0.402
	Tropical ≥ 20 °C	0

### Default HFCR modelling

Ammonia volatilisation is calculated according to the IPCC 2006 Guideline (IPCC, 2006) whereas a fraction of the applied nitrogen is emitted to the air as ammonia. A distinction is made in nitrogen applied by synthetic fertilisers and nitrogen applied by organic fertilisers as animal manure and compost.

$$\text{Formula 8: } NH_3 = (Fra_{C_{volS}} * N_{fert} + Fra_{C_{volO}} * N_{org}) * 17/14$$

Where:

$NH_3$  = annual amount of ammonia volatilisation, kg  $NH_3$ /yr

$Fra_{C_{volS}}$  = fraction of nitrogen from synthetic fertiliser that is volatilised as ammonia. This fraction is 10%.

$N_{fert}$  = annual amount of synthetic fertiliser nitrogen applied to soils or substrate, Kg N/yr

$Fra_{C_{volO}}$  = fraction of nitrogen from organic fertiliser (compost, animal manure, sewage sludge and other organic nitrogen) that is volatilised as ammonia. This fraction is 20%.

$N_{org}$  = annual amount of organic nitrogen (compost, animal manure, sewage sludge and other organic nitrogen) applied to soils or substrate, Kg N/yr

17/14 = Conversion factor of N- $NH_3$  to  $NH_3$

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## Nitrous oxide direct

The relationship of direct nitrous oxide emissions from N applied is described by the IPCC 2006 Guideline (IPCC, 2006). In this model the nitrous oxide emission is not depending on soil, climate, fertiliser type etc. A more specific modelling in which the relationship of N<sub>2</sub>O emissions to those factors is taken into account on a supra national level is not available. For instance, in the Netherlands-specific N<sub>2</sub>O emission factors are available (depending on soil type, fertiliser type and application method) but these are not applicable for other (EU) countries.

This means that as preferred modelling, the IPCC 2006 Guideline (IPCC, 2006) is followed. Nitrous oxide (N<sub>2</sub>O) emissions are calculated according to the IPCC 2006 Guideline (IPCC, 2006) whereas a fraction of the nitrogen input and nitrogen from organic soils is emitted as nitrous oxide (the N input from urine and dung from grazing animals is not taken into account).

Formula 9:  $N_2O\ direct = ((N_{fert} + N_{org} + N_{cr} + N_{som}) \times EF_1 + N_{os} \times EF_2) \times 44/28$

Where:

$N_{fert}$  = annual amount of synthetic fertiliser nitrogen applied to soils or substrate, Kg N/yr

$N_{org}$  = annual amount of organic nitrogen (compost, animal manure, sewage sludge and other organic nitrogen) applied to soils or substrate, Kg N/yr

$N_{cr}$  = annual amount of nitrogen in crop residues (above and below ground). The amount of crop residues and N content can be based on defaults (see Annex A). In soilless systems crop residues are negligible or not relevant because the living crop is sold together with the substrate (pot plants) or after the cultivation period the crop is either removed together with substrate or the crop remains growing on the substrate for the next production cycle (strawberries on substrate).

$N_{som}$  = annual amount of N mineralised in mineral soils associated with loss of soil C from soil organic matter as a result of changes to land use or management

$N_{os}$  = annual amount of N mineralised from organic soils/substrates

$EF_1$  = emission factor for N<sub>2</sub>O emissions from N-inputs (kg N<sub>2</sub>O-N per kg N input) = 0.01

$EF_2$  = emission factor for N<sub>2</sub>O emissions from drained managed organic soils (kg N<sub>2</sub>O-N per ha per year) = 8 for temperate climate, 16 for tropical climate (tropical: mean annual temperature > 18°C)

44/28 = Conversion factor of N- N<sub>2</sub>O to N<sub>2</sub>O

## Nitrous oxide indirect

Indirect nitrous oxide emissions are determined by ammonia volatilisation and nitrate leached. Ammonia volatilisation and nitrate leaching is calculated according to the most preferred option, see relevant sections above. The indirect nitrous oxide emissions based on these N-losses are calculated, following the IPCC Guidelines (IPCC, 2006).

Formula 10:  $N_2O\ indirect = (NH_3-N\ volatilisation * EF_{vol} + NO_3-N\ leaching \times EF_{leach}) * 44/28$

Where:

NH<sub>3</sub>-N volatilisation = ammonia volatilisation calculated according to the most preferred option, see section on ammonia volatilisation

$EF_{vol}$  = 0.01

NO<sub>3</sub>-N leaching = nitrate leaching calculated or measured according to the most preferred option, see section on ammonia volatilisation

$EF_{leach}$  = 0.0075

44/28 = Conversion factor of N-N<sub>2</sub>O to N<sub>2</sub>O

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## Nitrogen oxides

The preferred methodology for nitrogen oxide (NO<sub>x</sub>) emissions depends on the way ammonia volatilisation is calculated. If ammonia volatilisation is calculated using the fall-back option (conforming to IPCC Tier 1), nitrogen oxide emissions are not relevant because in the IPCC ammonia approach (IPCC, 2006) the NO<sub>x</sub> emissions are included.

If ammonia volatilisation is calculated using the preferred modelling, the following approach is preferred, based on EEA (2016):

Formula 11:  $N\text{-NO}_x = N_{\text{applied}} * EF_{\text{NO}_x} * 46/14$

Where:

N applied = N applied with synthetic and organic fertiliser

EF NO<sub>x</sub> = 0.04

46/14 = conversion factor of N-NO<sub>x</sub> to NO<sub>x</sub>

## Phosphate

The product environmental footprint category rules (PEFCR) guide 6.3 (European Commission, 2018) are, in order of preference:

1. 'The LCI should be modelled as the amount of P emitted to water after run-off, and the emission compartment "water" shall be used'
2. 'The LCI may be modelled as the amount of P applied on the agricultural field (through manure or fertilisers) and the emission compartment "soil" shall be used'

In the case of measured amounts of phosphate discharged in waste water to surface water or a sewage system, the first option should be used. Comparable with nitrate, phosphate measurements are only representative/accurate in completely closed recirculation systems, where all discharged water is monitored on phosphate content. In that case the phosphate emissions are calculated as volume of discharged water times the measured phosphate concentration. This implies that for cultivations in the soil, regardless of whether it is protected, measurements of phosphate emissions are not applicable.

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## Annex A

Nitrogen in crop residues (above and below ground) emission factor (van Bruggen et al. 2018)

	N in crop residue above ground (kg N/ha)	N in crop residue below ground (kg N/ha)
Strawberries	19	6
Endive	40	6
Asparagus	27	6
Gherkin	78	6
Cauliflower	132	14
Broccoli	156	14
Cabbage	122	14
Celeriac	75	14
Beetroot	95	14
Lettuce	37	6
Leek	82	4
Scorzonera	46	14
Spinach	30	6
Brussels sprouts	170	14
Industrial French beans	77	13
Runner beans	61	13
Broad beans green	16	13
Carrot	9	0
Winter carrot (Danvers)	65	0
Chicory	59	0
Other vegetables	78	6
Green manure following arable crop	51.5	14
Green manure following maize	19.5	5

## Annex B

Nitrogen content (kg/tonne fresh harvested product) in harvested products (Schoot and Dijk, 2001).

Crop	N content (kg/tonne fresh harvested product)
FOR POTATOES	3.3
FOR CONSUMPTION (CLAY SOIL)	
FOR CONSUMPTION (SANDY / PEAT SOIL)	3.3
FOR STARCH	3.7
- PROPAGATING MATERIAL (YOUNG PLANTS)	3.3
GRAIN	
- WINTER WHEAT	20.0
- SUMMER BARLEY	15.0
GRASS SEED (ENGLISH RYE GRASS)	21.0
MAIZE SILAGE	3.8
SUGAR BEET	1.8
STRAWBERRY	1.2
CAULIFLOWER	2.6
BROCCOLI	2.0
CHINESE CABBAGE	1.5
PEAS	7.5
CELERIAC	2.0
FLORENCE FENNEL	2.0
CARROT	
- BUNCHED CARROTS	1.5
- CARROT (WASHED AND CUT BEFORE SALE)	1.5
- WINTER CARROT	1.6
LEEK	3.0
LETTUCE	
- LETTUCE	2.0
- ICEBERG LETTUCE	1.5
SPINACH	3.5
BRUSSELS SPROUT	5.5
GREEN BEAN (BUSH TYPE)	2.2
ONION	2.2
CHICORY ROOT	2.3
WHITE CABBAGE	1.9

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### More information

Dr Irina Verweij-Novikova  
T +31 (0)6 41 33 49 56  
E [irina.verweij-novikova@wur.nl](mailto:irina.verweij-novikova@wur.nl)  
[www.wur.eu/economic-research](http://www.wur.eu/economic-research)

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