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LCA Crop Database Methodology Report

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Preface

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1 Introduction

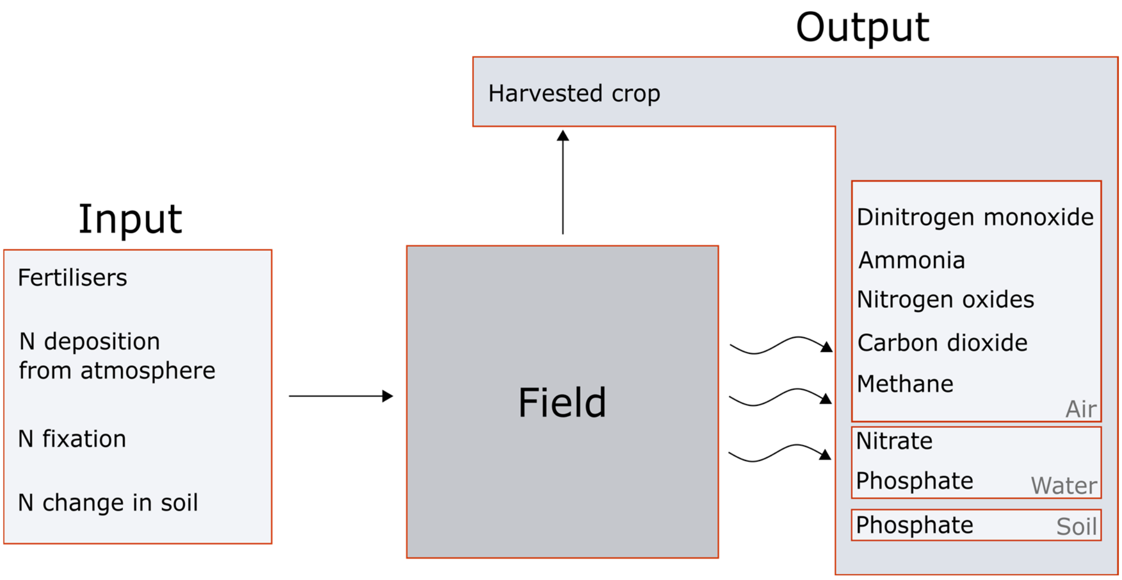
This report presents the methodology and data for calculating the greenhouse gas (GHG) emissions, nitrogen and phosphate leached to water, and phosphate leftover in the soil, related to the cultivation of crops. The GHG emissions include dinitrogen monoxide, ammonia, nitrogen oxides, and carbon dioxide.

The emissions, leaches, and leftovers are calculated using a model described by the intergovernmental panel on climate change (IPCC). Following the calculations are a summary where the inputs and the outputs of the model are outlined.

2 General outline of methodology

Emissions from fields stem from fertiliser and crop residue inputs. These emissions are nitrogen compounds, phosphate, and carbon dioxide. The nitrogen compounds include N_2O, NH_3, NO_x, and NO_3^-, where the latter leaches to water and the rest are emitted to the atmosphere while phosphate either leaches to water or remains in the field's soil. The nitrogen compounds and phosphate are calculated by examining field-balances. Carbon dioxide is emitted to the atmosphere through peat oxidation.

The fertiliser considered in this method is disaggregated into organic and synthetic fertiliser. Where the former is manure, and the latter is comprised of three types: N, P_2O_5, and K_2O. The amount of fertiliser used for crop cultivation is unique for each crop and default values are obtained from (Schmidt, Merciai, Muñoz, De Rosa, & Astudillo, 2021).



2.1 Calculation of fertiliser applied

The amount of fertiliser applied to the soil used for cultivation of a specific crop in a specific country is determined from the total fertiliser consumption including mineral and organic, of the country, the recommended amount of fertiliser for the crop, and the harvested area of the crop in the country. The total mineral fertiliser consumption per country and the total manure applied to soils per country are imported from (IFA, 2022) and (FAO, Livestock Manure, 2022), respectively. The recommended fertiliser input per crop and country is compiled from (Heffer, Gruère, & Roberts, 2017), (Landbrugsstyrelsen, 2021), and (Roy, Finck, Blair, & Tandon, 2006). The harvested area per crop in each country is imported from (FAO, Crops and livestock products, 2022).

The amount of fertiliser applied is calculated for each of the fertiliser types: N, P_2O_5, and K_2O. The procedure is similar for all types but organic fertiliser.

The total mineral fertiliser consumption per country is, and the total manure applied to soils per country are summed to calculate the total fertiliser as:

$$F_{total,country} = \text{Total mineral fertiliser}_{country} + Eff_{manure} \cdot \text{Total manure}_{country}$$

Where the units are [kg fertiliser] and Eff_{manure} is the efficiency of the manure which describes the ratio of the amount of fertiliser applied to the fertiliser uptake of the plants. Values for the efficiency is imported from (Plantedirektoratet, 2004/05). The total amount of fertiliser is divided among all the crops in the country according to the recommended amount ($F_{recom.,crop,country}$) and the harvested area ($A_{crop,country}$). This is done by weighting the distribution of fertiliser with a normalisation factor for each crop as:

$$\text{Factor}_{norm.,x,country} = \frac{F_{recom.,x,country}}{\sum_i F_{recom.,i,country}}$$

Where “x” is a given crop and “i” is the iterable. The amount of N-fertiliser applied to a crop “x” in units of [kg fertiliser/ha] is calculated as:

$$F_{applied,x,country} = \text{Factor}_{norm.,x,country} \cdot \frac{F_{total,country}}{A_{x,country}}$$

3 Methodology – Mathematical approach

This chapter is divided into sections according to GHG emissions, nitrate and phosphate leaches, and phosphate leftover in soil. The emissions of N_2O occur through a direct and an indirect pathway. The former being directly from the soil to which the N is added. The latter due to volatilisation and leaching from the soil. The method used for calculation of N2O emissions is described in (IPCC, 2019) and is applicable to both annual and perennial crops.

3.1 Direct dinitrogen monoxide (N_2O)

According to (IPCC, 2019) the direct N_2O-N emissions can be calculated as:

$$N_2O_{direct}\text{-}N = N_2O\text{-}N_{Ninputs} + N_2O\text{-}N_{OS} + N_2O\text{-}N_{PRP}$$

Where,

- N_2O_{direct}-N is the annual direct N_2O-N emissions produced from managed soils, kg N_2O-N yr^{-1}
- $N_2O\text{-}N_{Ninputs}$ is the annual direct N2O-N emissions from N inputs to managed soils, kg N_2O-N yr^{-1}
- $N_2O\text{-}N_{OS}$ is the annual direct N2O-N emissions from managed organic soils, kg N_2O-N yr^{-1}
- $N_2O\text{-}N_{PRP}$ is the annual direct N2O-N emissions from urine and dung inputs to grazed soil, kg N_2O-N yr^{-1}

In the following, the three terms on the right hand side of the equation are explained from left to right.

$N_2O\text{-}N_{Ninputs}$:

$$N_2O\text{-}N_{Ninputs} = (F_{SN} + F_{ON} + F_{CR} + F_{SOM}) \cdot EF_1$$

Where,

- F_{SN} is the annual amount of synthetic fertiliser N applied to soils, kg N yr^{-1}
- F_{ON} is the annual amount of animal manure, compost, sewage sludge, and other organic N additions applied to soils, kg N yr^{-1}. Since the inputs of organic fertilisers are by-products of the farm industry they are constrained and thus all inputs of organic fertilisers are corrected for fertiliser efficiency. Therefore F_{ON} is modelled as mineral fertiliser in this consequential model.
- F_{CR} is the annual amount of N in crop residues (above-ground and below-ground), including N-fixing crops, and from forage/pasture renewal, returned to soils, kg N yr^{-1}
- F_{SOM} is the 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 in regions where leaching/runoff occurs, kg N yr^{-1}. This parameter is assumed to be zero since it is assumed that the change in carbon content of the mineral only occur in a limited period of time after establishment of a certain crop and that annual changes in the long term are regarded as insignificant.
- EF_1 is the emission factor for N_2O emissions from N inputs, kg N_2O-N (kg N inputs)$^{-1}$. Data is obtained from (IPCC, 2019) table 11.1. Disaggregated emission factors are used, i.e. distinction is made between e.g. wet/dry climate. The type of climate has been assigned manually to each country based on information on the latitude, average temperature and cultivated crops.

$$F_{CR} = AGR \cdot N_{AG} \cdot \left(1 - Frac_{Remove} - (Frac_{Burn} \cdot C_f)\right) + BGR \cdot N_{BG}$$

Where,

- AGR is the annual total amount of above-ground residues, kg N (kg d.m.)$^{-1}$
- N_{AG} is the N content of above-ground residues, kg N (kg d.m.)$^{-1}$. Data obtained from (IPCC, 2019) table 11.1A.
- $Frac_{Remove}$ is the fraction of above-ground residues removed annually for purposes such as feed, bedding, and construction, dimensionless. No data on this parameter could be found and therefore no removal is assumed.
- $Frac_{Burn}$ is the fraction of annual harvested area which is burnt, dimensionless. No data on this parameter could be found and therefore it is assumed to be zero.
- C_f is the combustion factor, dimensionless.
- BGR is the annual total amount of below-ground crop residue, kg d.m. yr^{-1}
- N_{BG} is the N content of below-ground residues, kg N (kg d.m.)$^{-1}$. Data is obtained from (IPCC, 2019) table 11.1A.

$$\mathrm{AGR} = \mathrm{AG_{DM}} \cdot \mathrm{Area} \cdot \mathrm{Frac_{Renew}}$$

Where,

- AG_{DM} is the above-ground residue dry matter, kg d.m. ha^{-1}. Data for all crops are imported from (Wirsenius, 2000).
- Area is the total annual area harvested crop, ha yr^{-1}
- $Frac_{Renew}$ is the fraction of total area under crop that is renewed annually, dimensionless. For countries where pastures are renewed on average X years, $\mathrm{Frac_{Renew}} = 1/x$. For annual crops, $\mathrm{Frac_{Renew}} = 1$.

$$\mathrm{BGR} = (\mathrm{Crop} + \mathrm{AG_{DM}}) \cdot \mathrm{RS} \cdot \mathrm{Area} \cdot \mathrm{Frac_{Renew}}$$

Where,

- RS is the ratio of below-ground root biomass to above-ground shoot biomass for crop, kg d.m. ha^{-1} (kg d.m. ha^{-1})$^{-1}$. Data is obtained from (IPCC, 2019) table 11.1A.

N_2O-N_{OS}:

$$\mathrm{N2O\text{-}N_{OS}} = \mathrm{F_{OS}} \cdot \mathrm{EF_2}$$

Where,

- F_{OS} is the annual area of managed/drained organic soils, ha. This parameter is inserted in percentage relative to the total cropland. If no value is entered, a default value from the Food and Agriculture Organization of the United Nations (FAOSTAT), is used.
- EF_2 is the emission factor for N_2O emissions from drained/managed organic soil, kg N_2O-N (ha yr)$^{-1}$. Data is obtained from (IPCC, 2013) table 2.5.

$N_2O\text{-}N_{PRP}$:

$$N2O\text{-}N_{PRP} = F_{PRP} \cdot EF_3$$

Where,

- F_{PRP} is the annual amount of urine and dung N deposited by grazing animals on pasture, range, and paddock, N kg yr^{-1}. This parameter is set to zero and not included in the calculations.
- EF_3 is the emission factor for N_2O emissions from urine and dung N deposited from pasture, range, and paddock by grazing animals, kg N_2O-N (kg N input)$^{-1}$.

3.2 Indirect dinitrogen monoxide (N_2O)

According to (IPCC, 2019) the indirect N_2O-N emissions can be calculated as

$$N_2O_{indirect}\text{-}N = N_2O_{ATD}\text{-}N + N_2O_L\text{-}N$$

Where,

- $N_2O_{indirect}$-N is the annual indirect N_2O-N emissions from N volatilised and leached from the field, kg N_2O-N yr^{-1}
- N_2O_{ATD}-N is the annual amount of N_2O-N produced from atmospheric deposition of N volatilized from managed soils, kg N_2O-N yr^{-1}
- N_2O_L-N is the annual amount of N_2O-N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, kg N_2O-N yr^{-1}

N_2O_{ATD}-N:

$$N_2O_{ATD}\text{-}N = [F_{SN} \cdot Frac_{GASF} + (F_{ON} + F_{PRP}) \cdot Frac_{GASM}] \cdot EF_4$$

Where,

- $Frac_{GASF}$ is the fraction of synthetic fertilizer N that volatilizes as NH_3 and NO_x, kg N volatilized (kg of N applied)$^{-1}$.
- $Frac_{GASM}$ is the fraction of applied organic N fertilizer materials (F_{ON}) and of urine and dung N deposited by grazing animals (F_{PRP}) that volatilizes as NH_3 and NO_x, kg N volatilized (kg of N applied or deposited)$^{-1}$. Data is obtained from (IPCC, 2019) table 11.3.
- EF_4 is the emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, kg N_2O-N (kg NH_3-N + NO_x-N volatilized)$^{-1}$. Data is obtained from (IPCC, 2019) table 11.3.

$$Frac_{GASF} = \sum_{i=1}^{n} Frac_{fert,i} \cdot Frac_{GASF,i}$$

Where,

- $Frac_{fert,i}$ is the fraction of fertilizer type which is used in a country. The types of fertilizer used is urea, ammonium-based, nitrate-based, and ammonium-nitrate-based. Data is imported from the International Fertilizer Association (IFASTAT)
- $Frac_{GASF,i}$ is the fraction of synthetic fertilizer of type "i" that volatilizes as NH_3 and NO_x, kg N volatilized (kg of N applied)$^{-1}$. Data is obtained from (IPCC, 2019) table 11.3.

N_2O_L-N:

$$N_2O_L\text{-}N = (F_{SN} + F_{ON} + F_{PRP} + F_{CR} + F_{SOM}) \cdot Frac_{LEACH\text{-}(H)} \cdot EF_5$$

Where,

- $Frac_{LEACH\text{-}(H)}$ is the fraction of all N added to/mineralized in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, kg N (kg of N additions)$^{-1}$. Data is obtained from (IPCC, 2019) table 11.3.
- EF_5 is the emission factor for N_2O emissions from N leaching and runoff, kg N_2O-N (kg N leached and runoff)$^{-1}$. Data is obtained from (IPCC, 2019) table 11.3.

3.3 Ammonia (NH_3) and Nitrogen oxides (NO_x)

The nitrogen in ammonia and nitrogen oxides is calculated based on $Frac_{GASF}$ and $Frac_{GASM}$ which is the proportion of N in synthetic and organic fertilizer, respectively, that is volatilized as ammonia and nitrogen oxides. Using a relationship between ammonia and nitrogen oxides the proportion of the two emissions is determined. This relationship yields the distribution 88% and 12% for NH_3-N and NO_x-N, respectively, according to (Schmidt & Dalgaard, 2012).

3.4 Carbon dioxide (CO_2)

The carbon dioxide emitted from managed drained organic soils are calculated as

$$CO_2\text{-}C = F_{OS} \cdot EF_{peat}$$

Where,

- CO_2-C is the carbon dioxide emission from managed drained organic soils, kg CO_2-C yr^{-1}.
- EF_{peat} is the peat emission factor for CO2 emissions from managed drained organic soils, kg CO_2-C (ha yr)$^{-1}$. Data is obtained from (IPCC, 2013) table 2.1.

3.5 Phosphate (PO_4)

Phosphate is emitted through two pathways: Leaching/runoff and eroded sediments. The phosphate emitted to the atmosphere is calculated by considering the amount of phosphorus applied to the soil by adding fertilizer and the amount removed when the crop is harvested. The amount of leached phosphate can be calculated as a fraction of the phosphorus accumulated in the soil since phosphorus binds strongly to soil particles. The fraction is, according to (Hamilton, et al., 2018), 2.9%. The remaining is accumulated in the soil.

3.6 Nitrate (NO_3)

Nitrate is emitted to water through leaching/runoff and the NO3-N emission is calculated according to (IPCC, 2019) based on $Frac_{LEACH-(H)}$ since it is the fraction of N added to/mineralized in managed soils that is lost as leaching.

3.7 Methane (CH4)

Flooded rice fields produce a significant amount of methane from anaerobic decomposition of organic material, which escapes to the atmosphere. The methane emissions from rice cultivation are calculated according to the procedure in (IPCC, 2019b). The emissions are calculated as:

$$CH_4 = \sum_{i,j,k} EF_{i,j,k} \cdot t_{i,j,k} \cdot A_{i,j,k}$$

Where,

- CH_4 is the annual methane emissions from rice cultivation kg CH_4 yr^{-1}
- $EF_{i,j,k}$ is the daily emission factor for i, j, and k conditions, kg CH4 ha^{-1} day^{-1}
- $t_{i,j,k}$ is the cultivation period of rice for i, j, and k conditions, day
- $A_{i,j,k}$ is the annual harvested area of rice for i, j, and k conditions, ha yr^{-1}
- i,j,k represents different ecosystems, water regimes, type and amount of organic amendments, and other conditions under which CH_4 emissions from rice may vary

The daily emission factor is estimated for each of the conditions with the following equation

$$EF_i = EF_c \cdot SF_w \cdot SF_p \cdot SF_o$$

Where,

- EF_c is the baseline emission factor for continuously flooded fields without organic amendments
- SF_w is the scaling factor to account for the differences in water regime during the cultivation period
- SF_p is the scaling factor to account for the differences in water regime in the pre-season before the cultivation period
- SF_o is the scaling factor which should vary for both type and amount of organic amendment applied

The baseline emission factor is applied at a regional level as seen in the table below.

Region	**Emission factor [kg CH4 ha^{-1} day^{-1}]**
Africa	1.19
East Asia	1.32
Southeast Asia	1.22
South Asia	0.85
Europe	1.56
North America	0.65
South America	1.27

Since paddy rice is considered, the scaling factor SF_w is set to 0.6 as according to (IPCC, 2019b).

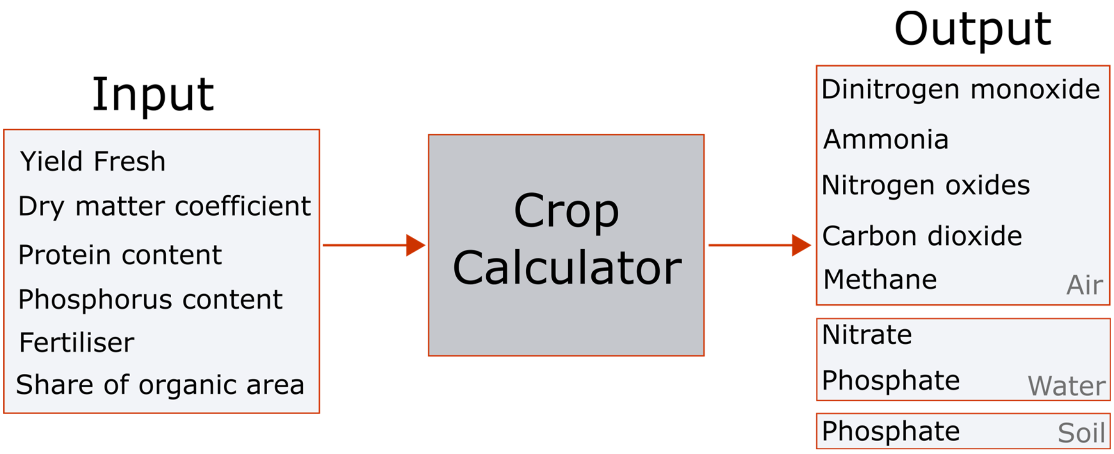
For the scaling factor for the pre-season water regimes an aggregated case is considered where $\mathrm{SF_p}$ is set to 1.22.

The organic amendments applied to the soil is assumed to be rice residue left on the fields and not incorporated into the soil as country specific data on this was not available. Therefore, $\mathrm{SF_o}$ is assumed to be equal to one as specified by (IPCC, 2019b).
The cultivation period of rice is considered on a regional level as seen in the table below.

Region	Cultivation period [day]
Africa	113
East Asia	112
Southeast Asia	102
South Asia	112
Europe	123
North America	139
South America	124

4 Summary of inputs and outputs

The equations introduced in the former chapter involves parameters for which there are no default values. These parameters are the user-inputs in the model and must be entered in order to calculate the emissions. Some of the inputs are crop specific such as dry matter coefficient and phosphorus content, and some are related to the amount of fertiliser used. A summary of the inputs and outputs can be seen in the figure below.



If the fertiliser inputs are not supplied, default values from (Schmidt, Merciai, Muñoz, De Rosa, & Astudillo, 2021) are used. Default values for the dry matter coefficient, protein content, and phosphorus content, are also available if they are not inputted. The default values are obtained from (Møller, 2005) and (Gebhardt & Thomas, 2002).

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