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Swedish Environmental Emissions Data

Evaluation of the IPCC model for N mineralization

An overview on N_2O emissions, N mineralization and
C:N ratios from projects recently conducted at SLU and
from other Swedish sites

Sabine Jordan and Mattias Lundblad, SLU

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SMED is short for Swedish Environmental Emissions Data, which is a collaboration between IVL Swedish Environmental Research Institute, SCB Statistics Sweden, SLU Swedish University of Agricultural Sciences, and SMHI Swedish Meteorological and Hydrological Institute. The work co-operation within SMED commenced during 2001 with the long-term aim of acquiring and developing expertise within emission statistics. Through a long-term contract for the Swedish Environmental Protection Agency extending until 2014, SMED is heavily involved in all work related to Sweden's international reporting obligations on emissions to air and water, waste and hazardous substances. A central objective of the SMED collaboration is to develop and operate national emission databases and offer related services to clients such as national, regional and local governmental authorities, air and water quality management districts, as well as industry. For more information visit SMED's website www.smed.se.

Innehåll

Summary

SMED is short for Swedish Environmental Emissions Data, which is a collaboration between IVL Swedish Environmental Research Institute, SCB Statistics Sweden, SLU Swedish University of Agricultural Sciences, and SMHI Swedish Meteorological and Hydrological Institute.

A smaller literature study and a data retrieval on N_2O emissions, N mineralization and C:N ratios from projects recently conducted at SLU and from other Swedish sites have been performed to evaluate whether the current IPCC Tier 1 approach with a default emission factor of 1% (EF_1) for N_2O emissions from agricultural soils and other land use categories should be changed to a higher Tier with more specific EFs.

The study showed that the use of a default N_2O EF of 1% of the N applied to soils would either under- or overestimate N_2O emissions. It was also concluded that there is no relationship between total N input and N_2O emissions, i.e. high fertilizer input must not be related to high N_2O emissions and low fertilizer input can result in high N_2O emissions. Even though N_2O emissions from different Swedish land use categories were lower as the default EF_1 in 8 of the 21 reported data sets, there is clear evidence to change from the IPCC Tier 1 approach for N_2O emissions to more adjusted EFs related to a country-specific methodology. The strong relationship between C:N ratios and N_2O emissions from drained forested histosols may be used to improve our ability to predict N_2O emissions from other land use categories such as grassland and cropland.

Keywords: C:N ratio, emission factor, greenhouse gas, IPCC Tier 1, land use category, N mineralization, nitrous oxide, production areas

Background

N_2O-emissions due to nitrogen (N) mineralization are reported for:

- Cropland under category 3.D.a.5 in the agriculture sector and is used to calculate the indirect emissions in category 3.D.1-2.
- All other land use categories and land use change categories in the LULUCF-sector, category 4(III) for direct and 4(IV) for indirect emissions.
- Land use and land use change activities under the Kyoto protocol under 4(KP-II)3.

Today, Sweden uses the IPCC default method (Tier 1) with default emission factors (EF). The method is based on the carbon stock change for the actual land use or land use change category, the C:N ratio and a general EF which represents the loss of N_2O relative to the released N due to the soil disturbance (corresponds to N_2O emission per application of N fertilizer).

Since the size of the carbon stock change in soils (ΔC) may be large and may have large variations from year to year, there are reasons to assess the method and the parameters involved to reduce the uncertainties in the estimate as much as possible.

The current IPCC Tier 1 approach (default EF_1 of 1%) for N_2O emissions from agricultural soils does not account for any effects of crop type, climatic conditions or crop management. Thus, using simplified EFs can result in erroneous conclusions (Lesschen *et al.* 2011, Rees *et al.* 2013). Many authors (e.g. Bouwman *et al.* 2002, Charles *et al.* 2017, Rochette *et al.* 2008) associated four major weaknesses with simplified EF_1 values:

1) An assumption of a linear relationship between total N input and N_2O emissions (not considering that biological thresholds for N_2O emissions might exist),

2) A large range of uncertainty that varies from 0.3% to 3%,

3) The dataset used to generate the default factor EF_1 is biased towards mid-latitude and temperate regions and

4) The EFs do not account for differences between N inputs from synthetic fertilizer and organic amendments on N_2O emissions across soil types, agronomic systems and environmental conditions.

Further, a mechanism to assess the potential impact of future climate and land-use change is excluded (Flynn *et al.* 2005).

Although these weaknesses exists, the default value for EF_1 has been set as 1% of the N applied to soils or released through activities that result in mineralization of organic matter.

Only a few countries already developed Tier 2 approaches for soil N_2O emissions for specific sources, e.g. Canada (Rochette *et al.* 2008) and New Zealand (De Klein and Ledgard 2005). Regional fertilizer-induced emission factors in the semi-arid brown soil zone of the Prairies and in the humid eastern provinces in Canada ranged from 0.0016 kg N_2O -N kg^{-1} N to 0.017 kg N_2O –N kg^{-1} N, respectively. The country specific N_2O emission factor for animal excreta deposited during grazing was 0.01 kg N_2O -N kg^{-1} N for New Zealand.

IPCC also encourages countries to use a Tier 2 approach in which N_2O EFs are disaggregated based on environmental and crop management related factors (Lesschen *et al.* 2011). However, whole-farm analysis by the use of farm scale models (Bonesmo *et al.* 2012) that will lead to a country-specific methodology should be recommended for future development of the method. This will further account for regional climatic and land use impacts on N_2O emission factors. By this, several potential N_2O driving parameters, that are otherwise not included in the IPCC default approach (such as bulk density, pH value, ratio of carbon and nitrogen, thickness of peat layer, air temperature, soil temperature, precipitation, groundwater table, water-filled pore space, nitrate concentration, ammonia concentration, mineral nitrogen concentration, organic and mineral nitrogen fertilization), will be considered (Leppelt *et al.* 2014, Rochette *et al.* 2008).

Aim

The aim of this study was to evaluate the IPCC method for calculating N_2O emissions in the context of N mineralization by:

- Performing a smaller study of current SLU research on both mineral and organic soils with forest, cropland and grassland, including a literature review, to evaluate potential changes to the current coefficients that could make them more specific for Sweden.
- Check if the activity data used (carbon stock change) can be differentiated for a more robust calculation.
- Propose a refined methodology and new factors for the calculation of N_2O emissions in connection with N mineralization.

The work aims for an improved reporting to the UNFCCC and the EU.

Material and methods

The project was partitioned into four activities that included (i) a data retrieval on N_2O emissions, N mineralization and C:N ratios from projects recently conducted at SLU and (ii) from other Swedish sites. In a third (iii) activity all retrieved data was related to land use categories and was compiled with other relevant studies about N_2O emission factors in this report (iv).

N_2O emission data

N_2O emission data was only used when soil type, land use category, geographical coordinates and C:N ratio were reported. The indication of water table level and the used amount of fertilizer have been included as well whenever available in the reports. The latter is important for estimating the N_2O:N factor, i.e. the portion of the directly emitted N_2O of the N applied to soils.

After the N_2O emission data filtration, a quality control has been done to secure comparability among the data material. Different measurement units in the studies have been standardized to a common unit (kg N_2O-N ha^{-1} y^{-1}). Some studies reported measurements with only some single values whereas others showed a wide distribution of many data points. Some measurements were done during the vegetation season only, others sampled during the frost-free season or during summer. In some few cases measurements were done over one whole year. The different measurement strategies have been considered in the evaluation of the results.

N_2O emissions during winter were considered to be 10 to 30 % of one year's emission but emissions can differ largely (Alm *et al.* 1999). Thus, a simple equation (annual emission = emission during vegetation period + winter emissions) has been used. Unfortunately, this equation is afflicted with a certain unbalance because of a huge amount of data material from the vegetation period (summer, frost-free season) facing the few data points from winter seasons.

Regional C:N ratios

The soil and crop inventory for mineral soils (mark och grödoinventeringen) was used to find regional values of C:N ratios. The inventory data has been regionalised and allowed to divide Sweden into 8 production regions.

Results and Discussion

Data summary

Our literature search resulted in 52 N_2O flux measurement data sets (table 1) including 38 from organic soils (36 fen peat, 2 *Sphagnum* peat), 7 from mineral soils (Cambisols, Clay soils, Podsols, Umbrisols), 3 from the litter horizons of mineral soils and 4 from peaty marls. From the organic soils, 7 N_2O flux measurements have been done in drained forest sites, 13 on drained cropland and 15 on drained grassland sites, 1 on a pristine mire and 2 in a rewetted site after peat extraction. From the mineral soils, N_2O emissions were measured on 3 sites with forest clear cut/stump harvest (where also the above named 3 organic litter horizons have been investigated), 3 sites on cropland and 1 site on drained forest sites. Nitrogen fertilizers were used on grassland and cropland sites.

Table 1: Overview input data such as land use category, production area, N_2O data sets and references

Land use category	**Production areas (4 of 8)**	**Included N_2O data sets (n)**	**Reference**
Forest	Southern Forestland (5)	2	Aurangojeb 2017
	Southern Forestland (5)	1	He *et al.* 2016
	Southern Forestland (5)	2	Ernfors *et al.* 2011
	Southern Forestland (5)	3	von Arnold *et al.* 2005
	Central Plains (4) and Central Forestland (6)	6	Strömgren *et al.* 2016
Cropland	Central Plains (4) and Southeastern Coastal (2)	14	Norberg *et al.* 2016
	Central Plains (4)	3	Rychel (not published)
	Southern Forestland (5)	3	Kasimir Klemedtsson *et al.* 2009
Grassland	Central Plains (4)	8	Norberg *et al.* 2016
	Central Plains (4) and Southern Forestland (5)	4	Berglund *et al.* 2011
	Southern Forestland (5)	3	Kasimir Klemedtsson *et al.* 2009
Undrained mire	Southern Forestland (5)	1	von Arnold *et al.* 2005a
Rewetted	Central Forestland (6)	2	Jordan 2016

Peat of the fen peat sites mainly consisted of H9-10 (grade of decomposition, strongly humified peat, von Post 1924), but H7-8, H3-6 and H1-2 (undecomposed or less decomposed peat)2 were also found. Geographically, the study sites range from 57.08°N, 14.45°E to 60.03°N, 17.45°E and encompass 4 of the 8 production areas (table 2): Götalands mellanbygder (Southeastern Coastal), Svealands slättbygder (Central Plains), Götalands skogsbygder (Southern Forestland) and Mellersta Sveriges skogsbygder (Central Forestland).

Spruce and Pine were the dominant species at the forest sites. For the cropland sites, spring wheat, barley, oats, carrots and potatoes were typically grown on organic and mineral soils as well as on the peaty marls[1]. N_2O emission fluxes from fields with parsnip, spring oilseed rape and spring triticale were also measured.

Due to the fact that N_2O emission data was only used when C:N ratios for each data set was also reported, 52 values for C:N ratio were included as well (45 for organic soils and 7 for mineral soils). The C:N ratio at the sites ranged between 9 and 60 and between 11.8 and 19.7 in the organic and mineral soils, respectively. The forest sites had higher C:N ratios (27.5 for the organic soils and 18 for the mineral soils) than the cropland and grassland sites (both 14.7 for the organic soil sites and 11.8 for the Cambisol). The C:N ratios were 47 and 60 for the pristine mire and for one of the rewetted sites (H3-6), respectively.

Regional C:N ratios

The C:N ratios for the four production areas (Southeastern Coastal, Central Plains, Southern Forestland and Central Forestland) reported in the soil and crop inventory are listed in table 3. The values represent an average value for three inventory events. For all regions, a variation over time was observed (increased C:N ratios) but more information is needed to assess whether these changes are real or just a random effect of sampling. The C:N ratio formerly used was the default value of 10, which indicates that changing the C:N ratios by using the regional values may have a significant effect on the emissions in some of the regions. Mean C:N ratios from this report's 7 N_2O flux measurement data sets on mineral soils for the production areas 4, 5 and 6 (table 2) were not, slightly or much higher as the reported values for C:N ratios from the soil and crop inventory (table 3) but were in the C:N ratios min-max range.

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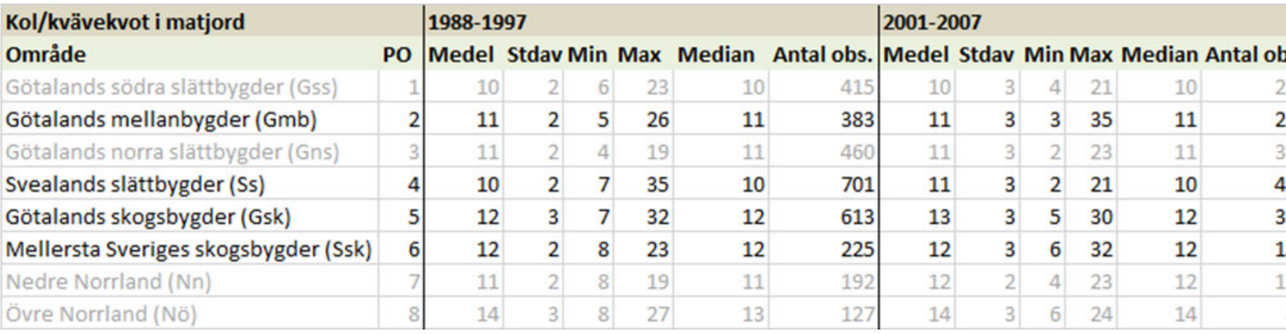
[1] Peaty marls are lacustrine sediments and often underlying peat bogs.

Table 2: C:N ratios and production areas from this report's 7 N_2O flux measurement data sets on mineral soil, separated in land use category and soil type

	Central Plains (4)		**Southern Forestland (5)**	**Central Forestland (6)**	
	Eutric cambisol, spring wheat, cropland	Haplic cambisol, forest, clear cut	Umbrisol, forest, drained	Gley, arable soil planted with spruce in the 1960s, forest, clear cut	Haplic podzol/gleyey till, forest, clear cut
C:N (n)	11,8 (3)	19,4 (1)	18,3 (1)	14,3 (1)	19,7 (1)

Table 3: C:N ratios and production areas from the soil and crop inventory on mineral soils (grey font – not included in this report)



Kol/kvävekvot i matjord		**1988-1997**						**2001-2007**					
Område	**PO**	**Medel**	**Stdav**	**Min**	**Max**	**Median**	**Antal obs.**	**Medel**	**Stdav**	**Min**	**Max**	**Median**	**Antal ob**
Götalands södra slättbygder (Gss)	1	10	2	6	23	10	415	10	3	4	21	10	2
Götalands mellanbygder (Gmb)	2	11	2	5	26	11	383	11	3	3	35	11	2
Götalands norra slättbygder (Gns)	3	11	2	4	19	11	460	11	3	2	23	11	3
Svealands slättbygder (Ss)	4	10	2	7	35	10	701	11	3	2	21	10	4
Götalands skogsbygder (Gsk)	5	12	3	7	32	12	613	13	3	5	30	12	3
Mellersta Sveriges skogsbygder (Ssk)	6	12	2	8	23	12	225	12	3	6	32	12	1
Nedre Norrland (Nn)	7	11	2	8	19	11	192	12	2	4	23	12	1
Övre Norrland (Nö)	8	14	3	8	27	13	127	14	3	6	24	14	

Observed N_2O emissions in relation to C:N ratio

Some studies (Ernfors *et al.* 2007, Klemedtsson *et al.* 2005) showed that the C:N ratio is a useful parameter to predict N_2O emissions from drained organic (forest) soils. A threshold C:N level of 25 can be applied where N_2O emissions increase at C:N ratios less than 25 and where almost no N_2O emissions occur when greater than 25.

In general and when looking at all five land categories at the same time, the N_2O emissions are in line with above named relationship (figure 1). Thus, N_2O emissions were low from the soils with a C:N ratio > 25 but increased very quickly when C:N ratio was below 25. The highest N_2O emission fluxes occurred on cropland and grassland sites. When considering the land categories one by one, the N_2O emissions from the land use category 'forest' are in line with above named C:N ratio - N_2O emissions relationship from organic forest soils: almost no N_2O emissions when C:N ratio greater than 25. However, no tendency for higher emission at low C:N ratios has been found. Further, mineral forest soils depict low emissions at a C:N < 25. The C:N ratio for the 'cropland' and 'grassland' sites from the data summary ranged between 9 and 20 but within the range, no tendency (e.g. higher emission at low C:N ratio) was found. Independently from the C:N ratio, the undrained mire and the rewetted peatland sites have no significant N_2O emissions. This pattern is in line with other authors, e.g. Leppelt *et al.* (2014).

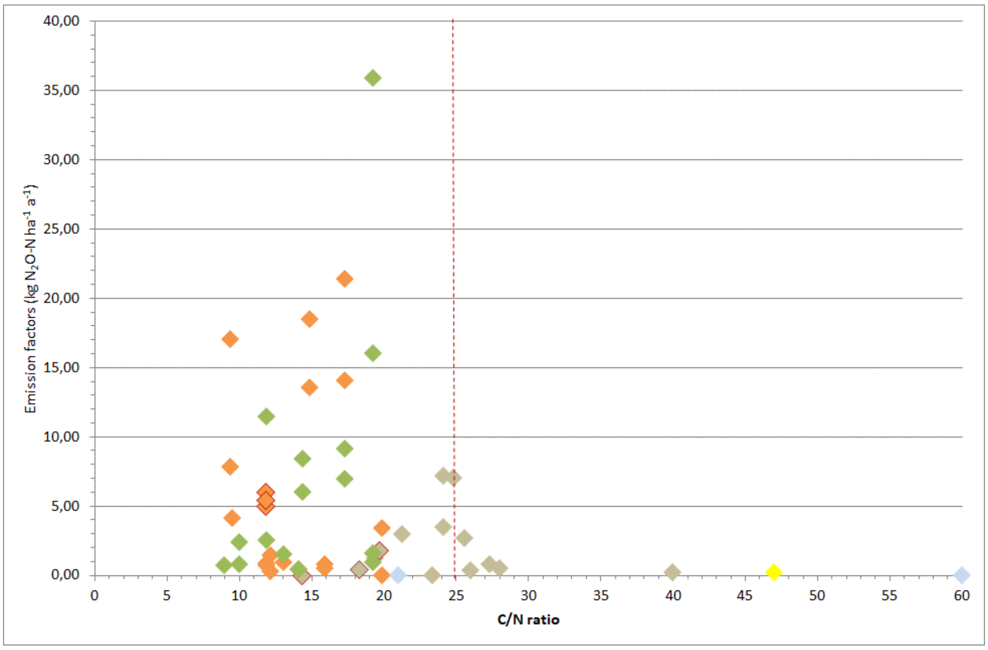


Figure 1: Emission factors (kg N_2O-N ha^{-1} a^{-1}) in relation to C:N ratio from different land use categories (greyish-green = forest, orange = cropland, green = grassland, yellow = undrained mire, light-blue = rewetted peatlands, rectangles with red line = mineral soils)

Amount applied fertilizer to the soil and observed N_2O emissions (EFs) in relation to C:N ratio (grassland and cropland only)

In general, there is no relationship between total N input and N_2O emissions. However, low N fertilizer rates can result in high N_2O emissions and high N fertilizer rates might not be related to high N_2O emissions (figures 2 and 3). Here, this pattern could be explained by the use of different crops having different N-use efficiencies. Compared to annual plants many perennial plants have a high N use efficiency being the key to reduce N_2O emissions and they have the potential to take up mineral N all year around and thus can mitigate N_2O production during wintertime (Don *et al.* 2012). There were no sites with C:N ratio >20 being fertilized, except one of the rewetted sites (C:N ratio 21) that was used as a potato field and thus fertilized long before peat extraction. Anyway, no N_2O emissions have been observed from this site (figure 1).

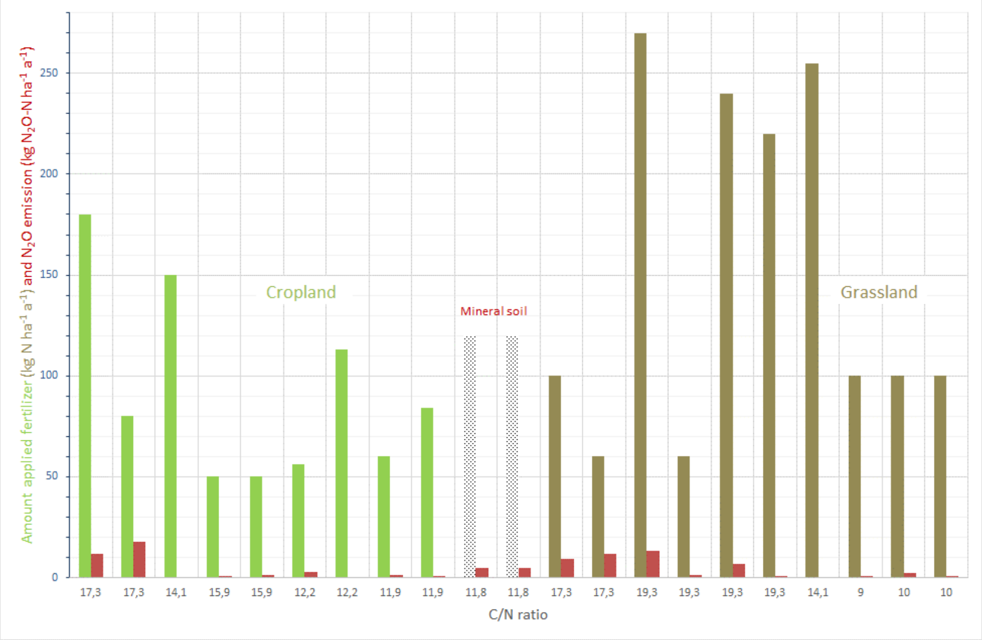


Figure 2: Amount applied fertilizer (kg N ha^{-1} a^{-1}) and N_2O emission (kg N_2O-N ha^{-1} a^{-1}) in relation to C:N ratio for the land use categories cropland (green) and grassland (brown) on organic and mineral soils (dotted)

Observed N_2O emissions (EFs) in relation to C:N ratio and default IPCC N_2O EFs of 1% of the N applied to the soil

Measured N_2O EFs have been related to the default IPCC N_2O EF of 1% of the N applied to the soil. It was identified that the use of a simplified N_2O EF following the Tier 1 methodology would underestimate the real N_2O emission in most of the cases (figure 3). This would lead to erroneous conclusions. In only 8 of 21 cases (i.e. on the organic grassland and cropland soils) the measured N_2O EFs were significantly lower as the default EF_1 (figure 3).

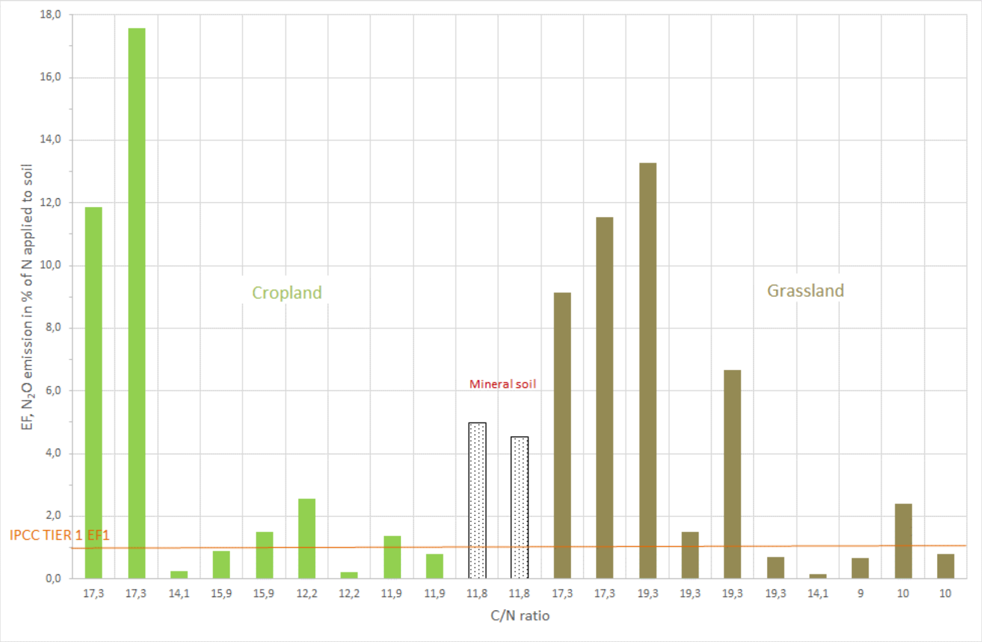


Figure 3: N_2O emission factors (EF) from measured data (EFs in %) of N applied to the soil in relation to C:N ratio for the land use categories cropland (green) and grassland (brown) on organic and mineral soils (dotted). Orange line = simulated IPCC TIER 1 EF_1 (reference situation)

Conclusions

With the help of retrieved literature data from direct N_2O emission measurements, we showed that the use of a default N_2O emission value of 1% of the N applied to soils would either under- or overestimate N_2O emissions. We also can conclude that there is no relationship between total N input and N_2O emissions, i.e. high fertilizer input must not be related to high N_2O emissions and low fertilizer input can result in high N_2O emissions. This result is in line with other authors, e.g. Rochette *et al.* (2008). Even though N_2O emissions from different Swedish land use categories were lower as the default EF_1 in 8 of the 21 reported data sets, we clearly see evidence to change from the IPCC Tier 1 approach for N_2O emissions to more adjusted EFs related to a country-specific methodology.

The strong relationship between C:N ratios and N_2O emissions from drained forested histosols (Klemedtsson *et al.* 2005) may be used to improve our ability to predict N_2O emissions from other land use categories such as grassland and cropland.

The carbon stock change data used for different land use and land use change categories was differentiated for the four (out of eight) production areas for cropland which allows a more precise use of parameters (C:N ratios). For land use change categories, other projects have improved the carbon stock change factors to some extent but more improvements are still needed.

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