Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Federal Department of Economic Affairs FDEA
Agroscope Reckenholz-Tänikon Research Station ART

Estimating direct field and farm emissions

Thomas Nemecek

Agroscope Reckenholz-Tänikon Research Station ART
CH-8046 Zurich, Switzerland
http://www.agroscope.ch
thomas.nemecek@agroscope.admin.ch

October 2013

Agroscope

Estimating direct field and farm emissions

Ideal emission models should

- Reflect the underlying environmental mechanisms
- Be site and time dependent
- Consider the effect of soil and climate
- Consider the effect of management
- Be applicable under a wide range of different situations
- The different models should have a similar level of detail
- But also be usable:
  - Parameters are measurable
  - Data can be collected in a reasonable time
  - Calculation is feasible

A compromise is needed!

Agroscope

Estimating direct field and farm emissions

- Usually no measurement on site possible

Two options:

- 1. Literature values, experiments: take a value for a given situation
  - → Specific for the situation
  - → Difficult to find
  - → Not flexible
  - → Mitigation options usually cannot be considered
- 2. Modelling
  - → More flexible
  - → Mitigation options can be considered, depending on the model
  - → Level of detail should be consistent across the models
  - → No globally usable emission models available

Comparison of emission models and recommendation

Emission	Current SALCA	ecoinvent v3	Agri-BALYSE	Recommended ecoinvent
Ammonia (NH_3)	Menzi et al. (1997)	Agrammon (Tier 3 methodology for CH)	EMEP (2009) Tier 2	EMEP (2009) Tier 2
Nitrous oxide (N_2O)	IPCC (2006) crops: Tier 1 animals: Tier 2	IPCC (2006) crops: Tier 1 animals: Tier 2	IPCC (2006) crops: Tier 1 animals: Tier 2	IPCC (2006) crops: Tier 1 animals: Tier 2
Nitrate (NO_3^-)	SALCA-Nitrate (Richner et al. 2011)	SALCA-Nitrate (Europe) SQCB (overseas)	Arvalis method (Tailleur et al. 2012)	SALCA-Nitrate (Europe) SQCB (overseas)
Phosphorus (P, PO_4^{3-})	SALCA-P Prasuhn (2006)	SALCA-P Prasuhn (2006)	SALCA-P Prasuhn (2006)	SALCA-P Prasuhn (2006)
Heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn)	Freiermuth (2006) (SALCA method)	Freiermuth (2006) (SALCA method)	Freiermuth (2006) (SALCA method)	Freiermuth (2006) (SALCA method)
Methane (CH_4)	IPCC (2006) Tier 2	IPCC (2006) Tier 2	IPCC (2006) Tier 2	IPCC (2006) Tier 2

New nitrogen emission models used in ecoinvent V3

N compound	Applied	Emission model used
Ammonia (NH_3)	Global	AGRAMMON
Nitrate (NO_3)	Europe	SALCA-NO3
	Non-European countries	SQCB / de Willigen (2000)
Nitrous oxide (N_2O)	Global	IPCC 2006, Tier 1

For further datasets: same emission model recommended, with the exception of NH3: use of EEA/EMEP (2013) models recommended.

NH3 emissions from mineral fertilisers

Fertilizer type	Emmission factor (% of total N)
Ammonium sulphate (AS)	8
Ammonium nitrate (AN)	2
Calcium ammonium nitrate (CAN)	2
Anhydrous ammonia	4
Urea	15
Urea ammonium nitrate (UAN)	8
Di-ammonium phosphate (DAP)	5
Mono-ammonium phosphate (MAP)	2
Other complex NK, NPK fertilizers	2

Constant emisssion factors in function of the fertiliser type

Source: EEA, 2006, Table 4-1

Emission factors for NH3 related to animal production

Source: from EEA, 2013, Table 3.7

- Distinction between total N and NH4-N
- Emissions in
  - Housing → Manure storage → Spreading
  - Yard → Manure storage → Spreading
  - Grazing
- Effects of
  - Animal housing system
  - Storage system
  - Contact surface between manure and air
  - Spreading technique
  - Dilution of slurry/liquid manure
  - Weather conditions: temperature + relative humidity → saturation deficit
  - …

Emission factors for NH3 related to animal production

Livestock	Housing period d a^{-1}	Nex	Proportion of TAN	Manure type	EF housing	EF yard	EF storage	EF spreading	EF grazing/ outdoor
Dairy cows	180	105	0.6	liquid	0.20	0.30	0.20	0.55	0.10
	180	105	0.6	solid	0.19	0.30	0.27	0.79	0.10
Other cattle (young cattle, beef cattle and suckling cows)	180	41	0.6	liquid	0.20	0.53	0.20	0.55	0.06
	180	41	0.6	solid	0.19	0.53	0.27	0.79	0.06
Fattening pigs (8–110 kg)	365	12.1	0.7	liquid	0.28	0.53	0.14	0.40	*0.25*
	365	12.1	0.7	solid	0.27	0.53	0.45	0.81	*0.25*
Sows (and piglets to 8 kg)	365	34.5	0.7	liquid	0.22	*0.53*	0.14	0.29	0.25
	365	34.5	0.7	solid	0.25	*0.53*	0.45	0.81	0.25
Sheep (and goats)	30	15.5	0.5	solid	0.22	0.75	0.28	0.90	0.09
Horses (and mules, asses)	180	47.5	0.6	solid	0.22	*0.35*	0.35	0.90	0.35
Laying hens (laying hens and parents),	365	0.77	0.7	solid	0.41	*0.70*	0.14	0.69	*0.09*
	365	0.77	0.7	liquid	0.41	*0.70*	0.14	0.69	*0.09*
Broilers (broilers and parents)	365	0.36	0.7	solid	0.28	*0.70*	0.17	0.66	*0.09*
Other poultry (turkeys)	365	1.64	0.7	solid	0.35	*0.70*	0.24	0.54	*0.09*
Other poultry (ducks)	365	1.26	0.7	solid	0.24	*0.70*	0.24	0.54	*0.09*
Other poultry (geese)	365	0.55	0.7	solid	0.57	*0.70*	0.16	0.45	*0.09*
Average (from Agri-BALYSE)				liquid	0.25	0.48	0.16	0.51	0.09
				solid	0.28	0.48	0.28	0.71	0.09

Values taken from Agrammon

Average values from Agri-BALYSE

Same values as for sows

Same values as for fattening pigs

Source: from EEA, 2013, Table 3.7

N_2O emissions according to IPCC 1996/2001 vs. 2006

$$N_2O = \frac{44}{28} \cdot \Big(\underbrace{0.0125 \cdot \big(Nav - \frac{14}{17} NH_3 + Ncr + 0.6 \cdot Nbf \big)}_{\text{direct}} + \underbrace{0.01 \cdot \frac{14}{17} NH_3 + 0.025 \cdot \frac{14}{62} \cdot NO_3^-}_{\text{indirect}} \Big)$$

N_2O	N_2O emissions (kg N_2O ha^{-1})
Nav	available N (kg N ha^{-1})
Ntot	total N (kg N ha^{-1})
Ncr	N in crop residues (kg N ha^{-1})
Nbf	N from biological N fixation (kg N ha^{-1})
NH_3	ammonia volatilisation (kg NH_3 ha^{-1})
NO_3^-	nitrate leaching (kg NO_3^- ha^{-1})

IPCC Guidelines 2006 (Tier 1):

$$N_2O = \frac{44}{28} \Big(0.01 \, (N_{tot} + Ncr + 0.0 \; Nbf) + 0.01 \, \frac{14}{17} \, NH_3 + 0.0075 \, \frac{14}{62} \, NO_3^- \Big)$$

-20% (0.01) | +x% (N_{tot}) | +y% | -100% (0.0) | -70% (0.0075)

N2O emissions from manure management

Tier 2 methodology after EEA (2013) and IPCC (2006)

		Without natural crust	With natural crust	Pit storage below animal confinements
Livestock		EF kg N2O-N / kg TAN entering store	EF kg N2O-N / kg TAN entering store	EF kg N2O-N / kg TAN entering store
Dairy cows	liquid	0.0%	1.0%	0.4%
Dairy cows	solid	8.0%		
Other cattle (young cattle, beef cattle and suckling cows)	liquid	1.0%	1.0%	0.4%
Other cattle (young cattle, beef cattle and suckling cows)	solid	8.0%		
Fattening pigs (8–110 kg)	liquid	0.0%	1.0%	0.3%
Fattening pigs (8–110 kg)	solid	5.0%		
Sows (and piglets to 8 kg)	liquid	0.0%	1.0%	0.3%
Sows (and piglets to 8 kg)	solid	5.0%		
Sheep (and goats)	solid	7.0%		
Horses (and mules, asses)	solid	8.0%		
Laying hens (laying hens and parents),	solid	4.0%		
Laying hens (laying hens and parents),	liquid	0.0%		
Broilers (broilers and parents)	solid	3.0%		
Other poultry (turkeys)	solid	3.0%		
Other poultry (ducks)	solid	3.0%		
Other poultry (geese)	solid	3.0%		
Buffalo	solid	3.0%		

Source: EEA, 2013. EMEP/EEA air pollutant emission inventory guidebook 2013 - Technical guidance to prepare national emission inventories. European Environment Agency, Luxembourg, EEA Technical report No 12/2013. Available at http://www.eea.europa.eu.

N_2O emissions from grazing

- 2% of N excreted for cattle (dairy, non-dairy and buffalo), poultry and pigs
- 1% for sheep and other animals
- Source: IPCC (2006)

NOx emissions

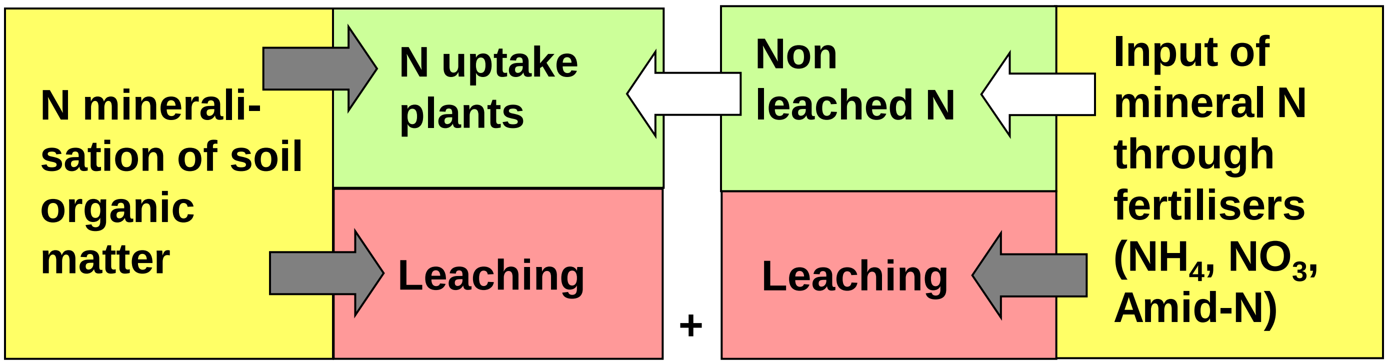
- Emission factor for the application of mineral and organic fertilisers: 2.6% kg NOx-N/kg N applied (EEA, 2013, Tab. 3-1)
- Emission factor for manure management: 0.01% for liquid manure and 1.0% for solid manure (EEA, 2013, Tab. 3.8)
- Conversion factor from N to NO is 30/14

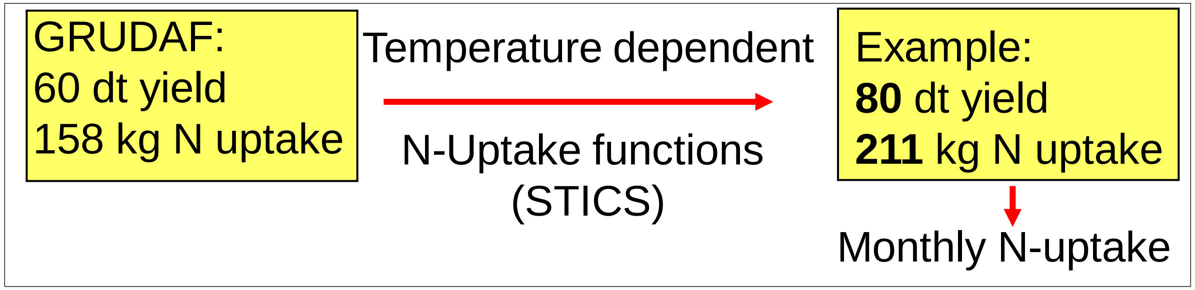
Agroscope

Model SALCA-NO3

- Modelling of nitrate leaching in monthly intervals in function of
  - Pedo-climatic conditions
    - Soil characteristics (clay and humus content, rooting depth)
    - Precipitation during winter
    - Temperature
  - Crop management:
    - Crop rotation, sowing and harvest dates
    - Soil tillage
  - Characteristics of the crop:
    - Nitrogen uptake dynamics during the year (in function of the yield, modelled by STICS)
  - Inputs:
    - Mineral and organic fertilisers (including long term-effect of org. fert.)
    - Dates of N fertilisation
- Source: Richner *et al*. (2011)

SALCA emission models SALCA-nitrate





Source: Richner *et al*. (2006)

Nitrate leaching SQCB model

- Regression model according to de Willigen (2000), Roy et al. (2003), Faist Emmenegger *et al.* (2009):

$$N = 21.37 + \frac{P}{c * L}\left[0.0037 * S + 0.0000601 * N_{org} - 0.00362 * U\right]$$

N	= nitrate leaching [kg NO_3-N/ha]
P	= precipitation + irrigation [mm]
c	= clay content [%]
L	= rooting depth [m]
S	= N fertilisation [kg N/ha]
N_{org}	= N in soil organic matter [kg N/ha]
U	= N uptake by the vegetation [kg N/ha]

CH4: enteric fermentation

- Enteric fermentation: $EF = \left[\frac{GE*\left(\frac{Ym}{100}\right)*365}{55,65}\right]$ (Tier 2 method)
  - EF = CH4 emission kg CH4/head/year)
  - GE = gross energy intake (MJ/head/day)
  - Y_m = methane conversion factor (%GE converted to CH4)
  - 55.65 MJ/kg CH4 = energy content of methane

Animal category	Methane conversion factor (Ym)
Mature sheep	6,5 %
Lambs < 1 year	4,5 %
Dairy cows	6,5 %
Other cattle	6,5 %

- For the other animal categories, Tier 1 factor (constant rates per head) can be used.

Source: IPCC (2006)

Agroscope

CH4: Manure storage

- $EF_{(T)} = (VS_{(T)} * 365) * \left[B_{0(T)} * 0{,}67kg/m^3 * \sum_{S,k} \frac{MCF_{S,k}}{100} * MS_{(T,S,k)}\right]$
  - EF(T) = annual CH4 emission factor for livestock category T, kg CH4 animal-1 yr-1
  - VS(T) = daily volatile solid excreted for livestock category T, kg dry matter animal-1 day-1
  - 365 = basis for calculating annual VS production, days yr-1
  - Bo(T) = maximum methane producing capacity for manure produced by livestock category T, m3 CH4 kg-1 of VS excreted
  - 0.67 = conversion factor of m3 CH4 to kilograms CH4
  - MCF(S,k) = methane conversion factors for each manure management system S by climate region k, %
  - MS(T,S,k) = fraction of livestock category T's manure handled using manure management system S in climate region k, dimensionless
- $VS = \left[GE * \left(1 - \frac{DE\%}{100}\right) + (UE * GE)\right] * \left[\left(\frac{1-ASH}{18{,}45}\right)\right]$
  - VS = volatile solid excretion per day on a dry-organic matter basis, kg VS day-1
  - GE = gross energy intake, MJ day-1
  - DE% = digestibility of the feed in percent (e.g. 60%)
  - (UE • GE) = urinary energy expressed as fraction of GE. Typically 0.04GE can be considered urinary energy excretion by most ruminants (reduce to 0.02 for ruminants fed with 85% or more grain in the diet or for swine). Use country-specific values where available.
  - ASH = the ash content of manure calculated as a fraction of the dry matter feed intake (e.g., 0.08 for cattle). Use country-specific values where available.
  - 18.45 = conversion factor for dietary GE per kg of dry matter (MJ kg-1). This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock.

SALCA emission models Phosphorus (P)

4 kinds of P-emissions in water:

- Surface run-off in rivers (solved PO_4^{3-})
- Drainage losses in rivers (solved PO_4^{3-})
- Erosion in rivers (P bound to soil particles)
- Leaching in ground water (solved PO_4^{3-})

Emissions are dependent of:

- Soil characteristics (granulation, bulk density, soil water balance) and drainage
- Quantity of P-fertiliser
- Type of P-fertiliser (manure, compost, mineral)
- Field slope and distance to rivers
- Quantity of eroded soil
- Plant available P in upper soil

Further parameters are available in the model related to soil, site characteristics and hydrology

Source: Prasuhn (2006)

PO4 leaching to ground water

- P leaching to the ground water was estimated as an average leaching, corrected by P-fertilisation:
  - $P_{gw} = P_{gwl} * F_{gw}$
  - P_{gw} = quantity of P leached to ground water (kg/(ha*a))
  - P_{gwl} = average quantity of P leached to ground water for a land use category (kg/(ha*a)), which is
    0.07 kg P/(ha*a) for arable land and
    0.06 kg P/(ha*a) for permanent pastures and meadows.
  - F_{gw} = correction factor for fertilisation by slurry (-)
  - $F_{gw} = 1 + 0.2/80*P_2O_{5sl}$
  - P_2O_{5sl} = quantity of P_2O_5 contained in the slurry or liquid sewage sludge (kg/ha).

Phosphate run-off

- Run-off to surface water was calculated in a similar way to leaching to ground water, if slope >= 3%:
  - $P_{ro} = P_{rol} * F_{ro}$
  - P_{ro} = quantity of P lost through run-off to rivers (kg/(ha*a))
  - P_{rol} = average quantity of P lost through run-off for a land use category (kg/(ha*a)), which is

    0.175 kg P/(ha*a) for open arable land,
    0.25 kg P/(ha*a) for intensive permanent pastures and meadows and
    0.15 kg P/(ha*a) for extensive permanent pastures and meadows
  - F_{ro} = correction factor for fertilisation with P (-), calculated as:
  - $F_{ro} = 1 + 0.2/80 * P_2O_{5min} + 0.7/80 * P_2O_{5sl} + 0.4/80 * P_2O_{5man}$

    P_2O_{5min} = quantity of P_2O_5 contained in mineral fertilisers (kg/ha)
    P_2O_{5sl} = quantity of P_2O_5 contained in slurry or liquid sewage sludge (kg/ha)
    P_2O_{5man} = quantity of P_2O_5 contained in solid manure (kg/ha)
- If the field slope is <%, then $P_{ro} = 0$

Phosphorus emissions through soil erosion

- P emissions through erosion of particulate phosphorous to surface water were calculated as follows:
- $P_{er} = S_{er} * P_{cs} * F_r * F_{erw}$
  - P_{er} = quantity of P emitted through erosion to rivers (kg P/(ha*a))
  - S_{er} = quantity of soil eroded (kg/(ha*a)) (see below)
  - P_{cs} = P content in the top soil (kg P/kg soil). The average value of 0.00095 kg/kg was used.
  - F_r = enrichment factor for P (-). The average value of 1.86 was used (Wilke & Schaub 1996). This factor takes account of the fact that the eroded soil particles contain more P than the average soil.
  - F_{erw} = fraction of the eroded soil that reaches the river (-). The average value of 0.2 was used.

Soil erosion

- Erosion by water:
  - Diffuse erosion
  - Linear erosion
- Erosion by wind: not considered so far (but should be considered, if relevant)
- Diffuse erosion by water: RUSLE2 model recommended

RUSLE2 FACTORS

Daily Soil Loss

$$\mathbf{a = r\ k\ l\ s\ c\ p}$$

Daily Factors

r - Rainfall/Runoff

k - Soil erodibility

l - Slope length

s - Slope steepness

c - Cover-management

p - Supporting practices

Average annual soil loss = sum of daily soil loss values

Different formulation from USLE and RUSLE1

From http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Training_Slide_Set.htm

RUSLE FACTORS (Sediment Production)

- Climate → r
- Soil → k
- Topography → ls
- Land Use and Management → lscp

From http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Training_Slide_Set.htm

Heavy metal emissions

- Input-Output-Balance (caused by farmer) per field for:

  Cd, Cu, Zn, Pb, Ni, Cr, Hg
- Inputs:
  - Fertilisers (mineral and organic)
  - Seed
  - Pesticides
  - Feedstuff and auxiliary materials for animal breeding
- Outputs:
  - Exported primary products (e.g. grains, meat)
  - Exported co-products (e.g. straw, animal manure)
  - Leaching to groundwater and drainage to surface water
  - Erosion to surface water
  - Emissions to the soil
- Allocation for inputs caused by the farmer
- The final balance can be negative!

Source: Freiermuth (2006)

Heavy metal leaching

$M_{leach\ i} = m_{leach\ i} * A_i$

- $M_{leach\ i}$ agricultural related heavy metal *i* emission
- $m_{leach\ i}$ average amount of heavy metal emission

	Cd	Cu	Zn	Pb	Ni	Cr	Hg
mg/ha/year	50	3600	33000	600	n.a.	21200	1.3

- A_i allocation factor for the share of agricultural inputs in the total inputs for heavy metal *i*

Agroscope

Heavy metal erosion

$$M_{erosion\ i} = c_{tot\ i} * B * a * f_{erosion} * A_i$$

- $M_{erosion}$ agricultural related heavy metal emissions through erosion [kg ha^{-1} a^{-1}]
- $c_{tot\ i}$ total heavy metal content in the soil (Keller & Desaules 2001 [kg/kg], Swiss data)

Land use	Cd [mg/kg]	Cu [mg/kg]	Zn [mg/kg]	Pb [mg/kg]	Ni [mg/kg]	Cr [mg/kg]	Hg [mg/kg]
Permanent grassland	0.309	18.3	64.6	24.6	22.3	24.0	0.088
Arable land	0.24	20.1	49.6	19.5	23.0	24.1	0.073
Intensive crops	0.307	39.2	70.1	24.9	24.8	27.0	0.077

- B amount of soil erosion according to Oberholzer *et al*. (2006) [kg ha^{-1} a^{-1}]
- a accumulation factor 1.86 (according to Prasuhn 2006 for P) [-]
- $f_{erosion}$ erosion factor considering the distance to river or lakes with an average value of 0.2 (considers only the fraction of the soil that reaches the water body, the rest is deposited in the field) [-]
- A_i allocation factor for the share of agricultural inputs in the total inputs for heavy metal *i* [-]

Heavy metal soil balance

Soil balance:

$M_{soil\ i} = (\Sigma\ inputs_i - \Sigma\ outputs_i) * A_i$

The soil balance can become negative!

$A_i = M_{agro\ i} / (M_{agro\ i} + M_{deposition\ i})$

- A_i allocation factor for the share of agricultural inputs in the total inputs for heavy metal *i*
- $M_{agro\ i}$ total input of heavy metal from agricultural production in mg/(ha*year) (fertilisers + seeds + pesticides)
- $M_{deposition\ i}$ total input of heavy metal from atmospheric deposition in mg/(ha*year)

Fossil CO_2 after urea and lime application

- After application of urea and lime, fossil CO_2 is released to the air.
- The worst case approach is used, so that the total amount of CO_2 is considered as released to the air
- Urea: 1.57 kg CO_2/kg Urea-N (=12/60*60/28*44/12)
- Limestone (default factors from IPCC, 2006):
  - 0.12 * 44/12 = 0.44 kg CO2/kg CaCO3 (limestone)
  - 0.13 * 44/12 = 0.477 kg CO2/kg (Ca Mg)CO3 (dolimite)

- Source: IPCC (2006)

Carbon sequestration in and carbon release from the soil

- Use IPCC (2006) Tier 1 methodology
- Mainly related to LUC, but also to some management options

- See also slides on LUC modelling

Pesticides: current and new modelling

- Until now the pesticide applications have been modelled as 100% emission to agricultural soil
- This approach has been criticised
- Different approaches in inventory and impact modelling lead to inconsistencies (double-counting or ignorance of processes)
- Workshop at SETAC conference 2013: new proposal

Agroscope