Estimating direct field and farm emissions

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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!
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

<table>
<thead>
<tr>
<th>Emission</th>
<th>Current SALCA</th>
<th>ecoinvent v3</th>
<th>Agri-BALYSE</th>
<th>Recommended ecoinvent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrate (NO₃⁻)</td>
<td>SALCA-Nitrate (Richner et al. 2011)</td>
<td>SALCA-Nitrate (Europe) SQCB (overseas)</td>
<td>Arvalis method (Tailleur et al. 2012)</td>
<td>SALCA-Nitrate (Europe) SQCB (overseas)</td>
</tr>
</tbody>
</table>
New nitrogen emission models used in ecoinvent V3

<table>
<thead>
<tr>
<th>N compound</th>
<th>Applied</th>
<th>Emission model used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia (NH$_3$)</td>
<td>Global</td>
<td>AGRAMMON</td>
</tr>
<tr>
<td>Nitrate (NO$_3$)</td>
<td>Europe</td>
<td>SALCA-NO3</td>
</tr>
<tr>
<td></td>
<td>Non-European</td>
<td>SQCB / de Willigen (2000)</td>
</tr>
<tr>
<td></td>
<td>countries</td>
<td></td>
</tr>
<tr>
<td>Nitrous oxide (N$_2$O)</td>
<td>Global</td>
<td>IPCC 2006, Tier 1</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Fertilizer type</th>
<th>Emission factor (% of total N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium sulphate (AS)</td>
<td>8</td>
</tr>
<tr>
<td>Ammonium nitrate (AN)</td>
<td>2</td>
</tr>
<tr>
<td>Calcium ammonium nitrate (CAN)</td>
<td>2</td>
</tr>
<tr>
<td>Anhydrous ammonia</td>
<td>4</td>
</tr>
<tr>
<td>Urea</td>
<td>15</td>
</tr>
<tr>
<td>Urea ammonium nitrate (UAN)</td>
<td>8</td>
</tr>
<tr>
<td>Di-ammonium phosphate (DAP)</td>
<td>5</td>
</tr>
<tr>
<td>Mono-ammonium phosphate (MAP)</td>
<td>2</td>
</tr>
<tr>
<td>Other complex NK, NPK fertilizers</td>
<td>2</td>
</tr>
</tbody>
</table>

Source: EEA, 2006, Table 4-1

Constant emission factors in function of the fertiliser type

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Direct field and farm emissions
Thomas Nemecek | © Agroscope Reckenholz-Tänikon Research Station ART
Emission factors for NH3 related to animal production

- 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
  - …

Source: from EEA, 2013, Table 3.7
Emission factors for NH3 related to animal production

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

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
**N₂O emissions according to IPCC 1996/2001 vs. 2006**

\[
N₂O = \frac{44}{28} \left( 0.0125 \left( N_{\text{tot}} - \frac{14}{17} N_{\text{NH₃}} + N_{\text{cr}} + 0.6 \cdot N_{\text{bf}} \right) + 0.01 \cdot \frac{14}{17} N_{\text{NH₃}} + 0.025 \cdot \frac{14}{62} N_{\text{NO₃}^-} \right)
\]

- **N₂O**: N₂O emissions (kg N₂O 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)
- **NH₃**: ammonia volatilisation (kg NH₃ ha⁻¹)
- **NO₃⁻**: nitrate leaching (kg NO₃⁻ ha⁻¹)

**IPCC Guidelines 2006 (Tier 1):**

\[
N₂O = \frac{44}{28} \left( 0.01 \left( N_{\text{tot}} + N_{\text{cr}} + 0.0 \cdot N_{\text{bf}} \right) + 0.01 \cdot \frac{14}{17} N_{\text{NH₃}} + 0.0075 \cdot \frac{14}{62} N_{\text{NO₃}^-} \right)
\]

- 20% **-20%**
- x% **+x%**
- 100% **-100%**
- y% **+y%**
- 70% **-70%**
## N2O emissions from manure management

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

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

N2O 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
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

N mineralisation of soil organic matter → N uptake plants → Leaching

Non leached N → Input of mineral N through fertilisers (NH₄, NO₃, Amid-N)

GRUDAF: 60 dt yield 158 kg N uptake

Temperature dependent N-Uptake functions (STICS)

Example: 80 dt yield 211 kg N uptake

Monthly N-uptake

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: \( EF = \left[ \frac{GE \times \left(\frac{Y_m}{100}\right) \times 365}{55.65} \right] \) (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

<table>
<thead>
<tr>
<th>Animal category</th>
<th>Methane conversion factor (Ym)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mature sheep</td>
<td>6.5 %</td>
</tr>
<tr>
<td>Lambs &lt; 1 year</td>
<td>4.5 %</td>
</tr>
<tr>
<td>Dairy cows</td>
<td>6.5 %</td>
</tr>
<tr>
<td>Other cattle</td>
<td>6.5 %</td>
</tr>
</tbody>
</table>

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

Source: IPCC (2006)
CH4: Manure storage

\[ EF_T = (VS_T \times 365) \times \left[ B_0(T) \times 0.67 \text{kg/m}^3 \times \sum S,k \frac{MCF_{S,k}}{100} \times MS_{T,S,k} \right] \]

- \( EF_T \) = 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
- \( B_0(T) \) = 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

\[ VS = \left[ GE \times \left( 1 - \frac{DE\%}{100} \right) + (UE \times GE) \right] \times \left[ \left( \frac{1-ASH}{18.45} \right) \right] \]

- \( VS \) = 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%)
- \( (UE \times GE) \) = 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 $\text{PO}_4^{3-}$)
- Drainage losses in rivers (solved $\text{PO}_4^{3-}$)
- Erosion in rivers (P bound to soil particles)
- Leaching in ground water (solved $\text{PO}_4^{3-}$)

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:
  - \( P_{gw} = P_{gwl} \times F_{gw} \)
  - \( P_{gw} \) = 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 (-)
  - \( F_{gw} = 1 + 0.2/80\times P_{2O5sl} \)
  - \( P_{2O5sl} \) = quantity of P\(_2\)O\(_5\) 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 $\geq$ 3%:
  - $P_{ro} = P_{rol} \times F_{ro}$
  - $P_{ro}$ = 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:
    - $F_{ro} = 1 + 0.2/80 \times P_{2O_{5min}} + 0.7/80 \times P_{2O_{5sl}} + 0.4/80 \times P_{2O_{5man}}$
    - $P_{2O_{5min}}$ = 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 phosphorus to surface water were calculated as follows:

\[ P_{er} = S_{er} \times P_{cs} \times F_r \times F_{erw} \]

- \( P_{er} \) = 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
\[ a = r k l s c p \]

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*
RUSLE FACTORS
(Sediment Production)

- Climate → r
- Soil → k
- Topography → ls
- Land Use and Management → ls_{cp}

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

\[ M_{\text{leach } i} = m_{\text{leach } i} \times A_i \]

- \( M_{\text{leach } i} \)  
- \( m_{\text{leach } i} \)  

- \( A_i \)  

agricultural related heavy metal \( i \) emission

average amount of heavy metal emission

<table>
<thead>
<tr>
<th></th>
<th>Cd</th>
<th>Cu</th>
<th>Zn</th>
<th>Pb</th>
<th>Ni</th>
<th>Cr</th>
<th>Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>mg/ha/year</td>
<td>50</td>
<td>3600</td>
<td>33000</td>
<td>600</td>
<td>n.a.</td>
<td>21200</td>
<td>1.3</td>
</tr>
</tbody>
</table>

allocation factor for the share of agricultural inputs in the total inputs for heavy metal \( i \)
Heavy metal erosion

\[ M_{\text{erosion}}^i = c_{\text{tot}}^i \times B \times a \times f_{\text{erosion}} \times A_i \]

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

\[
\begin{array}{|c|cccccccc|}
\hline
\text{Land use} & \text{Cd [mg/kg]} & \text{Cu [mg/kg]} & \text{Zn [mg/kg]} & \text{Pb [mg/kg]} & \text{Ni [mg/kg]} & \text{Cr [mg/kg]} & \text{Hg [mg/kg]} \\
\hline
\text{Permanent grassland} & 0.309 & 18.3 & 64.6 & 24.6 & 22.3 & 24.0 & 0.088 \\
\text{Arable land} & 0.24 & 20.1 & 49.6 & 19.5 & 23.0 & 24.1 & 0.073 \\
\text{Intensive crops} & 0.307 & 39.2 & 70.1 & 24.9 & 24.8 & 27.0 & 0.077 \\
\hline
\end{array}
\]
Heavy metal soil balance

Soil balance:
\[ M_{\text{soil } i} = (\Sigma \text{ inputs}_i - \Sigma \text{ outputs}_i) \times A_i \]

The soil balance can become negative!

\[ A_i = \frac{M_{\text{agro } i}}{M_{\text{agro } i} + M_{\text{deposition } i}} \]

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

- 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