Manure management to combat climate change

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Our research: livestock and environment

We work on the following themes:

- atmosphere (gaseous emissions, particulate matter, low-emission animal housing systems);
- soil (soil quality, water, minerals and fertilisation, pasturing, grassland and feed crops);
- closing mineral cycles (animal-manure-crop cycles, manure technology).

Examples:
measurements of emissions from poultry house and after field application of slurry
The Netherlands: a small country on the North Sea

- 40,000 km²
- 17 million people
- 4 million cattle
- 12 million pigs
- 100 million poultry
Too much pig and cattle slurry

- Most livestock farms in the Netherlands produce more manure than is allowed to be applied on their own land

- Transportation of surplus manure at high cost (5-20 €/ton)

- Dry poultry manure suitable for export and incineration

- Pig and cattle slurry not suitable for long distance transport
High water content of pig and cattle slurry...

![Diagram showing the composition of pig and cattle slurry, with a significant portion of water content.]
Rule of thumb: numbers of animals per hectare
(estimates based on manure production)

≈ 2 dairy cows / hectare
≈ 20 fattening pigs / hectare
≈ 7 sows with piglets / hectare

A farm with 200 dairy cows needs approx. 100 hectares
A farm with 2.000 fattening pigs needs approx. 100 hectares

Not enough land ?!
Manure distribution or export or processing !
Manure production and transport in the Netherlands

- Solid poultry manure: 1,400,000 tonnes/year
- Pig slurry: 12,400,000 tonnes/year
- Cattle slurry: 54,800,000 tonnes/year

- Agricultural land: 2,000,000 hectares

- Transported pig slurry: 10,000,000 tons per year
- Transported cattle slurry: 7,000,000 tons per year
Slurry production per animal:

- Dairy cattle: 25 tons per dairy cow per year
- Fattening pigs: 1.2 tons per pig (place) per year
- Sows with piglets: 4.3 tons per sow per year
- One truck load: 35 tons...
Key elements of the NL / EU manure policy:

- Control of animal numbers (pigs & poultry) and milk production (but what will happen after abolition of milk quota in 2015 ?!)
- Application standards for nitrogen (N) and phosphate (P₂O₅) from animal manure and from chemical fertilizers
- Manure application ban in autumn and winter
- Mandatory low-emission storage and application methods
- Monitoring of manure distribution and export (incl. weighing, GPS-tracking and chemical analyses of N and P₂O₅ content of every load)
- Financial support for R&D on manure management and processing technology
- Measurement of the environmental effects of the manure policy, feedback and adjustments if necessary...

But no rules with regard to GHG emissions from livestock production!
No manure application during winter!

350 measuring points

Nitrate levels in upper groundwater in sandy, clay and peat soils, 1992 - 2011

Fig. 14: Verloop van de nitraatconcentratie in het uitspoelingswater van de regio’s

bron: RIVM
Groundwater and surface water are used for the production of drinking water!
Application limits for nitrogen (N) and phosphate (P$_2$O$_5$) from animal manure (EU-Nitrate Directive / Water Framework Directive)

- Nitrogen (N) 30 - 385 kg/ha/year (crop dependant), from animal manure + from chemical fertilizer!

- max 170 kg N/ha/year from animal manure ('Derogation' = max 250 kg for cattle farms with grassland)

- Phosphate application standard depending on soil phosphate condition: 55 – 100 kg P$_2$O$_5$/ha/year (P$_2$O$_5$ = P * 2.29)

- In the Netherlands the phosphate application rate is limiting >> mandatory export of manure 28.000 – 47.000 tonnes of phosphate in 2015
Animal manure: Waste or Fertilizer? Fertilizer!

The choice of housing system determines the manure management requirements for the whole farm.

Use of straw results in solid manure.

No straw results in liquid manure.

Slatted floors with slurry storage underneath.
Why do we use organic fertilizers?

Because we keep animals!

Traditionally, we practiced mixed farming.

With the development of the inorganic fertilizer industry, it became possible to grow crops without having animals nearby. So we could decouple the animal production from the crop production.

Farmers concentrated on just one kind of production. So did entire regions. Western Europe, for instance, now produces large numbers of pigs and chickens. But we don't grow much of the feed. We haul in the feed ingredients from far away.
Nitrogen efficiency of animal manures and fractions

(Chemical fertilizers have 100 % nitrogen efficiency by law !)

- Cattle slurry (with/without grazing) 45/60 %
- Pig slurry (on clay and peat / sand and löss) 60/70 %
- Liquid fraction and muck water (‘gier’) 80 %
  (also for mineral concentrate from Reverse Osmosis)
- Solid cattle manure (depending on system) 30-60 %
- Solid pig and poultry manure 55 %
- Phosphate ($P_2O_5$) from animal manure / fertilizer 100 %
Example of calculation of fertilizer allowance  
(on top of the nutrients from pig slurry)

- Arable land (potatoes): max. 170 kg N/ha/year from animal manure  
  Total N-application standard for potatoes: 225 kg N/ha/year  
  Phosphate application standard on arable land: 85 kg P$_2$O$_5$/ha/year.

- Pig slurry: 7 kg N/ton and 4 kg P$_2$O$_5$/ton

- N: 170 : 7 = 24 ton pig slurry per hectare
- P$_2$O$_5$: 85 : 4 = 21 ton pig slurry per hectare Phosphate is limiting!
- 21 * 7 = 147 kg N from pig slurry, N-efficiency 60%: 0.6 * 147 = 88 kg effective N per hectare
- 225 – 88 = 137 kg N-fertilizer allowance
The desired situation:

but losses occur at all transitions...
We feed the animals rationally

Macromineral requirements of growing/fattening pigs (% of diet)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca</td>
<td>0.75</td>
<td>0.60</td>
<td>0.70</td>
<td>0.72</td>
<td>0.70</td>
</tr>
<tr>
<td>Total P</td>
<td>0.65</td>
<td>0.50</td>
<td>0.58</td>
<td>-</td>
<td>0.56</td>
</tr>
<tr>
<td>Available P</td>
<td>0.34</td>
<td>0.23</td>
<td>0.29</td>
<td>0.25⁶</td>
<td>0.32</td>
</tr>
<tr>
<td>Mg</td>
<td>-</td>
<td>0.04</td>
<td>-</td>
<td>0.04</td>
<td>0.10</td>
</tr>
<tr>
<td>Na</td>
<td>-</td>
<td>0.10</td>
<td>&gt; 0.10</td>
<td>0.17</td>
<td>0.18</td>
</tr>
<tr>
<td>Cl</td>
<td>-</td>
<td>0.08</td>
<td>-</td>
<td>0.16</td>
<td>0.12</td>
</tr>
<tr>
<td>K</td>
<td>-</td>
<td>0.23</td>
<td>-</td>
<td>0.25</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Maximal levels of trace minerals in mg/kg allowed in pig diets in the European Union-25

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>1,250</td>
<td>750</td>
</tr>
<tr>
<td>Cu</td>
<td>35¹</td>
<td>25²</td>
</tr>
<tr>
<td>Zn</td>
<td>250</td>
<td>150</td>
</tr>
<tr>
<td>Mn</td>
<td>250</td>
<td>150</td>
</tr>
<tr>
<td>Co</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Se</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>I</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Mo</td>
<td>2.5</td>
<td>2.5</td>
</tr>
</tbody>
</table>

These old figures are just examples!
With everything they need in every stage

Table 2. Efficiency of Different Sources of Energy When Used for Maintenance or for Growth, %

<table>
<thead>
<tr>
<th>Diet component</th>
<th>Maintenance</th>
<th>Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat</td>
<td>90</td>
<td>102</td>
</tr>
<tr>
<td>Starch</td>
<td>82</td>
<td>82</td>
</tr>
<tr>
<td>Crude protein</td>
<td>58</td>
<td>69</td>
</tr>
<tr>
<td>Fiber</td>
<td>58</td>
<td>56</td>
</tr>
</tbody>
</table>

Source: Adapted from Nobelet, 1994

<table>
<thead>
<tr>
<th>Swine Classification</th>
<th>Crude Protein %</th>
<th>Lys %</th>
<th>Tryp %</th>
<th>Threonine %</th>
<th>Met+ %</th>
<th>Cys</th>
<th>Ca %</th>
<th>P %</th>
<th>Available P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developing Replacement Gilts</td>
<td>15</td>
<td>0.70</td>
<td>0.12</td>
<td>0.45</td>
<td>0.40</td>
<td>0.80</td>
<td>0.60</td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>Gestating Sows</td>
<td>13</td>
<td>0.60</td>
<td>0.11</td>
<td>0.44</td>
<td>0.37</td>
<td>0.80</td>
<td>0.65</td>
<td>0.38</td>
<td></td>
</tr>
<tr>
<td>Lactating Sows*, .33 lb/day piglet gains, 10 pigs</td>
<td>17</td>
<td>0.90</td>
<td>0.18</td>
<td>0.59</td>
<td>0.45</td>
<td>0.90</td>
<td>0.70</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>Lactating Sows*, .44 lb/day piglet gains, 10 pigs</td>
<td>19</td>
<td>1.00</td>
<td>0.19</td>
<td>0.63</td>
<td>0.48</td>
<td>1.00</td>
<td>0.70</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>Segregated Early Weaned Pigs, &lt; 12 lb</td>
<td>23</td>
<td>1.50</td>
<td>0.27</td>
<td>0.98</td>
<td>0.86</td>
<td>0.90</td>
<td>0.70</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>Starter Pigs, Phase 1-Day 1-7, 10-14lb</td>
<td>21</td>
<td>1.40</td>
<td>0.25</td>
<td>0.89</td>
<td>0.79</td>
<td>0.85</td>
<td>0.68</td>
<td>0.42</td>
<td></td>
</tr>
<tr>
<td>Starter Pigs, Phase 2-Day 8-14, 14-20lb</td>
<td>20</td>
<td>1.30</td>
<td>0.23</td>
<td>0.83</td>
<td>0.73</td>
<td>0.75</td>
<td>0.65</td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>Starter Pigs, Phase 3, 20-45lb</td>
<td>19</td>
<td>1.15</td>
<td>0.21</td>
<td>0.74</td>
<td>0.65</td>
<td>0.70</td>
<td>0.60</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>Barrows &amp; Gilts*, 45-110lb</td>
<td>18</td>
<td>0.95</td>
<td>0.17</td>
<td>0.61</td>
<td>0.64</td>
<td>0.65</td>
<td>0.55</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Barrows*, 110-175lb</td>
<td>15</td>
<td>0.72</td>
<td>0.13</td>
<td>0.47</td>
<td>0.41</td>
<td>0.55</td>
<td>0.45</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>Gilts*, 110-175lb</td>
<td>16</td>
<td>0.82</td>
<td>0.15</td>
<td>0.54</td>
<td>0.47</td>
<td>0.60</td>
<td>0.50</td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td>Barrows*, 175-265lb</td>
<td>13</td>
<td>0.57</td>
<td>0.10</td>
<td>0.38</td>
<td>0.33</td>
<td>0.45</td>
<td>0.40</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Gilts*, 175-265lb</td>
<td>14</td>
<td>0.64</td>
<td>0.12</td>
<td>0.44</td>
<td>0.38</td>
<td>0.50</td>
<td>0.45</td>
<td>0.17</td>
<td></td>
</tr>
</tbody>
</table>
From the animal feed to manure:

- Nitrogen and phosphorus efficiency 30-40 % (NL), and less for many other feed components (trace minerals)

- The bulk of the nutrients (> 70 %) ends up in the manure

- **Manure is a valuable fertilizer** (if applied in the right quantities and in the right period)
Soil balance: input nutrients – crop uptake = losses

Input:
Manure nutrients + carbon
Synthetic fertilizer nutrients

Crop uptake in growing season
(and some retention of nutrients by
organic matter, crop residues,
phosphate fixation)

Excess nutrients lost to
atmosphere or to surface-and groundwater

Volatilization
\( \text{NH}_3, \text{N}_2\text{O}, \text{N}_2, \text{CH}_4 \)

Runoff and leaching
\( \text{NO}_3^- , \text{P}_2\text{O}_5, \text{K}_2\text{O} \)
The most important nutrient: nitrogen
Green House Gas emissions cause Global Warming

- GHG from livestock supply chains 14,5 % of human induced emission (FAO 2013)
- Methane emission from ruminants: enteric fermentation
- Methane emission from manure storage (slurry in deep pits !) and nitrous oxide from manure application
- Nitrogen and phosphorus losses contribute indirectly to Global Warming, because eutrophic surface waters produce GHG
- Plant material (animal feed) is part of the short-term carbon cycle, the carbon dioxide (CO₂) emission from decomposing organic matter in manure is not considered as additional GHG emission
Losses during storage and after manure application

Gaseous losses from organic matter degradation:

- Anaerobic storage conditions (slurry): mainly CH₄
- Aerobic storage conditions (solid manure): mainly NH₃ (some N₂O)

Losses after manure application:

- Superficial spreading: mainly NH₃
- Subsurface injection: mainly N₂O
- Depending on climate, season and soil conditions: leaching of NO₃⁻
Non-CO$_2$ GHG-emission intensity of livestock production (methane CH$_4$ and nitrous oxide N$_2$O)

<table>
<thead>
<tr>
<th>Species</th>
<th>Product</th>
<th>kg CO$_2$-eq./kg product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle</td>
<td>Milk</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>Meat</td>
<td>18.2</td>
</tr>
<tr>
<td></td>
<td>Specialized beef</td>
<td>68</td>
</tr>
<tr>
<td>Buffalo</td>
<td>Milk</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>Meat</td>
<td>55</td>
</tr>
<tr>
<td>Sheep</td>
<td>Milk</td>
<td>8.4</td>
</tr>
<tr>
<td></td>
<td>Meat</td>
<td>23.4</td>
</tr>
<tr>
<td>Goat</td>
<td>Milk</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td>Meat</td>
<td>23.3</td>
</tr>
<tr>
<td>Pig</td>
<td>Meat</td>
<td>6.1</td>
</tr>
<tr>
<td>Chicken</td>
<td>Eggs</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td>Meat</td>
<td>5.4</td>
</tr>
</tbody>
</table>
Livestock emissions/excretion per animal per year

<table>
<thead>
<tr>
<th></th>
<th>Manure kg/animal/yr</th>
<th>N-NH₃ kg/animal/yr</th>
<th>P₂O₅ kg/animal/yr</th>
<th>CH₄ kg/animal/yr</th>
<th>N₂O kg/animal/yr</th>
<th>PM2.5 g/animal/yr</th>
<th>Odor OUₑ/s/animal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cow</td>
<td>25.000</td>
<td>65</td>
<td>30</td>
<td>130</td>
<td>40</td>
<td>0.2</td>
<td>40</td>
</tr>
<tr>
<td>Pig</td>
<td>1.000</td>
<td>9</td>
<td>5</td>
<td>2</td>
<td>6</td>
<td>0.02</td>
<td>7</td>
</tr>
<tr>
<td>Chicken</td>
<td>20</td>
<td>0.6</td>
<td>0.4</td>
<td>0.3</td>
<td>-</td>
<td>0.02</td>
<td>4</td>
</tr>
</tbody>
</table>

Focus on methane and nitrous oxide

E = enteric
M = from manure

NB: in intensive production systems
Efficiency: kg CO$_2$-eq./kg milk...we’re so good!

But environmental factors vary greatly between countries... with effects on the national mitigation potentials.
GHG-Emission intensity per unit of land area...

FAO Global Livestock Environmental Assessment Model

FIGURE 27B. Emission intensity per unit of land area

Tonnes of CO₂ equivalent per square km
- <10
- 10 - 25
- 25 - 50
- 50 - 100
- 100 - 250
- 250 - 500
- > 500
- Protein production < 75 kg per square km

Source: GLIAM.

Not so good! And it looks very similar to:
The uneven distribution of Phosphorus

More and more fertilizers and meat

20% more meat in next decade = 20% more manure
American beef, a 120,000 head feedlot in Colorado
Manure is a valuable fertilizer... if applied correctly and in the right quantities!

But an environmental risk in a surplus situation:

- Western Europe
- South and East Asia
- US Corn Belt
- The densely populated coastal regions of the world
- Around large urban centres
Increasing nutrient loads in sweet and salt waters gives increase in algal blooms worldwide.....
Effect of excess nutrients on beaches in France and China
Table 1: Classification of the FAO proposed GHG mitigation options into two categories: Category 1 undisputedly effective (possibly after technical optimisation), Category 2 effectivity disputed (further investigation is necessary on effectiveness, direct and indirect GHG emissions and possible trade-offs)

<table>
<thead>
<tr>
<th>Technique</th>
<th>Effectivity undisputed</th>
<th>Effectivity disputed</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Housing</td>
<td></td>
<td>X</td>
<td>Effect disputed because of trade-offs (N\textsubscript{2}O, energy)</td>
</tr>
<tr>
<td>• Biofiltration</td>
<td></td>
<td>X</td>
<td>Protection needed against adverse climatic influence</td>
</tr>
<tr>
<td>• Rapid manure evacuation from the animal house to outside storage</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manure treatment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Anaerobic digestion</td>
<td>X</td>
<td></td>
<td>If combined with short storage time and prevention of CH\textsubscript{4} leaks</td>
</tr>
<tr>
<td>• Slurry separation</td>
<td>X</td>
<td></td>
<td>Good management needed to reduce risk of trade-offs</td>
</tr>
<tr>
<td>• Aeration of slurry (n)</td>
<td>X</td>
<td></td>
<td>Effect disputed because of trade-offs (N\textsubscript{2}O, energy)</td>
</tr>
<tr>
<td>• Slurry acidification</td>
<td>X</td>
<td></td>
<td>Further investigation needed on GHG effectivity</td>
</tr>
</tbody>
</table>
## Proposed GHG mitigation options II

### Manure storage

<table>
<thead>
<tr>
<th>Option</th>
<th>Effectivity undisputed</th>
<th>Effectivity disputed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreased storage time</td>
<td>X</td>
<td>Timing of application critical</td>
</tr>
<tr>
<td>Storage cover (slurry)</td>
<td></td>
<td>Effect disputed</td>
</tr>
<tr>
<td>Covered heap (solids, litter stacking)</td>
<td>X</td>
<td>High risk of trade-offs makes good management critical</td>
</tr>
<tr>
<td>Composting</td>
<td></td>
<td>Agronomic justification, but with trade-offs</td>
</tr>
<tr>
<td>Storage temperature (cooling)</td>
<td>X</td>
<td>If energy demand (trade-off) does not outweigh GHG reduction</td>
</tr>
</tbody>
</table>

### Manure application

<table>
<thead>
<tr>
<th>Option</th>
<th>Effectivity undisputed</th>
<th>Effectivity disputed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsurface injection of slurry</td>
<td>X</td>
<td>Effect disputed because of N₂O emission</td>
</tr>
<tr>
<td>Timing of application</td>
<td>X</td>
<td>Can conflict with decreased storage time</td>
</tr>
<tr>
<td>Soil nutrient balance</td>
<td>X</td>
<td>Requires knowledge on soil- and manure properties and crop requirements</td>
</tr>
<tr>
<td>Nitrification inhibitor / urease inhibitor, applied on grassland</td>
<td>X</td>
<td>Effect disputed, possible trade-offs, further investigations needed</td>
</tr>
<tr>
<td>Sound soil management including erosion control</td>
<td>X</td>
<td>To conserve organic matter and to avoid nutrient losses</td>
</tr>
</tbody>
</table>

Air scrubber...

- **Polluted air** flows into the packing material.
- **Packing** contains spray nozzles that distribute fresh water.
- Fresh water and air mix, cleansing the air.
- **Cleansed air** exits the system.
- **Waste water** is collected and discarded.

**Key Components**:
- Packing
- Spray nozzles
- Pump

**Logos**:
- Livestock Research Wageningen UR

**Diagram Details**:
- Arrows indicate the flow of air and water.
- Green lines highlight the 'packing' section.
Ammonia removal with acid scrubber
Acid scrubber: chemical process

- **Dissolution:**
  \[ \text{NH}_3 \text{ (g)} \rightarrow \text{NH}_3 \text{ (aq)} \rightarrow \text{NH}_4^+ \text{ (aq)} + \text{OH}^- \text{ (aq)} \]

- Dosing of sulphuric acid (low pH) drives equilibrium to right side

- **Net reaction:**
  \[ 2 \text{ NH}_3 \text{ (g)} + \text{H}_2\text{SO}_4 \rightarrow 2 \text{ NH}_4^+ \text{ (aq)} + \text{SO}_4^{2-} \text{ (aq)} \]

- Ammonium sulphate solution is discharged from system (30 g N/L)
Bioscrubber (biofiltration): bacterial conversions

- **Nitrification:**
  \[
  \text{NH}_3 + \text{H}_2\text{O} \rightarrow \text{NH}_4^+ + \text{OH}^- \quad \text{(Dissociation / Dissolution)}
  \]
  \[
  \downarrow 1.5 \text{O}_2 \quad \text{Nitrosomonas Sp.}
  \]
  \[
  \text{NO}_2^- + \text{H}^+ + 2 \text{H}_2\text{O} \quad \text{(Nitrobacter Sp.)}
  \]
  \[
  \downarrow 0.5 \text{O}_2 \quad \text{NO}_3^- + \text{H}^+ + 2 \text{H}_2\text{O}
  \]

- Ammonium nitrite/nitrate solution is discharged (3 g N/L))
- Odour removal:
  - mixture of many compounds
  - oxidation to CO\(_2\), H\(_2\)O and ‘by-products’

Incomplete biological nitrification process: also produces N\(_2\)O!
Chemical and biological air scrubber for digestate drier

To reduce ammonia and odor emissions

Capacity drier: 7,000 tonnes of solid fraction per year
No manure application in autumn and winter:
covered manure storage capacity for 7 month!

Manure storage under the barn or outside the barn
Anaerobic digestion of slurry, biogas production

Organic carbon is transformed into flammable methane (CH₄), all nutrients N,P,K etc. remain in the digestate
Leak detection with infrared imaging
Sufficient residence time in the reactor!
Manual slurry application (Kerala, India)

The slurry problem:
no equipment for transport and application
Preference for solid manure!

Solid manure is sold, Burundi
Aeration: Biological treatment of veal calf slurry after separation

Nitrification and denitrification, nitrogen is lost, phosphate is precipitated into sludge, similar to Waste Water Treatment Plants
Solid fraction from slurry separation

30 % dry matter, spontaneous composting in piles!
Slurry mixing during storage with air bubbles...

For homogenization and odor reduction during land application
Composting ("biothermal drying") of solid manure

- Stable organic matter
- Reduction of weed seeds and pathogens
- Suitable for transport and storage (export)
- High in nutrients N, P, K and other (trace) elements (Mg, Ca, S, Cu, Zn, B, etc.)
- Attention for nitrogen loss during composting (up to 60% !)
Slurry spraying is not allowed anymore...

High nitrogen losses from ammonia volatilization, complaints about odor
Low emission slurry application is the standard!

Less ammonia and odor emission, but more nitrous oxide emission after slurry application!
Phosphate rock mining in North Carolina (US)

Fossil deposits....a finit resource
Nitrogen fertilizer production: the Haber process
from atmospheric nitrogen and natural gas

Fertilizer prices follow the prices of oil and gas...
Discussion:

- Mitigation of GHG emissions and other nutrient losses from manure is possible to a certain extent, but biological processes are difficult to control.

- Can we compensate for the expected increase in livestock production?

- Watch out for trade-offs:
  - Energy/chemicals consumption (indirect GHG emissions)
  - Undesired/unforeseen emissions from technical measures, e.g., nitrous oxide from biofiltration, subsurface injection
  - Ammonia/odor emission reduction ≠ GHG emission reduction, e.g., storage cover, manure acidification

- Be aware of socio-economic constraints, e.g., traditional agricultural practices, the lack of funding, the North-South controversy about GHG reduction.
and the challenge is to recycle manure nutrients instead of subsidizing synthetic fertilizer!