How to detect and quantify inefficient use of nutrients in livestock systems?

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- What agriculture once looked like
- Why do inputs generally exceed outputs nowadays?
- Metrics: inputs, outputs, surpluses and (in)efficiencies
- Which measures?
- Usual pitfalls in input-output analyses
- Pros and cons of intensification

Conclusions
What agriculture once looked like (1)

Diagram:
- **VEGETATIONS**
  - NO$_3$, PO$_4$
  - CO$_2$, H$_2$O

- **ANIMALS** → **HUMANS**
  - CH$_2$O, O$_2$

- **PROTEIN**
  - NO$_3$, NH$_3$
What agriculture once looked like (2)

ancient subsistence farm

NP Inputs
flooding, deposition, 'clover' N
NP collected via grazed range land

animal

production, processing, consumption

crop

manure

soil

NP emissions
What agriculture looks like today (1)
What agriculture looks like today (2)

modern commercial farm

Inputs
fertilizers, animal feeds, (young) animals, bedding,
flooding, deposition, 'clover' N

NP collected via grazed range land

Outputs to processors and consumers 'elsewhere'
milk, meat, eggs, wool, leather (old) animals
arable crops

animal

crop

manure

soil

NP emissions
Why do NP inputs generally exceed NP outputs?

- Any conversion in living systems is associated with losses

- Moreover:
  - Specialisation and globalisation complicate recycling and made ‘wastes’ out of what were once ‘by-products’,
  - Maximization of profits: NP suppletions based on fossile reserves pay!
  - Productivity improvement may initially require ‘idle’ investments (P)
  - Innoscence, indolence, indifference concerning manure appreciation

- NP use efficiency will not be improved by knowledge transfer only: carrots and sticks are inevitable

- Indicators are needed to target these policy measures
- NP surpluses may serve as indicators
Inputs, outputs, surpluses, (in)efficiencies

Definitions:
- N surplus = N input - N output: \( S = I - O \),
- N efficiency = N output / N input = \( O/I \),
- N inefficiency = \( 1 - O/I \)

N surplus ≈ N losses to the environment

Identical reasonings, *mutatis mutandis*, for phosphorus (P)
Inputs, outputs, surpluses, (in)efficiencies

- **Local loss issues:**
  - e.g. nitrate, ammonia, ammonium
  - kg N surplus/ ha = kg N input /ha – kg N output/ha: \( S = I - O = I \times (1 - O/I) \)
  - So: surplus *per unit area* is the relevant indicator

- **Global loss issues:**
  - e.g. N\(_2\)O, nitrate
  - kg N surplus = population \( \times \) (ha’s/capita \( \times \) N output/ha) \( \times \) (N surplus/ha) / (N output/ha)
  - = population \( \times \) N output/capita \( \times \) (N surplus/ha) / (N output/ha)
  - = ‘population \( \times \) diet’ \( \times \) S / O
  - So: surplus *per unit product* is the relevant indicator

- Identical reasonings, *mutatis mutandis*, for phosphorus (P)
What a balance sheet could look like:

<table>
<thead>
<tr>
<th>Terms:</th>
<th>kg per ha per year:</th>
<th>Inputs:</th>
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<tbody>
<tr>
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<td>N</td>
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</tbody>
</table>
Conversion coefficients underlying O/I (1)

feed import, etc IM
lost into air (1-CA)
fertilizers, deposition, clover, etc

crop EX CA SC

animal AP (1- AP)

manure MS (1- MS)

soil

lost into water

arable crop export

animal products

lost into water

lost into air
Conversion coefficients underlying O/I (2)

- \( O/I = \frac{p}{q} \)
- \( p = \frac{AP + (EX \times (1-IM)/(CA \times (1-EX)))}{IM + (p-AP)/(EX \times SC)-(1-AP) \times MS} \)
- \( q = (IM + (p-AP)/(EX \times SC) - ((1-AP) \times MS)) \)

Lost N:
- Per unit area: input \( \times (1 \cdot p/q) \)
- Per unit output: \( q/p - 1 \)

Check: Schröder \textit{et al.}, 2003
## Typical conversion coefficients: beef<dairy<chicken

<table>
<thead>
<tr>
<th>Path</th>
<th>N (%)</th>
<th>P (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP: from feed to milk &amp; meat</td>
<td>10-45</td>
<td>15-50</td>
</tr>
<tr>
<td>(1- AP: from feed to manure)</td>
<td>(55-90)</td>
<td>(50-85)</td>
</tr>
<tr>
<td>MS: from manure to soil</td>
<td>50-90</td>
<td>90-100</td>
</tr>
<tr>
<td>SC: from soil to crop</td>
<td>40-80</td>
<td>50-100</td>
</tr>
<tr>
<td>CA: from crop to animals</td>
<td>80-90</td>
<td>80-100</td>
</tr>
<tr>
<td>Whole farm, livestock</td>
<td>10-40</td>
<td>20-100</td>
</tr>
</tbody>
</table>
Knobs and handles to improve the efficiency of animal products.

- Animal type,
- Ration composition incl. phase feeding,
- Phytase,
- Produce type (meat or milk)

Coefficients interact:

Synergies: low N diet reduces N excretion and also the NH3 loss

Antagonisms: bedding reduces NH3 loss from housings, but frustrates positioning and synchronisation in field

\[ \frac{O}{I} = \frac{SC \times CA \times AP}{(1-SC) \times CA \times (1-AP) \times MS} \]
Imagine 3 livestock farms within one village:

- farm A: \( \text{N output} / \text{N input} = 23\% \)
- farm B: \( \text{N output} / \text{N input} = 25\% \)
- farm C: \( \text{N output} / \text{N input} = 28\% \)

Which of these 3 has the most efficient manager of N fluxes?
### Pitfalls: Externalisation (2)

- **Efficiency**

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>Farm A</th>
<th>Farm B</th>
<th>Farm C</th>
</tr>
</thead>
<tbody>
<tr>
<td>animal N to milk &amp; meat N: AP</td>
<td>0.25</td>
<td>0.225</td>
<td>0.20</td>
</tr>
<tr>
<td>manure N to soil N: MS</td>
<td>0.90</td>
<td>0.70</td>
<td>0.50</td>
</tr>
<tr>
<td>soil N to crop N: SC</td>
<td>0.60</td>
<td>0.55</td>
<td>0.50</td>
</tr>
<tr>
<td>crop N to animal N: CA</td>
<td>0.95</td>
<td>0.925</td>
<td>0.90</td>
</tr>
<tr>
<td>fraction of crop N exported</td>
<td>0.00</td>
<td>0.00</td>
<td>0.40</td>
</tr>
<tr>
<td>fraction of feed N imported</td>
<td>0.00</td>
<td>0.55</td>
<td>0.00</td>
</tr>
<tr>
<td>N output / N input</td>
<td>23%</td>
<td>25%</td>
<td>28%</td>
</tr>
</tbody>
</table>

- Farms differ in externalisation
- Farm with lowest output/input ratio, can still have the best N manager!
- Compare only like with like or dip into the subsystems O/I’s!
Pitfalls: The efficiency paradox: specialised system seemingly more efficient: 33% > 28% > 21%

\[
O/I = \frac{(10 + 25)}{(5 + 160)} = 0.21 \text{ (livestock farm and processing industries)}
\]

\[
O/I = \frac{30}{(10 + 80)} = 0.33 \text{ (herd level)}
\]

\[
O/I = \frac{(20 + 30)}{(10 + 170)} = 0.28 \text{ (livestock farm)}
\]
Pitfalls: Stock changes

- Depletion of soil fertility: misleading output / input ratio: Farm D 29% versus Farm A 23%

FARM D: output / input \( \frac{(kg \, N \, per \, ha)}{(kg \, N \, per \, ha)} = \frac{24}{83} = 29\% \)
Pitfalls: Gross and net fluxes

- Same farm, differently defined subsystem output / input ratio’s!
- Accurate definitions of the states matter!
Pros and cons of intensification

- **Intensification**: *more output with, ideally, a subproportional increase of inputs, i.e. improved resource use efficiency through addition of technology & information*

- **Pros**
  - Potential savings on land, energy, water and NP inputs per unit output
  - Intensification pays, so higher farm income

- **Cons**
  - Potential loss of local environmental quality, as surplus = *input* x (1 - O/I)
  - Loss of small-scale mosaics due to upscaling
  - Specialisation frustrates proper recycling
  - Rural unemployment
  - Stronger reliance on external capital, information & fossil resources
  - Lost proximity: transport costs, alienation of urban public
Conclusions

- NP surpluses (≈ emissions) per unit area and per unit output are both relevant indicators
- NP use efficiencies will not improve automatically
- Measures are needed, but try to target them by analysis:
  - define system boundaries and states
  - compare like with like only!
  - *subsystem* analysis shows where leaks occur and where to focus efforts
- In general: prioritize manure-soil-crop part (*MS, SC*) over feed conversion (*CA, AP*) part of the cycle
Thank you for your attention!