Mineral fertilizer, climate effects and options for improvement

LMDs konferanse om klima og landbruk, Oslo, 03 June 2009
Frank Brentrup, Yara Int., Research Centre Hanninghof
Crops need mineral nutrients to grow

Crops absorb mineral nutrients and water from the soil

Mineral nutrients are essential building blocks for crops
Mineral fertilizers replace the nutrients that are exported with the harvest

Supply of crop residues and organic fertilizer

Export of nutrients with the harvest

The soil is depleted without mineral fertilizers
Mineral fertilizers are needed

Today, nearly 50% of the world’s population is nourished from the use of mineral fertilizers

Source: adopted from Erisman et al. (2008), Nature Geoscience
More people – Less arable land

We must produce more food per hectare
Environmental effects of N fertilizer use

**Benefits**
- Increased biomass production
  - Food, Feed, Energy
- Potential for land preservation
  - Efficient land use
- Carbon fixation

**Impacts**
- Eutrophication
  - Nitrate leaching
  - Ammonia volatilisation
- Off-site acidification
  - Ammonia volatilisation
- Global warming
  - CO2 emissions
  - N2O emissions
Climate gas emissions

GLOBAL
= 49 bn t CO2eq
( agriculture contributes 26% )

Production of mineral N fertilizer (0.8%)*
N2O from mineral N fertilizer use (1.3%)*
N2O from organic N sources (3.8%)
Other agricultural GHGs, mainly CH4 (8.4%)
Land use change for agriculture (12%)

Based on IPCC (2007), Bellarby et al. (2008), *EFMA calculation
Climate gas emissions

GLOBAL
= 49 bn t CO2eq
( agriculture contributes 26%)

- Land use change for agriculture (12%)
- Production of mineral N fertilizer (0.8%)*
- N2O from mineral N fertilizer use (1.3%)*
- N2O from organic N sources (3.8%)
- Other agricultural GHGs, mainly CH4 (8.4%)

Based on IPCC (2007), Bellarby et al. (2008), *EFMA calculation

EU-27
= 5 bn t CO2eq
( agriculture contributes 9%)

- Other sources (90%)
- Land use change for agriculture (3.2%)
- Production of mineral N fertilizer (4.6%)
- N2O from mineral N fertilizer use (1.1%)
- N2O from organic N sources (1.1%)

Based on UNFCCC (2008), * EFMA calculation

Emission from land use change is large, but not in Europe
Less intensified agriculture in Europe → more deforestation → more emission
Sources of agricultural GHG emissions (EU-27, 2005)

Agriculture contributes 9% to the total GHG emission of 5014 mio. t CO$_2$eq

- N$_2$O from mineral N fertilizer use (13%)*
- N$_2$O from organic N sources (35%)
- Other agricultural GHGs, mainly CH$_4$ from cattle and manure (52%)

Source: United Nations Framework Convention on Climate Change (UNFCCC;2008)
* EFMA calculation
Sources of N$_2$O from agriculture

EU27: 240 mio t CO$_2$eq

Emission after volatilization & leaching 33%

Mineral fertilizer N 25%

Biological Nitrogen Fixation 3%

Crop residues 8%

Organic soils 5%

Manure application & grazing animals 14%

20% 12%

Source: United Nations Framework Convention on Climate Change (UNFCCC;2008)
A life-cycle perspective on fertilizer

Production

Natural gas (feedstock)
Fuel
Minerals

Logistic

Fuel

Application

Fuel

Uptake

Biomass

Sunlight

CO₂

CO₂, N₂O, ...
CO₂, NOₓ, ...
NH₃, NO₃, N₂O, N₂ ...

Sunlight

CO₂

Land

N₂

C₃H₄

N₂H₃, N₂O, N₂ ...

Sunlight

CO₂

Land
Different fertilizers have different impacts

Fertilizer production

Application to soil

Life-cycle perspective: Production & application

kg CO2eq/kg N

A life-cycle perspective on fertilizers is important (otherwise regulators may wrongly favour urea)

* CAN production includes N2O abatement catalyst
High intensity in crop production
- Problem or solution?
Yield response to nitrogen application in a long-term field trial with winter wheat

Long term trial: Rothamsted, UK
The carbon footprint of wheat production increases with the N application rate.
On the other hand the positive GHG balance “ex-field” is enhanced by fertilizer use.
If the harvested crop is used as food or feed, the CO2 fixation is only short-term.

The CO2 fixation can be regarded as a real CO2 saving, only if the harvested biomass is used as bio-fuel and, thus, replaces fossil fuels.
To achieve the same yield, reduced production intensity needs more land and increases GHG emissions.

**Global warming: kg CO2 eq. / ha**

- **without N**
- **50% of optimum**
- **economic optimum N rate**

CO₂ release due to additional land use needed to compensate for lower yields.
Options to improve the carbon footprint of fertilizers in crop production
Contribution of the single GHG emissions to the total carbon footprint per ha

Based on a long-term field trial with winter wheat (UK), N source = Ammoniumnitrate

![Graph showing contribution of single GHG emissions to total carbon footprint per ha.](image)
Improvements in nitric acid production

Nitric acid plant

Nitrous oxide (N2O) abatement catalyst
Impact of the de-N2O catalyst on the carbon footprint of crop production

Based on a long-term field trial with winter wheat (UK), N source = Ammoniumnitrate

Wheat produced at economic optimum N rate
Two natural soil processes release $\text{N}_2\text{O}$

**Nitrification**

Urea/Ammonium $\rightarrow$ Nitrate

Soil organisms use ammonium ($\text{NH}_4$) as energy source

**Denitrification**

Nitrate $\rightarrow$ $\text{N}_2$ gas

Conditional: if oxygen ($\text{O}_2$) is depleted (water logging), soil organisms use oxygen from nitrate ($\text{NO}_3$) for respiration

$\text{N}_2\text{O}$ from both processes $\approx 1\%$ of N (IPCC, 2006)
Impact of soil and climate on the carbon footprint of crop production

<table>
<thead>
<tr>
<th>Drainage:</th>
<th>good</th>
<th>poor</th>
<th>poor</th>
<th>poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texture:</td>
<td>loam</td>
<td>loam</td>
<td>clay</td>
<td>clay</td>
</tr>
<tr>
<td>Climate:</td>
<td>temp</td>
<td>temp</td>
<td>temp</td>
<td>trop</td>
</tr>
</tbody>
</table>

4.67% of total N input as N2O_field *

Other important factors:
- Soil organic carbon
- Soil pH
- Fertilizer type

* Calculated according to Bouwman model (Bouwman et al., 2002), uncertainty range –40% to +70%
Average N$_2$O emissions are lower from Nitrates than from urea and ammonium fertilizers

- Up to now, N$_2$O emissions from N fertilizers are estimated independently from the N form (default IPCC factor, red bar in the graph below).
- But a new analysis of about 900 in-field measurements from 139 experiments shows differences in N$_2$O emissions from different N fertilizers.

Source: Bouwman et al. (2002)
Options to reduce in-field N2O emission

- Any means that improve nitrogen use efficiency, in particular
  - Adjust N application rate to actual crop N demand (soil and plant analysis)
  - Synchronize N application with crop N uptake (split application, “just-in-time” fertilization)
- Apply nitrate-based N sources on well aerated and non-waterlogged soils
- Maintain a good soil structure (no compaction, good drainage)
Yara develops tools to support Good Agricultural Practices and to increase N use efficiency

Software and crop monitoring tools help to calculate the right nutrient rate

=> these tools helped to improve nutrient use efficiency
The nitrogen use efficiency in Europe is increasing

N use efficiency (NUE in %) = (N removal/N application) x 100

Source: own calculation based on FAO and Efma data
The N$_2$O emissions from soil are decreasing

Source: United Nations Framework Convention on Climate Change (UNFCCC, 2008)
The N use efficiency in Europe will further improve

<table>
<thead>
<tr>
<th></th>
<th>Average EU27 2006/07</th>
<th>Average of 139 field trials**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain yield t per ha</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- fresh matter*</td>
<td>4.9</td>
<td>9.3</td>
</tr>
<tr>
<td>N-content in grain dry matter (%)</td>
<td>2.00</td>
<td>2.09</td>
</tr>
<tr>
<td>N removal in grain (kg N/ha)</td>
<td>82</td>
<td>167</td>
</tr>
<tr>
<td>N fertilizer application (kg N/ha)</td>
<td>111</td>
<td>181</td>
</tr>
<tr>
<td>N deposition (kg N/ha)</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td><strong>N use efficiency</strong></td>
<td><strong>62 %</strong></td>
<td><strong>83 %</strong></td>
</tr>
<tr>
<td>(N removal/ N input) * 100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: * FAO, ** Yara field trials
The Key Facts

- Fertilizers are needed for feeding the world

- Agricultural land must be used in the most efficient way, to protect wildlife and minimize climate change

- Fertilizers, used correctly, will contribute to solving climate change

- Europe has today the most efficient production plants and the most modern agriculture

- N₂O is released by natural processes regardless of the origin of the nitrogen in the soil

- To reduce N₂O the field the nitrogen use efficiency shall be improved by good agricultural practices