CONTROLLING NITROUS OXIDE EMISSIONS FROM AGRICULTURE: EXPERIENCES IN THE NETHERLANDS
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ABSTRACT
We report on strategy, approach and results in a research project in the Netherlands (2000 – 2003) to identify options for decreasing N$_2$O emission from agriculture in the Netherlands. Implementation of such measures would help to satisfy the target of decreasing the total emissions of greenhouse gas emissions. A farm systems analysis approach was used to identify potential mitigation options for the main sectors in agriculture. Options for mitigation at farm level were categorized into management measures, technological measures and structural measures and implemented in a decision support system MITERRA DS. Recent structural measures by the government have decreased N$_2$O emissions by 10%. Many technological measures are expensive, site specific and may have unwanted side effects. Management measures directed towards improving N use efficiency are the most promising and cheap measures for decreasing N$_2$O emissions. As a result of implementation of manure policy in the Netherlands, on average, N use efficiency at farm level will increase by a factor of 2 between 1998 and 2003 and decrease N$_2$O emissions by appr. 30%. The overall potential is in the order of minus 40%.

1.0 INTRODUCTION
1.1 NON – CO$_2$ EMISSIONS FROM AGRICULTURE
Agriculture is a main source for nitrous oxide (N$_2$O) in the atmosphere. Dutch agriculture in 1997 produced 25.3 Gg N$_2$O (or 7.8 Mton CO$_2$ equivalents) which is appr. 35% of the total N$_2$O production in the Netherlands (table 1). The N$_2$O production comes primarily from soils and is strongly related to N input, e.g. via fertilizer and manure application. Most studies focus on measuring and understanding the spatial and temporal variations of N$_2$O emissions from soils. The other important greenhouse gas is methane from enteric fermentation and manure storage and 423 Gg CH$_4$ was produced in 1999 in the Netherlands. Especially in dairy farming, the emission of N$_2$O is linked to the emission of CH$_4$.

Table 1. Emissions of N$_2$O (in Gg N$_2$O) from agricultural soils in the Netherlands in 1990, 1997 and 2000 (National Inventory by Olivier et al., 2003) and in 2010 (Reference projection by Beker and Peek, 2002)

<table>
<thead>
<tr>
<th></th>
<th>1990</th>
<th>1997</th>
<th>2000</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct N$_2$O from agricultural soil</td>
<td>13.0</td>
<td>17.1</td>
<td>15.4</td>
<td>11.9</td>
</tr>
<tr>
<td>Animal production (grazing and storage)</td>
<td>3.8</td>
<td>3.5</td>
<td>2.5</td>
<td>2.6</td>
</tr>
<tr>
<td>Indirect N$_2$O from agricultural soils</td>
<td>4.7</td>
<td>4.7</td>
<td>4.7</td>
<td>4.7</td>
</tr>
<tr>
<td>Total</td>
<td>21.5</td>
<td>25.3</td>
<td>22.6</td>
<td>19.2</td>
</tr>
</tbody>
</table>
Estimates for the net exchange of these greenhouse gases between agriculture and atmosphere are uncertain, because sources are diffusely spread over the countryside and influenced by environmental factors, which greatly vary in space and time. This uncertainty frustrates accurate accounting and as such may obstruct the successful implementation of policies and measures that aim at mitigating emissions of \( \text{N}_2\text{O} \) and \( \text{CH}_4 \) from agriculture.

1.2 DEVELOPMENTS IN AGRICULTURE IN THE NETHERLANDS
Agriculture in the Netherlands ranks among the highest in the world in terms of production level and resource use per unit surface area (Oenema et al., in press). Agricultural land in the Netherlands is used for dairy farming (60%) with grassland and silage maize as fodder crops, arable farming (30%) with potatoes, sugar beet and wheat as dominant crops, and intensive livestock farming (5%) with silage maize as dominant crop. Substantial additional imports of feed accommodate intensive agriculture.

Increased awareness of the environmental impacts of the intensification of agricultural production and of the relationships between the Common Agricultural Policy in the EU and surpluses drastically changed the agricultural policies in the Netherlands from the mid 1980’s onwards (Henkens and van Keulen, 2000). The implementation in 1998 and onwards of the nitrogen (N) and phosphorus (P) accounting system \( \text{MINAS} \) with target N and P surpluses at farm level forced farmers to lower the input of N and P via fertilizers, animal feed and animal manure and to increase N and P use efficiency (Aarts et al., 2000). N and P surpluses decreased and are expected to further decrease in the next 5 years (Oenema et al., in prep.). This trend negatively affects the emission of nitrous oxide and methane (table 1) and benefit mitigation policy.

1.3 DEVELOPING MITIGATION OPTIONS FOR \( \text{N}_2\text{O} \)
Between 2000 and 2003, a major research project (ROB – agro or Reduction Plan non – \( \text{CO}_2 \) Greenhouse Gases) was carried out in the Netherlands to identify options for decreasing \( \text{N}_2\text{O} \) emission from agriculture in the Netherlands, so as to satisfy the target of decreasing the total emissions of greenhouse gas emissions by 6% in 2008 relative to 1990. This paper reports on the strategy, approach and results of this ROB-agro project on primarily \( \text{N}_2\text{O} \). Our research was focused on the main sectors in Dutch agriculture.

2.0 OPTIONS FOR MITIGATION OF NON – \( \text{CO}_2 \) GREENHOUSE GASES
2.1 STRATEGY
Many mitigation measures for \( \text{N}_2\text{O} \) and \( \text{CH}_4 \) emissions from agriculture have been identified, including measures on animal feed, housing system, manure handling, fertilizer and manure application, grazing, and crop residues. Sofar, the mitigation potentials are uncertain, as many have not been tested at farm level in the field. This uncertainty further relates to the interactions between measures, the risk of unwanted side effects (e.g. increase in \( \text{NH}_3 \) emissions and nitrate leaching) and interference’s with other environmental issues (e.g. effects of agriculture on eutrophication of surface water and ground water quality). In most papers it has been implicitly assumed that farmers are able and willing to implement the proposed measures. The major challenge of policy makers is to formulate effective and efficient policies and measures,
using the potentials of the abatement measures proposed so far, and in an international setting with still highly uncertain cause-effect relationships.

2.1 APPROACH
A farm systems analysis approach was used to identify potential mitigation options (Oenema et al., 2002). Six coherent sub-projects were defined with a focus on soil and grassland management, fertilizer and manure management, clover, grazing management, crop residues, and water management, respectively. The following steps were taken:

- Each of the projects commenced with a systems analysis in which the pros and cons of the various possible mitigation measures were identified using literature data and simulation modelling. Possible trade-offs in terms of changes in the emissions of other unwanted substances (CO₂, CH₄, nitrate leaching, ammonia volatilization, energy use, etc.) were included as well as economic cost of measures where possible.
- Next, measures with high potential were tested in laboratory screening experiments (Velthof et al., 2002; 2003) and field experiments to extract emission factors (Burczyk et al., 2001; van Groenigen et al, in press).
- Finally, the results of the systems analyses and experiments were integrated into a decision support system MITERRA-DS (Velthof et al., 2002). This decision support system was developed as a tool for scientists and policy makers in quantifying effects of measures on CO₂, N₂O and CH₄ emissions as well as on NH₃ and NOₓ emission and N leaching.

2.2 DECISION SUPPORT
MITERRA-DS (Velthof et al., 2002) is set up to calculate the emissions of CO₂, CH₄, N₂O as well as NH₃, and NOₓ from animals, animal housing, manure, and agricultural land and the N leaching from agricultural land (figure 1). The flows of nitrogen and manure are calculated using data from agricultural statistics, practical farms, and scientific studies. The gaseous C and N emissions and N leaching are calculated using emission factors derived from literature, ongoing experiments and expert judgement. MITERRA-DS calculates the (side-) effects of various policies and measures on a national basis.

Figure 1. Schematic representation of MITERRA-DS (Velthof et al., 2002).
2.3 IDENTIFICATION OF MITIGATION MEASURES
The measures were categorized into (i) management measures, (ii) technological measures, and (iii) structural measures (Oenema et al., 2001):

- **technological measures** such as type of housing system, manure application technique, manure treatment, fertilizer type, additions to animal feed, and refinement of fertilizer application;
- **management measures** focus on improving resource use efficiency (energy, water, feed and nutrients) and include adjustment of grazing system, changes in crop rotations, and changing permanent grassland in temporal grassland;
- **structural measures** such as extensification and buying out animal or production rights, changing to organic farming and conversion of agricultural land in nature.

3.0 RESULTS
Over 30 measures that could decrease emission of N\textsubscript{2}O from agriculture were identified. Many of the tested measures showed a response in terms of changes in the emissions of N\textsubscript{2}O (Burczyk et al., 2001; van den Pol-van Dasselaar et al., 2002; van Groenigen et al., 2004). For example, inorganic fertilizer in grassland results in lower emissions of N\textsubscript{2}O than cattle slurry (when applied to grassland on a sandy soil in the amounts recommended by good agricultural practice). Applying fertilizer in smaller doses reduces the emission of N\textsubscript{2}O from grassland. The lowest N\textsubscript{2}O emissions were observed when AS 100 or CAN 50/50 had been used as fertilizer application protocols (figure 2). Only few of the measures yielded consistent and uniform patterns for all soils tested or for all growing seasons concerned or were without unwanted side effects.

Figure 2. Accumulated N\textsubscript{2}O emission (in kg N per ha per year) for grassland fertilized with mineral fertilizer (Ammonium nitrate – CAN or ammonium sulfate – AS) alone or CAN in combination with cattle slurry and either applied in one dressing or as split application. The grassland was cut 6 times per year and fertilized with 330 kg N per ha in 5 dressings (Dolfing et al., in prep.).

Many additional measures have potential, but these measures require a lot of site-specific information and skill to be able to implement these measures in
practice successfully. For example, anaerobically digested animal manure applied to land decreased emissions on sand soil but increased emission on clay soil, relative to undigested manure (Velthof et al., in prep). Manipulation of crop residues had an effect on sand soil, but not on clay soil. Split applications of fertilizers tended to decrease emissions, while injections of animal manure and fertilizers at 5 or 10 cm depth in the soil tended to increase $N_2O$ emissions, relative to broadcast applications at once.

### 3.1 IMPROVING N USE EFFICIENCY

The very best and most simple measure that emerged is improving N use efficiency and decreasing the total N input into the system. In the highly intensive agriculture in the Netherlands, N is not used efficiently. This provides a large scope for decreasing N input and also decreasing $N_2O$ emissions. The implementation of manure policy, the N and P accounting system MINAS was introduced in 1998 on all farms. This governmental policy instrument forces farmers to drastically increase N use efficiency. On average, N use efficiency at farm level will increase by a factor of 2 between 1998 and 2003 (Aarts et al., 2000) and as a result $N_2O$ emissions will decrease.

### 3.2 MITIGATION POTENTIAL

Introduction of the mineral accounting system MINAS will improve N use efficiency and decrease $N_2O$ emissions by up to 20%. The major results are (see table 2):

- restricted grazing decreases $N_2O$ and NO$_x$ emission, but increases CH$_4$ and NH$_3$ emissions
- applying less N fertilizer decreases emissions of $N_2O$, NH$_3$, NO$_x$, and N leaching, but does not affect CH$_4$ emission
- lower livestock numbers decreases emissions of CH$_4$, $N_2O$, NH$_3$, and NO$_x$ and N leaching
- most housing systems with low NH$_3$ emission decrease emissions of NH$_3$, $N_2O$ and NO$_x$, but increase CH$_4$ emission and N leaching
- combined measures decrease all emissions, but the sum of the single measures differs from the combined effect, indicating interactions between the measures.

Implementation of a selection of the 10 most effective measures from the ROB AGRO research programme (table 3) would decrease the emission of $N_2O$ and CH$_4$ by 3.5 - 6.0 Mton CO$_2$ eq.

As some of the measures listed in table 2 and 3 may overlap, the overall potential is in the order of -40% of the agricultural greenhouse gas emissions.

### 4.0 DISCUSSION

The results indicate clear potentials for mitigating $N_2O$ and CH$_4$ emissions, though part of the measures may increase NH$_3$ and NO$_x$ emissions and/or N leaching. Several classes of measures were identified and their effectivity was assessed:

- Technological measures (fertilizer technology, application techniques, crop residue manipulation, manure treatment, irrigation) appear expensive, site-specific and often have unwanted side effects.
- Structural measures, i.e. decreasing the volume of production and number of animals via quotas, are also effective, but are very expensive. Recent
structural measures by the government (buy-out of animal rights, and lowering the milk quota) have decreased N$_2$O emissions by 10%.

- Management measures directed towards improving N use efficiency and decreasing total N input into the system are the most promising and cheap measures for decreasing N$_2$O emissions. On average, improving N use efficiency at farm level will decrease N$_2$O emissions by up to 20%. Improving N use efficiency on animal farms means improving the N use efficiency in the whole chain, from soil via animal feed and animal to animal waste and to soil again. As such, the manure policy instrument MINAS is an effective instrument for decreasing N$_2$O emissions from agriculture.

These measures are currently implemented in MITERRA DS and effects are quantified in terms of effectivity (CO$_2$-eq), acceptability by farmers and economy (cost). The economic costs of measures and the acceptability among farmers are also considered in MITERRA-DS. Using linear programming, MITERRA-DS can be used as tool for scientists and policy makers to optimize mitigation strategies for greenhouse gas emissions, taking into account agricultural and economical constraints and constraints arising from other environmental issues.

The success of greenhouse gas mitigation policies largely depends on the response of farmers to these policies as well as to other policies (i.e. manure policy) and developments in the market and technology. Crucial factors here are personal skill and characteristics of individual farmers (preference, ambition, vision and entrepreneurship), farm characteristics (type, size and intensity) and local environment (soil, climate). Successful implementation by farmers on all sites may be achieved by quantification of effects in mechanistic models and site- and farm-specific information.

5.0 CONCLUSIONS
Summarizing, many of the tested measures showed a response in terms of changes in the emission of N$_2$O. The most cost-effective measure for mitigation in the short term is improving resource use efficiency with additional benefits through reduced total resource input. These and many additional measures require a lot of site-specific information and management skill of farmers for them to be able to implement these measures in practice successfully. Successful strategies for less greenhouse gas emissions are determined by willingness and skilfulness of individual farmers and by elimination of negative trade-offs with other policies and measures to prevent emissions to air and water. Farmers can reduce emissions of N$_2$O if specific emission factors for a range of agricultural activities that aim to improve N use efficiency are developed and are applied in the national inventory.

The potential of cost-effective measures to decrease N$_2$O emissions in the Netherlands is about 40%. Priority should be given to chain-oriented measures that aim at an increased carbon, nitrogen and water use efficiencies in the whole food chain, above source-oriented measures that aim at decreased emission from specific sources. Chain-oriented measures can only be (cost)effective if they fit in with other environmental policies that aim at increasing resource use efficiency.
Table 2. Effects of a series of measures on emissions of CH$_4$, N$_2$O, NH$_3$, and NO$_x$, and NO$_3$ leaching from agriculture in the Netherlands calculated with MITERRA-DS, in comparison to the year 2000.

<table>
<thead>
<tr>
<th>Year</th>
<th>Change in comparison to 2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000 restricted grazing</td>
<td>CH$_4$, Mton CO$_2$-equivalents yr$^{-1}$</td>
</tr>
<tr>
<td>25% less N fertilizer</td>
<td>Direct N$_2$O, Mton CO$_2$-eq. yr$^{-1}$</td>
</tr>
<tr>
<td>25% less pigs</td>
<td>Indirect$^1$ N$_2$O, Mton CO$_2$-eq. yr$^{-1}$</td>
</tr>
<tr>
<td>25% less poultry</td>
<td>NH$_3$, Gg N yr$^{-1}$</td>
</tr>
<tr>
<td>25% less cattle</td>
<td>NO$_3$, Gg N yr$^{-1}$</td>
</tr>
<tr>
<td>low NH$_3$ housing</td>
<td>NO$_x$, Gg N yr$^{-1}$</td>
</tr>
</tbody>
</table>

$^1$ indirect N$_2$O emission is N$_2$O derived from NH$_3$ and NO$_x$ emission and N leaching from agriculture.

Table 3. Selection of 10 most effective measures for mitigation of non – CO$_2$ greenhouse gases from agriculture in the Netherlands.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Effectivity (Mton CO$_2$ eq ref 1990)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replace ammoniumnitrate by ammoniumsulphate fertilizer on grassland</td>
<td>- 0.25</td>
</tr>
<tr>
<td>Split application of N fertilization on grassland</td>
<td>- 0.10</td>
</tr>
<tr>
<td>Grassland renovation: refrain from ploughing and improve grassland management</td>
<td>- 0.8 – 1.3</td>
</tr>
<tr>
<td>Replace mineral N fertilizer by biological nitrogen fixation in clover in grassland</td>
<td>- 0.1 – 1.0</td>
</tr>
<tr>
<td>Precision fertilization (follow fertilization advice more strictly)</td>
<td>- 0.2 – 0.8</td>
</tr>
<tr>
<td>Feeding cattle with more mais in ration</td>
<td>- 0,2</td>
</tr>
<tr>
<td>Optimal manure management</td>
<td>- 0.5 – 0.8</td>
</tr>
<tr>
<td>Fertilization application choice: mineral N on arable, manure on grass</td>
<td>-0.5 – 1.0</td>
</tr>
<tr>
<td>Add nitrification inhibitors to manure</td>
<td>- 0.3</td>
</tr>
<tr>
<td>Fermentation of manure to prevent CH$_4$ emission from manure and replace fossil fuel</td>
<td>- 0.7 – 1.5</td>
</tr>
<tr>
<td>Total</td>
<td>- 3.5 – 6.0</td>
</tr>
</tbody>
</table>
6.0 REFERENCES