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_2O 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_2O 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_2O 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_2O 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_2O) in the atmosphere. Dutch agriculture in 1997 produced 25.3 Gg N_2O (or 7.8 Mton CO_2 equivalents) which is appr. 35% of the total N_2O production in the Netherlands (table 1). The N_2O 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_2O 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_2O is linked to the emission of CH_4.

Table 1. Emissions of N_2O (in Gg N_2O) 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)

	1990	1997	2000	2010
Direct N_2O from agricultural soil	13.0	17.1	15.4	11.9
Animal production (grazing and storage)	3.8	3.5	2.5	2.6
Indirect N_2O from agricultural soils	4.7	4.7	4.7	4.7
Total	21.5	25.3	22.6	19.2

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 N_2O and 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 *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 N_2O

Between 2000 and 2003, a major research project (ROB – agro or Reduction Plan non – CO_2 Greenhouse Gases) was carried out in the Netherlands to identify options for decreasing N_2O 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 N_2O. Our research was focused on the main sectors in Dutch agriculture.

2.0 OPTIONS FOR MITIGATION OF NON – CO_2 GREENHOUSE GASES

2.1 STRATEGY

Many mitigation measures for N_2O and 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 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 (CO_2, CH_4, 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 CO_2, N_2O and CH_4 emissions as well as on NH_3 and NO_x emission and N leaching.

2.2 DECISION SUPPORT

MITERRA-DS (Velthof *et al*., 2002) is set up to calculate the emissions of CO_2, CH_4, N_2O as well as NH_3, and NO_X 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.

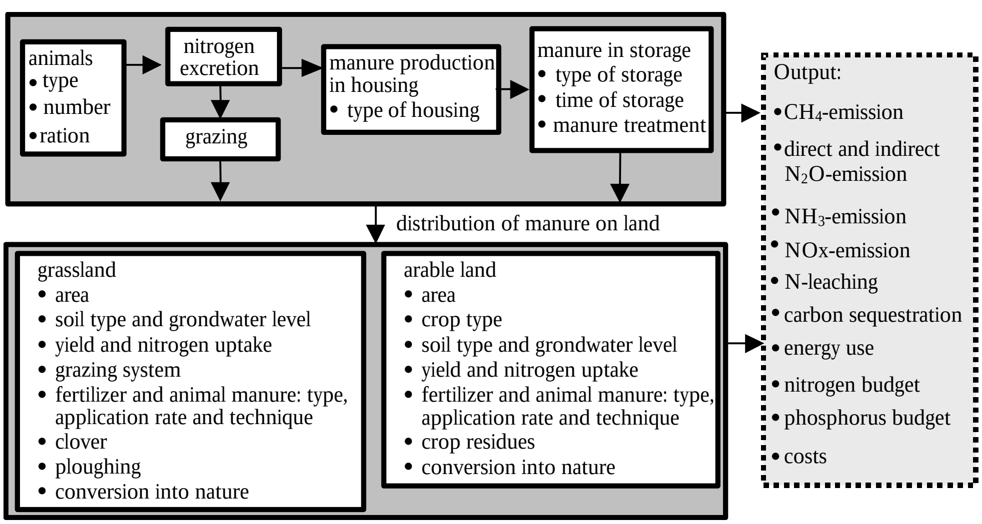

Figure 1. Schematic representation of MITERRA-DS (Velthof *et al*., 2002).

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_2O from agriculture were identified. Many of the tested measures showed a response in terms of changes in the emissions of N_2O (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_2O 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_2O from grassland. The lowest N_2O 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.

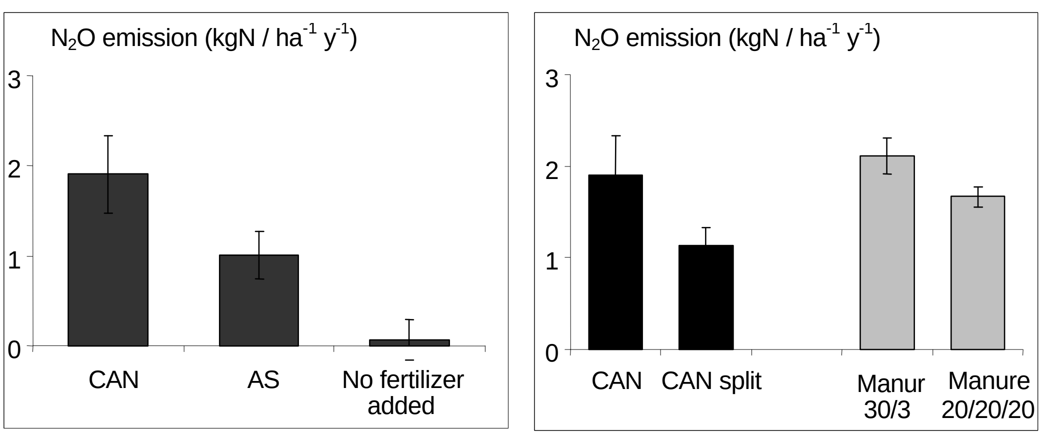

Figure 2. Accumulated N_2O emission (in kg N per ha per year) for grassland fertilized with mineral fertilizer (Ammonium nitrate – CAN or ammonium sulfate – AS) alone or CAN in combination with cattle slurry and either applied in one dressing or as split application. The grassland was cut 6 times per 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_2O 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_2O emissions. On average, improving N use efficiency at farm level will decrease N_2O 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_2O 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_2O. 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_2O 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_2O 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_2O, NH_3, and NO_x, and NO_3 leaching from agriculture in the Netherlands calculated with MITERRA-DS, in comparison to the year 2000.

	Year 2000	Change in comparison to 2000						
		restricted grazing	25 % less N fertilizer	25% less pigs	25% less poultry	25% less cattle	low NH_3 housing	combined measures
CH_4, Mton CO_2-equivalents yr^{-1}	8.80	+ 0.10	0	- 0.37	- 0.04	- 1.73	+ 0.08	- 1.66
Direct N_2O, Mton CO_2-eq. yr^{-1}	8.83	- 0.51	- 0.82	- 0.26	- 0.12	- 0.75	- 0.04	- 1.57
Indirect[1] N_2O, Mton CO_2-eq. yr^{-1}	2.06	+ 0.01	- 0.34	- 0.14	- 0.05	- 0.31	- 0.01	- 0.66
NH_3, Gg N yr^{-1}	117	+ 6	- 1	- 10	- 3	- 14	- 19	- 31
NO_3, Gg N yr^{-1}	116	- 1	- 27	- 7	- 3	- 19	+ 7	- 40
NO_X, Gg N yr^{-1}	16.0	- 1.1	- 1.4	- 0.3	- 0.1	- 1.4	- 0.2	- 3.0

[1] indirect N_2O emission is N_2O 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.

Measure	Effectivity (Mton CO_2 eq ref 1990)
Replace ammoniumnitrate by ammoniumsulphate fertilizer on grassland	- 0.25
Split application of N fertilization on grassland	- 0.10
Grassland renovation: refrain from ploughing and improve grassland management	- 0.8 – 1.3
Replace mineral N fertilizer by biological nitrogen fixation in clover in grassland	- 0.1 – 1.0
Precision fertilization (follow fertilization advice more strictly)	- 0.2 – 0.8
Feeding cattle with more mais in ration	- 0,2
Optimal manure management	- 0.5 – 0.8
Fertilization application choice: mineral N on arable, manure on grass	-0.5 – 1.0
Add nitrification inhibitors to manure	- 0.3
Fermentation of manure to prevent CH_4 emission from manure and replace fossil fuel	- 0.7 – 1.5
Total	- 3.5 – 6.0

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