Environmental RTDI Programme 2000–2006

CLIMATE CHANGE – Estimation of Emissions of Greenhouse Gases from Agriculture and Strategies for their Reduction

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Synthesis Report

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Prepared for the Environmental Protection Agency

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DISCLAIMER

CLIMATE CHANGE

The Climate Change Section of the Environmental RTDI Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in this area. The reports in this series are intended as contributions to the necessary debate on climate change and the environment.

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1 Summary

This research project was carried out jointly by UCD and Teagasc against the background of greenhouse gas emissions in Ireland being in excess of the amount permissible under the Kyoto Protocol (68.46 million t of carbon dioxide (CO_2) equivalent emitted in 2004, *vs* 63 million t allowed under Kyoto). In Ireland, agriculture is the source of a much larger share of greenhouse gas emissions (28%) than in most other developed countries due to the importance of agriculture in the economy. The key objectives of this project were to provide information to allow a more accurate inventory of agricultural greenhouse gas emissions (i.e. move as much of the inventory as possible from a Tier 1 methodology to a Tier 2 methodology), and to advise on possible practices to mitigate these emissions. Specifically, it was proposed to:

- Develop new emission factors for methane (CH_4) from enteric fermentation and manure management for the Irish cattle herd to allow the inventory move to a Tier 2 methodology

- Identify practices that could reduce CH_4 emissions from the cattle herd

- Provide information on nitrous oxide (N_2O) emissions from grazed grassland with particular emphasis on the effect of nitrogen (N) fertiliser inputs and to evaluate the Intergovernmental Panel on Climate Change (IPCC) default values in the light of data generated.

The results of the project lead to the following key conclusions:

- The inventory can move to a Tier 2 methodology for CH_4 emissions (both enteric fermentation and manure management) from the cattle herd, as a result of new emission factors being developed.

- The new emission factors are higher than the default values previously used and will increase both the current and 1990 inventories. However, fortuitously, using the Tier 2 approach has a beneficial effect on the national inventory. Under the Tier 1 approach, emissions of CH_4 from the cattle herd in 2003 were reduced by 3,600 t CH_4 relative to 1990. This is increased to 15,500 t CH_4 using the Tier 2 methodology. Thus, the effect of moving to a Tier 2 methodology is a net reduction in the national inventory of 11,900 t CH_4 (15,500 minus 3,600) or 0.25 million t CO_2 equivalent.

- These emission factors are dynamic and will change in line with changes in animal production systems. They are derived by quite detailed models which will be able to accommodate most mitigation practices that might be adopted to reduce CH_4 emissions. This is an important and valuable attribute of the models developed in this project.

- A number of practices are available to reduce enteric CH_4 emissions from the cattle herd. If fully implemented, these would reduce enteric CH_4 emissions by 5.6% or 0.47 million t of CO_2 equivalent per year. While some of the practices are likely to occur without any government intervention, some of the other more important ones are dependent on market forces for their implementation. Thus, these practices may not materialise at all, or may happen very slowly without some incentives. It is recommended that consideration should be given to such incentives, as applies to other sectors of the economy.

- It is recommended that no change be made to the current N_2O emission inventory methodologies. This recommendation is made on the basis of the relatively short-term nature of the research conducted, large inter-annual variability and the identification of a large soil-type effect on N_2O emission rates from lysimeter studies. Therefore, to move from a Tier 1 to a Tier 2 approach, further data from long-term multi-site (covering a range of soil types and N inputs) monitoring studies are required.

- Control of N_2O emissions will be difficult, but improving N efficiency of farms will reduce them.

2 Background

2.1 The Kyoto Protocol and Ireland

Irish greenhouse gas emissions were 23.1% higher in 2004 than in 1990, at 68.46 million t of CO_2 equivalent (Ireland National Inventory Report, 2006), compared to an allowable 13% increase. Figure 2.1 shows the main sources of greenhouse gases by sector. There has been a large rise (+144%) in emissions from transport sources (mainly road traffic) since 1990. Agricultural emissions rose during the 1990s but have declined back towards 1990 levels in recent years, mainly due to a fall in livestock numbers. As a result, agriculture's share of the total has declined from 36% in 1990 to 28% in 2004. This is a much higher share than in most other developed countries due to the importance of agriculture to Ireland's economy.

2.2 Sources of Greenhouse Gases in Agriculture

There are three main sources of greenhouse gas emissions in agriculture: enteric fermentation, agricultural soils and manure management (Fig. 2.2). There is also some CO_2 emitted from fossil fuel burning in agriculture. Enteric fermentation (fermentation in the digestive tract) is a natural part of the digestion process which results from the activity of microorganisms in the digestive tract. Digestion in ruminants (e.g. cattle and sheep) differs from that in monogastrics (e.g. pigs and poultry) in that substantial fermentation occurs in their large stomach called the rumen, resulting in large quantities of CH_4 being produced which are voided through erudication (belching). Methane is a greenhouse gas, and it is 21 times more potent than CO_2 per unit mass (thus 1 kg CH_4 has a global warming potential 21 times that of 1 kg of CO_2). Differences exist between animals in the amount of CH_4 produced which are a direct result of the amount of feed consumed and the type of diet. In addition, dietary additives can have an effect. Due to their greater size and intake, cattle produce substantially more CH_4 than sheep, and, in Ireland, the cattle herd accounts for 91% of the CH_4 arising from enteric fermentation.

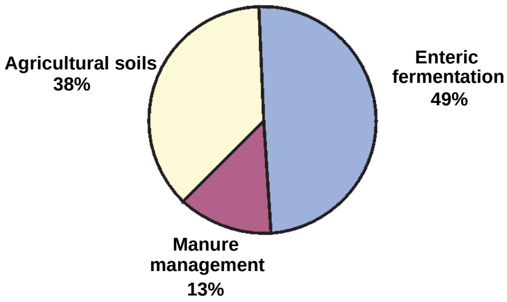

Figure 2.2. Main sources of greenhouse gas emissions from Irish agriculture in 2004 (Ireland National Inventory Report, 2006).

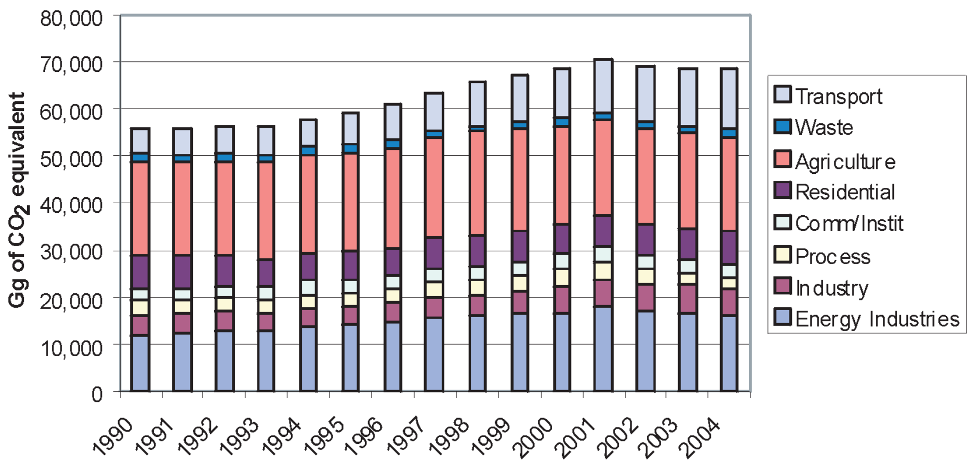

Figure 2.1. Greenhouse gas emissions (Gg of CO_2 equivalent) by sector in Ireland (1990 to 2004). (Source: Department of the Environment, Heritage and Local Government, 2006).

The nitrogen (N) cycle in soils is complex with many factors (biological, chemical and physical) determining the fate of N in mobile pools in the soil. There are eight major processes in the N cycle. One of these processes is denitrification, which can result in the formation of N_2O which is emitted from soils to the atmosphere. Nitrous oxide is a greenhouse gas that is 310 times more potent than CO_2 per unit mass (i.e. 1 kg N_2O has a global warming potential equal to 310 kg CO_2). The calculation of national N_2O emission totals, or inventory calculation, is currently based on the sum of the following:

- Direct soil emissions resulting from inputs of N from synthetic fertiliser, animal manure, sludges, fixation by N-fixing crops, crop residues returned to soils, and cultivation of organic soils
- Emissions associated with N excreted by grazing animals
- Indirect emissions due to N deposition resulting from the emissions of ammonia (NH_3) and oxides of nitrogen (NO_x) in agriculture and from nitrate leaching.

The main factors controlling N_2O emissions from soil are the levels of soil carbon (C) and soil N, the soil temperature and soil moisture. In general, emissions will increase as the soil N levels increase, with higher emission where there is a plentiful supply of C in wetter heavier soils.

Methane and N_2O are also emitted from animal manures. The quantity depends on the storage system and the length of storage period. Liquid-type waste management systems (e.g. slurry) give rise to higher emissions of CH_4 than solid-type systems, while N_2O losses are higher in solid systems than in liquid systems.

Current (2004) estimates suggest that enteric fermentation, soils and manure account for 49%, 38% and 13%, respectively, of greenhouse gas emissions on a CO_2 equivalent basis (Fig. 2.2).

2.3 Objectives of this Project

The key objectives of this project were to provide information to allow a more accurate inventory of agricultural greenhouse gas emissions, and to advise on possible strategies to mitigate these emissions. Specifically, it was proposed to:

- Develop new emission factors for CH_4 from enteric fermentation and manure management for the cattle herd
- Identify strategies that could reduce CH_4 emissions from the cattle herd
- Provide information on N_2O emissions from grazed grassland with particular emphasis on the effect of N fertiliser inputs and to evaluate the IPCC default values in the light of data generated.

3 Emission Factors for Methane from Enteric Fermentation and Manure Management for the Cattle Herd

Prior to this project, CH_4 emissions were calculated using a Tier 1 methodology. This is the simplest methodology proposed by the IPCC for national inventories. It uses easily available national input data (e.g. animal number) and default emission factors from the IPCC (e.g. Fig. 3.1) to derive the total emissions from that source category.

For example, for *Enteric fermentation – dairy cattle*, the number of dairy cows is multiplied by the default emission factor of 100 kg CH_4/head/year, so emissions for 1990 (when the number of dairy cows was 1.36 million) were

1,360,000 × 100 kg = 134,200 t CH_4
(2.856 million t of CO_2 equivalent)

In the Tier 1 approach used, the cattle herd was only split into two categories, dairy cows and other cattle. This latter category contained a range of different types of cattle, from young cattle less than 1 year old to mature suckler (beef) cows. Broad categories such as dairy cows and other cattle and the use of default emission factors inevitably lead to imprecision in the inventory calculations. Therefore, the IPCC recommends that a Tier 2 approach be used for source categories that make a significant contribution to a country's total emissions. This requires generating country-specific emission factors, and using a more detailed categorisation of the cattle herd.

In this project, emission factors for CH_4 from enteric fermentation and manure management were developed using a modelling approach for the categories of the Irish cattle herd for which data on animal numbers are available from the Central Statistics Office (CSO) (Table 3.1).

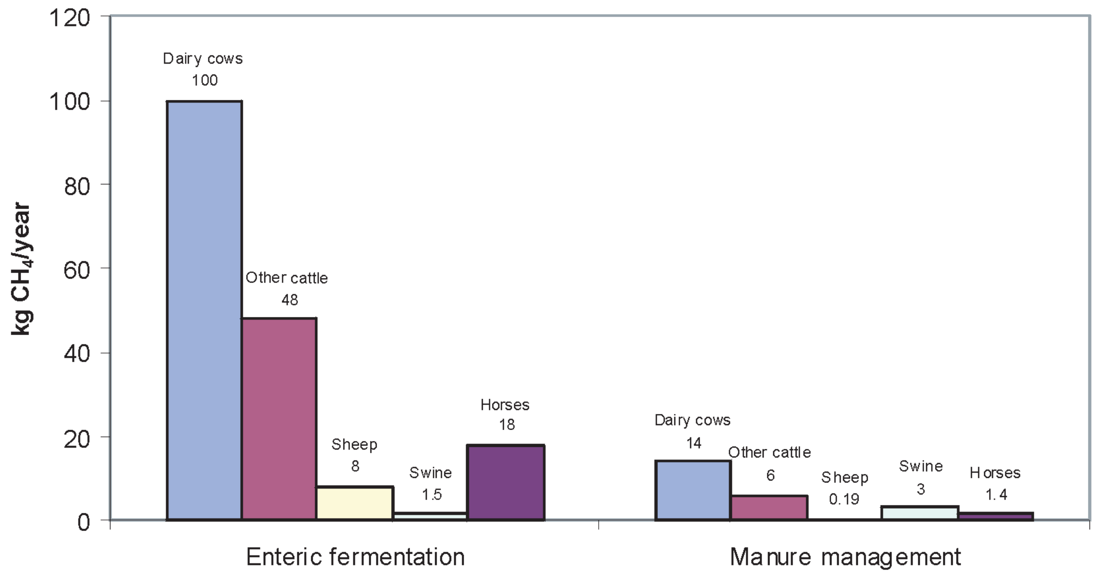

Figure 3.1. IPCC (1997) default emission factors for methane from enteric fermentation and manure management.

Table 3.1. Animal categories for which emission factors were developed.

Dairy cows	Cattle 1–2 years old, male	Bulls for breeding
Beef cows	Cattle 1–2 years old, female	In-calf heifers, dairy
Cattle <1 year old, male	Cattle >2 years old, female	In-calf heifers, beef
Cattle <1 year old, female	Cattle >2 years old, male	

The process of deriving these emission factors for each category had the following steps:

- The country was divided into three regions based on length of grazing and housing periods. Region 1 comprised Carlow, Cork, Dublin, Kildare, Kilkenny, Laois, Offaly, Tipperary, Waterford, Wexford and Wicklow. Region 2 comprised Clare, Galway, Kerry, Limerick, Longford, Louth, Mayo, Meath, Roscommon, Sligo and Westmeath. Region 3 comprised Cavan, Donegal, Leitrim and Monaghan. It was possible to determine the number of dairy and beef (suckler) cows in each region, but not the other categories of animals. In these cases, the country was treated as a single region. For most categories of animals, sub-categories were created to give a more accurate assessment of their emissions. Thus, 12, 18, 13 and 14 sub-categories were modelled for dairy cows, beef cows, non-breeding beef females and non-breeding beef males, respectively.

- The production system in each region was defined in terms of diet, animal performance and characteristics such as size, calving date, and dates of winter housing and spring turnout to grass, based on farm survey data collected for the project.

- The CH_4 conversion factor (i.e. percentage of dietary energy intake converted to CH_4) was established for each of the diets concerned, based on measurements made in this project and international literature on the subject.

- From this information, the annual emissions of CH_4 from enteric fermentation and manure management were calculated for each animal sub-category in each region. The annual emissions of the sub-categories within a category were then combined on a weighted basis to give a single national emission factor for the category.

The emission factors so derived are summarised in Table 3.2. There are many differences in comparison to the default factors recommended by the IPCC (1997). These differences reflect the different production systems in Ireland. These emission factors are dynamic, and will change each year in line with changes in production systems. The methodology to derive them is quite detailed. It has the advantage of being able to account for the impact of most mitigation practices that might be adopted to reduce CH_4 emissions. This is an important and valuable attribute of the models developed in this project.

The number of dairy and beef (suckler) cows to be used in inventory calculations should be determined as the average of CSO June and December data. However, the project team considered that the CSO data on livestock

Table 3.2. Methane emission factors (kg/head/year) for enteric fermentation and manure management for 2003 and 1990.

	2003		1990	
	Enteric	Manure	Enteric	Manure
Dairy cows	108.8	20.53	101.38	21.57
Beef (suckler) cows	74.2	13.9	74.03	14.02
Male cattle				
<1 year	29.53	8.5	30.46	9.73
1–2 years	60.37	14.25	62.22	16.68
>2 years	34.27	1.48	55.08	4.57
Female cattle				
<1 year	27.86	8.28	27.05	8.79
1–2 years	44.6	9.34	53.54	14.74
>2 years	22.46	0.34	21.65	0.33
Bulls for breeding	81.55	18.95	86.38	23.79
In-calf heifers – dairy	50.16	10.93	51.82	13.4
In-calf heifers – beef	53.58	12.87	55.42	15.61

numbers at the end of June are more appropriate to use in the inventory calculations for non-breeding beef cattle than using the average of June and December figures.

The implications of using the new specific emission factors (both enteric fermentation and manure management) for the calculation of the national inventory are shown in Fig. 3.2. The Tier 2 values give higher total emissions than the current Tier 1 methodology for both 1990 and 2003, and using June-only numbers for non-breeding cattle gives a further increase. However, using the Tier 2 methodology fortuitously has a beneficial effect on the national inventory. Under the Tier 1 approach, the drop in 2003 emissions of methane from the cattle herd relative to 1990 is 3,600 t CH_4. This is increased to 9,400 t CH_4 by using the Tier 2 approach, and using June numbers further enhances the reduction to 15,500 t CH_4. Thus, the effect of moving to a Tier 2 methodology is a net reduction in the national inventory of 11,900 t CH_4 (15,500 minus 3,600) or 0.25 million t CO_2 equivalent.

It is recommended that:

1. The national inventory for CH_4 from enteric fermentation and manure management is calculated on a Tier 2 basis using the emission factors in Table 3.2.

2. June cattle numbers (CSO) should be used to calculate the Tier 2 inventory for non-breeding cattle.

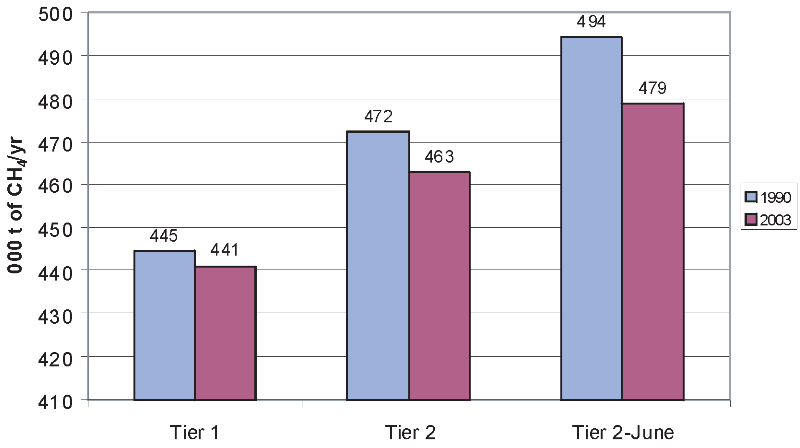

Figure 3.2. National emissions of methane from enteric fermentation and manure management for 1990 and 2003 using Tier 1 default values, Tier 2 specific Irish emission factors, and using specific Irish emission factors in combination with June animal numbers for non-breeding beef cattle.

4 Strategies to Reduce Enteric Methane Emissions from the Cattle Herd

Recent studies on the effect of CAP reform suggest that there will be a reduction in the cattle herd over the coming years. This will have the consequential impact of reducing enteric fermentation and manure management emissions. In addition, it will also reduce N_2O emissions as there will be a reduction in N fertiliser use. The discussion document recently published by the government in advance of the revision of the National Climate Change Strategy suggests that reductions in agricultural emissions will be in the order of 2.4 million t of CO_2 equivalent/year when compared to the 1990 value. This is obviously dependent on the anticipated falls in animal numbers and N fertiliser use materialising.

One of the objectives of this project was to investigate nutritional and management practices that could reduce emissions from enteric fermentation. A number of experiments were carried out to investigate possible mitigation practices. Specifically, the addition of plant oils to the diet of beef cattle, and increased concentrate feeding for beef cattle and dairy cows were researched. These are but two of several practices that can be considered. Therefore, a more comprehensive analysis of mitigation possibilities was conducted using both the results of the present research project and data from the international scientific literature. The analysis is speculative in nature as many of the reduction practices considered are still at the research stage, and there are still uncertainties regarding their effectiveness and potential for uptake by farmers.

A number of practices that reduce enteric CH_4 emissions have been identified. In terms of the state of development from basic research level to application at farm level, these can be classified into the following stages:

- Basic research level, discovery – fundamental studies to understand processes

- Proof of function/concept – research that demonstrates the feasibility of the technology and establishes the parameters for its use and the scope of the measure

- Product development/on-farm testing – testing at level of production system/farm

- Technology transfer/implementation.

Table 4.1 summarises the practices considered and indicates the stage of development of each. Eight are at the stage where the technology is sufficiently well known to allow them to be applied at farm level, and their emission reduction potentials are shown in Table 4.1. Lifetime management of beef cattle (e.g. slaughtering cattle at a younger age, or switching from steer beef to bull beef production) has the potential to give large reductions in CH_4 emissions (170,000 t CO_2 equivalent), if market conditions move beef production in the direction of systems with lower emissions. Feeding oils to beef cattle could give significant reductions (63,000 t CO_2 equivalent) in CH_4 emissions, but there is little incentive currently for beef farmers to adopt the practice as it is financially neutral from their perspective.

Genetic improvement will lead to reductions of CH_4 emissions from the dairy herd (of over 39,000 t CO_2 equivalent per year by 2015), assuming that milk quotas remain. Genetic improvement in beef cattle is much slower than with dairy cows, and while there may be a small reduction in CH_4 emissions, this is much more uncertain, and will be much less, and has not been quantified here. Improvements in technology and management on dairy farms resulting in increased milk yield over and above increases due to genetic gain could give substantial (118,000 t CO_2 equivalent) additional reductions. Replacing roughage with concentrates for dairy cows will give reductions in CH_4 while quotas remain, but this practice is only financially viable on a minority of farms. Thus, the practice will not have a major impact, unless the ratio of concentrate to forage price changes substantially to favour a large increase in concentrate feeding. However, the practice has more potential with beef cattle where it could result in reductions of 72,000 t CO_2 equivalent. Feeding propionate precursors is currently financially unviable.

Table 4.1. Summary of practices to reduce enteric methane emissions and the amount of CO_2 abatement possible.

Practice	State of development	Financially viable	Abatement possible (t CO_2 equivalent/year)
Replacing roughage with concentrate for dairy cows	Being applied on farms	On a minority of farms	7,593
Replacing roughage with concentrate for beef cattle	Being applied on farms	Yes (with further research required)	71,558
Genetic improvement of the dairy herd	Being applied on farms	Yes	39,276
Improvement in milk yield additional to genetic progress	Being applied on farms	Yes	118,000
Genetic improvement of beef cattle	Being applied on farms	Yes	
Lifetime management of beef cattle: halve number of cattle slaughtered over 30 months	Being applied on farms	Depends on market conditions	80,000
Lifetime management of beef cattle: increase number of young bulls slaughtered to 100,000/year	Being applied on farms	Depends on market conditions	90,800
Feeding dietary oils to beef cattle	Ready to apply on farms	Marginal	63,000
Feeding dietary oils to dairy cows	Establishing scope of measure (no programme currently in place to do this)		
Propionate precursors for beef and dairy cattle	Ready to apply on farms	Not currently	
Feeding maize silage to dairy cows	Establishing scope of measure (no programme currently in place to do this)		
Feeding maize silage to beef cattle	Establishing scope of measure		
Feeding other cereal silages instead of grass silage	Establishing scope of measure		
Improved grazing management	Establishing scope of measure		
Forage species and legume inclusion	Basic research stage/ Establishing scope of measure		
Probiotics	Basic research stage		
Halogenated compounds	Basic research stage		

A total annual reduction of approximately 470,000 t of CO_2 equivalent could be achieved by the adoption at farm level of the practices that do not impact negatively on farm profitability. This is approximately 5.6% of current enteric CH_4 emissions from the cattle herd (total emissions were 8.3 million t CO_2 equivalent in 2004). It is small in comparison to the reduction of 2.4 million t per annum forecast for the whole agriculture sector by 2008–2012 as a result of CAP reform, but nevertheless is significant.

There are a number of other measures which could be applied at farm level, or which are currently being applied, but for which the effect of the practice on CH_4 emissions has not been established. Examples are feeding maize silage or other cereal silages to dairy cows or beef cattle, improved grazing management, and use of legumes/other forage species. If it were established that these practices result in reductions in CH_4 emissions and the magnitude of the reduction is quantified, then their current effect on national emissions could be quantified, or the effect of the adoption or expansion of such practices could be determined. Research currently under way will allow this to be achieved in some cases in about 3 years. In addition, there are a number of promising practices at a basic research level. Over a longer time frame, these may prove effective for reducing CH_4 emissions.

While some of the practices are likely to occur without any government intervention (e.g. improvement in milk yield of dairy cows due to genetic gain and other technological and management innovations), it is important to point out that some of the other more important ones (lifetime management of beef cattle, and feeding oils to beef cattle) are dependent on market forces for their implementation. Thus, these practices may not materialise at all, or may happen very slowly without some incentives. It is recommended that consideration should be given to such incentives, as applies to other sectors of the economy.

Finally, some limitations of this analysis need to be highlighted. Many of the practices require further research before on-farm adoption. Also, an analysis of the effect of a mitigation practice on emission of just one greenhouse gas (e.g. CH_4 from enteric fermentation) provides only limited information. Account needs to be taken of any impacts on other agricultural sources/gases and, importantly, of impacts outside the farm gate in emissions associated with supply of agricultural inputs, for instance. In parallel with this project, a model has been developed to do this with dairy production systems. This has shown the importance of accounting for all greenhouse gases. There is now new research developing a similar model for beef production systems.

5 Nitrous Oxide Emissions from Agricultural Soils

Currently the inventory of these emissions is calculated by estimating total N inputs to agricultural soils (e.g. from fertiliser, manure, sludges, deposition by grazing animals, deposition resulting from NO_x and NH_3 emissions), and then applying a constant default emission factor to these inputs (e.g. 1.25% of mineral N in fertilisers is assumed to be emitted as N_2O). These are default IPCC emission factors and, as well as not being specific to this country, it is recognised that there is a high degree of uncertainty around them. One of the key objectives of this project was to provide information on emissions of N_2O from soils under grassland, the predominant agricultural land use in Ireland, and to examine how appropriate the default emission factor is in an Irish context.

A field-scale experiment was conducted over 2 years on a grassland site on an imperfectly drained soil. Three levels of N application were used: 0, 225 and 390 kg N/ha/year. The results showed that N_2O emissions were related to N fertiliser use, as expected. The emission of N_2O followed an irregular pattern throughout the year (Fig. 5.1) and was affected by the N application rate, grazing management practices, seasonal variations in soil temperature and soil moisture status.

The emissions were generally concentrated within relatively short periods (1–2 weeks) following grazing and fertiliser N applications. There were marked differences in emissions between treatments and the relative patterns and magnitudes of emissions rates at different times of the year and between years. Estimated N_2O-N losses for

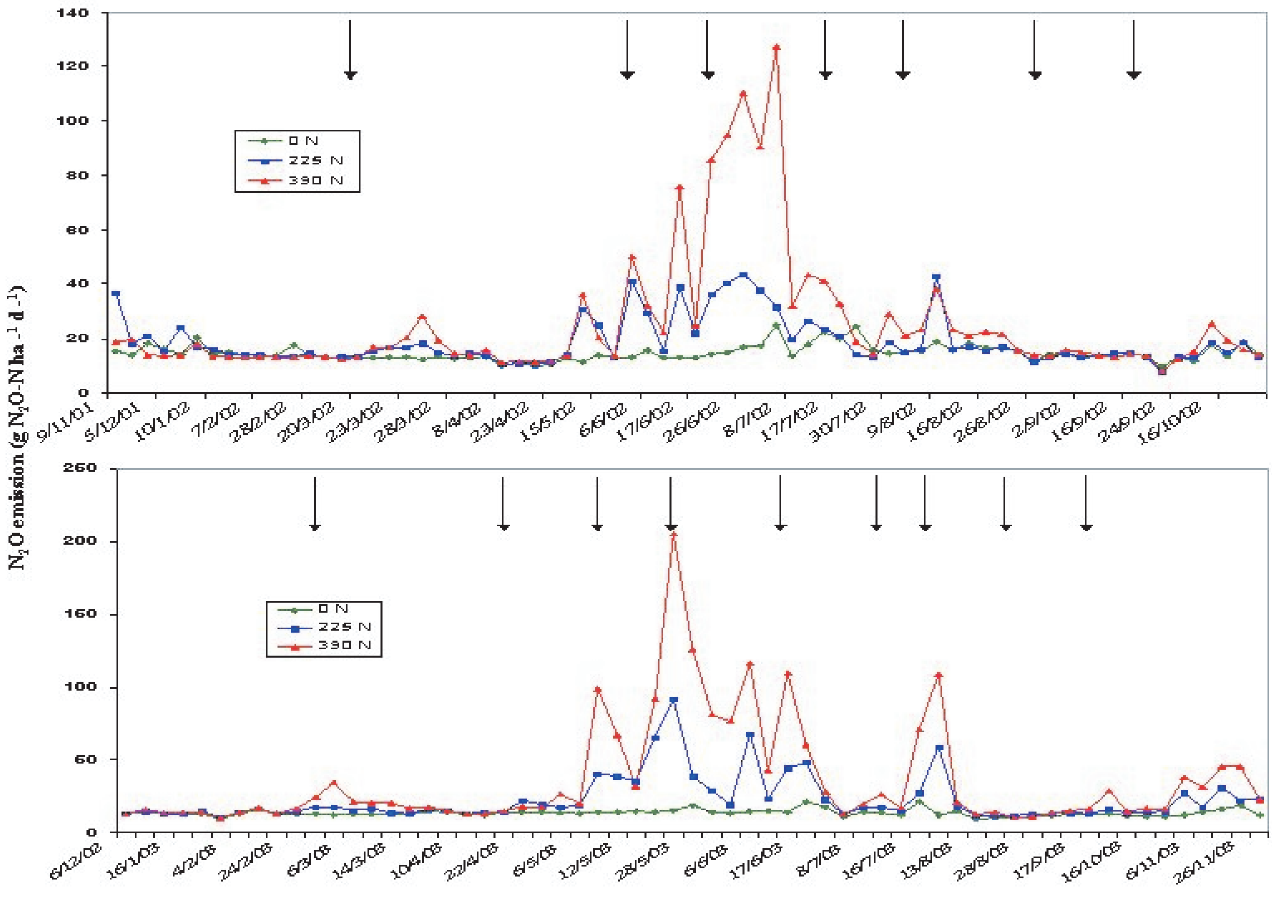

Figure 5.1. Pattern of N_2O emission rates in Year 1 (a) and Year 2 (b). Fertiliser N applications are indicated with the arrows.

Table 5.1. Estimated N_2O-N emission (minus background emissions) and percentage loss for both study years.

	Treatment (kg N/ha)	Total N input* (kg N/ha)	Total N_2O-N evolved minus background emission (kg/ha)	Emission factor** (% N evolved)
Year 1				
	225	310	2.24	0.72
	390	429	8.34	1.80
Year 2				
	225	303	13.85	4.56
	390	493	24.27	4.92

*Total N input = applied N fertiliser + N from dung and urine deposition.
**% loss = (kg N_2O-N loss per kg N applied) × 100.

Year 1 (Table 5.1) are within the range of values used for inventory reporting purposes for N-fertilised grasslands under IPCC calculation procedures. In contrast, calculated emission factors for Year 2 (Table 5.1) are substantially higher.

It is evident from Fig. 5.1 and Table 5.1 that the relative contributions of dung and urine deposition on grazed pastures and their interaction with fertiliser application regimes and soil and environmental variables need to be examined for distinct periods during the grazing season to provide more robust estimates of emissions rates from fertilised and grazed grassland.

The soil type used in the study presented is classified as a grey–brown podzolic. Because of its imperfect drainage, heavy texture and weak structure, this soil is mainly used for grassland. However, in this study and others it has been established that inherent soil properties strongly influence the magnitude of N_2O formation and subsequent emission. In general, larger N_2O fluxes can be expected from clayey soils than from sandy soils because they are wetter and partially anaerobic from time to time. In addition, larger fluxes are expected from peat soils, because they contain large quantities of organic C. It has been suggested that soil type and regional climatic fluctuations can have a greater impact on N_2O emissions than parameters such as crop type, fertiliser type and rate of application. It is therefore difficult to apply the results of the studies presented to regional and national scales without making large assumptions as to the relative effects of soil moisture and temperature regimes, inherent soil properties and grassland management on N_2O emissions.

Additionally, in a lysimeter experiment aimed at measuring N_2O emissions from five soil types which range from the seriously impeded, through to moderately well drained to a very well drained soil, preliminary indications are that the effect of soil type appears to be as great as the effect of fertiliser application with higher emissions associated with the seriously impeded soils.

Scenario analysis indicated that total annual emissions were reduced when fertiliser application was timed to coincide with low soil moisture levels, as opposed to when fertiliser was applied on the first day of each month of the application season. However, this reduction was small relative to total annual emissions, and repeated simulations of these fertiliser application scenarios indicated that this reduction will not always take place.

It is recommended that, on the basis of the results presented, no change be made to the current N_2O emission inventory methodologies until further research can be conducted. This recommendation is made on the basis of the relatively short-term nature of the research conducted, large inter-annual variability and the identification of a large soil-type effect on N_2O emission rates from lysimeter studies. Therefore, to move from a Tier 1 to a Tier 2 approach, further data from long-erm multi-site (covering a range of soil types and N inputs) monitoring studies are required.

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