A Review of Research to Identify Best Practice for Reducing Greenhouse Gases from Agriculture and Land Management

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Abbreviations used:

AD, anaerobic digestion
CH_4, methane
CO_2, carbon dioxide
CO_2e, carbon dioxide equivalent: CO_2 = 1, CH_4 = 21, N_2O = 310
FACTS, Fertiliser Adviser Certification and Training Scheme
GHG, greenhouse gas
ha, hectare
IPCC, Intergovernmental Panel on Climate Change
kg, kilogram
kt, kilotonne
LULUCF, land use, land use change and forestry
N, nitrogen
N_2O, nitrous oxide
NH_3, ammonia
NH_4, ammonium
NO_3, nitrate
NVZ, Nitrate Vulnerable Zone
t, tonne

CONTENTS

1 SUMMARY

1.1 Based on current scientific evidence and our understanding of greenhouse gas (GHG) emissions derived from previous (largely) Defra funded research, we have identified mitigation methods *currently* available for farmers and land users to follow/use as best practice to reduce GHG emissions. Four of the mitigation methods apply solely to reducing nitrous oxide (N_2O) emissions, two apply to reducing methane (CH_4) emissions (although one may also result in reduced N excretion and hence contribute to reduced emissions of N_2O), and two apply largely to carbon dioxide (CO_2) emission mitigation as a result of land use change.

1.2 The methods fall into three broad categories:

1. *Management practices and agronomy* – where farmers and land uses can improve on what they already do.
2. *New or different technology* – where farmers and land users would need to be willing to make bigger changes.
3. *Structural changes to the farming business* – where farmers and land users would need to make large changes, e.g. use land differently, change manure management system etc.

1.3 The eight main mitigation methods identified are:

1. Do not exceed crop N requirements (RB209/PLANET).
2. Make full allowance of manure N supply (MANNER).
3. Spread manure at appropriate times/conditions.
4. Increase livestock nutrient use efficiency.
5. Make use of improved genetic resources.
6. Make use of anaerobic digestion technology for farm manures and slurries.
7. Change land use - to establish permanent grasslands/woodlands
8. Change land use - to grow biomass crops.

1.3.1 Methods 1 to 3 fall into the management practices category. Methods 4 to 6 fall into the new technology category. Methods 7 and 8 fall into the structural changes category.

1.4 We also identified a number of methods that offer the potential to reduce emissions of N_2O, CH_4 and CO_2, but which are currently at a stage where further evidence of their efficacy and/or long-term consequences is required. These include reduced/zero tillage methods, movement of stock off ‘wet’ ground to reduce poaching, change from a solid manure to slurry system (to reduce N_2O emissions), use of methods to increase dairy cow efficiency (nutrition, breeding), use of nitrification inhibitors, mineral N fertiliser timing strategies, and the use of plants with improved N use efficiency.

1.5 Finally, we have identified a number of speculative methods that are still at the concept stage, where some evidence for the potential to reduce GHG emissions is available, but the methods by which they could be implemented and/or what their true potential is, are unknown at this time. These include methods for improved animal feed characterisation, vaccination of ruminants against methanogenic rumen bacteria, modification of the rumen population by antibiotics and natural products, and natural nitrification inhibitors produced by crops.

1.6 We have quantified the size of the target source gas based on the Intergovernmental Panel on Climate Change (2005) inventory, and where possible quantified the potential effectiveness in GHG emission reduction by each of the methods. We have discussed the mechanism of action of each method, and highlighted gaps in knowledge that require further investigation.

1.7 The main knowledge gaps identified by the review can be grouped into a number of areas as follows:

- *Nitrous oxide* – there is a need to develop mineral N fertiliser application rate and timing policies, and manure/anaerobic digestion digestate timing (particularly on heavy soils) policies. Also, there is a need to carry out field-based research on the potential of nitrification inhibitors to reduce N_2O emissions.
- *Methane* – there is a need to further understand the potential of dietary manipulation (including forages and supplements) to reduce enteric and manure emissions, and to carry out full lifecycle analysis of the GHG benefits of anaerobic digestion
- *Soil carbon storage* – there is a need to quantify the benefits of peatland restoration and management, arable reversion and reduced tillage on soil carbon storage and emissions (including other GHGs).
- *Modelling* – there is a need to develop integrated models that are able to quantify GHG emissions from whole farm systems under a range of scenarios, to enable potential best practices to be chosen and implemented.
- *Inventory* – the structure and chosen methodology of the UK GHG inventory (i.e. essentially Tier 1 methodology) is insensitive to many of the potential mitigation methods highlighted in this report. Therefore, inventory development to Tier 2 methodology should be a priority, together with the field testing of the most promising mitigation methods.

2 INTRODUCTION

2.1 Background

2.1.1 Based on the current Intergovernmental Panel on Climate Change (IPCC) inventory methodology, UK emissions of the greenhouse gases (GHG) carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) in 2005 were 554,200 kt, 128 kt and 2,348 kt, respectively (Defra, 2007b). In terms of carbon dioxide equivalents (CO_2e), this equates to 39,680 kt for N_2O and 49,308 kt for CH_4. Land use, land use change and forestry (LULUCF) accounted for a net reduction of total UK CO_2 emissions of approximately 2,100 kt, or 0.4% of total CO_2 emissions. However, agriculture was the source of 67% of UK emissions of N_2O in 2005 (Defra, 2007b, equivalent to 26,400 kt CO_2e), with 62% of N_2O emitted from agricultural sources arising from direct soil emissions and 32% from indirect sources (N deposition and nitrate (NO_3) leached). Similarly, agriculture was the source of 37% of UK emissions of CH_4 in 2005, with 749.5 kt CH_4 (15,739 kt CO_2e) from enteric sources (mostly ruminants) and 119.5 kt CH_4 (2,509 kt CO_2e) from waste (mostly manures and slurries).

2.1.2 The UK is committed to the United Nations Framework Convention on Climate Change, which was agreed in 1990 and came into force in 1994. European Union countries adopted the Kyoto Protocol in 1997 and agreed a reduction of GHG emissions of 8% of 1990 levels by 2012, with the UK agreeing to a reduction of 12.5% as part of the overall EU 'bubble'. The UK government's draft Climate Change Bill, introduced in March 2007, aims to unilaterally implement statutory target reductions of CO_2 emissions of 60% (not including international aviation and shipping emissions) by 2050, and 26-32% by 2020, against 1990 baseline levels.

2.1.3 For the prioritised mitigation methods, we have been as quantitative as possible when describing the efficacy of the method to reduce GHG emissions, and have indicated the size of the GHG pool that is being targeted. We have also indicated where there are potential secondary effects, both positive (i.e. 'win-wins') and negative (i.e. 'pollution swapping'). It is also important to note that UK agriculture has to comply with a number of EU directives aimed at reducing diffuse water pollution, for example the Nitrates Directive (91/676/EC) in designated Nitrate Vulnerable Zones (NVZs) and Water Framework Directive (2000/60/EC). There are also emission ceiling targets for diffuse air pollutants, including ammonia (NH_3) under the National Emissions Ceilings Directive which is currently being re-negotiated. The impact of the mitigation methods on NH_3 and NO_3 losses are therefore included.

2.1.4 For N_2O, it is important to note that there are both direct and indirect emissions. Direct emissions are those emissions resulting from N inputs to soil (e.g. from faeces and urine at pasture, inorganic N fertilisers, manure applications to land), manure storage, crop residues and biological fixation by legumes. Indirect emissions are those associated with NO_3 leaching and N deposition from the atmosphere. Therefore, any mitigation methods that reduce NO_3 leaching or NH_3 volatilisation will also reduce indirect N_2O emissions.

2.2 Scope of report

2.2.1 There are three approaches to GHG mitigation from agriculture:

(i) Reducing direct emissions (CO_2, CH_4 and N_2O) from land and livestock management.

(ii) Enhancing removals, i.e. withdrawing CO_2 from the atmosphere.

(iii) Avoiding/displacing emissions, e.g. reducing fossil fuel consumption by use of alternative energy sources.

2.2.2 The project specification, and hence this report, focuses on the first of these approaches (options to *reduce* GHG emissions) and touches on the second (enhancing removal). There are many options open to farmers and land managers in the second and third set of approaches that are beyond the scope of this study (including use of wind generated power, restoration of degraded peatlands to reduce CO_2 emissions/enhance soil carbon storage, bringing unmanaged farm woodlands back into management, cooperative localised transport to reduce energy requirements) which may all make a valuable contribution to reducing net GHG emissions.

2.2.3 It should be recognised that not all of the measures listed are applicable to all farming systems of a given type, in particular in relation to farms managed organically. It should also be recognised that many farmers and land managers are already carrying out best practice methods where appropriate, but without further investigation the current and future industry uptake of best practices is difficult to quantify.

2.3 Methods

2.3.1 Several Defra-funded projects have reviewed previous Defra work (e.g. projects CC0229, CC0262, CC0272, and ES0127 which summarised the main research findings from more than 60 Defra-funded projects) and have been consulted in this study, as the results of those reviews are still valid. The original work was reviewed for this study (available from http://randd.defra.gov.uk), together with other appropriate source material, including published scientific studies and reviews (Boadi et al., 2004, Kebreab et al., 2006, McAllister et al., 1996, Moss et al., 2000). To avoid repetition, all cited references and projects are listed at the end of this document.

2.3.2 In general, GHG emission reduction options fall into one or more of the following categories:

(i) Arable land/cropping management

(ii) Grazing management

(iii) Land use/management changes

(iv) Livestock management

(v) Manures/biosolids management

(vi) Bioenergy/biofuels cropping

2.3.3 None of these approaches are completely independent, which makes it difficult to categorise any particular potential emission reduction method into a single category. The management of interactions between different methods is frequently the key to successful GHG emission reduction.

2.3.4 We have prioritised the list of best practices for reducing emissions based on robust scientific evidence. Additional methods are cited in the report, but had been either trialled overseas or at a small-scale – neither of which we deemed to be sufficiently robust to promote to farmers/land managers without further investigation – or were seen as even more speculative. We have also reviewed potential practices that would require some additional research and development to determine their efficacy under UK conditions, as well as more speculative methods which are still at the concept stage. It should be noted that within each section methods are given in no particular order.

2.3.5 Each of the prioritised mitigation methods is summarised in Table 3.1. Where robust estimates of the effects of a particular measure are available, potential values for these are provided (in relative terms and as a value in kt CO_2e of the target gas) for the individual GHG. Where robust estimates are not available, but there is evidence for the likely potential effects of a measure, the direction of change is indicated. When the effects of a particular measure is unknown, this is also indicated as a knowledge gap.

2.3.6 Potential secondary effects of GHG mitigation measures on NH_3 and NO_3 are also indicated in relative terms, where known. Estimates of effects on these compounds in terms of kt per year are not provided because the target pool sizes have not been calculated for this report.

2.3.7 Each of the prioritised mitigation methods is listed with a description of the method and its application, arranged into the following sections:

(i) *Description*: a description of the actions to be taken to implement the method.

(ii) *Rationale*: the broad reason for adopting the method as a means of reducing pollution.

(iii) *Mechanism of action*: a more detailed description of the processes involved and how the method may achieve a reduction in pollution.

(iv) *Potential for applying the method*: an assessment of the farming systems, regions, soils and crops to which the method is most applicable.

(v) *Practicability*: an assessment of how easy the method is to adopt, how it may impact on other farming practices, problems with maximising effectiveness and possible resistance to uptake.

(vi) *Effectiveness*: estimates are presented of the effectiveness of the method in reducing losses of each of the GHGs. In most cases, estimates were taken from previous Defra projects (e.g. Cuttle et al., 2007; Defra project WT0706).

(vii) *Secondary effects*: this section provides an assessment of how the emission of other pollutants included might either be reduced or increased if the method were to be adopted.

(viii) *Knowledge gaps*: this section lists main knowledge gaps identified for each method.

2.3.8 For each of the potential mitigation methods (Table 3.2), we briefly describe the mechanism of action, potential for applying the method and current level of understanding of their effectiveness, followed by what further research (or change in regulations) we believe would be necessary before having an adequate evidence base from which to advise farmers and land users on best practice.

2.3.9 For each of the speculative mitigation methods (Table 3.3), we briefly describe the possible mechanism of action, the current understanding of the method, and what research (or change in regulations) we believe would be necessary to explore the potential of the method.

2.4 Farm numbers

2.4.1 The numbers of farms in the UK in 2005 in various census sectors were taken from Defra (2007a) and are summarised in Table 2.3.1 to provide an indication of the magnitude of farm numbers where a mitigation method could be applied. For each of the methods listed, estimates of the numbers of the farms potentially affected are given, based on the figures in Table 2.3.1. These are likely to be overestimated because livestock included in ‘mixed’ farms are not broken down into individual species, and current uptake of listed methods is unknown. Is it not possible to combine data from Tables 3.1 to 3.3 with the farm census data in Table 2.3.1 to provide estimates of reductions in GHG emissions for each farm type. Calculation of this data would require knowledge of each farms current practices, areas of land used, and details of practicable methods.

2.4.2 Farms listed in the ‘Other’ category have also not been taken into account, because it is unknown what these farms do. However, it is likely that these are smallholdings and hobby farmers that although large in number account for a relatively small area of land and a small proportion of UK productive (and GHG) output.

Table 2.3.1 Number of holdings (thousands) by type in the UK in 2005 (Defra, 2007a). ‘Other’ holdings include smallholders/hobby farmers.

	England	Wales	Scotland	Northern Ireland	Total
Dairy	12.1	2.9	1.6	4.2	**20.7**
Cattle and sheep (LFA[1])	11.5	12.4	13.7	15.5	**53.1**
Cattle and sheep (lowland)	35.1	3.4	2.3	4.6	**45.4**
Cereals	22.9	0.3	4.0	0.5	**27.7**
General cropping	9.4	0.1	2.3	0.2	**12.0**
Pigs and poultry	7.9	0.7	1.2	0.6	**10.4**
Horticulture	9.5	0.5	0.9	0.3	**11.2**
Mixed	10.7	0.7	2.5	1.0	**14.9**
Other	73.9	14.9	22.4	0.7	**111.9**
Total	**192.8**	**35.9**	**50.8**	**27.6**	**307.1**

[1] Less favoured areas

2.5 *Smarter inventories*

2.5.1 At present, the structure and chosen methodology of the UK GHG inventory (i.e. essentially **Tier 1 methodology**) is insensitive to many of the potential mitigation methods highlighted in this report and some of those already adopted. Research is currently being conducted in England and Wales (e.g. Defra project AC0101) and several other countries in the world to disaggregate emission factors according to land use sector, soil type and management within each sector, in other words, to create smarter GHG inventories that could utilise the IPCC Tier 2 methodology. Both field experiments and modelling are being used, but until these studies are completed and have been taken up into the official IPCC approved methodologies for the UK, most mitigation methods implemented on farms will not be accounted for in the current inventory, unless they result in changes in livestock numbers or quantity of nitrogen (N) fertiliser used.

2.5.2 As an example of the problems with current IPCC (Tier 1) inventory methodology, changes in livestock management would currently only register a reduction in GHG emissions if livestock numbers are reduced. On the face of it, this method would be relatively simple to implement – reducing stocking rate reduces the amounts of N deposited in fields in excreta and handled in manures, it allows a reduction in mineral N fertiliser inputs, and it reduces CH_4 output. Indeed, in NVZs there are overall livestock manure-N loading rate limits (i.e. 170 kg total livestock manure N per ha on arable land and grassland in the proposed ‘new’ NVZ Action Programme), which is effectively a farm stocking rate limit. Livestock numbers in the Great Britain have been declining, and are likely to continue to decline in the immediate future, influenced by the 2005 changes in Common

Agricultural Policy support payments and the introduction of the Single Farm Payment Scheme (see Defra project IS0208). Regardless of this, wide scale imposition of this method would also have a significant impact on farm profitability and sustainability, UK food security, and would most likely increase GHG emissions in other countries that increase production (and transport) to supply the UK market. Smarter inventory methods are therefore required to ensure that positive action by UK farmers and land managers is properly taken into account and acknowledged.

2.6 Use of modelling to integrate effects of management

2.6.1 It is prohibitively expensive and time consuming to conduct experiments to evaluate the effectiveness of GHG emission mitigations at the systems scale. Yet it is only at this scale that the interactive effects of mitigation methods implemented singly or in combination with others on all the system outputs and component processes can be examined. Moreover, it is also expensive in time and money to evaluate GHG emission mitigation strategies on a range of land-use systems, each with a sufficiently representative range of soil types, climatic zones and system managements. Mathematical modelling of nutrient flows and losses in whole systems is now considered an invaluable tool with which to perform such examination and quantify whole farming system impacts. The models used must be capable of accurately simulating the effects of the mitigations within current and non-standard systems of agriculture. Appropriate models can in principle be used to evaluate effects of potential mitigations which are not yet technically feasible, to assess where resources for research and development should targeted. Such models (e.g. SIMSdairy, UK-DNDC, SUNDIAL, WELL-N, MANNER etc) have been developed over recent years with Defra funding (including Defra projects CC0226, IS0214 and KT0105).

2.6.2 **Modelling of strategies for GHG emission mitigation can identify risks and quantify the potential direction and degree of change in whole systems in a range of land-uses, site conditions and managements. It can also be used to quantify the range of variability in such effects. Modelling is limited only by lack of appropriate model simulations and the usability of the models. However, this type of modelling is not practical for use directly by farmers, but is more appropriate for their advisors, researchers and policy-makers.** This type of modelling is very effective at bringing to light potential ‘pollution swapping’ and ‘win-win’ options for mitigation, and mitigation measures that need further experimental evaluation. Project WQ0106 – underpinning evidence and new model frameworks for mitigating multiple diffuse pollutants from agriculture – will provide a consistent and logical framework for developing an integrated approach to reducing diffuse pollution to water. The model framework will also provide a qualitative assessment of the impacts of mitigation methods on gaseous emissions.

2.6.3 This type of modelling is very effective at bringing to light potential 'pollution swapping' and 'win-win' options for mitigation, and mitigation measures that need further experimental evaluation. Project WQ0106 – underpinning evidence and new model frameworks for mitigating multiple diffuse pollutants from agriculture – will provide a consistent and logical framework for developing an integrated approach to reducing diffuse pollution to water. The model framework will also provide a qualitative assessment of the impacts of mitigation methods on gaseous emissions.

2.6.4 One of the challenges for predicting the effects of mitigation methods on national GHG emissions is scaling up from this farm system level. Robust scaling methodologies need to be explored. For example, model UK-DNDC can be used to generate N_2O emission factors for specific fertiliser, manure and grazing managements that reduce emissions for a range of soil and climatic conditions. These emission factors can then be used as inputs to a smarter spatially explicit N_2O inventory. Likewise, the CH_4 mitigation modelling approach used in project CC0270, which scaled from animal-to-herd-to-national scale could be used to inform a smarter CH_4 inventory. Consideration of the degree of implementation and efficacy of the mitigation methods under different soil and climate conditions would need to be taken into account.

2.6.5 Importantly, the smarter GHG inventories will need to be linked, not only to each other, but also to the NH_3 inventory (NARSES) and any proposed pollutant inventories, e.g. phosphorus, NO_3 and faecal indicator organisms. The links should include the use of common data sets (fertiliser use, animal numbers, manure management, grazing management, land use etc) and be constructed at the appropriate scale (e.g. 10×10 km grids or by catchment) and allow the impacts of mitigation methods for each of the individual pollutants to be determined on all of the others. Future optimisation routines would then need to be developed to determine which mitigation methods are most appropriate (cost-effective) for a chosen target pollutant in a specific area.

2.7 Farmer responses to potential benefits of mitigation methods

2.7.1 The effectiveness of GHG mitigation methods depends to a large extent on the farmer or land user's response to any potential economic benefits or penalties due to implementation. Farmers generally respond to benefits in nutrient use efficiency, for example, by increasing production for the same application rate of mineral fertiliser, or by maintaining production at lower nutrient input levels. Therefore, we advocate that methods of mitigation implementation should include information about how farmers are expected to respond. Education will be a key part of this process (see Defra project CC0365).

3 SUMMARY TABLES OF MITIGATION PRACTICES

3.1 Main mitigation methods

Methods that are considered to be practical now (not listed in any order of priority), with a robust scientific evidence base are summarised in the table below. Estimates of potential effects (in % and kt CO_2e of target gases: N_2O, CH_4 and CO_2) are given where possible. The percentage changes for N_2O, CH_4, CO_2, NH_3 and NO_3 relate to the ***specific source***. Where estimates are not possible (i.e. there is no evidence base), a direction of change only is given: ↓ = reduction (positive effect); ↑ = increase (negative effect); ? = unknown (knowledge gap); ~ = neutral effect.

		Magnitude of source and target gas (kt CO_2e)[1]	Direct effects			Secondary & indirect effects	
			N_2O	CH_4	CO_2	NH_3	NO_3
Nitrous oxide:							
1	Do not exceed crop N requirements	13,670[a]	↓5% ↓680 kt	~	↓	↓5%	↓5%
2	Make full allowance of manure N supply	2,260[b]	↓5% ↓110 kt	~	↓	~↓ 5%[f]	↓5%[f]
3	Spread manure at appropriate times/conditions	2,260[b]	↓2-10% ↓40-230 kt	~↑	~	↑10-20%	↓5-15%
4	Increase livestock nutrient use efficiency	21,000[c]	↓6% ↓1260 kt	↓?	↓	↓3-10%	↓2-6%
Methane:							
5	Make use of improved genetic resources	21,000[c]	↓3% ↓630 kt	↓3% ↓630 kt	~	↓2-5%	↓1-3%
6	Anaerobic digestion	2,420[d]	?	↓90% ↓2,180 kt	~	?	?
Change land use:							
7	Establish permanent grasslands/woodlands	21,600[e]	↓?	~	↓?	~↑	↓50-95%
8	Grow biomass crops	21,600[e]	↓?	~	↓?	~↓	~↓

[1] Data are calculated in CO_2 equivalents: kt $CO_2 \times 1$, kt $CH_4 \times 21$ and kt $N_2O \times 310$.

[a] N_2O emissions from soils, i.e. inorganic fertilisers (FERT), manure spreading (FAW) and grazing (GRAZ).

[b] N_2O emissions from organic fertiliser applications (FAW). This value includes both slurry and solid manure.

[c] N_2O emissions from AWMS (manure storage) and organic fertiliser applications (FAW), includes both slurry and solid manure (= 2,800 kt CO_2e). CH_4 emissions from enteric fermentation and animal manures (= 18,200 kt CO_2e).

[d] CH_4 emissions from animal manures, assuming that as a result of anaerobic digestion 90% of CH_4 emissions from storage are avoided.

[e] No account taken of CO_2 sinks.

[f] Reductions due to lower mineral fertiliser N rates applied rather than from manure applications directly.

N.B. FERT, FAW, GRAZ and AWMS are terms used in the IPCC N_2O inventory.

3.2 Future potential mitigation methods

Methods that are considered to have future potential (not listed in any order of priority), but require further research or change of regulations are summarised in the table below. Estimates of potential effects (in % and kt CO_2e of target gases: N_2O, CH_4 and CO_2) are given where possible. The percentage changes for N_2O, CH_4, CO_2, NH_3 and NO_3 relate to the ***specific source***. The direction of change is also indicated: ↓ = reduction (positive effect); ↑ = increase (negative effect); ? = unknown (knowledge gap); ~ = neutral effect.

		Magnitude of source and target gas (kt CO_2e)	Direct effects			Secondary & indirect effects	
			N_2O	CH_4	CO_2	NH_3	NO_3
1	Reduced/zero tillage	21,600[a]	?	~	↓<1%	~	↓
2	Take stock off 'wet' ground	13,670[b]	↓	↑?	~	↑?	↓?
3	Change from a solid manure to slurry system	5,220[c]	↓15% ↓780 kt	↑	↑	↑ (cattle) ↓ (pigs)	↑
4	Use of hormones and increased milking frequency	5,590[d]	↓	↓	~	↓	↓
5	Use of nitrification inhibitors	13,670[e]	↓	~	~	~	↓
6	Improved mineral fertiliser N timing strategies	13,670[e]	↓	~	~	~	↓
7	Use plants with improved nitrogen use efficiency	13,670[e]	↓	~	↓	↓	↓

[a] No account taken of CO_2 sinks
[b] N_2O emissions from soils, i.e. inorganic fertilisers (FERT), manure spreading (FAW) and grazing (GRAZ).
[c] N_2O emissions from AWMS (manure storage) and organic fertiliser applications (FAW), includes both slurry and solid manure (= 2,800 kt CO_2e). CH_4 emissions from animal manures (= 2,420 kt CO_2e).
[d] CH_4 from dairy cattle enteric fermentation and manures.
[e] N_2O emissions from soils, i.e. inorganic fertilisers (FERT), manure spreading (FAW) and grazing (GRAZ).

3.3 Speculative mitigation methods

Mitigation methods that are still at the concept stage (not listed in any order of priority), with some evidence to suggest that there is future potential for reducing GHG emissions are summarised in the table below. Estimates of potential effects (in % and kt CO_2e of target gases: N_2O, CH_4 and CO_2) are given where possible. The percentage changes for N_2O, CH_4, CO_2, NH_3 and NO_3 relate to the ***specific source***. The direction of change is also indicated: ↓ = reduction (positive effect); ↑ = increase (negative effect); ? = unknown (knowledge gap); ~ = neutral effect.

		Magnitude of source and target gas (kt CO_2e)	Direct effects			Secondary & indirect effects	
			N_2O	CH_4	CO_2	NH_3	NO_3
1	Improved feed characterisation	21,000[a]	↓	↓	~	↓	↓
2	Vaccination against methanogens	18,200[b]	?	↓8% ↓1,460 kt	~	?	~
3	Modification of rumen microbial fermentation by ionophores and natural extracts	18,200[b]	?	↓	~	?	?
4	Production of natural nitrification inhibitors by plants	13,670[c]	↓	~	~	↓	↓
5	Use of cloned animals	18,200[b]	↓	↓	~	↓	↓
6	Genetic manipulation of livestock	18,200[b]	↓	↓	~	↓	↓

[a] N_2O emissions from AWMS (manure storage) and organic fertiliser applications (FAW), includes both slurry and solid manure (= 2,800 kt CO_2e). CH_4 emissions from enteric fermentation and animal manures (= 18,200 kt CO_2e).

[b] CH_4 emissions from enteric fermentation and animal manures.

[c] N_2O emissions from soils, i.e. inorganic fertilisers (FERT), manure spreading (FAW) and grazing (GRAZ).

4 CURRENT MAIN MITIGATION PRACTICES

4.1 Do not exceed crop N requirements

Dairy	Cattle & sheep	Pigs & poultry	Cereals	General cropping	Horticulture	Mixed
✓	✓	✓	✓	✓	✓	✓

4.1.1 Number of farms potentially affected by practice: 195 thousand.

4.1.2 **Description**

- Use a recognised fertiliser recommendation system (e.g. RB209 (MAFF, 2000), PLANET (Planning Land Applications of Nutrients for Efficiency and the Environment; www.planet4farmers.co.uk) and other supplementary guidance (e.g. on precision farming, canopy management techniques) to plan fertiliser applications to all crops.
- Do not exceed optimum (economic) recommended rates. Indeed, the proposed new NVZ – Action Programme for England stipulates overall farm crop N requirement maxima for specified crop types to ensure that crop N requirements are not exceeded (which would exacerbate NO_3 leaching losses etc).
- Time fertiliser applications to minimise the risk of loss of N (e.g. avoid autumn N applications and early spring timings to drained clay soils).
- Take full account of manure inputs when planning mineral fertiliser applications.
- Ensure accurate use of mineral fertilisers by proper maintenance, setting and calibration of spreading machinery and the use of good quality fertilisers.
- Farmers should be Fertiliser Adviser Certification and Training Scheme (FACTS) qualified or use a professional FACTS adviser.

4.1.3 **Rationale**

4.1.3.1 Fertiliser recommendation systems take account of the following factors:

- Soil nutrient supply based on soil analysis or climate, previous cropping and soil type.
- Crop nutrient requirements for a given soil and climate.
- Crop requirements for nutrients at various growth stages.
- The amount of nutrients supplied to the crop by added manures and by previous manure applications.
- Soil pH and the need for lime.
- Adoption of a fertiliser recommendation system will reduce the risk of applying more fertiliser nutrients than the crop needs and will minimise the risk of excess N in the soil at risk of N_2O losses.

4.1.4 **Mechanism of action**

4.1.4.1 A good fertiliser recommendation system ensures that the necessary quantities of essential crop nutrients are only available when required for uptake by the crop (Figure 4.1.4.1). Nutrients are only applied as mineral fertiliser when the supply of nutrients from all other sources is insufficient to meet crop requirements. As a result, the amount of excess nutrients in the soil is reduced to a minimum. The system also ensures that the soil is in a sufficiently fertile state to maximise the efficient use of nutrients already in the soil, or supplied from other sources such as organic manures. Maintaining an appropriate balance of other nutrients (P, K, S) is also important to maximise efficient plant N uptake and reduce losses to a minimum.

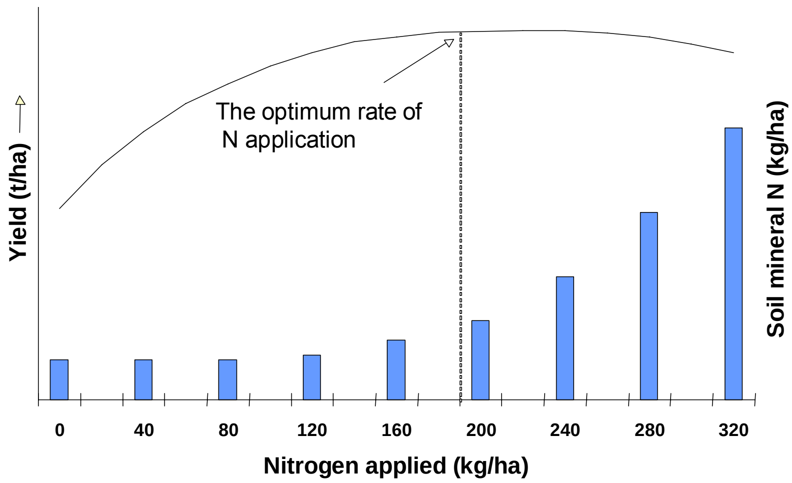

Figure 4.1.4.1 Example of the relationship between rate of N application, crop yield (line) and soil mineral N status (bars).

4.1.5 **Potential for applying the method**

4.1.5.1 Fertiliser recommendation systems can be used in all farming systems, but are particularly effective in intensive grassland, arable and horticultural systems. The method would have less impact in extensive grassland systems, as according to fertiliser practice surveys, most grassland soils receive less N than is recommended by RB209.

4.1.6 **Practicability**

4.1.6.1 The method would require investment in education and guidance (which should be helped by Defra project IF0114). At present, farmers in NVZs are permitted to exceed the RB209 recommendations provided that they can demonstrate the reasoning behind the additional fertiliser rates or applications, based on, for example, local trials data or market place needs.

4.1.7 **Effectiveness**

4.1.7.1 Direct N_2O: A decrease of approximately 5% in N_2O emissions is estimated to be possible (Defra project ES0203; Cuttle et al., 2007), compared to baseline losses from model farm systems.

4.1.7.2 Methane emissions would not be directly affected.

4.1.8 Secondary effects

4.1.8.1 Indirect N_2O: Fertiliser recommendation systems encourage the efficient use of N inputs and should thereby also reduce NO_3 leaching and indirect N_2O emissions.

4.1.8.2 Project ES0203 (Cuttle et al., 2007) concluded that this mitigation method could reduce NO_3 leaching from arable land and dairy grassland by about 5%.

4.1.8.3 There would also be a reduction (estimated at 5%) in NH_3 emissions through lower rates of mineral fertiliser N being applied.

4.1.8.4 There would be no negative impacts.

4.1.9 Knowledge gaps

4.1.9.1 The main knowledge gap for this method is in knowledge transfer – how to encourage farmers and land managers to ensure that fertiliser recommendation guidelines (RB209, PLANET etc) are being followed, and how to educate them to make use of available guidance and other information resources.

4.1.9.2 The main research gap for this method is to extend the work in Defra project AC0101 (on grazed grass and cereals) to a wider range of crop types and environmental conditions, to underpin the development of smart inventory emission factors. Preliminary results suggest that there is a non-linear relationship between fertiliser N application rate and N_2O emissions.

4.2 Make full allowance for manure N supply

Dairy	Cattle & sheep	Pigs & poultry	Cereals	General cropping	Horticulture	Mixed
✓	✓	✓	✓	✓	✓	✓

4.2.1 Number of farms potentially affected by practice: 195 thousand.

4.2.2 **Description**

- Use a recognised fertiliser recommendation system (e.g. RB209, PLANET, MANNER (MANure Nitrogen Evaluation Routine; www.adas.co.uk/manner; Chambers et al., 1999) and other supplementary guidance) to make full allowance of the nutrients applied in manures and reduce mineral fertiliser N inputs accordingly.
- Use manure analysis to gain a better understanding of nutrient applications and supply.
- Keep records of mineral fertiliser and organic manure inputs to individual fields.
- Farmers should be FACTS qualified or use a professional FACTS adviser.

4.2.3 **Rationale**

4.2.3.1 Robust recommendation systems can be used to provide a good estimate of the amount of nutrients supplied by manure applications. This information can then be used to determine the amount and ideal timing of additional mineral fertiliser required by the crop. The British Survey of Fertiliser Practice shows that farmers do not always fully allow for the nutrients in applied manure when calculating mineral fertiliser rates. In most cases, making proper allowance for the nutrients in manures will result in a reduction in mineral fertiliser inputs compared with current practice and a concomitant reduction in NO_3 losses.

4.2.4 **Mechanism of action**

4.2.4.1 The amount of N is reduced at source. Mineral fertiliser applications are reduced to no more than is required for optimum economic production levels. Excess N in the soil is reduced. When slurry is spread too soon after the application of N fertilisers, there is a risk of increased N_2O emissions through the process of denitrification. Current advice is to leave at least 5 days between applications of mineral N fertiliser and slurry to the same field.

4.2.5 **Potential for applying the method**

4.2.5.1 Most applicable to intensive grassland and arable systems which receive manures. The method is effective wherever mineral fertilisers are used to top-up the nutrients supplied in organic manures.

4.2.6 **Practicability**

4.2.6.1 The method could be easily implemented via advice, education and guidance. Particular guidance is required with soil and manure sampling, on-farm analysis of manure, and interpretation of results.

4.2.7 **Effectiveness**

4.2.7.1 Direct N_2O: Use of manure N to its full potential would reduce mineral N fertiliser use, and therefore a reduction of N_2O emissions would be expected. The value of this reduction would depend on the reduction in mineral N fertiliser, and the quantity of manure N supply, which we estimate to be around 5% (Cuttle et al., 2007)

4.2.7.2 Methane emissions would not be directly affected.

4.2.8 **Secondary effects**

4.2.8.1 Indirect N_2O: Cuttle et al. (2007) concluded that this mitigation method could reduce NO_3 leaching from arable land and diary grassland by about 5% through reduced mineral fertiliser N applications. This assumed no change in the timing of manure applications.

4.2.8.2 There may be an additional benefit in reducing NH_3 emissions if manures are more rapidly incorporated into arable land (projects ES0115 and ES0116) or slurries are applied using shallow injection or trailing shoe/hose equipment rather than being broadcast on the soil surface (projects ES0114 and ES0115).

4.2.9 **Knowledge gaps**

4.2.9.1 As with the use of mineral N fertilisers, the main knowledge gap for this method is in knowledge transfer – how to encourage farmers and land managers to ensure that recommended guidelines on manure N supply (RB209, PLANET, MANNER etc) are followed, and how to educate them to make use and have confidence in available guidance and other information resources.

4.3 *Spread manure at appropriate times*

Dairy	Cattle & sheep	Pigs & poultry	Cereals	General cropping	Horticulture	Mixed
✓	✓	✓	✓	✓	✓	✓

4.3.1 Number of farms potentially affected by practice: 195 thousand.

4.3.2 **Description**

4.3.2.1 Do not apply slurry or poultry manure to fields at times when there is little crop requirement, e.g., too late in the season (autumn/early winter) or when there is no crop to utilise the added N.

4.3.3 **Rationale**

4.3.3.1 Slurry and poultry manure have high contents of readily-available N, compared with (straw-based) farmyard manure which is low in readily-available N, i.e. most of the N is organically bound. Avoiding applications of high readily-available N manures when there is little or no crop demand reduces the risk of direct N_2O losses. Also, application of high readily-available N manures in autumn increases the risk of NO_3 leaching (Chambers et al., 2000). A proportion of the leached N will also be lost as N_2O (indirect loss).

4.3.4 **Mechanism of action**

4.3.4.1 The method reduces the source of inorganic N in the soil that is at risk either of nitrification (NH_4-N) or denitrification (NO_3-N) loss, thus reducing direct N_2O emissions. The method would also reduce indirect N_2O losses, via NO_3 leaching.

4.3.4.2 If slurry or poultry manure is spread late in the growing season, they add inorganic-N to the soil at a time when there is little N uptake by the crop. Therefore, applications in autumn and early winter should be avoided. Applications later in winter present less of a risk, as low temperatures slow the rate of conversion of ammonium to NO_3 and there is less opportunity for direct N_2O losses.

4.3.5 **Potential for applying the method**

4.3.5.1 The method is limited to those farms using slurry or poultry manure. High-risk times for direct N_2O losses will be most frequent in high rainfall areas and on soils with a high clay content (Defra project CC0241 and CC0251). Indirect N_2O losses will be greater on shallow or sandy soils and on artificially drained soils where there are preferential loss pathways. There are around 6 million hectares of drained clay soils in England and Wales.

4.3.6 **Practicability**

4.3.6.1 This method will only be applicable on farms that have sufficient storage capacity to allow a choice of when to apply slurry. Even where storage is adequate for normal conditions, exceptional weather or poor planning can create a situation where stores are full during a high-risk period so that land spreading is the only option. It would generally be acceptable to apply slurry to grass later in the season than for other crops, as long as the sward continued to take up N (i.e. was still growing).

4.3.7 **Effectiveness**

4.3.7.1 Direct N_2O: Moving slurry applications from late autumn/winter to spring on free draining grassland soils has been shown to reduce direct N_2O emissions. Project ES0115 (Thorman et al., 2007) measured a reduction of approximately 50% in direct N_2O emissions by such a change in application timing (Fig 4.3.7.1). Additionally, there were also reductions in indirect N_2O emissions as a result lower NO_3 leaching losses.

4.3.7.2 Methane emissions would not be directly affected by this method.

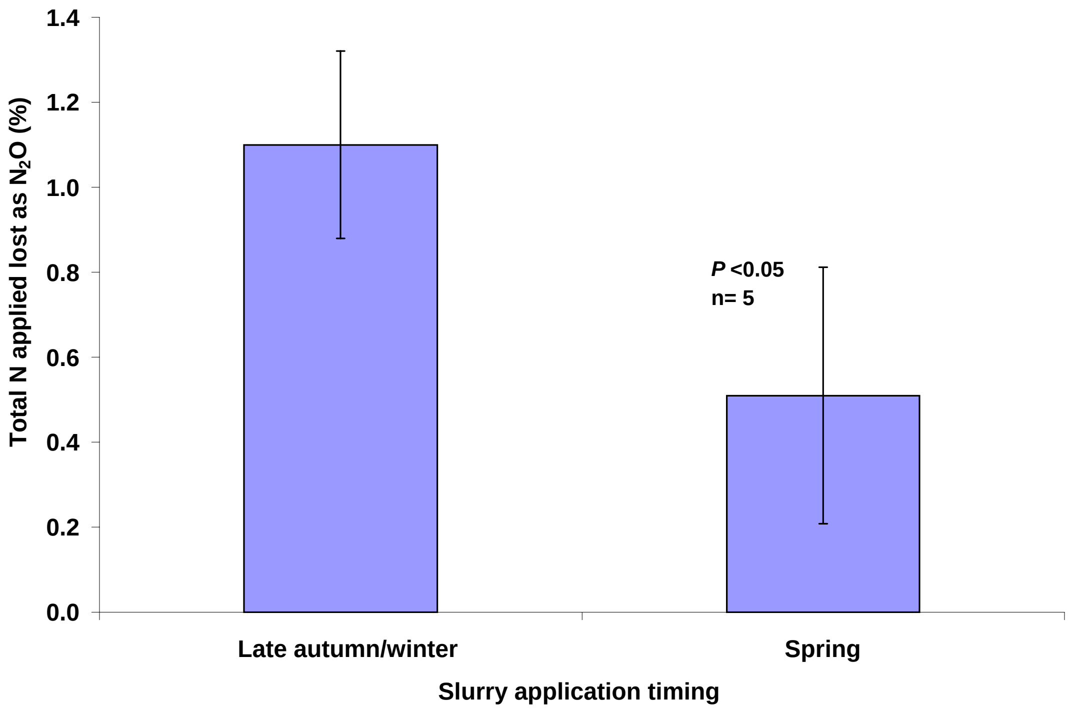

Figure 4.3.7.1 Direct N_2O emissions following late autumn/winter and spring cattle slurry applications to free draining grassland soils (Defra project ES0115).

4.3.8 **Secondary effects**

4.3.8.1 Project ES0203 (Cuttle et al., 2007) estimated that on arable land NO_3 leaching losses would typically be reduced in the range 5-15% and on dairy grassland by 10-15% through such a change in application timing.

4.3.8.2 There are likely to be greater NH_3 emissions from spring slurry applications to arable land and following summer applications to grassland, which were estimated to be in the range 10-20% depending on the increased proportion of slurry applied in spring/summer (Defra project WT0706).

4.3.8.3 There are also likely to be small increases in CH_4 emissions from the increased period of slurry storage and small increases in NH_3 emissions because of the increase in slurry store surface area, as a result of the greater amount of slurry storage capacity needed to facilitate these changes in application timing.

4.3.9 **Knowledge gaps**

4.3.9.1 Knowledge transfer is key to this method, ensuring that farmers and land managers have clear and accurate guidance to ensure that best practice is followed. Therefore, training and advice is required together with regular updates to ensure guidance is up to date.

4.3.9.2 The key research gap is to quantify how changing slurry application timing from late autumn/winter to spring/summer (as proposed under the 'new' NVZ rules) would affect both direct and indirect N_2O emissions from heavy (clay) soils – all previous work has been on sandy soils.

4.4 Increase livestock nutrient use efficiency

Dairy	Cattle & sheep	Pigs & poultry	Cereals	General cropping	Horticulture	Mixed
✓	✓	✓				✓

4.4.1 Number of farms potentially affected by practice: 145 thousand.

4.4.2 **Description**

4.4.2.1 Improve the diets and feeding regimes of livestock to decrease wastage of feed nutrients (particularly protein and energy-yielding compounds) for productive purposes:

- Avoid diets that contain N in excess of the dietary requirement of the animal.
- Balance diets for energy and protein to increase the efficiency of N utilisation by the animal.
- Target specific livestock nutrient requirements for correct genetic potential (i.e. breed), age, sex and production stage.
- Adjust management regimes to allow more efficient production (e.g. 3x daily milking of dairy cows).

4.4.3 **Rationale**

4.4.3.1 Avoiding excess N in the diet, correctly balancing protein with energy requirements, and/or making dietary N more available for digestion allows the concentration of these nutrients in the diet to be reduced without adversely affecting animal performance. These methods reduce the amount of N excreted, either directly to fields or via manure, and thereby minimise additions to the pools of N that are sources of diffuse pollution.

4.4.4 **Mechanism of action**

4.4.4.1 Farm animals are often fed diets with higher than recommended contents of crude protein as a safeguard against a loss of production arising from a deficit through inaccurate analysis and/or formulation. In practice, however, surplus N is not utilised by the animal and is excreted. Defra project WA0322 suggested that the main source of dietary N use inefficiency, the dairy cow at least, is the rumen. Restricting diets to recommended levels of N can limit the amounts excreted without affecting animal performance. Excretion can also be reduced by changing the composition of the diet to increase the proportion of dietary N utilised by the animal; for example, by optimising the balance of N to carbohydrate in ruminant diets or by reducing the proportion of rumen-degradable protein. In practice, this means that better characterisation of animal diets (e.g. conserved forages) is required to allow any supplementary feeds (concentrates or straight mix feeds) to be chosen to complement them. Use of nutritional advisors and feed companies that use ration formulation software with the most up-to-date advice (e.g. Feed into Milk for dairy cows; Defra LINK project LK0604; Offer et al., 2002). In all livestock N excretion can also be reduced by increasing the digestibility of the ration so long as the biological value of the absorbed amino acid mixture is appropriate for the productive requirements; amino acids supplied in excess of requirements may contribute to the energy metabolism of the animal, but excess N is excreted.

4.4.4.2 Correctly formulated diets can increase the efficiency of nutrient utilisation without reducing growth rate or milk production. Reducing the N contents of excreta and manures will have benefits of reducing NO_3 leaching, N_2O and NH_3 emissions.

4.4.5 Potential for applying the method

4.4.5.1 Benefits will be greatest on outdoor ruminant units where grazed forage often constitutes the greatest part of the diet – it is less applicable to outdoor pig and poultry units in which a concentrate diet will still be fed. Most outdoor pig units have no or limited ground cover and certainly not enough to count as a substantial source of forage. The diets of indoor-fed animals and outdoor pigs and poultry are largely well controlled and formulated to contain minimum nutrient requirements to maximize production. Protein is one of the most expensive components of an animal's diet, and least cost formulations therefore aim to make the best use (i.e. most efficient) of N. Use of feed N is doubly important in the grazing animal because there is more potential for less efficient use by the animal and less potential to exert urine/manure management methods to mitigate the consequences of high rates of N excretion onto land.

4.4.5.2 While nutrient requirement standards for UK dairy cattle (Thomas, 2004) and pigs (Whittemore et al., 2003) of various ages and physiological conditions have been recently updated, UK nutrient requirement standards for poultry are very old (ARC, 1975) with US standards being published more recently, but still more than a decade ago (NRC, 1994). Changes in animal genetics, removal of antibiotic growth promoters, and inclusion of enzymes in poultry feed has made these references of limited relevance to the industry. Standards for nutrient requirements for beef cattle and sheep were last published in 1992 (AFRC, 1992). There is therefore an urgent need to update poultry, beef and sheep standards in light of modern agricultural practices and requirements to reduce pollutant emissions.

4.4.6 Practicability

4.4.6.1 The extent to which these methods can be applied depends on the proportion of farms currently feeding excess N or not already using feed supplements. Precise formulation of diets requires accurate analytical data about the chemical composition of the feedstuffs, which may not be readily available for forages.

4.4.6.2 Within the dairy sector there is already a focus on lowering total diet crude protein content, optimising protein:energy balance in the rumen and supplying adequate metabolisable protein. Reducing the crude protein content of the diet may be a significant challenge in areas relying on grass silage, in which case there is increased reliance on the use of energy-rich supplements (i.e. cereal grains). Also, matching requirement to performance has cost, labour and housing implications on many farms. There is more potential for improved ration formulation when animals are offered formulated diets (i.e. indoors), when there is greater control over what can be given to the animals. Jonker et al. (2002) found that North American dairy farmers fed on average 6.6% more protein than recommended by published guidelines (NRC, 1989), leading to a 16% increase in urinary N excretion, and the same is probably true for the UK where milk producers are keen to maintain high milk protein yields. Although increased frequency of ration formulation was associated with an increase in milk production it was not associated with increased N use efficiency; in other words safety margins built into the ration formulations were probably too high. Recent changes in plant breeding objectives (e.g. for increased water-soluble carbohydrate (WSC) concentrations in perennial ryegrass) offers the potential to reduce GHG emissions from animals at grazing by reducing the proportion of dietary N that is excreted in urine. An increased WSC concentration in ryegrass correlated with reduced proportions of urine N excretion (Figure 4.4.6.2; Defra LINK projects LK0615 and LK0638). Because urea in urine is a major source of N_2O emissions from grazed pastures increasing the WSC concentrations relative to proteins in grazed forages is likely to reduce direct N_2O emissions from grazing animals.

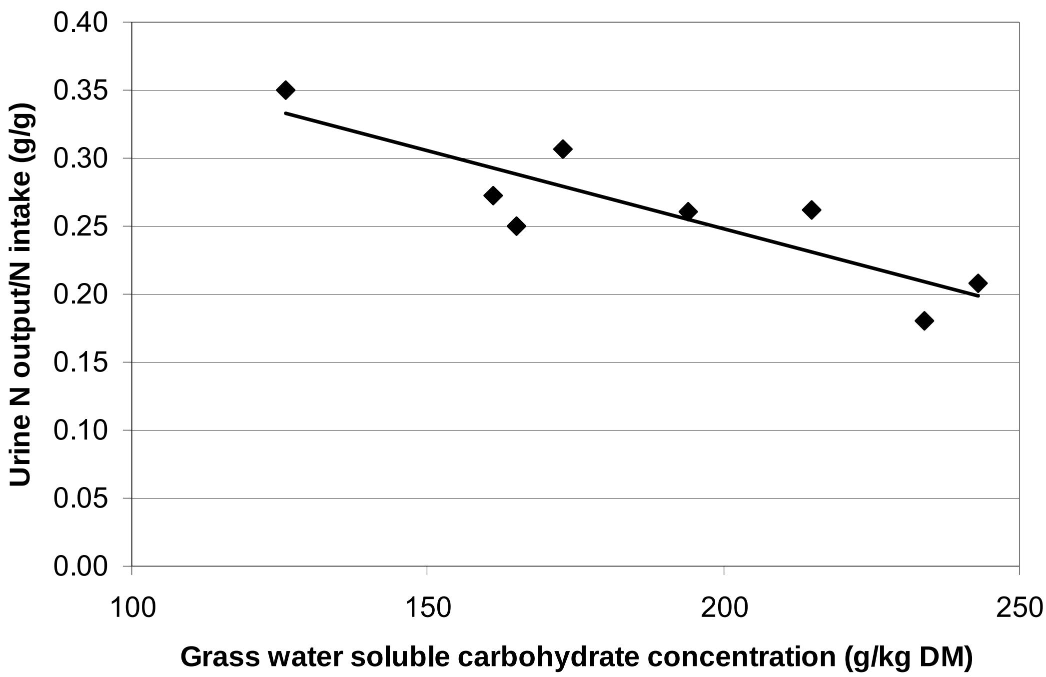

Figure 4.4.6.2. Relationship between perennial ryegrass water soluble carbohydrate concentrations and the excretion of N in urine relative to diet N intake (data from Defra LINK programmes LK0615 and LK0638).

4.4.6.3 For pigs and poultry, considerable steps have already been made through the use synthetic amino acids (although not in organic units). There is limited scope for further reducing the N content of pig and poultry diets without reducing productive output (e.g. Defra project LS3601). There are concerns that reducing nutrient inputs may also have adverse effects on reproductive performance and carcass quality. The scope to use more digestible materials in broiler diets is also very limited as most diets already employ feed materials of high digestibility.

4.4.7 **Effectiveness**

4.4.7.1 Direct N_2O: An increase in the efficiency of livestock N use efficiency of up to 10% is predicted to reduce direct N_2O emissions by about 6% (Defra project IS0214; Del Prado and Scholefield, 2007).

4.4.7.2 There may be a decrease in CH_4 emissions, depending on the diet formulation. Farms that seek to reduce the N content of the diet by replacing grass silage with maize silage may also reduce CH_4 emissions.

4.4.8 **Secondary effects**

4.4.8.1 On dairy farms reducing the crude protein content of the diet from 18 to 14% (with corresponding increases in efficiency of utilisation) was estimated by Cuttle et al. (2007) to reduce NO_3 leaching by 5-6%. Similarly, on pig/poultry farm reductions of 2-3% in NO_3 leaching losses were predicted.

4.4.8.2 Reducing the amount of N excreted will also reduce the potential for losses of NH_3 from urine and manure management, which are estimated to be in the range 3-10% (Defra project WT0706). However, where maize is included in a diet to improve nutrient use efficiency, it is important to ensure that land management practices do not result in negative impacts on water quality through enhanced nutrient and sediment losses in run-off.

4.4.9 **Knowledge gaps**

4.4.9.1 Nutrient requirement standards for UK beef, sheep and poultry are out of date, particularly considering changes in animal genetics and changes in the use of feed supplements (removal of antibiotics, inclusion of enzymes etc). There is therefore a need to update these standards to ensure that current information is available to livestock farmers and their advisors, to allow the efficiency of utilisation of feed nutrients to be maximised.

4.4.9.2 Many farmers are unaware of the importance of improving livestock efficiency and of the full implications of the effects of inefficient utilisation of feed nutrients. Therefore, knowledge transfer and training are key to ensuring that best practice is followed.

4.5 *Make use of improved genetic resources*

Dairy	Cattle & sheep	Pigs & poultry	Cereals	General cropping	Horticulture	Mixed
✓	✓	✓				✓

4.5.1 Number of farms potentially affected by practice: 145 thousand.

4.5.2 **Description**

4.5.2.1 Use of plant and animal genetic resources to improve lifetime efficiency of livestock systems:

- Increase efficiency of individual animals.
- Use of improved animal genetics for longevity (including calving ease for dairy cows), fertility, and other non-productive traits.
- Use of new forage plant varieties for improved nutritional characteristics (e.g. improved amino acid profile, reduced rumen protein degradation, improved fibre digestibility) under grazing and conservation conditions.

4.5.3 **Rationale**

4.5.3.1 The selection of useful traits is the core objective in plant and animal breeding programmes. For the last few decades selection goals have focussed on production characteristics and less (particularly in animal breeding) on health and robustness characteristics. While this approach achieved large advances in outputs of crops and animal products (meat, milk and eggs) other beneficial heritable traits were largely deemed to be of lesser importance. More recently, recognition of the need for improved nutritional characteristics in forage crops (e.g. improved amino acid balance, water-soluble carbohydrate content, fibre fermentability) and improved animal robustness (e.g. health, fertility) has led to these characteristics being incorporated into breeding programmes.

4.5.3.2 Cross-breeding is a key element of the egg-production industry, with parent stock birds of different breeds being used to produce highly productive hybrid layers. There is now increasing recognition of the potential to use similar techniques with dairy cows, particularly with a Holstein background, which have been bred with increased milk yields as a primary goal. This has made them more efficient in terms of daily milk production, but has been at the expense of long term efficiency and longevity.

4.5.3.3 While there is scope for improvement in the use of improved genetics across the whole of the UK livestock industry, the beef and sheep industries lag behind the others.

4.5.4 **Mechanism of action**

4.5.4.1 Livestock farmers generally aim to improve their stock as a matter of course, although there is still considerable scope for improvement, particularly in the sheep (upland and lowland) and beef cattle sectors.

Uptake of the best genetics is good in the poultry, dairy, and pig industries, largely through the highly integrated breeding and rearing mechanisms used in poultry (meat and egg) production and the use of artificial insemination (AI) in dairy and (increasingly) in pigs. However, historical selection goals have focussed on production and did not include lower heritability traits such as health and fertility traits (leading to less 'robust' animals). Today, breeding goals in most species are more balanced to include these latter factors, but there is still much scope for health and fertility traits to catch up with yield-related traits. Recent Defra funded work (LK0657 and LK0645) has aimed to increase dairy cow longevity through improved fertility and breeding more robust animals.

4.5.4.2 Increased efficiency through improvements in the supply and utilisation of end product beyond the farm gate would reduce production requirements and therefore GHG emissions commensurate with reduced livestock numbers. Breeding laying birds for improved egg shell quality would reduce breakages. In addition to reduced opportunistic losses during production, healthier animals would reduce carcase condemnation due to disease.

4.5.4.3 Reduced residual feed intake (consumption of food above that required for production) is heritable and breeding programmes that incorporate this trait could result in a permanent reduction in CH_4 output (Alford et al., 2006). Individual ruminants can have innately reduced CH_4 outputs, possibly associated with rumen protozoal populations, and may be of use in breeding programmes (Goopy et al., 2006)

4.5.4.4 Increasing the longevity of cows is expected to decrease CH_4 emissions and increase lifetime N use efficiency, although the inefficiencies of N use introduced by replacement cows is very small compared to those of milk production by mature animals (Defra project IS0213). However, it should be noted that dairy cows must breed to lactate and a reduction in livestock numbers can only be achieved with improved fertility in dairy cows if the dairy-bred calves can replace beef-cow calves, i.e. a beef bull is used to produce an animal destined for meat in place of a replacement dairy heifer. The use of sexed semen (sperm carrying the Y chromosome are individually mechanically separated and discarded using flow cytometers) would reduce the number of bull calves produced by dairy cows and slaughtered at birth, but this would also increase the total number of animals raised and therefore probably increase GHG emissions.

4.5.4.5 Similarly, plant breeding programmes have tended to concentrate on agronomic characteristics (yield, disease resistance, persistency) and nutritional characteristics are only now being considered as equally important by the farming industry. Defra funded plant breeding work at IGER has considered nutritional characteristics for many years, but

National Institute of Agricultural Botany (NIAB) recommended variety list trials still consider plant traits such as dry matter yield and disease resistance as being more important than the nutritional quality of the plant material grown. These traits are important, but greater importance on traits such as carbohydrate quality and protein degradability would help improve forage utilisation efficiency by animals. As discussed elsewhere, use of appropriate varieties at grazing and for conservation is expected to reduce N_2O emissions through improvements in livestock efficiency.

4.5.5 **Potential for applying the method**

4.5.5.1 The method is applicable to all livestock systems. Defra project AC0204 will assess the degree of the potential of this method.

4.5.6 **Practicability**

4.5.6.1 The use of artificial insemination on dairy and pig farms means that new genetics can be introduced very easily to herds. The use of AI in sheep flocks will likely increase and enable more rapid development of genetics as has occurred with dairy cows and pigs. The introduction of new forage varieties depends on the farming system, farm location, and soil type applicable to each forage.

4.5.7 **Effectiveness**

4.5.7.1 Alford et al. (2006) estimated breeding for lower residual feed intake in beef cattle could reduce annual CH_4 outputs by 3.1% on a national (Australia) basis, or to much greater reductions (up to nearly 16%) on an individual farm basis over a 25 year period.

4.5.7.2 Garnsworthy (2004) estimated that restoring fertility levels to 1995 levels (averages of 72 days to first insemination, 55% oestrous detection rate, 47% conception rate at first service, and 46% conception rate at subsequent services) would reduce CH_4 emissions by 10-11%. Further improvements in these values (reduced time to first service, improved oestrous detection and conception rates; see Garnsworthy, 2004) could reduce CH_4 emissions by up to 24%. The estimates of project IS0214 (Del Prado and Scholefield, 2007) were more conservative (3% reductions for both N_2O and CH_4), but concurred that improvements in fertility would reduce direct GHG emissions.

4.5.8 **Secondary effects:**

4.5.8.1 Garnsworthy (2004) estimated that restoring fertility levels to 1995 levels would reduce NH_3 emissions by 9%, and further improvements could reduce NH_3 emissions by 17%. Based on the figures from project IS0214 (Del Prado and Scholefield, 2007) we estimate that NH_3 emissions from livestock would be reduced in the range 2-5% and NO_3 leaching losses 1-3%.

4.5.9 **Knowledge gaps**

4.5.9.1 The full extent to which livestock breeding can help reduce GHG emissions by selection of naturally efficient individuals (e.g. low CH_4 emitting ruminants) is unknown. However, selection of such individuals currently requires intensive measurements to be performed (e.g. individual feed intakes, CH_4 emission measurements etc), and the development of novel techniques that allow cheap and easy selection would be beneficial.

4.5.9.2 Future plant breeding criteria (e.g. forage with low rumen protein degradability, improved amino acid profiles) are not fully defined, and require greater collaboration between plant breeding organisations and animal nutritionists to enable this.

4.6 Use of anaerobic digestion for farm manures

Dairy	Cattle & sheep	Pigs & poultry	Cereals	General cropping	Horticulture	Mixed
✓	✓	✓				✓

4.6.1 Number of farms potentially affected by practice: 145 thousand.

4.6.2 **Description**

4.6.2.1 Anaerobic digestion (AD) of farm manures to generate CH_4 for energy production.

4.6.3 **Rationale**

4.6.3.1 Methane produced from slurries and manures has valuable potential to replace fossil fuel use. Processing in digesters that capture the CH_4 for burning enables this energy to be used and at the same time reduces the global warming potential of the gas released into the atmosphere (CO_2 instead of CH_4). To increase CH_4 yield, food 'wastes' are commonly added to the digestion process. Additionally, the food 'wastes' provide a valuable source of income via gate-fees.

4.6.4 **Mechanism of action**

4.6.4.1 Anaerobic digestion of organic materials by microbial populations in a sealed container results in the formation of CH_4 and digestate. Methane produced by these processes can be used for heating and power, and the digestate returned to the land as a soil conditioner and fertiliser.

4.6.5 **Potential for applying the method**

4.6.5.1 Farms with significant numbers of housed (particularly pigs) livestock would be most appropriate for on-farm installations.

4.6.6 **Practicability**

4.6.6.1 Significant start-up and running costs would be anticipated for both on-farm and centralised AD facilities. This has previously discouraged the uptake of this technology in the UK on any significant scale. Market support measures now proposed by the government (e.g. 'banded' renewable obligation certificates (ROCs) and further escalation of landfill tax) have the potential to significantly improve the economic framework for AD. Further analysis is required to fully understand the effects of these proposals. Additional measures, such as advice and guidance, are likely to be required to facilitate the increase in the use of AD.

4.6.7 **Effectiveness**

4.6.7.1 Methane emissions from slurry storage would be significantly reduced (estimated at up to 90%) by this method compared with conventional slurry storage. Plus there would be additional energy produced that would replace fossil fuel use. Other emissions would most likely not be directly affected

4.6.8 Secondary effects

4.6.8.1 In order to fully realise the benefits of AD it is important that the system is operated well and that the digestate is correctly applied to land (particularly in terms of application timing, rate and method) so that the nutrients can be used effectively. During AD, organic N is mineralised to ammonium (NH_4) N. Furthermore, N can be added by the inclusion of other (e.g. food 'waste') materials. Hence, the N content of the digestate can be greater than that of the original 'raw' manure. This could potentially result in greater NH_3 (during both storage and following land spreading) and N_2O emissions, and NO_3 leaching losses following land spreading (depending upon application timing). However, digestate tends to have a lower dry matter content and is likely to more rapidly infiltrate into soil, thus potentially reducing NH_3 emissions compared with the 'raw' manure but also potentially increasing NO_3 leaching losses when applied in the autumn. If the crop/grass is not able to utilise this conserved N, then it is potentially at risk of loss as NO_3 or N_2O. Also, AD uses up readily available carbon in the production of biogas, hence, when digestate is spread on land there is less carbon to fuel nitrification and denitrification, hence N_2O emissions might be expected to be lower compared with the original 'raw' manure.

4.6.9 Knowledge gaps

4.6.9.1 The effects of animal feed on quality of manures produced for use in AD is unclear but is being addressed by ongoing research at IGER (Defra project, AC0406). The full implication of AD digestate application to soils as an alternative to 'raw' (unprocessed) manure is unknown, particularly where digesters are processing large volumes of municipal and industrial 'wastes'. The most important factor influencing emissions is likely to be the inclusion of additional N from food 'wastes', and this needs further investigation.

4.7 Change land use: establish permanent grasslands and woodlands

Dairy	Cattle & sheep	Pigs & poultry	Cereals	General cropping	Horticulture	Mixed
✓	✓	✓	✓	✓	✓	✓

4.7.1 Number of farms potentially affected by practice: 195 thousand.

4.7.2 **Description**

4.7.2.1 Increase soil carbon by changing the land use from cultivated land to permanent cropping (i.e. untilled land) which is either ungrazed (e.g. woodland, wildlife strips/zones) or pasture with a low stocking rate and zero or low fertiliser inputs. Such land use change would also reduce direct N_2O emissions through lower mineral N fertiliser inputs. Long-term biomass stocks would be increased with woodlands.

4.7.3 **Rationale**

4.7.3.1 Permanent cropping will increase soil carbon storage as soils are not annually cultivated which stimulates organic matter breakdown. Dawson and Smith (2006) estimated that converting arable land to permanent grassland/woodland could increase soil carbon storage by 1.9 – 7.0 tCO_2e/ha/year, with the range of values reflecting contrasting rates of soil carbon storage increase under different environmental conditions/management practices. However, it is unlikely that these increases will be sustained over the longer term (>50 years), as a new soil carbon equilibrium level is reached

4.7.3.2 In the case of woodlands, there will be carbon stored in the vegetation itself which Dawson and Smith (2006) estimated to range between 0.3 and 5.6 tCO_2e/ha/year depending on the tree species, harvest frequency and climatic conditions, although higher figures (>15 t CO_2e/ha/year) have been reported. Additionally, in the longer term there may be GHG substitution benefits through the increased use of timber products.

4.7.3.3 There are lower levels of mineral N fertiliser inputs into permanent extensive grassland and woodland than into arable and intensively managed grassland systems. Hence, lower losses of direct N_2O emissions will occur. Also, there will be lower NO_3 losses (indirect sources of N_2O) in drainage waters from arable reversion grasslands/woodlands etc.

4.7.3.4 Righelato and Spraklen (2007) suggested that when comparing the use of land for forestry or biofuel production, over a 30 year period an equivalent area would sequester two to nine times more carbon as forestry than would be avoided by the use of land for biofuel production. This applied to temperate regions as well as tropical regions, although to a smaller degree. This implies that the maintenance and restoration of UK forests would have a greater effect on net GHG emissions than using biofuels to replace fossil fuels.

4.7.4 **Mechanism of action**

4.7.4.1 Conversion to permanent grassland/woodland avoids the frequent cultivations that under arable cropping stimulate the mineralisation of organic matter and thereby increase both CO_2 emissions and the amount of NO_3 that is potentially available for leaching. Changing from intensive arable and grassland agriculture to extensive low-input systems is therefore expected to markedly reduce carbon and N losses.

4.7.5 **Potential for applying the method**

4.7.5.1 The method is applicable to all forms of arable farmland but is potentially most suited to marginal arable land that was historically kept as grazing land. Benefits for reducing indirect losses (via NO_3 leaching) will be greatest on sandy/shallow soils that are most prone to leaching losses.

4.7.6 **Practicability**

4.7.6.1 This is an extreme change in land use that is unlikely to be adopted by farmers without the provision of suitable financial incentives. It may be particularly suited to areas where the converted land would have amenity or conservation value. Grants are currently available to establish new woodlands (e.g. the Forestry Commission's English Woodland Grant Scheme).

4.7.7 **Effectiveness**

4.7.7.1 Direct N_2O: Emissions of N_2O would be reduced according to the area of land taken out of annual cultivation, and depending on the previous use of the land (arable cropping or intensive grassland) and mineral fertiliser N addition levels.

4.7.7.2 Soil carbon storage: Where land use change is to permanent grassland/woodlands, increased soil carbon storage is likely to initially be in the range 1.9 to 7.0 tCO_2e/ha/year. The actual value will depend on soil type, previous land use, and climate, and will be much lower when a new equilibrium of soil carbon is reached.

4.7.8 **Secondary effects**

4.7.8.1 The method is very effective for reducing NO_3 leaching. Conversion to ungrazed grassland has been estimated to reduce NO_3 losses by >95% (Cuttle et al., 2007). If the converted land is used for extensive grazing (e.g. beef/sheep farming) NO_3 leaching losses are likely to be reduced by >50% (Cuttle et al., 2007).

4.7.8.2 If the land is grazed (compared to previous tillage cropping) CH_4 emissions would increase at the farm level, due to grazing ruminants. However, this would only increase the national CH_4 emission if these were additional stock. Ammonia emissions would be greater as a result of the livestock and manure management.

4.7.8.3 There is much potential for change in the biodiversity value of land with changes in its use, although such improvements are not certain (e.g. Cole et al., 2007). A detailed analysis of this aspect of change in land use is beyond the scope of this study.

4.7.9 Knowledge gaps

4.7.9.1 There is a need to undertake more work to quantify the contribution that peatland restoration (as opposed to current peatland management practices) could make to both decreasing CO_2 emissions and increasing soil carbon storage as a component of land use change (e.g. Evans et al., 2006), and the reversion of arable land to permanent non-tillage land uses (e.g. riparian/valley bottom buffer strips). Such work should also include potential changes in N_2O (direct and indirect) and CH_4 emissions.

4.8 Change land use: grow biomass crops

Dairy	Cattle & sheep	Pigs & poultry	Cereals	General cropping	Horticulture	Mixed
✓	✓	✓	✓	✓	✓	✓

4.8.1 Number of farms potentially affected by practice: 195 thousand.

4.8.2 **Description**

4.8.2.1 Grow perennial biomass crops (e.g. willow, poplar, miscanthus) to displace fossil fuel use, either through direct combustion or through biofuel generation (e.g. by gasification). Also, because the land is not cultivated annually and mineral N fertiliser requirements are moderately-low, there will be GHG benefits beyond simply displacing fossil fuel use.

4.8.3 **Rationale**

4.8.3.1 The lack of cultivation following the establishment of perennial biomass crops (e.g. willow, poplar, miscanthus) will increase soil carbon storage, compared with conventional arable cropping, as soils are not annually cultivated which stimulates organic matter breakdown.

4.8.3.2 There are lower levels of mineral N fertiliser inputs into some energy crop systems (e.g. willow, poplar, miscanthus) than into conventional arable systems. Hence, lower losses of direct N_2O emissions will occur. Also, there will be lower NO_3 losses (indirect sources of N_2O) in drainage waters from biomass-cropped land.

4.8.4 **Mechanism of action**

4.8.4.1 Conversion to permanent perennial biomass cropping avoids the frequent cultivations that under arable cropping stimulate the mineralisation of organic matter and thereby increase both CO_2 emissions and the amount of NO_3 that is potentially available for leaching.

4.8.5 **Potential for applying the method**

4.8.5.1 The method is applicable to all forms of arable farmland. Benefits for reducing indirect losses (via NO_3 leaching) will be greatest on sandy/shallow soils that are most prone to leaching losses.

4.8.5.2 It should be noted that a change of land use from food (human and livestock) crops to energy crops has implications for the sustainability of food production in the UK. Increased use of prime land for energy crop production would lead to greater reliance on food imports, similar to the effect of reducing livestock numbers as a way of reducing GHG emissions (Section 4.9). Increased production of cereals in other countries to supply the UK needs may lead to greater deforestation of land to grow crops and use of practices (overseas) that result in a net increase of GHG emissions, in addition to increase fuel use for food transport.

4.8.6 **Practicability**

4.8.6.1 A change in land use to biomass cropping is unlikely to be adopted by farmers without the provision of suitable financial incentives. Defra's Energy Crop Scheme closed to new applications for establishment grants in June 2006.

4.8.7 **Effectiveness**

4.8.7.1 Direct N_2O: Emissions of N_2O would be reduced according reductions in mineral fertiliser N addition rates and the area of land taken out of annual cultivation for biomass production.

4.8.7.2 Soil carbon storage: Where land use change is to permanent biomass cropping, increased soil carbon storage is initially likely to be in the range 1.9-7.0 tCO_2e/ha/year depending on soil type and previous land use and climate. Dawson and Smith (2006) estimated a value of 2.4 t CO_2e/ha/year.

4.8.8 **Secondary effects**

4.8.8.1 The method will be effective for reducing NO_3 leaching from biomass cropped land because mineral fertiliser N rates are moderate or low and the land is not cultivated annually, which will reduce indirect N_2O losses.

4.8.9 **Knowledge gaps**

4.8.9.1 The overall long term effects of large-scale biomass cropping in the UK is unknown. However, this will only become known with time. Effects of biomass crops such as short-rotation coppice willow and miscanthus on biodiversity and wildlife value is encouraging (e.g. Sage et al., 2006) but is not entirely clear, and this is being investigated by Defra project IF0104.

5 POTENTIAL FUTURE MITIGATION PRACTICES

5.1 Reduced/zero tillage

Dairy	Cattle & sheep	Pigs & poultry	Cereals	General cropping	Horticulture	Mixed
		✓	✓	✓		✓

5.1.1 Number of farms potentially affected by practice: 65 thousand.

5.1.2 **Description**

5.1.2.1 Use discs or tines to cultivate the surface as a primary cultivation in seedbed preparation rather than deep ploughing. Or direct drill into stubbles (no-till).

5.1.3 **Rationale**

5.1.3.1 Minimal cultivation (rather than ploughing) can be a useful way to maintain surface organic matter, preserve good soil structure and break up surface crusts. The resulting soil conditions should improve infiltration and retention of water (Defra project SP0561).

5.1.4 **Mechanism of action**

5.1.4.1 Maintaining good structure and promoting water infiltration and through-flow reduces soil erosion risks. The reduction in surface run-off is particularly effective when a mulch of crop residues is left on the surface. Good structure also promotes the efficient use of soil nutrients. Conversion from ploughing to minimum or no cultivation systems in the short-term will generally decrease NO_3 leaching by a small extent through reduced mineralisation of soil organic matter in the autumn.

5.1.5 **Potential for applying the method**

5.1.5.1 This method is already being adopted on a number of arable farms, with around 1.5 Mha cultivated using discs or tines. It is most commonly applied to medium to heavy soils, although the practice is increasingly being carried out on lighter soils.

5.1.6 **Practicability**

5.1.6.1 No-till is generally unsuitable for light soils that are prone to capping. Minimum cultivation is less applicable in a very wet autumn and is only suitable where soil structural problems have been alleviated. Minimum tillage may increase resistant weed populations and disease problems (Davies et al., 2006), and therefore increase reliance on chemical control. Commonly minimum tillage land is ploughed every 3-4 years to relieve compaction problems and to control grass weeds.

5.1.7 **Effectiveness:**

5.1.7.1 Direct N_2O: There is some limited evidence that reduced/no tillage results in a greater soil water holding capacity and hence can result in increased direct N_2O emissions. Recommended mineral fertiliser N application rates are the same on ploughed and reduced/zero tilled land (MAFF, 2000).

5.1.8 **Secondary effects:**

5.1.8.1 Indirect N_2O: Reduced tillage was estimated by Cuttle et al. (2007) decrease NO_3 leaching by 0-5 kg N/ha compared with ploughing.

5.1.8.2 Ammonia emissions may also be reduced where discs/tines are used to rapidly incorporate applied manure or where slurries infiltrate more rapidly into soils as a result of improved soil structural conditions.

5.1.8.3 Increased soil carbon storage has been estimated at 0.59 t CO_2e/ha/year from reduced tillage and 1.13 t CO_2e/ha/year from zero tillage compared with ploughing during the period of reduced/zero tillage (Defra project SP0561). However, it is likely that much of the increased soil carbon storage will be lost when the land is rotationally ploughed every 3-4 years.

5.1.8.4 Savings in energy consumption of 0.06 t CO_2e/ha/year have been estimated for reduced tillage and 0.08 t CO_2e/ha/year from zero tillage compared with ploughing (Defra project SP0561).

5.1.9 **Knowledge gaps**

5.1.9.1 The overall GHG balance of reduced/zero tillage systems needs to be evaluated, to assess where soil carbon storage increases are outweighed by enhanced N_2O emissions.

5.2 *Take stock off 'wet' ground*

Dairy	Cattle & sheep	Pigs & poultry	Cereals	General cropping	Horticulture	Mixed
✓	✓	✓				✓

5.2.1 Number of farms potentially affected by practice: 145 thousand.

5.2.2 **Description**

5.2.2.1 When soils are 'wet', the numbers of livestock per unit area or the time stock spend on the field should be reduced sufficiently to avoid severe poaching and compaction of the soil, which results in anaerobic soils, with high N and carbon contents due to grazing deposits. Such conditions are favourable for direct N_2O and, to a lesser extent, CH_4 emissions.

5.2.3 **Rationale**

5.2.3.1 Soils are more easily poached when they are wet. Reducing livestock numbers or the duration of grazing at these times reduces poaching damage and the potential for N_2O and CH_4 emissions.

5.2.4 **Mechanism of action**

5.2.4.1 Poaching reduces the infiltration of rain into the soil and increases the anaerobicity of the upper soil layers. Whilst stock are poaching the soil they are also depositing dung and urine enhancing conditions for N_2O generation. Reducing the amount of treading when soils are wet and most susceptible to structural damage reduces the anaerobicity. Lower stocking rates will also reduce the amount of excreta deposited in these areas and the amounts of pollutants available for loss.

5.2.5 **Potential for applying the method**

5.2.5.1 The method is applicable to all livestock farms where animals are kept outside, but most particularly to those with high stocking rates, where extended grazing is practised or where stock are wintered outdoors. On some farms, it may only be necessary to install temporary fences to exclude stock from temporarily wet areas of particular fields. Poaching is likely to be more severe with cattle grazing than with sheep. Although outdoor pigs can damage the soil, the method is somewhat less applicable to these units as they are usually set-stocked and commonly do not have the option of moving stock to other fields or indoors. Fine-textured, less-permeable soils are most susceptible to poaching and the risk is increased in high-rainfall areas.

5.2.6 **Practicability**

5.2.6.1 Implementation will be easier on farms with access to freely-drained, less easily-poached land that can provide alternative grazing during wet periods. Farms where most of the fields are susceptible to poaching may need to house animals earlier in autumn and delay turn-out in the spring. This will increase the amount of manure produced that needs to be stored/managed. The method will only be fully effective if methods are adopted to reduce losses from this additional manure, when it is spread onto land. Profitability would be seriously reduced on farms that are highly dependant on grass forage and are dominated by fine-textured soils.

5.2.7 Effectiveness

5.2.7.1 Direct N_2O (and to a lesser extent CH_4 emissions) and NO_3 leaching would be reduced by this method (provided that the additional stored manure was applied at times that did not enhance N_2O and NO_3 leaching losses).

5.2.8 Secondary effects

5.2.8.1 The method would also reduce water pollution from sediment and P losses, because poaching and enhanced surface runoff losses would be reduced. However, if it required stock to be housed for longer, there would be a greater amount of manure produced that needs to be handled, stored and applied to land. This could potentially increase NH_3 and CH_4 emissions from manure sources, and gaseous emissions and transfers of pollutants to water, unless management activities were under taken to minimise losses.

5.2.9 Knowledge gaps

5.2.9.1 The overall effect of this method on the balance of GHG and NH_3 emissions to air, and water pollution needs to be quantified.

5.3 Change from a solid manure to slurry system

Dairy	Cattle & sheep	Pigs & poultry	Cereals	General cropping	Horticulture	Mixed
✓	✓	✓				✓

5.3.1 Number of farms potentially affected by practice: 145 thousand.

5.3.2 **Description**

5.3.2.1 Change from a system where the manure from housed animals is collected as a solid to one where animals are kept on a slurry based system to reduce N_2O emissions.

5.3.3 **Rationale**

5.3.3.1 Solid manures contain both aerobic and anaerobic micro-sites where ammonium-N can be nitrified to NO_3, providing a source of N_2O emission by denitrification. This can occur as the bedding material builds up in the animal house, and particularly once the bedding has been removed from the building and stored in heaps. Slurry, on the other hand, is anaerobic (until the time it is spread onto land) and there is little or no N_2O emission from slurry based buildings or slurry stores.

5.3.4 **Mechanism of action**

5.3.4.1 Converting from a solid manure based system to one that is slurry based results in little or no possibility of slurry NH_4-N being converted into NO_3 until it is spread onto land. Hence, N_2O emission are lower from slurry systems than straw-based systems, at least from the livestock housing and manure stores.

5.3.5 **Potential for applying the method**

5.3.5.1 The method is applicable to those farms with housed stock that currently handle all or part of their manure as a solid manure.

5.3.6 **Practicability**

5.3.6.1 Slurry based systems will require storage facilities that a farmer would not necessarily have required for the storage of solid manure, i.e. heaps in fields or on concrete pads/bunkers. The costs of slurry storage are high. Pumps and alternative spreading equipment would be required, but potentially less energy would be required to handle and spread slurry than solid manure. Buildings may also need to be changed, with slatted flooring and slurry collection pits and storage facilities being installed.

5.3.7 **Effectiveness**

5.3.7.1 Direct N_2O: Project IS0214 (Del Prado and Scholefield, 2007) predicted a reduction of 15% for dairy systems (overall from housing, storage and land spreading), with a similar reduction likely for pig systems.

5.3.7.2 However, CH_4 emissions are likely to be increased from slurry compared with solid manure storage, and may negate (to a lesser or greater extent) any benefits of reduced N_2O emissions from slurry based systems.

5.3.8 **Secondary effects**

5.3.8.1 Ammonia emissions from slurry based cattle systems (i.e. from housing, storage and land spreading) were higher than from straw-based systems (Defra project WA0632). However, for pigs, NH_3 emissions were lower from slurry than straw-based systems (Defra projects WA0632, WA0646 – Chambers et al., 2003 – and WT0706). In the case of pig manure systems, potential differences between solid and liquid systems are recognised as being uncertain; further work is being undertaken in Defra project AC0102, measuring NH_3 emissions from straw-based pig buildings.

5.3.8.2 Nitrate leaching losses are likely to be higher from slurry compared with solid manure systems, particularly where applications are made in autumn/winter.

5.3.9 **Knowledge gaps**

5.3.9.1 The overall balance of GHG and other gaseous (e.g. NH_3) emissions from slurry and straw-based manure management systems for cattle and pigs needs to be quantified.

5.4 Use of hormones and increased milking frequency

Dairy	Cattle & sheep	Pigs & poultry	Cereals	General cropping	Horticulture	Mixed
✓	✓					✓

5.4.1 Number of farms potentially affected by practice: 134 thousand.

5.4.2 **Description**

5.4.2.1 Increased production using recombinant bovine somatotropin (rbST; a synthetic version of natural growth hormone) alone or in combination with increased milking rates to increase efficiency of feed utilisation. Use of hormone implants to improve growth rates in growing animals.

5.4.3 **Rationale**

5.4.3.1 In North America, rbST (POSILAC®, Monsanto) is used extensively as a means of increasing and maintaining high milk yields in dairy cows. It is not licensed for use in the EU, and therefore cannot be used in the UK.

5.4.3.2 Hormone growth promoters used in beef production are licensed and widely used in North America and parts of Australasia. They have been banned for use in the EU since 1988. Hormonal implants increase the rate of live weight gain, allowing animals to be finished more quickly, reducing the amount of time on-farm where they produce CH_4 and contribute to N_2O emissions.

5.4.4 **Mechanism of action**

5.4.4.1 Recombinant bST acts to redirect absorbed dietary nutrients away from peripheral body tissues to the mammary gland, where they are used for enhanced milk production. With cows injected with rbST, milk yield is typically increased by 10-15% (Dohoo et al., 2003b), with milk yields increasing more than feed intakes (implying increased efficiency of nutrient utilisation). Nitrogen use efficiency can also be increased (Dunlap et al., 2000), either through use of rbST alone or in combination with three-times (3×) daily milking (Table 5.5.4.1). Increased milking frequency removes milk from the udder thereby stimulating further milk production. Similar results were found in a recent survey of 454 American dairy farms (Jonker et al., 2002), in which average N use efficiency for milk production was found to be 28.4%. Average N use efficiency in the UK is probably approximately the same as this, although there are no recent UK studies to support this.

Table 5.5.4.1 Mean effects (per cow) of adopting bST and/or 3 times a day milking (3×) on N utilisation efficiency (Dunlap et al., 2000).

Treatment	Control	rbST	3×	rbST + 3×
Milk yield, kg/d	29.1	33.3	32.3	36.2
N intake, g/d	470	515	500	543
N excretion, g/d	313	337	329	352
N use efficiency, %[1]	33.4	34.6	34.2	35.3

[1] ((N intake – N excretion) / N intake) x 100

5.4.4.2 Three times a day milking increases milk yield, and increases N use efficiency through a dilution of animal energy and N maintenance requirements (Dunlap et al., 2000). Increasing milking frequency can also increase the efficiency of utilisation of amino acids for milk production by reducing the turnover of milk and constitutive proteins in the mammary gland (Bequette et al., 1998). Effects such as these which increase the efficiency of incorporation of dietary N into milk naturally reduce excretion and the effects this has on subsequent N_2O emissions and related NO_3 leaching and NH_3 volatilisation.

5.4.4.3 Hormone implants, including natural hormones oestradiol 17β, testosterone and progesterone, and artificial analogues trenbolone and zeranol are used in beef production. They increase the rate of gate and feed use efficiency, probably through stimulation of the pituitary to release somatotrophin. Injections of rbST have also been used to increase growth rates and reduce carcase fatness in growing steers.

5.4.5 Potential for applying the method

5.4.5.1 The use of bST and other hormones is currently not allowable under EU regulations because of fears of endocronologically active residues in meat and milk, and would require a change in these to enable future use in European dairying and beef production.

5.4.5.2 Early data on the use of rbST in dairy cows indicated that there is little effect of rbST on dairy cow health (Cunningham, 1994). More recent data suggests rbST use leads to an increased risk of some health events (lameness, mastitis) – which may result from increased milk yields - but reduced the risk of others (ketosis), and increased the risk of cows failing to conceive and therefore being culled (Dohoo et al., 2003a). On the other hand, embryo survival in dairy cows once they have conceived is increased with rbST treatment (Thatcher et al., 2006). However, other management tools such as 3× milking have potential benefits. Three times daily milking is possible by most dairy farmers, and robotic milking systems offer the potential for even higher milking frequencies. Increased milking frequency, particularly in high genetic merit dairy cows, may have a benefit in terms of udder health (Dahl et al., 2004).

5.4.6 **Practicability**

5.4.6.1 Increased milking frequency would incur increased costs (labour and energy). Milking robots are currently expensive, and although labour is reduced a change in skills is required by the farmer. Increased milking frequency would mean more cow movements, to the point that robotic milking systems require animals to be kept close to the machines at all times (i.e. housed year round).

5.4.7 **Effectiveness**

5.4.7.1 Direct N_2O: the effect of use of rbST and other hormones or increased milking frequency is unknown (and has never been measured). However, reductions are likely because of increased efficiencies of utilisation of feed.

5.4.7.2 Methane: Sechen et al (1989) observed a 15% reduction in CH_4 output following rbST use in dairy cows, but could not explain the mechanism of action.

5.4.8 **Secondary effects**

5.4.8.1 Increased efficiency of utilisation of dietary nutrients for milk production reduce N excretion outputs, and therefore NH_3 emissions and NO_3 leaching losses are likely to be reduced.

5.4.9 **Knowledge gaps**

5.4.9.1 It is unlikely that bST or other hormones would become acceptable in the EU at the near future. However, if this were to happen sufficient knowledge from their use overseas means that best practice would be known. Likewise, increased milking frequency is well known and practiced by some farmers in the UK.

5.5 Use of nitrification inhibitors

Dairy	Cattle & sheep	Pigs & poultry	Cereals	General cropping	Horticulture	Mixed
✓	✓	✓	✓	✓	✓	✓

5.5.1 Number of farms potentially affected by practice: 195 thousand.

5.5.2 **Description**

5.5.2.1 Addition of nitrification inhibitors to applied mineral N fertilisers, manures and to grazed pastures.

5.5.3 **Rationale**

5.5.3.1 Nitrification inhibitors are chemicals that reduce the rate of conversion of NH_4 to NO_3. The rationale is that the rate of nitrification is reduced so that NO_3 is formed at a rate that the crop can use (i.e. slow release), increasing N efficiency and reducing environmental losses via N_2O emissions and NO_3 leaching.

5.5.4 **Mechanism of action**

5.5.4.1 Compounds such as nitrapyrin, dicyandiamide (DCD) and 3,4-dimethylpyrazole phosphate (DMPP) have been demonstrated to be effective in reducing N_2O emissions from fertiliser and animal slurries. Chemicals such as DCD have been evaluated for reducing N losses from autumn applied slurries for many years, but have generally failed to gain acceptance with the farming community due to their poor cost-effectiveness in terms of giving yield benefits and reduced NO_3 leaching losses (Chambers et al., 2000). However, Dittert et al. (2001) showed that inhibitors reduced N_2O emissions by about 30% when they were mixed with slurry and injected into grassland in late summer. More recent research conducted in New Zealand, has shown that nitrification inhibitors can be extremely effective when added to mineral fertiliser, manures and even dosed to animals in reducing N_2O emissions. In the laboratory, such inhibition has been shown to be potentially close to 100% efficient, while reducing to about 30% typically under field conditions (Hatch et al., 2005).

5.5.5 **Potential for applying the method**

5.5.5.1 Inhibitors can potentially be applied as part of mineral N fertiliser formulations, to manures in storage and when spread to land, be sprayed on grazed land periodically at critical times of enhanced nitrification or be dosed to animals via slow release boluses.

5.5.6 **Practicability**

5.5.6.1 Nitrification inhibitors could be spread at the same time as fertiliser/manure applications and all methods (except animal dosing) are easy to apply.

5.5.6.2 Nitrification inhibitors are currently expensive and this may reduce the uptake of their use by farmers, but the reduction in mineral fertiliser requirements through reduced N losses may offset this cost.

5.5.7 **Effectiveness**

5.5.7.1 Recent research in New Zealand (www.ravensdown.co.nz/products/national2005/specialist.html and www.ballance.co.nz/unewsapr07-05.html) points to high potential effectiveness. Ravensdown claim a 7-15% yield response rate to use and Ballance AgriNutrients suggest that use can reduce NO_3 leaching losses by up to 35%. However, New Zealand grazing paddocks, which are generally on free draining and have a long growing season, are very different to the UK situation (where soils are predominantly heavy textured and the growing season is much shorter).

5.5.8 **Secondary effects**

5.5.8.1 Unclear at this time, although New Zealand research suggests that NO_3 leaching losses should also be reduced.

5.5.9 **Knowledge gaps**

5.5.9.1 There is a need to quantify the potential benefits of nitrification inhibitor use to mitigate N_2O emissions from UK farming systems (from manure and fertiliser additions and from grazed pastures), and also to assess potential benefits in terms of increased N use efficiency (i.e. synchrony with crop needs) and water quality (NO_3 leaching) improvements.

5.6 *Improved mineral fertiliser N timing strategies*

Dairy	Cattle & sheep	Pigs & poultry	Cereals	General cropping	Horticulture	Mixed
✓	✓	✓	✓	✓	✓	✓

5.6.1 Number of farms potentially affected by practice: 195 thousand.

5.6.2 **Description**

5.6.2.1 Develop and apply tactical mineral fertiliser N application timing strategies that explicitly aim to avoid large amounts of NO_3 in the soil under wet and warm conditions.

5.6.3 **Rationale**

5.6.3.1 A substantial proportion of the N_2O emissions from productive agriculture arises due to the nitrification and denitrification of mineral N fertiliser applications to soils that are made periodically during the growing period. Such emissions are highly ‘event driven’ in that high emissions (greater than 0.5 kg N/ha/d) typically occur only during a small number of days when applications concur with wet and warm conditions in the soil. If such events could be avoided then large reductions in emission could be achieved. Avoidance might be possible using soil tests and/or weather forecasts.

5.6.4 **Mechanism of action**

5.6.4.1 The method avoids application of large amounts of mineral N fertiliser during wet and warm conditions.

5.6.5 **Potential for applying the method**

5.6.5.1 The method depends on development of farmer friendly, site-specific tests or forecasts. Potentially it could be applied in all circumstances and while it would be expected that the largest emissions would arise from ammonium NO_3 or NO_3-based fertilisers, recent Defra field experiments (NT26) have shown that the form of the fertiliser N has little impact on emissions.

5.6.6 **Practicality**

5.6.6.1 Would probably be easy to apply, but would have important consequences for the farmers’ day to day management and potentially on the periodicity of production during the growing season.

5.6.7 **Effectiveness**

5.6.7.1 Could be highly effective.

5.6.8 **Secondary effects**

5.6.8.1 If better N use efficiency is achieved, NO_3 leaching losses are also likely to be reduced.

5.6.9 **Knowledge gaps**

5.6.9.1 Underpinning knowledge and predictive forecasting approaches to the timing of mineral fertiliser N applications to minimise N_2O losses is lacking.

5.7 Use plants with improved nitrogen use efficiency

Dairy	Cattle & sheep	Pigs & poultry	Cereals	General cropping	Horticulture	Mixed
✓	✓	✓	✓	✓	✓	✓

5.7.1 Number of farms potentially affected by practice: 195 thousand.

5.7.2 **Description**

5.7.2.1 Use modern varieties of crop plants that have improved genetic traits for capture of soil N.

5.7.3 **Rationale**

5.7.3.1 During the growing period the efficiency of uptake of applied mineral fertiliser N typically ranges between 55-70% (MAFF, 2000), according to site conditions, the amount of soil N and the inherent physiology of the plant. If the plant can be rendered more competitive for soil N, even during periods when there is excess and the plant is not growing optimally, reduced N_2O emissions would be expected.

5.7.4 **Mechanism of action**

5.7.4.1 Plants remove more mineral N from the soil at a given concentration and so reduce the amount that can be denitrified. Defra is currently funding a number of projects to improve plant N use efficiency. Project LK0979, aims to use genetic variability in oilseed rape to breed for plants that require less N fertiliser at present; oilseed rape currently receives more N fertiliser than almost any other arable crop, but deposits relatively little of this in the seed. Project LK0959 aims to breed wheat varieties specifically for bioethanol production, for which the protein content (and therefore N fertiliser requirements) are reduced. Reducing plant N requirements for production reduces N fertiliser requirements in addition to cultivation actions that require fossil fuel use.

5.7.5 **Potential for applying method**

5.7.5.1 Can be applied in principle to all sectors of grassland and crop production agriculture.

5.7.6 **Practicality**

5.7.6.1 Depends on existence of high N use efficiency plants with seed at cost effective prices and no accompanying management or food quality disbenefits.

5.7.7 **Effectiveness**

5.7.7.1 The method would be directly effective in reducing N_2O emissions from soil, but for forage crops could also have secondary benefits in reduced amount of N excretion from animals, if used in conjunction with feed plans for improved rumen capture of N.

5.7.8 Secondary effects

5.7.8.1 If better N use efficiency is achieved, NO_3 leaching losses are also likely to be reduced.

5.7.9 Knowledge gaps

5.7.9.1 Defra funded work is ongoing to improve the N use efficiency of crops.

6 SPECULATIVE MITIGATION PRACTICES

6.1 Improved understanding of potential methane production of feeds

Dairy	Cattle & sheep	Pigs & poultry	Cereals	General cropping	Horticulture	Mixed
✓	✓					✓

6.1.1 Number of farms potentially affected by practice: 134 thousand.

6.1.2 **Description**

6.1.2.1 Use of laboratory methods to estimate potential CH_4 production from a feed before it is fed.

6.1.3 **Rationale**

6.1.3.1 There is currently no way of knowing how much CH_4 would be produced by a ruminant from a given diet unless is it fed to the animal and measured using complex direct or indirect calorimetry techniques.

6.1.4 **Mechanism of action**

6.1.4.1 *In vitro* techniques can be used for the measurement of CH_4 produced under rumen-like conditions in the laboratory. One such method, the gas production technique, uses rumen fluid as an inoculum, and the CH_4 produced following the incubation of a wide variety of feeds can be measured and quantified. Furthermore, the use of near-infrared spectroscopy (NIRS) to predict CH_4 production from specific feedstuffs offers potential for even more rapid and cheaper assessments of the CH_4 production potential of feeds in isolation or as part of a mixed diet. Defra project CC0220 found the gas production technique could be used to measure CH_4 production, although the results did not correlate well with *in vivo* measurements. NIRS was also found to be able to accurately predict CH_4 production from a range of diets, although the need to generate correlation equations using *in vivo* data severely limits this approach.

6.1.5 **Potential for applying the method**

6.1.5.1 Any method that could predict CH_4 output from specific feeds could be incorporated into a ration formulation system to enable CH_4 output to be minimised. Adequate characterisation of feedstuffs is required for efficient ration formulation in any livestock system. The addition of some measure of CH_4 potential for any basic feedstuff would be very valuable to enable other methods to be imposed to reduce CH_4 output (i.e. mixed diets could be formulated to minimise CH_4 production using a range of ingredients).

6.1.6 Practicability

6.1.6.1 A laboratory-based method would be relatively easy to implement, particularly since most feed composition is now predicted using NIRS.

6.1.7 Knowledge gaps

6.1.7.1 The methanogenic potential of a whole range of feeds would need to be investigated using *in vivo* methods to create calibration sets for NIRS predictions. The interaction between different feeds when fed to an animal would make the ability to predict the CH_4 production of a complete diet even more difficult. Defra project AC0209 is determining how the ruminant diet can be manipulated to reduce CH_4 emissions and N excretion.

6.2 *Vaccination against methanogens*

Dairy	Cattle & sheep	Pigs & poultry	Cereals	General cropping	Horticulture	Mixed
✓	✓					✓

6.2.1 Number of farms potentially affected by practice: 134 thousand.

6.2.2 **Description**

6.2.2.1 Vaccination of ruminant animals against methanogenic bacteria to reduce CH_4 output.

6.2.3 **Rationale**

6.2.3.1 Although rumen micro-organisms are generally commensal, a reduction or removal of certain groups or species within the population would lead to a decrease in the amount of CH_4 released. This would also increase the efficiency of the rumen fermentation process, because CH_4 production represents a loss of carbon (equating to between 2 and 15% of gross energy intake; Johnson and Johnson, 1995) that would otherwise be available to the animal for productive purposes.

6.2.4 **Mechanism of action**

6.2.4.1 The methanogens are a relatively well-defined group of micro-organisms in the rumen population and are well suited to this method. Immunisation against methanogenic archaea has been demonstrated (Baker, 1999, Wright et al., 2004), and the antimicrobial effects of host animal vaccination are thought to occur through the delivery of antibodies in saliva.

6.2.5 **Potential for applying the method**

6.2.5.1 This method would only likely to be applicable to ruminant livestock systems, although because enteric fermentation from ruminants accounts for the majority of CH_4 production. Vaccines can be used on organic farms where there is a known disease risk, it is unlikely that this method would be permitted under national organic livestock standards.

6.2.6 **Practicability**

6.2.6.1 Most livestock farms routinely vaccinate their animals against certain infectious diseases, and the addition of anti-methanogen vaccines to a standard prophylactic formula may be possible. It is uncertain whether public support for vaccination of animals for non-disease prophylactic purposes would be achieved. Potential CH_4 reductions of up to 8% have been seen in sheep (Wright et al., 2004).

6.2.7 **Knowledge gaps**

6.2.7.1 The rates of reduction cited above were achieved using vaccines that targeted less then 20% of the methanogens in the rumen, and greater efficacy may be achieved through the use of more targeted vaccine formulations. It is also unknown whether the removal of specific methanogens would simply result in subsequent increase in other species to take their place. Long term effects of vaccination of against gut organisms are also largely unknown, i.e. effects of animal health. The period of effectiveness is poorly understood and the frequency of vaccination needs to be determined.

6.3 Modification of rumen microbial fermentation by ionophores and natural extracts

Dairy	Cattle & sheep	Pigs & poultry	Cereals	General cropping	Horticulture	Mixed
✓						✓

6.3.1 Number of farms potentially affected by practice: 36 thousand.

6.3.2 **Description**

6.3.2.1 Modification of the rumen microbial population using antibiotic ionophores or natural plant extracts to reduce energy and protein losses.

6.3.3 **Rationale**

6.3.3.1 Fermentation in the rumen is subject to inefficiencies in energy (losses of CH_4) and protein (losses of NH_3), which can be modulated by the use of feed additives to enhance or inhibit specific microbial populations (Walker et al., 2005). Routine antibiotic use animal feeds is not permitted in the EU because of fears of increased microbial resistance to antibiotics used for therapeutic purposes (although now out of date due to more recent EU legislation, see Anadón and Martínez-Larrañaga, 1999). However, there is significant interest in the use of natural feed additives, such as essential oils, yeast products, and organic acids.

6.3.4 **Mechanism of action**

6.3.4.1 Some antibiotic ionophores, such as monensin and lasalocid, selectively inhibit Gram-positive bacteria. Gram-positive bacteria lack an outer cell membrane (which acts as a barrier to monensin in Gram-negative bacteria), and in its absence the lipophilic ionphore can be incorporated into the cytoplasmic cell membrane and disrupt normal cellular ion transport and balance (Russell, 1987).

6.3.4.2 Some monensin-sensitive rumen bacteria are key to the deamination of amino acids, and use of ionophores in ruminant feeds can reduce rumen NH_3 production (Yang and Russell, 1993), much of which is ultimately excreted in urine.

6.3.4.3 Dosing ruminants with ionophores can also decrease CH_4 output, but this effect is apparently transient (4-6 weeks in duration; Guan et al., 2006) and mediated through changes in rumen protozoal populations which can develop a mechanism to overcome the toxic effects of ionophores (Walker et al., 2005).

6.3.4.4 Essential oils are plant secondary metabolites that appear to be natural alternatives to the antibiotic additives in animal feeds. Some essential oils have been shown to reduce rumen NH_3-N concentration, and it has been suggested that they can inhibit proteolytic, peptidelytic and NH_3-producing bacteria, thereby reducing absorption and excretion of NH_3.

6.3.5 Potential for applying the method

6.3.5.1 Antibiotics are not applicable under current regulations. However, there is scope to incorporate various novel natural additives in the feed of all livestock.

6.3.6 Practicability

6.3.6.1 Since January 1 2006, the use of antibiotics for non-medicinal purposes has been illegal in the EU (regulation 1831/2003/EC) because of concerns that widespread use could lead to increased antibiotic resistance of pathogens responsible for human diseases. Therefore, monensin, which was one of the last antibiotics to be removed from feed by this ban, cannot be used to modulate rumen metabolism.

6.3.6.2 Availability of some essential oils for use in livestock feeds is currently limited and therefore very expensive. Future production methods for promising additives would have to be improved to increase their availability.

6.3.6.3 There are many supplements on the market for all livestock sectors, and adding to them requires authorisation by EC Regulation 1831/2003 on Feed Additives which can be difficult and expensive.

6.3.7 Knowledge gaps

6.3.7.1 The mechanisms of action of many novel feed additives are not well understood. Much of the initial work on essential oils, for instance, has been carried out *in vitro*, and *in vivo* studies are required to determine interactions with livestock (e.g. effect on feed intake). However, much work has already been done by the feed industry in the search for viable alternatives to antibiotic growth promoters, although much of this is commercially confidential and may never been seen in the public domain. Defra project AC0209 is determining how the ruminant diet can be manipulated to reduce CH_4 emissions and N excretion.

6.4 Production of natural nitrification inhibitors by plants

Dairy	Cattle & sheep	Pigs & poultry	Cereals	General cropping	Horticulture	Mixed
✓	✓		✓			✓

6.4.1 Number of farms potentially affected by practice: 162 thousand.

6.4.2 **Description**

6.4.2.1 Plants could be bred to express nitrification inhibitors that reduce the nitrification of manure and mineral fertiliser NH_4 to NO_3.

6.4.3 **Rationale**

6.4.3.1 Plants exude a large number of compounds into the rhizosphere, some of which help to release nutrients from the soil, and some of which are lost through diffusion. Some plants exude compounds that are natural nitrification inhibitors, which may be incidental or it may be a way for the plant to influence the rhizosphere microbial population (the reasons for which are not clear). Incorporation of this trait into agriculturally important plants could reduce N_2O emissions and thereby increase the efficiency of utilisation of applied N.

6.4.3.2 Incorporation of naturally occurring nitrification inhibitory traits into grains and forages could result in excretion in/with the faeces/urine and reduced losses of N_2O (and potentially NO_3 leaching) following manure spreading and during grazing.

6.4.4 **Mechanism of action**

6.4.4.1 Some plants, such as creeping signal grass (*Brachiaria humidicola*; Gopalakrishnan et al., 2007), an important pasture grass in tropical regions, and *Leucaena leucocephala* (Erickson et al., 2000), a tropical legume tree, are known to produce natural nitrification inhibitors in their roots. *B. humidicola* can suppress the function of nitrifying bacteria in the soil by releasing methyl-*p*-coumarate and methyl ferulate from the roots, thereby maintaining soil N in the NH_4-N form. Incorporation of this type of trait into arable and forage crops grown in the UK would reduce N_2O emissions from applied fertilisers and manures. Genetic modification is one potential route for the introduction of this trait, although this is currently likely to be of limited appeal to the UK public. Discovery of native plants, with similar properties, that are close enough taxonomically to commercially important crops, may allow conventional breeding techniques to be used.

6.4.5 **Potential for applying the method**

6.4.5.1 Likely to be applicable to all arable and livestock farms with grazing pastures.

6.4.6 **Practicability**

6.4.6.1 Use and applicability of new varieties of crops should be the same as current varieties.

6.4.7 **Knowledge gaps**

6.4.7.1 Knowledge of plants that produce natural nitrification inhibitors is limited, as is the route by which these traits could be bred (or otherwise transferred) into agriculturally important crops.

6.5 Use of cloned animals

Dairy	Cattle & sheep	Pigs & poultry	Cereals	General cropping	Horticulture	Mixed
✓	✓	✓				✓

6.5.1 Number of farms potentially affected by practice: 145 thousand.

6.5.2 **Description**

6.5.2.1 Use of cloning technologies to increase the number of animals with desirable characteristics, e.g. low residual feed intake/low CH_4 emission animals (Hegarty et al., 2007).

6.5.3 **Rationale**

6.5.3.1 Cloning would be a means of achieving more rapid breeding by allowing sufficient semen from desirable sires to be produced. This would be particularly advantageous for artificial insemination of pigs, where semen volume is relatively low and a number of identical sires could be created to produce sufficient semen supplies. The method could also be applied to bulls (and rams) to ensure continuity of semen supplies when the original animal dies. Maternal stock could also be cloned to ensure continuity of bloodlines.

6.5.3.2 Cloning could also be used for productive animals although the technology is not yet at a stage that currently makes this viable (i.e. economic). This might be used to increase numbers of animals that have characteristics that have very low heritabilities. It is likely to be used in the case of animals created by genetic modification.

6.5.4 **Mechanism of action**

6.5.4.1 Somatic cell nuclear transfer is used to transfer the nucleus of a cell from an adult donor animal into an enucleated donor egg. The egg is then stimulated to divide and grow *in vitro* and transferred into a surrogate dam. Embryo transfer methodology in a number of livestock species is now common practice and successful procedure for this stage of the process is well known.

6.5.5 **Potential for applying the method**

6.5.5.1 Apart from current technical difficulties in the cloning process, consumer acceptance of animal cloning in the UK (and the rest of the EU) is likely to be the biggest factor in terms of applying this method.

6.5.5.2 Assuming consumer acceptance, this method could be applied to all livestock sectors.

6.5.6 **Practicability**

6.5.6.1 Cloning mammals is a highly specialised process, although it is being commercialised and is likely to become more commonplace. Initial uptake would most likely be through breeding companies, although with increased routine practice, widespread use in livestock farming may become possible in the same way as AI and embryo transfer are now common practice.

6.5.7 Knowledge gaps

6.5.7.1 A number of companies worldwide offer commercial cloning services, although technological challenges remain. This is an area of heavy scientific investment, particularly in North America. A potential downside to cloning would be a reduction in genetic diversity to enable breeding programmes to continue, although this is likely to be of limited concern outside of breeding programmes.

6.6 Genetic manipulation of livestock

Dairy	Cattle & sheep	Pigs & poultry	Cereals	General cropping	Horticulture	Mixed
✓	✓	✓				✓

6.6.1 Number of farms potentially affected by practice: 145 thousand.

6.6.2 **Description**

6.6.2.1 Use of genetic manipulation (GM) technologies to create transgenic livestock that produce fewer GHG emissions during their lifetimes.

6.6.3 **Rationale**

6.6.3.1 Genetic manipulation could be used to increase the speed of current breeding programmes, e.g. to increase growth rates or milk yields, or improve disease resistance or to introduce new traits that would otherwise not be possible, e.g. introduce CH_4 inhibiting enzymes into ruminant salivary secretions.

6.6.4 **Mechanism of action**

6.6.4.1 Transgenic animals are produced by introducing DNA with required traits into the genome of pre-implantation embryos (Wheeler, 2007). There are numerous potential applications of this technique to reduce GHG emissions, including increased milk yields and faster growth rates, reduced residual feed intake, reduction of CH_4 output, increased efficiency of N digestion, reduced NH_3 production, increased disease resistance, and improved animal fertility.

6.6.4.2 Golovan et al. (2001) showed that transgenic pigs secreting salivary phytase produce low-phosphorus manure. Similarly, the addition of enzymes to the salivary secretions of ruminants could reduce CH_4 production and make more efficient use of rumen degradable protein, perhaps by selectively defaunating the microbial population or reducing amino acid deamination. Transgenic dairy cows secreting the antibiotic lysostaphin in milk resisted mastitis infections by *Staphylococcus aureus* (Donovan et al., 2005, Wall et al., 2005). Mastitis is one of the main causes of reduced milk production in dairy cows, leading to loss of efficiency and reduced longevity. Resistance of breeding/lactating livestock to common diseases would increased their robustness and reduce the requirements for replacement animals.

6.6.5 **Potential for applying the method**

6.6.5.1 Apart from current technical difficulties in the processes involved in creating transgenic animals, consumer resistance of GM crops in the UK is likely to be reflected – perhaps to a greater degree – in resistance of GM livestock. This is likely to have the greatest influence in terms of applying this method.

6.6.5.2 Assuming consumer acceptance, this method could be applied to all livestock sectors with appropriate applications.

6.6.6 **Practicability**

6.6.6.1 Genetic modification of animals is a highly specialised field. However, once a trait is introduced it is permanent.

6.6.7 **Knowledge gaps**

6.6.7.1 Genetic modification of animals (and plants) is still highly unpredictable. Identification of genes controlling the desired trait is the first step, and this is frequently very difficult – traits such as growth rate and milk production are controlled by many different genetic factors and interactions with the animal's environment. Incorporation of genes controlling these traits is also unpredictable, as is subsequent expression and efficiency of action, i.e. successful incorporation of a gene into an animal's genome does not mean that it will have any (or the expected) effect.

7 KEY KNOWLEDGE GAPS

7.1 At present, the structure and methodology of the UK IPCC inventory is principally driven by livestock number and fertiliser use statistics, and gives no ‘credit’ for improvements in management practices. There is a pressing need to develop smart inventory emission factors for N_2O, CH_4 and CO_2, that could be used to underpin the IPCC Tier 2 methodology. In particular, there is a need to develop smart emission factors for:

- Variable rate mineral fertiliser N applications. Some field work on grazed grassland and cereals is on going in Defra project AC0101 – this needs to be expanded to a wider range of crop types and environmental conditions etc. This non-linearity would have to be accommodated in any *smart* inventory
- Manure application timing on heavy clay soils. Previous field work has concentrated on sandy soils where emission reduction benefits are likely to be lower than from heavy (poorly drained) soils that predominate in the UK.

7.2 There is a need to carry out field-based experiments to quantify the potential of nitrification inhibitors to mitigate N_2O emissions from mineral fertiliser N and manure applications to land and grazed pastures, and associated potential benefits to crop N use efficiency and water quality improvements.

7.3 There is a need to develop improved mineral fertiliser N application timing policies that explicitly aim to reduce N_2O emissions.

7.4 There is a need to undertake a comprehensive lifecycle assessment of the GHG abatement potential of anaerobic digestion (AD) – including the use of digestate as a substitute for mineral fertiliser - and biomass/biofuel crops.

7.5 There is a need to assess the environmental footprint of AD digestate use compared with ‘raw’ manure – such studies should cover CH_4, N_2O and NH_3 emissions to air, NO_3 leaching, phosphorus and faecal indicator organism losses to water, and crop N and phosphorus recovery.

7.6 The GHG balance of reduced/zero tillage systems needs to be quantified in field experiments – are soil carbon storage increases outweighed by N_2O emissions?

7.7 There is a need to undertake more work to demonstrate whether specific land management practices can deliver quantifiable and verifiable decreases in carbon emissions and/or increases in soil carbon storage, particularly in the areas of peatland restoration (both upland and lowland) and arable reversion to permanent non-tillage land uses. The work should also encompass potential changes in N_2O (direct and indirect) and CH_4 emissions.

7.8 There is a need to fully explore how dietary manipulation could be used to reduce both direct and indirect GHG emissions from ruminants. This should include the use of feed additives (natural and chemical) with known efficacies, as well as diet formulations to mix and match ingredients to reduce GHG emissions.

7.9 There is a need to update poultry, beef and sheep standards in light of modern agricultural practices and requirements to reduce pollutant emissions.

7.10 There is a need to develop integrated models that are able to quantify GHG emissions from whole farming systems – this is a key modelling challenge.

7.11 There is a need for greater knowledge transfer to ensure that farmers and land managers obtain the best practical advice, with appropriate education and training to ensure that this advice is used.

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