Agricultural greenhouse gas mitigation feasibility study

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Executive summary

Introduction

The Climate Change Act (2008) introduced the 2050 UK target for reduction in greenhouse gas (GHG) emissions of 80% by 2050 from their 1990 level. The English agriculture sector in 2008 produced about 27.5M tCO_2e or 5.7% of all English GHGs[1]. In 2008 the agriculture sector in England was the source of 30% of English emissions of methane and 71% of English emissions of nitrous oxide.

An Agriculture Industry GHG Action Plan (GHGAP) has proposed a framework to reduce emissions from agriculture in England by 3M tCO_2e per annum from a 2008 baseline by the third budget period, 2018-22. The broad methods identified in the GHGAP relate to the management of nutrients and livestock. The 3M tCO_2e target came from a preliminary assessment of the Marginal Abatement Cost Curve for Agriculture (Project RMP4950 or MACC 1) that considered the initial estimates for abatement potential to be too high.

Direct emissions from the Agriculture, Forestry and Land Management (AFLM) sector are a consequence of growing crops and keeping livestock. Nitrogen from manures and fertiliser spread on crops and grassland increases the nitrogen in the system and leads to emissions of nitrous oxide. Cattle produce methane from fermentation in their digestive system. Modern high-input and high-output farming systems increase emissions per unit of input but efficiency gains mean that emissions per unit of output (grain, milk, meat) are reduced. The challenge is to reduce emissions from UK agriculture without reducing production.

Objectives

The project objectives were to identify farm level mitigation methods (MM) with the largest amount of cost effective mitigation and evaluate the economic and practical considerations for implementation at a farm level for a range of farm types and sizes. An assessment of the potential to increase abatement from these MMs required estimates of the current levels of uptake. Finally, the study aimed to identify the main drivers and barriers for changing practice at a farm level and evaluate the implications for maximising farm level GHG mitigation. The project covered England only.

Methodology

Four projects (RMP4950 also known as MACC 1, an unpublished update of RMP4950 also known as MACC 2, AC0206 and WQ0106) were reviewed to list the main mitigation methods (MMs) that have been considered for GHG reductions in the agriculture sector. The 67 MMs therein frequently overlapped and by applying a set of selection criteria, seven mitigation themes were identified. These were translated into 15 practical MMs (PMMs) that could be presented within a farmer survey and focus groups.

A model was developed to evaluate the economic consideration by farm type and size. Given the similar costs for some of these practical MMs, some were combined to produce 11 costed PMMs (CPMMs) that were used within the economic analysis.

[1] Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland: 1990 - 2008
S Sneddon, N Brophy, Y Li, J MacCarthy, C Martinez, T Murrells, N Passant, J Thomas, G Thistlethwaite, I Tsagatakis, H Walker, A Thomson and L Cardenas

The CPMMs were assigned to relevant farm types resulting in 50 combinations of CPMM and farm type. Most of these scenarios were evaluated for small, medium, and large farm sizes.

A telephone survey was conducted with 751 farmers of >0.5 Standard Labour Requirement (SLR) from 6 robust farm types – dairy, lowland beef and sheep, Less Favoured Area (LFA), beef and sheep, mixed, cereals and general cropping - and three farm sizes, to understand current uptake, drivers and barriers for uptake. Three focus groups were held, one arable, one dairy and one beef and sheep in order to explore key issues in depth. Depth telephone interviews were also conducted with pig and poultry farms. Please note any views or comments expressed in interview were wholly that of the respondent and do not necessarily represent that of Defra or its policies.

The evaluation model used Farm Business Survey financial data and estimates of potential uptake of each MM to evaluate the financial impact on each farm type and size. The potential for the implementation of the MMs to reduce CO_2e emissions were estimated from the stakeholder survey and applied to emission estimates from the CALM farm level emission model to estimate emission reductions from each MM. Two levels of uptake were analysed, a lower model and a maximum model. The lower model used the minimum potential uptake from the survey, i.e. excluding those who indicated they would not change practices, while the maximum model used the total numbers who currently do not implement the MM, along with those who may not be implementing it fully.

Findings

Mitigation method identification and selection

Seven mitigation themes were identified, with 15 practical mitigation methods (PMMs) of which 11 were taken through to costing analysis as costed practical mitigation methods (CPMMs) (Table ES 1)

Table ES 1 Mitigation methods for analysis

Mitigation theme	Practical mitigation method (PMM)	Costed PMM (CPMM)
Avoid excess nitrogen	a. Use N planning tool	CPMM1: RB209
	b. Estimate soil mineral nitrogen levels	CPMM2: Measure soil N
	c. Calibrate fertiliser spreader every year	CPMM3: Calibrate spreader
	d. Take account of N from manures	CPMM4: Manure N supply
Nitrogen timing	e. Avoid N fertiliser before crops start growing f. Avoid N fertiliser for 5 days after heavy rain g. Avoid N fertiliser for 5 days after manure applications h. Apply N fertiliser over 2 or 3 application timings	CPMM5: N Timing
Manure timing	i. Avoid manures before crops start growing	CPMM6: Manure timing
Crop choice	j. Include clover in grassland mixes	CPMM7: Clover
	k. Grow low N crops	CPMM8: Grow triticale instead of feed wheat
Livestock breeding	l. Dairy – use of bulls with high Profitable Lifetime Index (PLI) m. Beef – use of bulls with high Estimated Breeding Value (EBV)	CPMM9: Livestock breeding improvements
Livestock feeding	n. Use ration planning system	CPMM10: Optimal diet
Anaerobic digestion (AD)	o. Use of anaerobic digestion facilities	CPMM11: Anaerobic digestion

Current uptake

There was little previous direct evidence of current uptake levels of the practical mitigation methods. The survey conducted amongst farmers of >0.5 SLR within the six robust farm types gave an indication of current and potential uptake the specific PMMs. Uptake varied between 0% and 87% for different MMs (Table ES 2), however there were also differences within each MM for different farm types. There were few significant differences between farm sizes within each farm type in level of uptake.

Table ES 2 Current uptake

Mitigation theme	Practical mitigation method (PMM)	Estimated current uptake from survey (use all or most of the time)	
		% total farms surveyed	Comments
Avoid excess nitrogen	a. Use N planning tool	34%	Uptake higher on arable farms (66-72%) and larger farms
	b. Estimate soil mineral nitrogen levels	55%	Uptake higher on arable farms (78-85%)
	c. Calibrate fertiliser spreader every year	80%	Uptake very high on arable farms (97%) but lower on livestock (65-68%)
	d. Take account of N from manures	87%	Uptake higher on arable farms (96%) but lower on livestock (74-88%)
Nitrogen timing	e. Avoid N fertiliser before crops start growing	85%	Uptake higher in arable farms (87-92%)
	f. Avoid N fertiliser for 5 days after heavy rain	76%	Similar for all farm types
	g. Avoid N fertiliser for 5 days after manure applications	86%	Higher likelihood in general cropping farms (97%)
	h. Apply N fertiliser over 2 or 3 application timings	78%	Cattle and sheep farms least likely (51%)
Manure timing	i. Avoid manures before crops start growing	70%	Similar for all farm types.
Crop choice	j. Include clover in grassland mixes	80%	80% had some clover, 62% had at least 20% of area with clover Dairy farms more likely than others (5%)
	k. Grow low N crops – triticale instead of feed wheat	3%	
Livestock breeding	l. Dairy – use of bulls with high Profitable Lifetime Index (PLI)	56%	No significant differences between farm sizes
	m. Beef – use of bulls with high Estimated Breeding Value (EBV)	23%	
Livestock feeding	n. Use ration planning system	50%	Higher in dairy farms (71%)
Anaerobic digestion (AD)	o. Use of anaerobic digestion facilities	0%	Similar for all farm types

Economic evaluation of the PMMs

The economic model combined the **net cost** of implementing the CPMMs with **farm level carbon emissions**, and estimates of the **mitigation efficacy** of the MMs to produce farm level estimates of the **cost effectiveness of GHG reductions**. The farm level estimates were scaled up using Farm Business Survey data (2008/09) to produce industry level estimates.

The model schematic of MM evaluation is presented in Figure 1 (p34) of the main report.

Maximum estimates were derived from all those currently not adopting the method i.e. all farmers implementing the method all of the time. **Lower estimates** were derived by excluding from the maximum estimate those who indicated that they would not be willing to change.

The total estimated mitigation potential by farm type and size shows that the large dairy farms have the highest potential mitigation, with the smallest contribution from general cropping (Table ES 3). Total estimated mitigation potentials do not take into account interactions between measures and thus total potentials may be lower. Quantifying the effect of these interactions would involve extensive further research and consequently was outside the scope of this project.

Table ES 3 Mitigation potential by farm type and size of CPMMs 1-10 (based on 2008/09 farm business survey data)

Farm Type from FBS	Farm Size	Lower		Maximum	
		% of total mitigation potential	Total mitigation potential (M tCO_2e)	% ot total mitigation potential	Total mitigation potential (M tCO_2e)
Dairy	Small	4%	0.024	4%	0.061
	Medium	5%	0.033	6%	0.097
	Large	18%	0.110	19%	0.320
Lowland cattle and sheep	Small	6%	0.035	8%	0.130
	Medium	3%	0.017	3%	0.059
	Large	4%	0.027	6%	0.100
LFA cattle and sheep	Small	4%	0.027	5%	0.084
	Medium	3%	0.018	3%	0.059
	Large	5%	0.032	6%	0.100
Mixed	Small	3%	0.021	3%	0.059
	Medium	3%	0.016	3%	0.046
	Large	9%	0.055	9%	0.160
Cereal	Small	6%	0.038	5%	0.085
	Medium	5%	0.032	4%	0.071
	Large	11%	0.065	9%	0.150
General cropping	Small	2%	0.013	2%	0.028
	Medium	1%	0.008	1%	0.018
	Large	7%	0.040	5%	0.086
Total mitigation potential			**0.611**		**1.713**

Due to the large capital investment required, anaerobic digestion was treated separately in the cost evaluation. Mitigation potential was estimated at 6,500 tCO_2e per annum from installation of 1000 farm-based units.

The mitigation potential and cost effectiveness of each MM at an industry level shows that a number of CPMMs were shown as having greater than 100,000 tonnes of mitigation potential per annum but only two of these were estimated to produce such mitigation when lower levels of uptake were assumed - the inclusion of clover, and livestock breeding improvement (Table ES4). The high potential for low N use crops reflects the low level of current uptake. All three of these methods had estimated negative cost effectiveness per tonne of CO_2e abated, which results in a net benefit to farmers implementing the method.

Four of the 10 on-farm CPMMs were estimated to cost farmers money to implement – measure soil N, spreader calibration, N timing, and manure timing. The costs associated with these CPMMs are annual costs to the farmers. Whilst these might not be expected to be taken up voluntarily due to the cost, they represent almost 30% of the total reduction potential.

Table ES 4 Potential mitigation, cost and effectiveness by MM

CPMM	Total M tCO_2e Reduced		Total Cost		Cost per tCO_2e	
	Lower	Maximum	Lower	Maximum	Lower	Maximum
1: Fertiliser planning, RB209	0.052	0.123	-£0.6m	-£1.2m	-£14	-£11
2: Estimate Soil N	0.045	0.086	£10.8m	£23.6m	£259	£297
3: Spreader calibration	0.015	0.030	£2.9m	£7.2m	£231	£261
4: Manure N Supply	0.004	0.013	-£0.2m	-£0.7m	-£59	-£58
5: N Timing	0.084	0.220	£4.9m	£13.1m	£63	£64
6: Manure Timing	0.020	0.109	£1.2m	£7.2m	£66	£72
7: Clover	0.135	0.301	-£18.3m	-£40.1m	-£152	-£150
8: Grow triticale instead of feed wheat	0.075	0.151	-£8.3m	-£16.5m	-£114	-£115
9: Livestock Breeding	0.109	0.452	-£13.5m	-£63.7m	-£132	-£154
10: Optimal Diet	0.062	0.227	-£6.3m	-£23.0m	-£89	-£88
Total	**0.601**	**1.710**				

Green	Total CO_2 e reduced > 0.150M tpa, total costs > -£25m, cost effectiveness per tonne > -£100
Amber	Total CO_2 e reduced 0.050M – 0.150M tpa, total costs -£25m - £0m, cost effectiveness per tonne -£100 - £0
Red	Total CO_2 e reduced < 0.050M tpa, total costs > £0m, cost effectiveness per tonne > £53

The cost effectiveness of anaerobic digestion was very high at over -£4000/tCO_2e

Drivers of uptake

The primary reasons for MM adoption by those that had already adopted the measures was financial benefit. This often came directly through savings in fertiliser from correct planning and accurate spreading, or improved crop growth and production.

There were also market drivers such as the adoption of spreader calibration by the arable farms, driven by the farm assurance requirements which has encouraged high uptake despite the associated costs, although some arable farmers perceive that there is a direct benefit in saving fertiliser and improving crop production through reduced overlaps.

Good farming practice and the 'right thing to do' were also frequently mentioned by farmers who adopted the measures, putting a social focus on the effective drivers.

Barriers to uptake

It was clear from the general questions in the survey on understanding of greenhouse gases that there was often poor understanding of emissions from agriculture, and the importance of nitrous oxide. Only 11% mentioned N_2O as a greenhouse gas and there was poor recognition of nitrogen fertiliser as a source. Understanding was generally lower in the livestock sectors and the smaller farms. Over half the respondents did not feel it was important to consider greenhouse gases when making decisions. This was reflected in comments in the focus groups:

> *"Well it's not making any difference to our business it's just another pain" Cattle and sheep farmer*

> *"We daren't do any more than we need to do, it costs money" Arable farmer*

This lack of knowledge and awareness surrounding fertiliser use is a key barrier to improvements in fertiliser use.

There are significant barriers to further uptake of the MMs with a high proportion of farmers who currently do not adopt the MMs stating that there was nothing that would encourage them to implement the measures, with over two thirds unwilling or unable to change.

The barriers to uptake vary for each MM and farm type. For the simpler management methods such as nitrogen planning the main barriers were about knowledge and skills, but for nitrogen timing the weather was the main determinant in application timing, while for slurry applications, storage capacity was a main problem.

For the MMs that required a greater degree of change to the farming system, such as growing the low nitrogen crop triticale, the barriers included the poor returns from the crop despite lower inputs, and the difficulties in marketing. Local experience with the crop was a strong influence on attitudes.

Farmers' reliance on previous experience may also be a barrier to further uptake.

Caveats/limitations

MM selection

The MMs selected were based on previous work, but this covered most options for effective abatement. The project included only MMs associated with methane and nitrous oxide emissions, so those associated with carbon emissions or sequestration were not included. The MM selection criteria also excluded a range of MMs that are currently not an option due to EU regulation e.g. growth hormones (bovine somatotropin – bST), or too uncertain, e.g. drainage

Stakeholder consultation

The survey was designed so that there were equal numbers of each of the main farm types, and equal number of each farm size within farm type. This allows comparison between farm types and sizes but is not representative of the whole farm population without weighting.

The survey did not measure whether the MMs were being implemented correctly or to maximum effect. Similarly, the focus groups highlighted the reliance on experience of farmers, and this may mean that mitigation benefits might be achieved without formal use of MMs as measured in the survey.

The survey may have generated some false positive responses, with farmers saying what they know they ought to be doing. Because of the opportunity to opt out, there may be some bias to those with a more positive attitude compared with a random response.

Costs of MM implementation

MMs can be implemented in a variety of ways and the costs estimated here reflect just one of these. Amongst other things, implementation will reflect local conditions, the available capital and manpower, and the level of knowledge.

Little previous work has been carried out on actual costs of CPMMs so the costs were largely based on standard costs and personal communication with operatives in the field.

MM Abatement potential

Much of the abatement potential of the MMs is a product of the expert judgements made within the review of MACC 1[2] (referred to from this point forward as MACC 2). with some experimental evidence (referenced in AC0206, RMP4950). Supporting evidence from AC0221 is also used[3].

In line with variable costs of implementation, farms vary greatly in their physical characteristics, structure and management. As such it can be expected that the effectiveness of the MMs in reducing GHG emissions will similarly vary.

The model can be updated as new information becomes available.

Key Conclusions

- GHG mitigation from agricultural practices can contribute to the Government targets, however the level is lower than previous reports suggest.
- There is a low understanding by farmers of the importance of nitrous oxide in GHG emissions from agriculture.

[2] Review and update of the UK marginal abatement cost curves for agriculture (Committee on Climate Change, 2010)
[3] There is an existing programme of work ongoing that will further inform abatement potential – AC0213on nitrification inhibitors and AC0209 on dietary manipulations

- Of the MMs reviewed, the largest potential mitigation comes from increasing the use of clover in grass leys, the growing of low N use crops and improving livestock breeding.
- These all require strategic changes, and are dependent on factors such as the development of markets for low N crops, or reliable breeding information, but do offer a positive impact on farm income.
- Simple management changes, such as nitrogen and manure planning and timing, are often the implementation of best farm practice, but offer less GHG mitigation potential and some carry a net cost at a farm level.
- Economics and regulation are key drivers to current uptake of MMs and those with largest uptake have a positive impact on farm incomes, or have market or regulatory drivers e.g. requirement for fertiliser spreader calibration for arable crop assurance.
- Increasing awareness, acknowledgement of value of experience, and local evidence of successful practical application and benefits can encourage increased uptake.
- There are additional barriers for small farms and in the beef and sheep sectors where their perception of MMs is that they have high costs.

Summary of policy considerations

Key findings are summarised in table ES5.

Table ES 5 Summary of GHG impacts, costs to industry, level of uptake and key priorities to encourage uptake

CPMM	GHG reduction potential	Net cost to industry	Level of current uptake	Likelihood of increased uptake	Key measures to increase uptake	Recommended priority for future Defra attention
1:Fertiliser planning RB209	++	-	Moderate (cropping) Low (livestock)	Low (unless required in NVZ)	• Major challenge is encouraging change on beef and sheep farms • Better economic justification	Medium
2: Estimate Soil N supply	+	+	Moderate	Low	• Better economic justification, especially on small farms and beef/sheep	Medium
3: Spreader calibration	+	+	High (cropping) Moderate (livestock)	Low	• Better economic justification, especially on small farms and beef/sheep	Low
4: Manure N Supply	+	-	High (where manures applied)	Low	• Better economic justification, especially on small farms and where little manure used	Moderate
5: N Timing	+	+	High	Low (unless benefits shown)	• Better evidence on impact • More incentive/economic justification	Moderate
6: Manure Timing	+	+	Moderate	Moderate	• Need more information on benefits • Better economic justification	Moderate
7: Clover	+++	--	High (especially on dairy)	Moderate	• Include in schemes	High
8: Grow low N use crops (triticale)	+++	---	Very low	High (after initial barriers to uptake are overcome)	• Validate impacts and benefits • Improved education surrounding low N crops. • Work with supply industry to encourage demand • Overcoming short term barriers (such as education and awareness) is likely to result in higher uptake in the long term.	High

CPMM	GHG reduction potential	Net cost to industry	Level of current uptake	Likelihood of increased uptake	Key measures to increase uptake	Recommended priority for future Defra attention
9: Livestock Breeding Improvements	+++	--	Moderate (dairy) Low (beef and sheet)	Low	• Better evidence of economic impact	Moderate
10: Optimal Livestock Diet	++	-	Moderate (dairy) Low (beef and sheet)	High	• Better understanding of opportunities and advice • Better evidence and justification	High
11: Anaerobic Digestion	N/A	--	Low	Moderate/High	• Needs evidence that outputs can be used cost-effectively and in environmentally beneficial manner • Demonstrate how can be integrated in nutrient management plans	High

GHG reduction potential	Key		Cost to the industry	Key
Some reductions possible	+		Small net cost to industry	+
Reasonable reductions possible	++		Small net benefit to industry	-
Good reductions possible	+++		Medium net benefit to industry	--
			High net benefit to industry	---

Contents

1. Introduction

The Committee on Climate Change advises the Government on emissions targets, and reports to Parliament on progress made in reducing greenhouse gas emissions to meet the Climate Change Act (2008) commitment to reduce UK greenhouse gas (GHG) emissions by 80% by 2050 compared to the 1990 level. The agriculture sector accounts for around 5.7% of all GHG emissions in the England and abatement in this sector will contribute to the overall target.

A report by SAC in 2008 (Project RMP4950) reviewed the UK marginal abatement cost curves for the AFLM sector to 2022 and a scenario analysis for possible abatement options to 2050. The key outcomes from the report were a list of priority mitigation methods (MMs) for reducing greenhouse gas emissions in the sector based on maximum technical potential (MTP).

ADAS then conducted an analysis of policy instruments (PIs) for reducing greenhouse gas emissions from the AFLM (Project RMP5142). This report placed the MMs as defined by SAC within a broad range of policy options to evaluate the potential for policy to deliver emissions reductions.

Project RMP4950 focused on the mitigation per unit (head/hectare) and extent to which the method could be applied (total area or numbers of stock) and the maximum potential for reducing GHG emissions. There was no detailed analysis of the full costs of implementation, the cost impacts in different farming systems, the current level of uptake and implementation, or what might make particular mitigation methods more attractive to farmers in different farming systems. This project aimed to undertake this analysis.

2. Objectives

The overall aim of this project was to identify the MMs to reduce GHG emissions in the agriculture sector in England that have the greatest contribution to reduced emissions and to assess their implementation, costs and barriers over a range of farm types and sizes in order to provide evidence for policy development.

Specific objectives were:

- Evaluate and identify GHG MMs with lowest costs-biggest potential impact in the agriculture sector.
- Understand the practical and economic considerations at a farm level for a range of farm types and sizes.
- Understand the current level of uptake of MMs.
- Identify the main barriers/drivers for changing practice at a farm level and evaluation of implications for maximising GHG mitigation.

This project covers England only.

3. Methodology

3.1 Overview

The MMs which are most likely to result in the cost-effective reduction in GHG emissions were identified from previous projects and were evaluated to identify variation in practical and economic impacts, and efficacy in reducing GHG emissions. The current levels of uptake of the MMs were reviewed in order to identify those with most scope for further uptake. Stakeholders (farmers) were consulted through a telephone survey, workshop and in depth interviews to test assumptions and identify barriers for uptake. This informed the final evaluation of MMs to understand how the cost of their implementation varies across farm types and sizes. Finally, the results of the economic analysis and the stakeholder consultation were used to identify key policy considerations.

3.2 Detailed approach

3.2.1 Mitigation method selection

The MMs in this project were derived primarily from Defra projects RMP4950 (MACC 1) and its recent (unpublished) update (MACC 2). The MMs were largely in accordance with those used in other concurrent Defra projects AC0221 (Scoping the potential to reduce GHG emissions associated with N fertiliser applied to arable crops) and FFG0918 (Market segmentation in the agriculture sector). The four projects that were reviewed to identify MMs were:

- RMP4950: UK Marginal Abatement Cost Curves (MACC) for the Agriculture, Forestry, Land-use and Land-use Change Sector out to 2022 and Scenario Analysis for Possible Abatement Options out to 2050 (Defra 2008). Referred to in this report as MACC 1.
- Review and update of UK Marginal Abatement Cost Curves for the Agriculture (Report for the Committee on Climate Change, 2010). Referred to in this report as MACC 2.
- AC0206: A Review of Research to Identify Best Practice for Reducing Greenhouse Gases from Agricultural and Land Management (Defra 2007).
- WQ0106 Module 6: Quantitative Assessment of Scenarios for Managing Trade-Off Between Economics, Environment, and Media (Defra 2009).

The first three reports were specifically aimed at GHG mitigation, whereas the fourth was concerned with diffuse pollution and considered the impacts of MMs on a range of pollutants including GHGs.

In previous projects MMs were described in broad terms such as “avoid nitrogen excess’. In this project, and other current projects AC0221 and FFG0918, there was a requirement for the MMs to be more closely defined in order to assess scope for implementation at the farm level. This allowed a greater degree of focus on particular actions, but also resulted in some potential actions being excluded.

Final choices of MMs and their descriptions varied in this project (AC0222) and related projects AC0221 and FFG0918 to suit the individual project requirements.

This project had a focus on the economic feasibility of MMs and the associated abatement.

There were 67 MMs described in the previous reports, excluding those deemed to have limited scope for GHG reductions, or were illegal or technically impossible, and they are presented with varying degrees of detail. This list was refined for further analysis using the following selection criteria stages:

Preliminary filter criteria:

1. *Is emission reduction achieved through sequestration and/or land use change?*

   MMs that achieve GHG reductions through sequestration or land use change are beyond the scope of this project and were not included.

2. *Are the emission reductions achievable across the agriculture industry?*

   Any MMs that were very specialised to a particular sector were not included.

3. *Are the emission reductions achievable within a reasonable timescale i.e. within the second and third carbon accounting budget periods?*

The shortlist aimed to include both current methods and future methods but all achievable at some level by 2022. Current methods are those that have already been adopted to some extent (although how much is the subject of some uncertainty but addressed within this project) by some farms but have potential for further uptake. Future methods are those that have lower levels of current uptake, and may require a more significant change in management practices, but could be adopted widely.

Methods that passed these criteria were then scored using the following fine filter criteria:

***Fine filter criteria**:*

1. *Potential mitigation over time*

   Potential mitigation within the time periods up to 2012, 2017 and 2022 (as estimated in the previous reports) were used to estimate the expected annual mitigation, to select those that had the highest potential mitigation. MMs were scored for different emissions and time periods. For example. if emission reduction was more than 50k tonnes by 2012, more than 100k tonnes by 2017 and/or more than 150k tonnes by 2022 then the MM achieved a positive score for each. The emission reduction of 150k tonnes by 2022 represents 5% of the 2018-22 annual target reduction for agriculture[4].

[4] Agriculture Industry GHG Action Plan (2010) Framework for Action

2. *Cost-effectiveness*

   Any MM that had cost-effectiveness below the cost of carbon emissions, achieved a positive score. Values for carbon from Department of Energy and Climate Change (DECC)[5] were used to provide the threshold for cost-effective MMs, using the non-traded sector carbon value (those emissions not covered by the EU Emissions Trading Scheme). This new approach moves away from a valuation based on the damages associated with impacts, instead using the cost of mitigation as its basis. More precisely, the new approach will set the valuation of carbon at a level that is consistent with the UK Government's targets in the short and long term. The carbon value for 2012 from the DECC report is £53/t CO_2e. The variation in estimated cost effectiveness of the MMs from the above reports did not vary greatly through time. MMs that had a cost effectiveness below the DECC carbon value was therefore scored positively since they reduce emissions at a cost below the cost of carbon.

3. *Practicality*

   - All MMs selected were practical to implement at a farm scale by the third UK carbon accounting budget period (by 2022), and had the potential be adopted or used by a high proportion of farms. An expert opinion panel was used to make these assessments.

These course filter and fine filter selection criteria produced **7 mitigation method themes** with **15 practical mitigation methods** (PMMs) for further analysis. In the costings model, these practical mitigation methods were consolidated into those that had a similar economic impact in order to avoid double counting. These are termed **costed practical mitigation methods** (CPMMs) with 11 identified for further analysis (Table 1).

Detailed descriptions of the CPMMs can be found in Appendix 1.

[5] *Carbon Valuation in UK Policy Appraisal: A Revised Approach* (DECC, 2009)

Table 1 Mitigation themes and methods

Mitigation theme	Practical mitigation method (PMM)	Costed PMM (CPMM)
Avoid excess nitrogen	a. Use N planning tool	CPMM1:RB209
	b. Estimate soil mineral nitrogen levels	CPMM2:Measure Soil N
	c. Calibrate fertiliser spreader every year	CPMM3: Spreader
	d. Take account of N from manures	CPMM4:Manure N supply
Nitrogen timing	e. Avoid N fertiliser before crops start growing f. Avoid N fertiliser for 5 days after heavy rain g. Avoid N fertiliser for 5 days after manure applications h. Apply N fertiliser over 2 or 3 application timings	CPMM5: N Timing
Manure timing	i. Avoid manures before crops start growing	CPMM6: Manure Timing
Crop choice	j. Include clover in grassland mixes	CPMM7: Clover
	k. Grow low N crops	CPMM8: Grow triticale instead of feed wheat
Livestock breeding	l. Dairy – use of bulls with high Profitable Lifetime Index (PLI) m. Beef – use of bulls with high Estimated Breeding Value (EBV)	CPMM9: Livestock Breeding Improvements
Livestock feeding	n. Use ration planning system	CPMM10: Optimal Diet
Anaerobic digestion (AD)	o. Use of anaerobic digestion facilities	CPMM11: Anaerobic Digester

Context with other projects

Defra project AC0221, "Scoping the potential to reduce GHG emissions associated with N fertiliser applications to arable crops", ran concurrently with this project. It provides detailed analysis of the potential mitigation of a greater range of nitrogen timing aspects including avoiding autumn nitrogen and moving 3rd nitrogen split application 30 days earlier, along with analysis of the scope to reduce emissions through improving the precision of fertiliser use and use of nitrogen efficient varieties/species, including triticale in place of a proportion of second wheat crops.

Defra project FFG0918, "Market segmentation in agriculture" ran concurrently with this project. It reviewed the barriers to uptake based on farmer behavioural segmentation and recommends policy approaches to drive the process of cutting emissions. It used the same MMs as this project (Table 1) with some additions of MMs that may have some future potential.

3.2.2 Farm types and farm size

Robust farm types from the Defra Farm Business Surveys[6] were used as the base for farm level economic analysis. These robust farm types were: cereals, general

[6] http://www.farmbusinesssurvey.co.uk/index.html (March 2010)

cropping, dairy, mixed, Less Favoured Area (LFA) beef and sheep, lowland beef and sheep, horticulture, pigs, poultry, other.

However, only six farm types were taken forward for analysis - cereals, general cropping, dairy, mixed, LFA beef and sheep and lowland beef and sheep – and a minimum standard labour requirement (SLR) of 0.5 SLR.

Horticulture was excluded as there are few (if any) MMs in the literature that relate to horticulture other than energy use. Pigs and poultry were excluded from the telephone survey due to a low number of farms; however they were included in depth interviews in order to assess attitudes and potential barriers.

The focus on six farm types and farms >0.5 SLR represents approximately 36,000 farms out of a total of almost 60,000 farms of all farm types >0.5SLR and 120,000 farms including those <0.5SLR.

It is important to note that the land area covered by this analysis accounts for around 80% of the land area that was included in MACC 1 and MACC 2 projects but this varies by crop (e.g. the scaled up area in this project for winter wheat is 1.61m ha as compared to 1.82m in the MACC projects and 2m ha versus 3m ha for permanent grass).

3.2.3 Scenarios for evaluation

Approximately 50 scenarios were identified based on six farm types and appropriate mitigation methods (Table 2). Each of these scenarios was reviewed over three farm sizes where appropriate, increasing the total scenarios to 150.

CPMM11 Anaerobic Digestion, was included in the evaluation, but was costed using a different methodology as it required significant investment for uptake.

Table 2 Scenarios for farm level costing analysis

	Robust farm type					
	Cereal	General crops	Dairy	Beef & sheep upland	Beef & sheep lowland	Mixed
Costed Practical Mitigation Method						
1: N Management Plan: RB209	✓	✓	✓	✓	✓	✓
2: Measure Soil N	✓	✓	✓	✓	✓	✓
3: Fertiliser Spreader Calibration	✓	✓	✓	✓	✓	✓
4: Make Full Allowance for Manure N Supply	✓	✓	✓	✓	✓	✓
5: Improve Mineral N Timing	✓	✓	✓	✓	✓	✓
6: Improve Manure Timing			✓			
7: Use Clover in place of Grass			✓	✓	✓	✓
8: Grow low N use crops	✓	✓				✓
9: Livestock breeding improvement			✓	✓	✓	✓
10: Optimum diet formulation			✓		✓	✓

3.2.4 Literature review

A review of survey information and other sources including expert opinion, was undertaken to evaluate changing uptake of MMs since 1990 and potential for further uptake. Survey sources included the Defra Farm Practices Surveys and ADAS Farmers' Voice. Where no survey or other reliable source of information was available, an estimate was made based on a range of expert opinions.

3.2.5 Stakeholder consultation

Telephone interviews

The telephone survey was designed to provide awareness of the main GHG emissions from farms, current uptake of MMs, reasons for current use of MMs and factors which would encourage greater uptake.

Telephone interviews (751) were conducted amongst farmers across five farm types, namely cereals, general cropping, dairy, LFA beef and sheep and lowland beef and sheep. Interviews were conducted with 150 farmers from each type to enable analysis by farm type. Within each farm type 50 interviews were conducted with each of 3 farm size groups, i.e. small, medium and large farms.

The survey was designed and managed by ADAS in conjunction with a market research specialist, working to the MRS code of conduct. The interviews were conducted by a specialist interviewing agency. Each interview lasted up to 10 minutes and was conducted via CATI (computer assisted telephone interviewing). In line with the requirements of Defra survey control the survey was preceded by a mailing to allow farmers to opt out of the survey.

Respondents to the survey were cross-referenced to the specific river basin district (RBD) areas to identify spread but sample sizes were too small to analyse results by each RBD.

Focus groups and depth interviews

In order to explore and fully understand barriers to the use of GHG mitigation measures, 3 focus groups together with 10 telephone in-depth interviews were conducted once the telephone interviews had been completed and the topline results reviewed.

The focus groups were held amongst the main farm type groups i.e. cereals and general cropping (Lincoln), dairy (Cheshire), and beef and sheep (Herefordshire). In addition depth interviews were conducted amongst pig & poultry farmers across England.

The groups and depth interviewees were recruited from the contact lists provided by Defra. Respondents from the telephone survey were asked if they would be willing to take part in further research and only those willing to take part were re-contacted.

The focus groups comprised approximately 8 farmers and lasted up to 2 hours. The depth interviews lasted 20-30 minutes. The sessions were lead by an experienced moderator working with an ADAS technical expert.

3.2.6 Farm costs of MMs

Costs of each MM for each farm type were estimated on a partial budget basis[7], identifying the changes in costs and/or savings of adoption on a unit basis – per hectare or per head. These are referred to as net costs which can be positive or negative. The net cost calculation also included changes to revenue if the method gave rise to changes in production. Costs were based upon Nix[8] (2010) and prices taken from current trade press. In some cases ADAS sector experts were required to estimate some effects based upon expert knowledge.

The net costs for each method (on a per hectare or per head basis) were scaled to the appropriate robust farm types using the Farm Business Survey (FBS) 2008/09 data based on the average number of hectares and head by farm type and size, to calculate the cost of implementing the method to the whole ‘average’ farm.

The net costs per farm of each CPMM were used in the economic model with farm level effectiveness and current levels of farmer uptake to identify the cost-effectiveness of the MM in terms of GHG mitigation.

3.2.7 Farm level effectiveness

For each farm type and size, data from the FBS 2008/09 was input into the CALM[9] model (Carbon Accounting for Land Managers) to estimate farm level GHG emissions for each of the farm types and sizes. The CALM model is farm activity based and allows the emissions from activities upon which the CPMMs act, to be estimated. Details of the CALM model and rationale for use can be found in Appendix 7.

The farm level effectiveness of each CPMM was then calculated using estimates of abatement potential derived from MACC 2 and other references where appropriate. The abatement potential is the effect on the emissions on which the method acts e.g. the use of RB209 works on N_20 emissions via potentially reducing the amount of fertiliser applied.

This gave an estimate of the level of GHG reductions possible for each CPMM for average farms in each robust farm type.

3.2.8 Current levels of uptake

The CPMM uptake rates used in the model were calculated from the data obtained during the survey. The survey provided data with regard to the numbers of individuals already using the PMM for each farm type, those that did it “always”, “most of the time”, “some of the time”, “rarely” and “never”. Those that said they “always” used the method were assumed to use it 100% of the time and therefore there was no opportunity to expand this method among these individuals. Those that said they used the method “most of the time” were assumed to use it 66% of the time, “some of the time” 33%, “rarely” 5% and “never” 0% of the time. These assumptions may overstate the actual level of uptake since it could be that “always” actually means in excess of, say, 80%. This would have the effect of increasing the potential level of abatement from a CPMM.

[7] Many changes proposed for farm practice affect only part of the business. Only the relevant costs and incomes are included in a partial budget analysis. A change in farm practice will affect specific cost elements and may have an impact on revenue.
[8] The john Nix Farm Management Pocketbook (2010), 40th edition,
[9] CALM is a free web-based calculator designed by the CLA to help land managers work out the balance of greenhouse gases emitted by farming businesses. http://www.calm.cla.org.uk/

Combining the level of uptake with the assumed percentage for each stated level of uptake, showed the proportion of farmers that can either implement the CPMM for the first time or those that can increase the level of implementation e.g. from “rarely” to “most of the time”. The maximum increase in uptake is defined as the difference between the current uptake weighted as above and all farmers “always” implementing the CPMM. This represents the **maximum potential uptake** under a regulatory policy instrument.

To achieve a likely lower potential for uptake (akin to a voluntary or incentive based policy instrument) these maximum uptake figures were then combined with the responses from the survey of those who claimed that nothing would encourage them to use, or use more of, the method. Therefore the **lower potential uptake** increase in uptake is defined as the maximum increase in uptake less those who would never change.

Numerical example:

- From the survey, 20% say “always”, 60% say “most of the time”, and 20% “never”
- Assumed “most of the time” = 66% of the time
- Weighted total uptake = 20% + (60% x 66%) = 59.6%
- Maximum potential increase in uptake = 100% - 59.6% = 40.4%
- Excluding those who said “always”, the percentage that said that nothing could encourage them to do more = 40%
- Lower potential increase in uptake = 40% * 59.4% = 23.8%

3.2.9 Farm level cost-effectiveness

The cost of MM implementation and effectiveness of each CPMM in terms of GHG reduction were combined in a composite model to produce an estimated cost-effectiveness at the farm level (£/tCO_2e).

3.2.10 Industry level cost-effectiveness

Data from the Farm Business Survey Data Builder[10] on the total number of farms by farm type and size were included in the model to scale up the results for England. Information from the survey on current levels of uptake was also used to estimate how much more of the CPMMs could be implemented.

3.2.11 Policy considerations

The findings from the literature review, stakeholder survey and economic analysis were used to make comments on policy options with respect to the need for voluntary, mandatory or incentive based options.

[10] http://www.farmbusinesssurvey.co.uk/DataBuilder/
(accessed March 2010)

4. Study findings

4.1 Summary of stakeholder consultation and literature review

4.1.1 Overview

A telephone survey was conducted with 751 farmers representing the 5 main farm types – cereals, general cropping, dairy, LFA beef and sheep and lowland beef and sheep, and 3 farm sizes, small, medium and large. The target was to interview 150 farmers in each farm type with equal numbers of each farm size.

Following the telephone survey, three focus groups were held with groups of around eight farmers to investigate findings in more detail. In-depth interviews were also conducted with five pig farms and five poultry farms.

The survey was designed so that there were equal numbers of each of the main farm types, and equal numbers of each farm size within farm type. This allows comparison between farm types and sizes but is not representative of the whole farm population without weighting. The results below are for the survey sample.

Where results are statistically significant these are indicated by their confidence at the 95% or 99% level.

In addition information from other surveys and reports produced prior to this work has also been included to compare the findings to published figures.

The full literature review is presented in Appendix 2. The full telephone survey results including graphs and tables are presented in Appendix 3, the details of the focus groups in Appendix 4 and the depth interviews in Appendix 5.

In the related report AC0221 telephone interviews were carried out with 300 arable farmers that were from representative sample of cereal, general cropping and mixed farms. In addition four focus groups one of arable agronomists and three of arable farmers (groups of 7-8 people) were also questioned in relation to the scope for changing behaviours in fertiliser application practice. Where these results are relevant to the assessment made in AC0222 they have been included in this report. Full details of that survey and results are in the final report of AC0221.

In Defra project FFG0918 three farmer workshops were held to discuss the drivers and barriers to uptake of the same MMs as in AC0222, with the results analysed by market segmentation rather than farm type and size.

4.1.2 Telephone survey results

All results are for the survey conducted under AC0222 unless otherwise stated.

Sample background

- The sample comprised a mix of farmer ages, with the highest proportion in the 45-54 year (27%) and 55-64year age groups (30%).
- 54% of the sample grew arable crops, with the 40% of the sample growing feed wheat.

- 50% of the sample applied nitrogen fertiliser to crops, while 93% of those who grew crops used nitrogen fertiliser.
- 60% of the sample applied nitrogen fertiliser to grassland, while 68% of those who grew grass used nitrogen fertiliser.
- 68% of the sample had beef cattle, 46% had sheep.
- 77% of the sample applied manure to their land.
- 5% of the sample had land registered as organic.
- 44% of the sample had mainly medium soil type, 26% heavy, 14% light and 10% shallow over chalk or limestone. 5% had peat soils.

Understanding of greenhouse gas emissions

- The greatest awareness of GHG was for methane (42%) followed by carbon dioxide (28%) and nitrous oxide (11%). 42% were not aware of any of the GHG from agriculture.
- There was greater awareness of GHG in cereal and general cropping (sig at 99%).
- Sources of GHG emissions from farms varied with farm type, but over 50% of the arable farmers did not mention fertiliser as a source. Awareness of GHG from manure on beef and sheep farms was also low. Farmers of larger arable farms were more likely to mention nitrogen fertiliser as a source compared to farmers of small and medium farms.
- 10% of respondents believed it was very important to consider GHGs when making decisions, although a further 40% thought it was fairly important. 51% placed little or no importance on this.
- Cereal and general cropping farmers were significantly more likely than livestock farmers to believe it was important to consider GHGs in decisions (sig at 99%).
- Smaller cereal farmers were more likely to feel it was important to consider GHGs compared to large cereal farmers (sig at 95%), although it was the reverse for general cropping farmers (sig at 95%).
- 39% of the sample believed they were aware of the industry Greenhouse Gas Action plan published in February 2010, with little difference in awareness by farm type or size.

Mitigation theme: Avoid excess nitrogen

a. CPMM1: Use RB209, PLANET or other similar tool to work out how much nitrogen to apply?

Current uptake

- Around 25% of surveyed livestock farms used RB209 or similar tool.
- Uptake in surveyed arable farms was higher with 60-75% using a tool some or all of the time, although 25% did not make use of them.

- There was higher uptake on larger farms with up to 78% of large arable farms using a fertiliser planning tool compared to 49-57% of small farms (sig at 99%).
- Farms with sandy/light or shallow soils were more likely to use fertiliser planning tools than those with heavy or peaty soil (sig at 99%).
- In AC0221 the survey of 300 arable, general cropping and mixed farmers found that on average 72% of farms used some sort of fertiliser prediction tool, and 62% actually used either RB209 or PLANET.
- Use of RB209/Planet was lowest on mixed cropping farms in the AC0221 survey with just 35% compared to 59% and 65% of cereal and general cropping farms using RB209 or PLANET.
- The farming practices survey (2007) estimated that 36% of farmers used RB209/PLANET, again fewer mixed farms (24%) than cereal farms (58%) used RB209/PLANET.

Reasons for using (those who currently use fertiliser planning)

- There was a small sample size for livestock farmers due to low uptake. Sample size for other farm types was larger.
- Most used a fertiliser planning tool because it was the right thing to do (39%), have been recommended to do it (32%) and/or to ensure accurate nitrogen applications (26%).
- Regulation, particularly the Nitrate Vulnerable Zones (NVZs) was also a factor (23%).
- Small farms were more likely to mention adviser recommendations (58%) than medium (23%) or large farms (23%) (sig at 99%).
- Large farms were more likely to mention NVZ regulations (31%) than small (11%) or medium (23%) (sig at 99%)
- Saving money and avoiding waste were also mentioned, as was compliance with farm assurance schemes.

Barriers to uptake (those who did not use fertiliser planning)

- For 66% of those who never, rarely or sometimes use fertiliser planning tools, there is nothing that would encourage them to start using them or increase usage.
- The beef and sheep farms (68-73%) were more likely than dairy (54%) or arable (53-55%) farms not to change (sig at 95%).
- There were no clear differences in farm size in overcoming barriers.
- Depending on farm type, 16%-20% could be encouraged through more information about the practice or the need for the practice, and 7% with advice from an adviser.
- Others mentioned they would use fertiliser planning if they had a bigger farm, if they used more fertiliser, or if they were making more profit.

b. CPMM2: How often do you estimate the soil nitrogen supply (SNS) before deciding how much N to apply?

Current uptake

- 45% of all farms always estimate soil nitrogen supply, while 33% never estimate soil nitrogen supply.
- 65-68% of arable farmers always estimate soil nitrogen supply, but only 15% of LFA beef and sheep farmers do (sig at 99%).
- Based on mean scores[11] large farms were significantly more likely than the medium (sig at 95%) and small (sig at 99%) to estimate soil nitrogen supply.
- Farmers with peaty or heavy soils were least likely to always estimate soil nitrogen supply.
- The survey conducted in AC0221 of 300 cereal, general cropping and mixed farmers found that 70-80% of these farms accounted for soil nitrogen supply of which about 50-60% were estimated to measure in at least some fields.
- As part of AC0221 two major soil analysis labs were estimated to have processed soils samples from an estimated 2-3% of arable fields in the UK, indicating that only a small proportion of arable fields are assessed for soil nitrogen content each year.
- The survey conducted in AC0221 found that of farmers who applied manures 92% took soil nitrogen into account when estimating fertiliser requirements.
- There is no specific published information on the use of nitrogen planning tools, but the Defra Farm Practices Survey 2009[12] showed the following results.
    i. 68% of all farms surveyed regularly tested the nutrient content of their soil.
    ii. 51% of all holdings have completed a nutrient management plan and 62% have completed a manure management plan. Of those holdings with a nutrient management plan, 80% sought professional advice to complete the plan.
    iii. 89% of holdings indicated that they were aware of the Cross Compliance Guidance for Soil Management, and of these, 84% said they used this guidance when completing their Soil Protection Review. Of those using the guidance, 91% indicated that it was sufficient when completing the review. Respondents were also asked how the guidance could be improved. 14% stated that

[11] Mean scores were based on scores of 1 for never apply through to 4 for always apply and gives a measure of all responses.
[12] Defra (2009) The Farm Practices Survey https://statistics.defra.gov.uk/esg/publications/fps/2009%20FPS%20Full%20Results%20-%20General%20form.xls

existing sections could be more detailed and 12% stated that more topics could be covered.

iv. Soil mapping is used by 26% of cereal and general cropping holdings. Variable rate application and GPS (Geographical Positioning System) are the second most common techniques, used by 23% of cereal farms. 14% of all farms surveyed carry out soil mapping, and 13% use the technology for variable rate application.

Reasons for using (those who currently estimate soil nitrogen supply)

- The main reasons why farmers estimated the soil nitrogen supply were related to knowledge and information and costs savings – to ensure accurate nitrogen applications (46%), avoiding waste (29%), good farming practice (21%), to save money (18%).
- Regulations were given as reasons by 6% of the sample.
- Small farms were more likely to be influenced by an adviser (23%) compared to medium (11%) and large (5%) (sig at 95%).
- Larger farms were more likely than others to estimate soil nitrogen supply to ensure accurate nitrogen applications (58%) compared to medium (35%) and small (41%) (sig at 99%).
- In the survey of 300 cereal, general cropping and mixed farms conducted for AC0221 it was found that the main reason for not measuring soil nitrogen content was a lack of confidence that it would improve the precision of application (39%), that it was too expensive (31%) and that there was insufficient time (14%).

Barriers to uptake (those who did not estimate soil nitrogen supply)

- 59% of those who do not currently estimate soil nitrogen supply felt that there was nothing that would encourage them to do so.
- Beef and sheep farmers were least likely to change (65-67%). General cropping farmers were most likely to change (19%).
- Providing more information and advice together with evidence that the process was cost-effective and reliable appeared to be the most likely ways to encourage farmers to adopt this practice. This was supported by views of the farmers surveyed in AC0221.

c. CPMM3: How often to you calibrate your fertiliser spreader every year?

Current uptake

- Almost all cereal and general cropping farms calibrated their fertiliser spreaders every year (94% and 93% respectively).
- Uptake was lower for livestock farmers, with 59% of dairy farms, 62% of lowland beef and sheep and 67% of LFA beef and sheep farms always calibrating every year.
- Uptake was similar across all farm sizes, although small dairy farmers were least likely to calibrate annually.

- In the survey of 300 cereal, general cropping and mixed farmers conducted for AC0221 it was found that 91% of farmers had had their fertiliser spreader calibrated in the last year. Mixed farms were the least likely to have calibrated spreaders with 66% calibrating spreaders within the last year.
- The Defra Survey of Fertiliser Practice 2008[13] found that 36% of farmers check the accuracy of mineral fertiliser spreaders by using catch trays on an annual basis, with 6% of farmers checking at each change of fertiliser type and 23% never checking.

Reasons for using (those who currently calibrate spreaders)

- There were four main reasons why farmers calibrate their fertiliser spreader – to ensure accurate applications, it is good farming practice, to avoid wastage and to save money.
- Regulation and requirements of farm assurance schemes had little influence, despite it being a requirement under arable assurance schemes.

Barriers to uptake (those who did not calibrate spreaders)

- Around 67% of those currently not calibrating their fertiliser spreaders each year are unlikely to be encouraged to do so.
- The factors most likely to encourage uptake were a free service, or the provision of a grant, along with evidence to show that calibration brought increases in yield or reduced wastage.
- Cost relative to the size of farm and amount of fertiliser used is potential barrier, particularly in beef and sheep farms.

d. CPMM4: How often do you take into account the amount of N applied in manures when deciding how much nitrogen fertiliser to apply?

Current uptake

- 88% of the sample who applied manure or slurry and nitrogen fertiliser always or mostly took into account the nitrogen from the manure.
- Only 10% never took the nitrogen from the manure into account.
- The arable and dairy farms were significantly more likely to always take the manure nitrogen into account (sig at 99%).
- In the AC0221 survey of 300 cereal, general cropping and mixed farmers it was found that of the farmers who applied manures 92% always took manure nitrogen into account when calculating N application to the field, and 3% took manure nitrogen into account some of the time.

[13] Defra (2008) British Survey of Fertiliser Practise
https://statistics.defra.gov.uk/esg/bsfp/2008.pdf

- Nutrient and manure management plans are used by farmers and growers to plan their fertiliser and manure use, meet regulatory demands and protect the environment. In the Defra Farm Practices Survey 2009, for England, 51% of holdings have completed a nutrient management plan and 62% have completed a manure management plan[14]. 18% of holdings in England carried out nutrient testing of their manure by taking samples.
- The British Survey of Fertiliser Practice 2008[15], derived an indication of possible adjustments to fertiliser inputs due to manure use by comparing fields that used manure with those that did not (the farmers were not asked directly in the survey). This assessment showed that in the main tillage crops in Great Britain the application of manufactured nitrogen is consistently higher on all fields without the addition of manure, with the exception of spring oilseed rape, which had a very small sample size. The same cannot be said for grassland. Where manures are applied to grass fields there is typically a higher total amount of nitrogen applied to the fields than in fields that just receive artificial fertilisers.

Reasons for using (those who currently account for manure nitrogen)

- Minimising cost (42%) and wastage (52%) were the key factors motivating farmers to take account of nitrogen in manures.
- Ensuring accurate application (32%) and applying good farming practice (12%) was also important
- There were few differences between farm sizes or types.

Barriers to uptake (those who did not account for manure nitrogen)

- Of the farmers that did not already take into account nitrogen from manures, 73% said there was nothing that would encourage them to do more, but over 25% who may be influenced.
- Advice and information to help justify the practice (14%), together with low cost methods of assessing manure nitrogen (5%) may help persuade farmers.
- Other barriers included small size and low use of manures.
- There were no significant differences between farm types and sizes.
- From the AC0221 survey of 300 farmers of cereals, general crops and mixed farms 7% did not take manure N into account and a further 29% had never thought to take manure N into account implying that there was a knowledge gap for these farmers.

[14] Defra (2009) Farm Practices Survey 2009 – England DEFRA Economics & Statistics -
[15] Defra (2009) The British Survey of Fertiliser Practice http://www.defra.gov.uk/evidence/statistics/foodfarm/enviro/fertiliserpractice/documents/2009.pdf

Mitigation theme: Nitrogen timing

e. CPMM5: How often to you apply nitrogen fertiliser before the crop starts growing in the spring?

Current uptake

- Overall, 75% of the sample always avoided applying nitrogen fertiliser before crop starts growing in the spring and a further 10% most of the time.
- Dairy farms were significantly least likely to avoid early nitrogen applications (sig at 99%).
- There was no significant difference between farm sizes.
- The AC0221 survey of 300 cereal, general cropping and mixed farmers found that 54% of farmers applied N dependent upon the growth stage of the crop, 8% by time period, and 37% by a combination of time period and growth stage.

Reasons for using (those who currently avoid early nitrogen)

- The main reasons for not applying early nitrogen are to avoid waste (55%) and to save money (20%).
- There was general awareness of the technical reasons for avoiding early nitrogen including ineffective (15%), avoid leaching (13%), good farming practice (11%).
- Cereals farmers were more likely to mention avoiding leaching and good farming practice (sig at 95%).

Barriers to uptake (those who do not avoid early nitrogen)

- Amongst farmers who did not avoid early nitrogen, the majority (75%) felt that there was nothing that would persuade them to do more.
- A small proportion indicated that it would depend on the weather. More information or incentives were needed by others.

f. CPMM5: How often do you avoid nitrogen fertiliser applications for 5 days after heavy rain?

Current uptake

- Around 60% of the sample always avoided applying nitrogen fertiliser for at least 5 days after heavy rain, with a further 16% most of the time and 13% some of the time.
- No clear differences were evident between farm sizes.
- Lowland beef and sheep farms and dairy farms were more likely to shorten the interval (sig at 95%).
- In the AC0221 survey of 300 cereal, general cropping and mixed farmers it was found that 71% of farmers were likely to avoid N applications for 5 days after heavy rains (with 33% very likely to avoid application in this time period).

- From the AC0221 survey it was found that farmers on heavy soil types were more likely to avoid applications during this period than farmers on other soil types.

Reasons for using (those who currently avoid nitrogen applications after rain)

- The main reasons given for avoiding nitrogen after rain were to reduce wastage (61%) and avoid leaching (41%).
- Other reasons included: to save money (9%), good farming practice (8%), avoid damage to soil (6%), and too wet for machinery (5%).
- Dairy farmers were more conscious of leaching (71%) and less conscious of wastage (19%) compared to arable farmers (30% and 74% respectively).
- Small farms tended to mention reduced wastage (70%) more often than medium (54%) and large farms (60%) (sig at 99%).

Barriers to uptake (those who did not avoid nitrogen fertiliser after heavy rain)

- 54% of farmers would not be encouraged to avoid nitrogen fertiliser application following heavy rain.
- 25% said that decisions were dependent on weather forecast with more likely to go on if rain is forecast.
- More information and evidence to show the need to follow this practice was required to persuade other farmers to wait.
- Beef and sheep farmers were least likely to be encouraged to change practice.

g. CPMM5: How often do you avoid nitrogen fertiliser applications for 5 days after manure applications

Current uptake

- 80% of farmers always avoided applying nitrogen within 5 days of manure application, while a further 10% did so most or some of the time.
- The general cropping farmers were more likely to avoid nitrogen applications close to manure spreading.
- No clear differences were evident between the farm sizes.

Reasons for using (those who currently avoid using nitrogen fertiliser within 5 days of manure spreading)

- The main reason for not apply fertiliser within 5 days of manure was to reduced wastage (43%), to save money (16%), to make the manure last longer (16%) and for good farming practice (16%).
- No clear differences were evident between farm sizes.

Barriers to uptake (those who did not avoid nitrogen fertiliser within 5 days of manure spreading)

- 75% of farmers felt that there was nothing that would persuade them to change their behaviour.
- More information (7%), evidence of benefit (3%) and incentive (3%) or regulation (3%) may encourage the remaining farmers to change.

h. CPMM5: How often do you spread the application of nitrogen fertiliser over several applications rather than one application?

Current uptake

- 71% of farmers spread nitrogen applications over several applications.
- The cereals (92%) and general cropping (85%) farms were more likely than the other farm types to spread applications (sig at 99%).
- Beef and sheep farms were least likely to split applications (upland 43% and lowland 50%).
- There was no difference between farm sizes.
- In report AC0221 the survey of 300 cereal, general cropping and mixed farmers found that 71% of farmers were likely to apply nitrogen in 1 additional split if it reduced air pollution and the farm's carbon footprint.
- From AC0221 it was identified that cereal farmers were the most likely to adopt split applications, with 37% very likely responses, vs 19% of mixed farms being very likely to use split applications.
- Defra report RMP 5142[16] suggests that there is very limited scope for improving fertiliser N application timings to improve fertiliser N utilisation by crops. It was suggested that there was scope for implementation on 10% of land for all categories where as RMP4950 had estimated 70% for grassland, 80% for arable, 70% for root crops and 50% for other crops".
- The British Survey of Fertiliser Practice 2009 has applications by month. The standard advice is that autumn nitrogen is not required for winter cereals, as economic yield benefits are rare and autumn-applied nitrogen is vulnerable to leaching loss. The Great Britain values have remained below 10% for both winter cereal crops since 2003, and, despite some minor fluctuations, the trend is for reduced dressing cover of autumn applied nitrogen on winter cereals. Autumn nitrogen at 30 kg/ha is recommended for winter oilseed rape, unless the soil has a high nitrogen fertility, as the crop normally requires more nitrogen than winter cereals during the autumn growth period.

[16] ADAS (2009) RMP/5142 Analysis of Policy Instruments for Reducing Greenhouse Gas Emissions from Agriculture, Forestry and Land Management
http://www.defra.gov.uk/foodfarm/landmanage/climate/documents/climate-ag-instruments.pdf

Reasons for using (those who are currently splitting nitrogen)

- The reasons for splitting nitrogen applications were mainly to maximise crop yield (30%), avoid waste (30%), good farming practice (17%), match crop needs (29%).

Barriers to uptake (those who did not split nitrogen)

- 69% of farms will not be persuaded to change practices and split nitrogen applications.
- The majority are livestock farmers and mainly cite low fertiliser use (7%), cost of implementation (4%) and low profits (2%) as barriers. More information about the practice might encourage some (4%).
- The survey in AC0221 found that the main reason for not applying additional N splits was lack of time (33%), cost (25%) a lack of belief that it would affect air pollution (25%) and insufficient days when the weather would be suitable (22%).

Mitigation theme: Manure timing

i. CPMM6: How often do you avoid spreading manures before crops start growing?

The spreading of manures and slurries can be dependant on the weather conditions which can delay establishment of crops and rainfall which may leach out vital nutrients, affect soil chemistry and nutrient availability.

Current uptake

- Almost 70% of farmers always or mostly avoid applying manure before the crop starts growing in spring. However 24% rarely or never considered this.
- There were no significant differences for farm type or farm size.
- From the literature it is observed that there is a prevalence for applications of manures in August and September for winter sown crops (prior to drilling), and application between November and April for spring sown crops and grass fields. No data could be found on whether farmers spread manure or slurries at times of the year other than that recommended and if so why they may do this.
- In the British Survey of Fertiliser Practice 2007 farmers were asked about how often fields received organic manures. Of all the fields surveyed, 72% did not receive manure in the current year. On farms where some manure was used, 41% of fields received at least one application of at least one type of manure or slurry[17]. For fields that were known to have received manure in the past, the average frequency of application was 34% received manure every year, 15% in alternate years and gradually decreasing to 8% receiving manures once in 7 years or more.

[17] Defra (2007) British Survey of Fertiliser Practice https://statistics.defra.gov.uk/esg/bsfp/2007.pdf

Reasons for using (those who currently avoid manure applications before crop growth starts)

- The main reason given for avoiding manure applications before crop growth starts was to avoid waste (42%) and to save money (15%).
- Other reasons included making manure last longer (9%), unnecessary (9%), maximising crop yield (9%) and avoiding leaching (8%).

Barriers to uptake (those who do not avoid early manure applications)

- 80% of farms say that nothing will encourage them to change practices.
- A small proportion (5%) indicated that regulation would make them change, while others felt that more information would help (4%).

Mitigation theme: Crop choice

j. CPMM7: How often do you include clover in your grass leys?

Current uptake

- 80% of all dairy farms and beef and sheep farms had sown some of their grassland with grass/clover mix, with the dairy farms being most likely to do so (sig at 95%).
- The proportion of grassland sown with clover varied from under 20% to 100% with a mean of 47%.
- Results by farm size were broadly similar.
- Recent research into the proportion of leys with clover could not be found but expert opinion suggests that many leys have clover in them and that the vast majority of reseeded pastures include some clover to help reduce reliance on bought in fertiliser. High sugar grasses have also been developed so that there is more efficient use of nutrients in the rumen – a better balance of carbohydrate and protein.
- Currently, EBLEX are undertaking R&D projects ‘Genetic improvement of perennial ryegrass and red clover to increase nitrogen use efficiency and reduce N losses from pastures and silo’ and ‘Genetic improvement of perennial ryegrass and white clover to increase the efficiency of nitrogen use in the rumen’, both of which are due to finish in 2013. EBLEX state that the inclusion of white clover increases the N uptake of companion grasses by 10-19%, offering the potential to reduce N fertilisation, and that in one study where white clover was included in pastures the rate of live weight gain increased from 1.0 kg per day to 1.1 kg per day, but 80% less fertiliser was used[18].

[18] Eblex (2006) Grassland Management for Clover http://store.eblex.org.uk/articles/dodownload.asp?a=store%2Eeblex%2Eorg%2Euk%2E25%2E7%2E2006%2E9%2E55%2E24%2Epdf&i=281210

Reasons for using (those who currently have more than 40% of area with clover)

- The main reason given for planting clover was because it fixes nitrogen (37%) but maximising performance of livestock (18%), reducing nitrogen requirements (14%) and good farming practice (13%) were also important.
- Larger farms tended to mention nitrogen fixing more than smaller or medium farms.

Barriers to uptake (those who have less than 40% of area with clover)

- 50% of livestock farmers felt nothing would encourage them to plant more of their grassland with clover.
- This was broadly similar for farm size and farm type.
- Clover could be encouraged by incentives (4%), inclusion in Environmental Stewardship (4%), more information (4%), easier weed control (3%), low levels of wild clover (3%) and many others.

k. CPMM8: How often do you grow triticale instead of winter feed wheat?

Nitrogen fertilisers are responsible for over half of the GHG emissions that are associated with the production of cereals and the use of low nitrogen species or varieties would be an advantage. In a recent study Kindred *et al*[19] found that on a clay loam soil in a second cereal position triticale could out-yield wheat by 2 t/ha, requiring 50 kg/ha less nitrogen in order to do so. Other breeding developments aim to find efficient varieties, but triticale is available now so this was used as an example.

Current uptake

- Only 4% of the sample have ever grown triticale instead of winter feed wheat.
- Dairy farmers were the most likely to grow triticale.
- No significant differences were evident by farm size.
- According to the 2008 Pesticide Usage Survey[20], there were 17,200 ha of triticale grown in Great Britain during 2008. There was about a 4.4% increase in the area of rye, mixed corn and triticale grown in 2009 as reported by the Defra June Census[21], which indicates that there could have been almost 18,000 ha of triticale grown for harvest in 2009.

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[19] **Kindred, D., Weightman, R., Roques, S. and Sylvester-Bradley, R.** (2010). Low nitrogen input cereals for bioethanol production. *Aspects of Applied Biology 101 Non Food Uses of Crops* **101**, 37-44.
[20] Garthwaite DG, Thomas MR, Parrish G, Smith L & Barker I. (2010) Pesticide usage survey report 224. Arable Crops in Great Britain 2008. Pesticide Usage Survey Team FERA. http://www.fera.defra.gov.uk/plants/pesticideUsage/documents/arable2008.pdf
[21] June Survey of Agriculture and Horticulture – UK Final results (2009) DEFRA http://www.defra.gov.uk/evidence/statistics/foodfarm/landuselivestock/junesurvey/documents/june_UK.pdf (27/07/10)

Reasons for using (those who currently grow triticale – very small sample)

- There were a range of reasons for growing triticale including secondary uses (18%), food farming practice (12%), maximise crop yields (12%) and maximise livestock growth (12%), suitable soil type (12%), tolerance to rabbit grazing (12%), reduced fertiliser inputs (6%), easier to grow (6%), better weed control (6%).

Barriers to uptake (those who did grow triticale)

- 73% of the sample felt there was nothing that would encourage them to grow triticale, especially dairy (90%), upland beef and sheep (92%) and lowland beef and sheep (83%).
- Approximately half the arable farmers would consider it, but the key issue was whether there was a market (12%) and if it was profitable to grow (3%).

Mitigation theme: Livestock breeding

I. CPMM9: How often do you use dairy bulls with high PLI for breeding?

Profitable Lifetime Index (PLI) has been designed to identify animals that can transmit the greatest financial improvement over their lifetime and is recommended as the best tool for producing a short list of sires for the majority of herds.

Current uptake

- Around 50% of farmers always use a high PLI bull when breeding dairy cows.
- Large farms are more likely to use bulls with a high PLI
- From the literature there are no indicators of how widespread the use of the PLI tool is, or other breeding improvements.

Reasons for using (those who currently use high PLI bulls)

- The main reason for using high PLI bulls was to maximise livestock growth and productivity (73%) and maximise profit (40%), although good farming practice was also cited (11%) and to improve herd genetics (10%).
- There was no difference between dairy farm sizes.

Barriers to uptake (those who did not use high PLI bulls)

- Just over 75% of dairy farms felt that nothing would persuade them to use bulls with a high PLI.
- Higher profitability would encourage some (6%) and more knowledge and advice would help (both 3%).

m. CPMM9: How often do you use beef bulls with high EBV for breeding?

For the beef and sheep sectors, genetic potential is expressed in the Estimated Breeding Value (EBV) of sires. An EBV is an indication of the breeding potential of an animal for a range of traits[22]

Current uptake

- 23% of beef and sheep farms use bulls with high EBV all of the time or most of the time.
- 66% never used a bull with high EBV.
- No significant differences between farm sizes or farm types.
- An indication of the uptake of EBVs by beef and sheep farmers can be found in an EBLEX stock briefing[23]. In a sample of 80 English beef and sheep producers that undertake enterprise costings for their businesses, 40% indicated that they regularly used EBVs when purchasing terminal sires. However uptake is likely to be lower across the wider beef and sheep industry.
- Expert opinion suggests that around 90% of the bulls at the major breed sales are performance recorded. Participation by the pedigree sheep sector is lower, with the majority from the terminal sire breeds.
- In 2007 EBLEX estimated that around 15% of lambs and 20% of suckler beef presented for slaughter had been sired by performance recorded rams and bulls. When dairy-bred beef are included this increases to an estimated one third of all the beef due to the widespread use of Artificial Insemination (AI) in dairy herds.[24]

Reasons for using (those who currently use high EBV bulls)

- The main reasons for using high EBV bulls were to maximise productivity (59%), to maximise profit (39%) and to improve herd genetics (23%).
- There were no differences between farm sizes.

Barriers to uptake (those who did not use high EBV bulls)

- 75% of beef and sheep farmers felt that nothing would encourage them to use high EBV bulls.
- Barriers included the costs (7%), evidence that it sells (6%), evidence that it improves productivity (3%). Small farm size was also a barrier.

[22] EBLEX (2007) Stock briefing 07/03 (6 July 2007)
[23] http://store.eblex.org.uk/index.asp?299233

[24] ADAS 2009 Beef and Sheep Intelligence report prepared for Defra

Mitigation theme: Livestock feeding

n. CPMM10: How often do you use a ration formulation programme?

There are a variety of ways of producers developing a ration formulation programme including specialist diet formulation programmes such as RUMNIT[25], free, on-line rationing programmes such as the Beef Rationing model that was developed from beef production experiments undertaken at AFBI Hillsborough[26] and specific on farm advice.

Current uptake

- 71% of dairy farms always used a ration formulation programme when planning feeding regimes, while 21% never did so.
- Around 30% of beef and sheep farms always used a diet formulation programme, while 50% never did so.
- The farmers of large and medium dairy herds were significantly more likely to always use a ration programme than small diary farmers (sig at 95%).
- It has not been possible to find objective, independent evidence of the extent of use of on-farm diet formulation for the ruminant livestock sector. However expert opinion suggests that the vast majority of dairy producers use feed rationing in some form for their business. Uptake amongst beef and sheep farmers is considered to be lower. An indication of the use by beef and sheep farmers can be found in an EBLEX stock briefing[27] which shows 51% of producers reported regular use of a nutritionist and 56% analysis of silage. These figures need to be treated with caution due to the small sample size and therefore can not be reliably broken down to specific beef and sheep production systems. In addition, the businesses participating in the enterprise costing are likely to be more forward thinking and proactive than average and the level of use across the wider beef and sheep industry is likely to be lower. Feed rationing programmes and nutrition advice are more likely to be used by producers finishing beef cattle, particularly those that use home mixed, TMR (Total Mixed Ration) systems or use a range of straight feeds and by-products.

Reasons for using (those who currently use ration formulation programme)

- Farmers used ration programming primarily to maximise livestock growth (52%) but good farming practice (39%) and maximising profit (17%) also featured.

Barriers to uptake (those who did not use ration formulation programme)

- 66-75% of livestock farmers felt that nothing would encourage them to use a ration formulation programme.

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[25] (http://www.rumnut.com
[26] http://www.afbini.gov.uk/index/services/services-specialist-advice/beefmodel.htm
[27](http://store.eblex.org.uk/index.asp?299233)

- Large farms were more likely to feel that nothing would encourage them (sig at 95%).
- A mix of information (4%), advice (3%) and evidence (2%) would encourage uptake, but a number of farmers felt their farms were not big enough (4%), or were not making enough profit (4%) to justify the cost.

Mitigation theme: Anaerobic digestion

o. CPMM11: How often do you use anaerobic digestor?

Current uptake

- Only 2 farms in the overall sample, less than 0.5%, put manure into an anaerobic digester. Both were LFA beef and sheep farms but subsequent discussion suggested that the manure was in fact put into a covered storage facilities rather than a digester.
- In 2008, Defra carried out a fairly intensive review of the use of Anaerobic Digestion (AD) on farms and published their results in the Farm Practices Survey, 2008. It showed that 57% of farms surveyed have heard of AD, 1% already process slurries by AD and 4% plan to in the future.
- There are currently 40 operational AD plants in the UK[28], with more in the planning stages. Of those that are currently operational 22[29] are on-farm anaerobic digesters and the rest are off-farm. It is not clear what proportion of these plants take manures, although the majority of plants are concentrated in the livestock regions of the UK, implying that a good proportion of them do take manures.

Reasons for using (those who currently use an anaerobic digester)

- Good farming practice and preventing rainwater getting in were cited.

Barriers to uptake (those who did not use fertiliser planning)

- 54% of the sample said there was nothing that would encourage them to put manures in an anaerobic digester.
- Beef and sheep farmers were significantly less likely to be encouraged to use an anaerobic digester (sig at 99%), but 66% of dairy farms and 49% of beef and sheep farms would consider it.
- Grants and incentives were favoured by 26% with costs being one of the main barriers.
- Information (5%) would help, and the availability of a local facility would encourage (3%).

[28] International Energy Agency http://www.biogas-info.co.uk/index.php/faq-qa (27/07/10)
[29] Map of AD plant location in the UK. http://biogas-info.co.uk/maps/index2.htm

4.1.3 Focus group results

Three focus groups were held looking at arable MMs (Lincoln), dairy MMs (Cheshire) and beef and sheep MMs (Herefordshire).

Understanding of climate change and greenhouse gases

Farmers who participated in the focus groups held mixed opinions with discussions on whether climate change was a natural cycle or caused by human activity. Although there was general acceptance that farming did contribute to the emission of some GHGs, it was considered by participants that manufacturing and transportation had a greater contribution than farming to climate change.

Farmers were clearly profit focused, implementing changes in order to increase profits or as a result of regulation. Making the most cost effective use of inputs to maximise yields and productivity. It is noted that many of these practices are in line with practices that would reduce emissions.

Carbon dioxide and methane were the GHGs that farmers were most aware of, with nitrous oxide understanding being notably lower. After the presentation by the ADAS specialist, farmers often expressed surprise at the level of emissions from agriculture and the potency of nitrous oxide. Farmers also had a low level of awareness of the Government's targets to reduce agriculture emissions. Most were concerned that targets would reduce their ability to farm profitably and ability of UK agriculture to provide sufficient food.

Mitigation Measures

Mitigation theme: Avoid excess N

a. CPMM1: Use RB209 Planning tool

The majority of arable farmers used a nitrogen planning tool as a guide, and most to comply with NVZ regulations. Experience was seen as most important in achieving the appropriate application and one used college notes and experience. Dairy farmers also used N planning tools driven by need to comply with assurance schemes. A small number of beef and sheep farms who were in NVZ areas used N planning tools while those not in NVZ areas relied on experience. They felt they were already applying the right amount.

b. CPMM2: Estimate soil N before deciding how much manufactured N to apply

Arable farmers took soil N into account based on experience, RB209 or testing. Testing was seen as a net cost, although benefits in testing were seen among those who had not tested previously due to the potential fertiliser reduction. The drivers for uptake were mainly agronomic in order to reduce the risk of crop lodging and to avoid waste.

c. CPMM3: Calibrate the spreader

Arable farmers calibrated their spreaders and indicated this was to comply with farm assurance schemes. They consider calibration offered a net benefit. This was supported by the findings from the AC0221 focus groups.

Dairy and beef and sheep farms did not in general calibrate their spreaders. The low amounts of N applied did not justify the cost of calibration, although they were aware of the symptoms of poor spread pattern.

d. CPMM4: Full account of N applied in Manure when applying manufactured N to apply

Arable farmers who applied manure reduced the manufactured N applied, and this resulted in a perception of a positive cost benefit. Only a small number tested the manure with most relying on experience, due to perceived inaccuracy of tests and lack of awareness of testing

Dairy farmers all consider slurry N, estimating it by a mix of experience, RB209/PLANET, or advice. Manure testing was suggested as a requirement of the farm assurance scheme, although it was considered too expensive.

Mitigation theme: N timing

e. CPMM5: Avoid applying manufactured N before crops starts growing in spring

The arable farmers applied N only to growing crops, and doing so was also a requirement of Cross Compliance. The livestock farmers also avoided application before the crop started growing to ensure maximum uptake and minimise any losses of N.

f. CPMM5: Don't apply manufactured nitrogen for at least 5 days after heavy rain

This was common practice amongst the arable farmers and considered common sense. The dairy farmers indicated that the extent of the rainfall influenced the decision when to travel on the land to apply the N. Most did not apply within 5 days.

In the AC0221 focus groups on cereal, general cropping and mixed farms, it was found that farmers generally waited until land was fit for travelling on, but the time interval from a rain event to application varied dependent upon soil type, with farmers on light land able to travel soonest. Where there were forecasts of more rain to come some farmers were concerned that if they did not apply the fertiliser before more rain, they would not be able to apply it until too late.

g. CPMM5: Don't apply manufactured nitrogen for at least 5 days after applying manure

Standard practice for arable farmers was to apply the manure well in advance of manufactured nitrogen, with 3-5 weeks being mentioned. This was to make full use of the manure/slurry N before adding an additional source, and it is likely that this is cost motivated.

h. CPMM5: Spread the application of bagged N over 2-3 applications rather than just one

Arable farmers already did this to maximise N uptake and yields. Net cost was the reason for not doing so. Additional man hours were considered a fixed cost and therefore should not be considered an extra cost unless applied by a contractor.

From the AC0221 focus groups of cereal, general cropping and mixed farmers it was found that most arable farmers perceived that they already applied the maximum number of splits practicable. Smaller and more mixed farms were likely to apply fewer splits due to lack of time.

Mitigation theme: Manure timing

i. CPMM6: Avoid applying manure/slurry before the crop starts growing in spring

The beef and sheep farmers applied manure or slurry after the silage had been cut ready for the new growth for maximum benefit and to avoid problems with water pollution.

Dairy farms mostly had 5 months of storage and therefore slurry was mostly applied at the right time. The storage regulations coming into effect in 2012 were a worry because of the cost.

Mitigation theme: Crop choice

j. CPMM7: Plant grassland with clover

All the beef and sheep and the majority of the dairy farms had clover in their grassland. They could use less N and thus reduce cost and sell lambs sooner. Dairy farmers said sprays that do not kill the clover were less effective and more costly. The dairy farmers were also concerned about too much clover reducing yields.

k. CPMM8: Grow Triticale instead of feed wheat for the animal feed market or use on the farm

None of the farmers had grown triticale and only a few were aware of others who had.

Many farmers understood that it required a lower N input, but the low yield negated this benefit. Farmers thought it may be advantageous to grow triticale on poor ground where wheat would not grow, although the majority were not prepared to try it. To grow it they need substantial evidence that it would yield well and that it could be sold as it was perceived that there was no market. One farmer had tried and failed to source triticale.

Mitigation theme: Breeding improvements

l. CPMM9: Use bulls with a high profitable lifetime index

Dairy farmers aimed for genetic improvements of their herds and most used PLI as a guide for bull selection.

m. CPMM9: Use bulls with a high EBV or estimated breeding value when breeding beef

Knowledge of the EBV varied within the beef and sheep group. Most seemed to want to improve their herd genetics, but did not necessarily look to the EBV to do this, using visual appearance instead. There were a number of barriers to relying on the EBV score and it was not appropriate for use across breeds.

Mitigation theme: Livestock feeding

n. CPMM10: Use a ration formulation programme or nutritional advice from an expert when planning the feeding regime for your livestock

Generally not used at all for suckler cows or for sheep. A number of the farmers took advice on balancing forage rations for fattening beef, as this produced a cost saving. All the dairy farmers used a ration formulation programme and were required to do so under the dairy assurance scheme.

Mitigation theme: Anaerobic Digestion

o. CPMM11: Put manure into an anaerobic digester

The perceived cost of building an anaerobic digester on farm was prohibitive to all the farmers. A number of farmers could not see the value in putting the muck in a digester when it could be put straight on the land. Transporting the slurry or manure off farm to a digester based elsewhere only for it to be returned for use on the land was thought to defeat the object of trying to save energy and greenhouse gases. Advantages of using the digestate were mention in that it could be more consistent than the slurry with a known nutrient content.

4.1.4 Depth interviews

Depth interviews were conducted with 5 pig farmers and 5 poultry farmers.

MM: Improve slatted floor design (Pigs)

The pig farmers felt there was no improvement needed in the design of the slatted floors as there currently was little dung left on top of the slats. Two of the larger more intensive pig farms had slatted floors within the pig sheds. Another farm used slatted floors only for the farrowing sheds, with other pig housing on the farm having straw and not slats. Two smaller farms used only straw.

MM: Frequent removal of slurry from beneath slat storage in pig housing

Emptying the tanks either coincided with the removal of the pigs from the housing or was carried out once the tanks were full. More frequent emptying of the tanks was possible. Several farmers did not seem aware that the warmer conditions increased ammonia emissions. One farmer was planning to carry out a major clean of the housing in order to comply with an enforcement notice. This clean would take 3 men about 3 months to complete. The farms with straw rather than slats cleaned the housing out more frequently, often several times a week.

MM: Install air scrubbers or bio-trickling filters to mechanically ventilated pig and poultry housing

None of the pig or poultry farms currently had either air scrubbers or bio-trickling filters installed. There was mixed awareness of the systems and benefit. It was considered impractical to fit into the old housing due to logistical difficulties and cost.

One farmer indicated that a grant would be needed to encourage him to install the new air scrubbers or filters whilst another would need to see an improvement in pig health, although he doubted whether the scrubbers would provide this benefit.

MM: Storing/composting solid manure (Pig and Poultry)

None of the farmers was composting solid manure.

MM: Calibrate the manure/slurry spreader (Pig and Poultry)

Several of those spreading solid manure did not calibrate, but instead use experience to apply the right amount to each field. One poultry and one pig farmer did calibrate their spreaders.

Do not apply manure/slurry to high risk areas or at high risk times (Pigs and Poultry)

The pig and poultry farmers were aware of the need to avoid spreading on steep slopes, near watercourses and within the NVZ closed periods.

Incorporate manure into the soil (Pigs and Poultry)

All the pig farmers who grew crops incorporated manure. There was mixed behaviour and opinion with regard to injecting the slurry. Some farmers felt that incorporating the slurry would be a net cost.

Transport manure to neighbouring fields (Pigs and Poultry)

The pig farmers tended to spread the solid manure on their own land, all the poultry farmers exported all or most of the manure.

Frequent manure removal from layer hen housing with manure belts (Poultry)

Cleaning out the deep pits or litter usually coincided with the changeover of birds. More frequent cleaning was not practical given that the birds would still be in the sheds.

In–house poultry manure drying (Poultry)

There was little storage of the poultry manure once cleared from the sheds and therefore no requirement for in-house drying in order to reduce emissions.

Manure additives (e.g. Alum) (Poultry)

Poultry farms saw little value in using additives given that the litter was relatively dry. The farmers were wary of adding any additional costs.

Incinerate poultry litter

The cost of environmental monitoring prevented the one interested poultry farmer from incinerating poultry litter to produce electricity and heat.

4.2 Economic evaluation of the practical mitigation methods

The economic model to analyse costs and effectiveness of the on farm mitigation methods was developed in Excel. The model components (Figure 2) include farm level net costs, farm level income and industry level analysis to produce analysis of the cost effectiveness of individual CPMMs by farm type and size.

Farm level net costs of implementing CPMMs for each farm type and size were estimated (details in section 4.2.1).

Farm level effectiveness were calculated using CALM model for emissions and estimates of abatement potential (details in section 4.2.2).

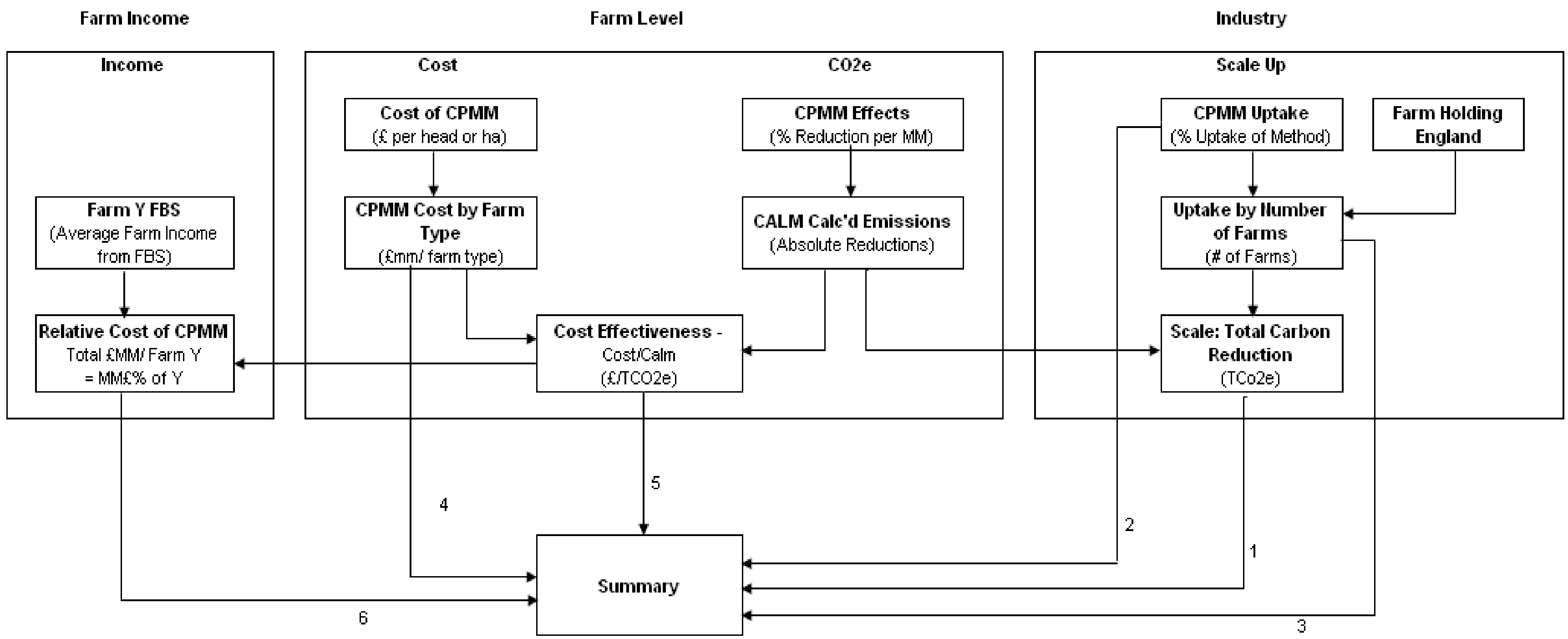
Farm level income of implementing CPMMs for each farm type and size were estimated (details in section 4.2.3).

Industry level mitigation was calculated using uptake figures from the stakeholder survey (details in section 4.2.4).

Cost effectiveness by farm type and size were calculated (details in section 4.2.5).

Notes on costing analysis:

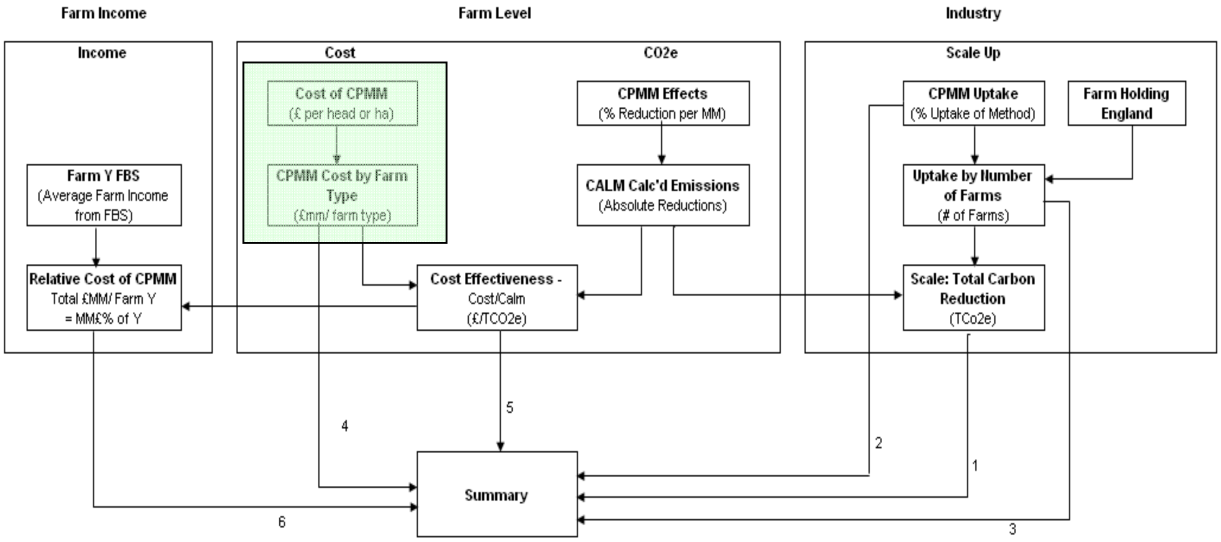
- The cost of implementing the CPMMs at the farm scale were estimated for different farm types and sizes.
- In terms of farm size, there is limited evidence suggesting significant differences in CPMM unit costs. It was therefore assumed that most of the CPMMs would exhibit linear cost characteristics since they tend to apply on a hectare or head basis. Therefore, most of the cost estimates did not require differentiation between farm sizes.
- All evaluations of effectiveness were undertaken for small, medium and large farms.
- The analysis focussed upon the 3 farm sizes (small, medium and large) reported in the Farm Business Survey. The economic evaluation focused on 6 main farm types: cereals, general cropping, dairy, lowland livestock, LFA livestock and mixed farms.
- Not all possible combinations were analysed since the CPMMs do not apply to all farm types.
- Anaerobic digestion requires significant capital expenditure and was analysed separately.



Notes: Line Number: 1. Total CO_2e Reduction 2. Uptake % 3. No farms using measure 4. Cost of measure to farm 5. Cost per tCO_2e reduced 6. Cost % of Net Farm Income (NFI) and Gross Margin (GM).

Figure 1 MM evaluation model schematic

4.2.1 Farm level net costs of MMs (CPMMs)



Variability of costs of implementing the CPMMs

Costs of implementing the CPMMs mostly involve changes in variable costs rather than capital expenditure. They can also result in changes in revenue due to yield changes. However, some MMs require capital expenditure for implementation, such as anaerobic digestion and increasing slurry storage capacity.

Applying costs to CPMMs is not straightforward and likely to be highly variable reflecting local context. For example, the capital costs of spreading manures at time of crop requirement and making full use of manure N supply is dependent on having sufficient storage facilities to make effective use of them in spring rather than spreading them in the autumn, when much of the N can be lost over the autumn and winter period.

Storage of solid manures (FYM) is relatively straightforward and requires little investment. However storage of slurry requires significant capital investment and under the Nitrate Vulnerable Zone Action Plan, farmers are required to ensure they have five months slurry storage for dairy cows. Farm slurry stores vary in capacity and for some this requirement means a marginal increase in capacity which can be achieved by increasing the effectiveness of storage. One option may be to ensure all rainwater gutters are in working order and the water is diverted away from the slurry tank. Parlour washings can be collected separately from the slurry. This may avoid the cost of an additional or new slurry store. Other ways to avoid unnecessary filling of the slurry store are by ensuring that open areas are roofed or fenced off to prevent them being soiled.

Another example of the range of options is in fertiliser spreader calibration. Many farmers perceive this as simply checking operation against manufacturer's settings. However, particularly in arable crops, it is important to ensure an even spread pattern, which can be judged by driving the spreader over trays which catch the fertiliser. This can be carried out by farmers or specialist contractors at a range of costs. In the latter case, costs can include replacement parts. In addition, calibration can include re-calibration depending on fertiliser type, that is, prilled, compound, blends or changing from urea to ammonium nitrate, which all have different spreading characteristics.

Assumptions for costing the CPMMs

Costing the implementation of CPMMs at a farm level involved making a number of assumptions since many of the CPMMs could be implemented in different ways that can affect revenue and costs.

The cost information on the CPMMs uses Nix[30] (2010) and a number of ADAS sector experts.

The farm level cost structure within which the CPMMs were assessed was based upon those used for the Farm Business Surveys. The costs of implementing the relevant CPMMs were calculated on a partial budget basis. These compare the positive and negative effects of the proposed change on net income. The net cost of a given CPMM was the sum of the extra costs or reduction in revenue and the costs saved or additional revenue.

Some CPMMs had a net cost whilst others had a negative net cost, i.e. they were profitable CPMMs for the farmer to implement.

Mitigation theme: Avoid excess nitrogen

CPMM1: Use a fertiliser management plan: RB209

The cost of using a fertiliser planning tool was analysed, either on paper or online, to calculate fertiliser requirements. Costs include the time taken to collect the information and perform the calculations. The benefit of using the tool would in this case be in going through the calculations to ensure that excess N was not applied. It was assumed that the costs are linearly related to area for different farm sizes.

CPMM2: Estimate soil N supply

Estimation of soil N supply (SNS) is part of producing a fertiliser management plan. However, to measure it requires soil sampling to a depth of a metre at a cost of around £100 per field for sampling and analysis. Typically testing is undertaken on a proportion of fields so and estimated 4 samples per farm was used to provide an average cost per hectare. Since this would be part of a fertiliser management plan, no further savings were included. It is recognised that soil N supply testing costs may vary significantly between farms and production systems.

CPMM3: Spreader calibration

The costs were calculated based on a full spreader calibration involving a full spread pattern test by a trained third party operator (typically £500 per spreader) together with replacement of worn parts (up to £500 per spreader). The benefits of full calibration are diverse and difficult to quantify, particularly on grassland, so none were assumed, although survey respondents (especially arable) emphasised that ensuring accurate application was valuable, and as a requirement of farm assurance it meets the market requirements.

CPMM 4: Make full allowance for manure N supply

Making full allowance for manures can be done by using standard data for nutrient content of manures, such as those in RB209. The cost of the time involved is similar to CPMM1. Costs saved were calculated on a 7.5% reduction in nitrogen application

[30] The John Nix Farm Management Pocketbook (2010).

based on British Survey of Fertiliser Practices (2008) and nitrogen at £200/t for 34.5% N. Other savings were the reduction in spreading costs of the mineral N fertiliser.

Mitigation theme: Nitrogen timing

CPMM 5: Improved mineral N timing

The timing of the application of nitrogen to the land depends on the crop and its growth stage, the soil conditions and the weather. These were costed through allocation of management time to the task which is similar to that in CPMM1. It was assumed an additional split of the total application would be made at a cost of £10/ha. No financial benefit was included, since it cannot be guaranteed due to the large number of variables that determine output.

Mitigation theme: Manure timing

CPMM 6: Manure timing

In order to improve the timing of manure application, there needs to be sufficient slurry storage on the farm. In this case, flexibility was gained by installing a system to avoid rainwater and parlour washings entering the slurry store. In an area of 1050 mm rainfall, avoiding rain and parlour washings entering the slurry system can extend the storage time from three months to five without replacing or extending the slurry store assuming the area covered is equivalent to 5.75 m^2 per cow and parlour washings amount to 30 l/cow/day. Costs of are taken from Defra project WQ0206 and assume repair of rainwater goods and provision of a dirty water tank, both of which are capital costs that are amortised to produce an annual equivalent cost.

Mitigation theme: Crop choice

CPMM 7: Use clover in place of grass

The addition of clover to the sward can be achieved by including it in the seed mixture when the field is re-seeded, by broadcasting seed into the growing crop in the spring or by including clover seed in the ration, which is then spread around the farm in the dung as the cows graze. The main costs are for the seed. No additional costs were used for cultivations, since this would take place anyway whether or not clover was included in the seed mixture. The cost of seed was spread over a five year period to match the common lifetime of temporary grass leys. The saving in mineral N costs was assumed to be 50% together with a reduced cost of spreading. Nitrogen rates per farm were taken from RB209. Additional management costs were included at £5/ha per annum. Bloat can be a problem if the proportion of clover becomes too high, but this is less likely with white clover than the larger red clover.

CPMM 8: Grow low mineral N crops

Triticale was the example crop used in this costing, since it easily substitutes for wheat although other crops such as oats may be worth considering, or the breeding of nitrogen-efficient wheat. It was assumed that the triticale would replace second wheat crops and that N costs would be reduced by 50%, N application costs would be £10/ha lower and the cost of pesticides would be reduced by 20% compared with wheat. The sale price of triticale was 10% lower than wheat

Other issues relating to triticale production, marketing and use in livestock feed and biofuels are covered in Appendix 1.

Mitigation theme: Livestock breeding

CPMM9: Livestock breeding for fertility, yield and health

For dairy farms we assumed an increase in AI costs of £10 for higher quality sires, increased concentrate and bulk feed and two services per cow, and a 5% yield increase at 25ppl on the national average yield. Improved fertility and health were also assumed to reduce the replacement costs by 5%. All data were taken from Nix[31]. Slurry/FYM handling costs were taken from the ADAS SPREADS program[32] (£3.50/t) and volumes of production of slurry were taken from RB209.

For Beef and sheep farms a similar approach to dairy was used, but costs were an additional £10 for bull rental at 1.25 services per cow. We assumed no additional feeding costs. An output increase was assumed at 14% with 25% reductions in feed costs and 50% reduction in manure handling.

Mitigation theme: Livestock feeding

CPMM 10: Optimum diet formulation

Diet formulation is carried out to ensure a balanced ration is provided to livestock to ensure healthy growth and production using appropriate feeds. Costs assume an additional cost of £10/cow for feed formulation for dairy herds and £5/head for fattening beef. Ingredients with higher grade proteins were used to reduce methane production at an additional cost. The dairy herds were assumed to achieve a price premium of 0.5 pence per litre and at a yield of 7,000 l/cow. Additional income from beef was due to earlier finishing that required less feed.

Summary of CPMMs main impacts on net revenue

The output from the model based on these assumptions, across all farm types and sizes, shows that there is a net positive effect on income for all CPMMs except CPMM2: Measuring SNS, CPMM3: Calibrating spreader, CPMM5: Improving N timing and CPMM6: Improving manure timing (Table 3).

Table 3 Summary of model results: costs of CPMMs and impact on net income

Costed Practical Mitigation methods	Variable cost	Revenue	Capital expenditure	Net income change
1: RB209	↑↓	-		+
2: Measure Soil N	↑	-		-
3: Spreader	↑	-		-
4: Manure N Supply	↑↓	-		+
5: N Timing	↑	-		-
6: Manure Timing	↑	-	✓	-
7: Clover	↑↓	-		+
8: Grow low N crops	↓	↓		+
9: Livestock Breeding	↑↓	↑		+
10: Optimal Diet	↑↓	↑		+

[31] The John Nix Farm Management Pocketbook 40th Edition 2010, Andersons Centre
[32] Development of practical decision support tool for assessing economics & efficiency of manure spreading systems Defra project KT0101

The arrows in the variable cost and revenue columns show the assumed direction of those elements. Those with arrows in both directions have some costs increasing at the same time as others decrease. The final column shows the net effect on farm income with a + indicating that the CPMM is beneficial to farm finances.

The actual costs of each MM to different farm types (Table 4) show that some such as using RB209 (CPMM1) and managing manure N supply (CPMM4) have a minimal effect on farm income. However others such as estimating soil N supply (CPMM2), managing nitrogen and manure timing (CPMMs 5 and 6) have an overall cost to the farms that are more significant per hectare. Those that save the farm more significant amounts of money include spreader calibration (CPMM3), using clover in leys (CPMM7), growing low N crops (CPMM8), breeding for health and longevity (CPMM9) and optimal livestock diets (CPMM10).

The outcomes of the impacts are similar for all farm types although not all apply to all farm types. There are some differences with the benefits of clover less for lowland and LFA beef and sheep farms than for dairy farms, because they use less nitrogen. Similarly the benefits of using optimal diet formulations are lower for beef and sheep than for dairy farms.

Table 4: Estimated CPMM impacts per unit (ha or head) by farm type

	CPMM									
Farm type	1: Fertiliser planning RB209 (£/ha)	2: Estimate Soil N supply (£/ha)	3: Spreader calibration (£/ha)	4: Manure N Supply (£/ha)	5: N Timing (£/ha)	6: Manure Timing (£/ha)	7: Clover (£/ha)	8: Grow low N use crops (£/ha)	9: Livestock Breeding (£/head - cattle)	10: Optimal Livestock Diet (£/head)
Dairy	-£0.15	£19.20	£12.00	-£2.73	£13.00	£12.00	-£40.80		-£54.51	-£25.00
Lowland	£0.64	£12.93	£8.08	-£1.54	£13.00	£12.00	-£26.63		-£44.46	-£5.00
LFA	£0.64	£9.37	£5.85	-£1.54	£13.00	£12.00	-£26.63		-£44.46	-5.00
Mixed	-£0.78	£11.87	£7.42	-£3.67	£13.00	£12.00	-£40.80	-£32.73		-£25.00 -£5.00
Cereal	-£1.41	£6.69	£4.18	-£4.14	£13.00	£12.00		-£46.59		
General	-£1.10	£9.02	£5.64	-£3.67	£13.00	£12.00		-£46.59		

Notes:

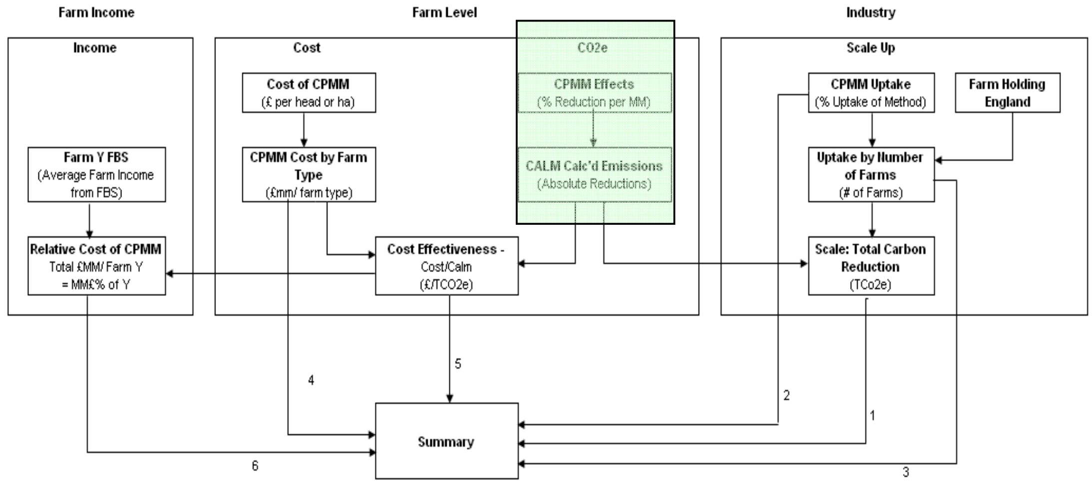
Figures in red are a net cost to the business; figures in green are a net benefit (cost savings).

There are two figures for mixed farms to cover dairy and non-dairy cattle.

Model: From CPMM to whole farm cost

The sheet within the model 'Cost of CPMM' used the estimates of the costs of CPMM implementation to calculate the cost of each CPMM to each farm type. The cost per farm of each CPMM (sheet: CPMM cost by farm type) uses unit data (head or area) from the FBS data as used for the CALM calculations. Total area farmed is taken from the FBS values for total area farmed (excl. shared rough grazing) for all farms other than LFA where temporary and permanent grass are summed to give an indication of the useable area farmed. The figures for livestock are attributed as in the CALM calculations. The cost per farm of each mitigation method is thus the unit data from the FBS multiplied by the unit cost from 'cost of CPMM' (savings are represented as a negative cost).

4.2.2 Farm level effectiveness



Farm level effectiveness was calculated using the abatement potential for the CPMMs estimated from previous reports (MM abatement potential) and the total farm emission calculated using the CLA CALM farm emission calculator tool using 2008/09 FBS data, i.e. showing the emission reductions achievable from a 2008/09 baseline.

MM abatement potential

The MM abatement potential was a synthesis of prior work as well as ongoing projects and discussions with the relevant ADAS sector experts (Table 5). The assumptions used in the revised marginal abatement cost curve project (MACC 2) for the Committee on Climate Change were also taken into account.

Table 5: MM abatement potential estimates and references

Costed Practical Mitigation Method		Estimated Mitigation Potential	Reference and comment
1	N Management Plan: RB209	5%	No direct MM comparisons. MACC 2 Appendix C page 117 Avoid excess N suggests abatement range of 1-10%. Given lack of direct references, assume 5% for each. NB 1 and 2 will not be additive but 3 is additive to 1 or 2 giving a maximum of 10% if combined.
2	Measure soil N (SMN)	5%	
3	Fertiliser Spread calibration	5%	
4	Make Full Allowance for Manure N Supply	8.5%	MACC 2 Appendix C page 115 suggests a range of 2-15% reduction in N used.
5	Improve Mineral N Timing	25%	Table 2.1 MACC 2 states mitigation potential of 0-0.3 tCO_2e/ha/year. Based on BSFP (2010) N application rates, GHG reduction equates to 0-17.4% for winter wheat to 0-68% for permanent grass. Using the mid-points of these and weighting by crop area would suggest around 25%. AC0221 suggested the maximum reductions in t CO_2e/ha achievable were 0.206 for winter wheat (by bringing 3rd split in May forward), 0.276 for winter barley (by reducing N by earlier application), and 0.357 for winter OSR (through combination of avoiding autumn N and reducing N required by delay).
6	Manure Timing	25%	No change from MACC 1 but the MM was acknowledged as being of high uncertainty (MACC 2 page 112). MACC 1, Annex B4 suggested abatement of 0.3 tCO_2e/ha/year but despite the uncertainty no lower level was suggested in MACC 2. Assuming a similar range to mineral N timing, the GHG reduction potential equates to 0-17.4% for winter wheat to 0-68% for permanent grass. Using the mid-points of these and weighting by crop area would suggest a figure approaching 25%. AC0206 suggested 2-10%. For this report we use the higher MACC 2 estimate.
7	Use Clover	50%	MACC 2 unchanged from MACC 1 (Crop soils species intro). Annex B4 0.5 tCO_2e/ha/year reduction. However, using BSFP rates of 48 kg/ha N and 87 kg/ha N for permanent and temporary grass respectively, the MACC 2 abatement co-efficient outweighs emissions. We took the view that in most cases, the average reduction in N use from clover would be 50%.
8	Grow crops that need less N	20%	MACC 2 Table 2.1 suggests abatement rate range of 10-30%.
9	Breeding for yield, fertility and health	12.5%	MACC 2 Table 2.1 suggests abatement rate range of 10-15%.
10	Optimum Diet Formulation	6.5%	No direct comparisons with MACC 1 (no changes to MACC 2). Increased high starch concentrate in diet MM assumed 7% GHG abatement for beef and dairy. AC0206 suggests 6%.

Note 1: The abatement rates for CPMM 5 and CPMM6 in MACC 2 are not in percentage form (rather in tonnes of CO_2e per hectare). The % figures are derived from expert opinion are in broad agreement with the MACC 2 report. Note 2: CPMM11 mitigation potential is adapted using expert opinion from ACO206. It is given a high mitigation potential in AC0206, but this includes the methane generated from the AD unit, which would be far greater than if the slurry had been left in the slurry store. In AC0206, an estimate of 10% reduction in methane emissions from slurry is suggested.

Farm level baseline emissions

To provide estimates of emissions from the average small, medium, and large robust farm types, the online CALM (Carbon Accounting for Land Managers, http://www.cla.org.uk/Policy_Work/CALM_Calculator/) tool was used. The tool is updated annually and the current version utilises the information within UK national inventory report, 1990 – 2008[33].

- Farm Business Survey data on the average scale of each farm type and size (in terms of hectares of crop and/or head of livestock) was input to the CALM tool. The CALM model and its use in this project are discussed in more detail in Appendix 7.

Typical output from CALM for each farm type gives emissions of carbon dioxide, methane, nitrous oxide and an overall carbon dioxide equivalent value for each MM (Table 6).

Table 6 Example output from the CALM model

Emission	Carbon Dioxide (CO_2) tonnes	Methane (CH_4) tonnes	Nitrous Oxide (N_2O) tonnes	CO_2 equivalent tonnes
Energy	0	0	0	0
Energy used in contracting	0	0	0	0
Fertiliser (nitrogen only)	0	0	0.77	238
Imported or exported organic manures	0	0	0	0
Lime	0	0	0	0
Dairy cows, beef & sheep	0	4.64	0.35	206
Other livestock	0	0.11	0.02	3
Crops and grass	0	0	1	311
Land use change (loss of soil carbon)	0	0	0	0
Organic soil (peat/fens)	0	0	0	0
Total emissions	0	4.75	2.14	758

Output from the CALM model shows the different emissions for different farm types and sizes (Table 7).

For the average large cereal farm total emissions, from the data entered, were 1,140 tCO_2e per annum. Most of this was generated from fertiliser applications (644 tonnes) and from crops and grass (residue emissions of 311 tonnes). Given the nature of the FBS data, the average cereal farm also has a number of beef and sheep (accounting for 185 tonnes of emissions The next highest baseline emissions after large cereal farms came from large dairy farms with 1,090 tonnes CO_2e per annum, and large mixed farms with 948 tonnes CO_2e per annum. It is worth noting that the MMs work only upon the emissions from fertiliser and livestock. As it was assumed that there were no yield changes, there were changes to crop residue emissions.

The CALM emissions output data were used to assess the average absolute reductions associated with each CPMM for each farm type and size. This linked the percentage reduction in CO_2e from the baseline emission estimates (Table 4) and the

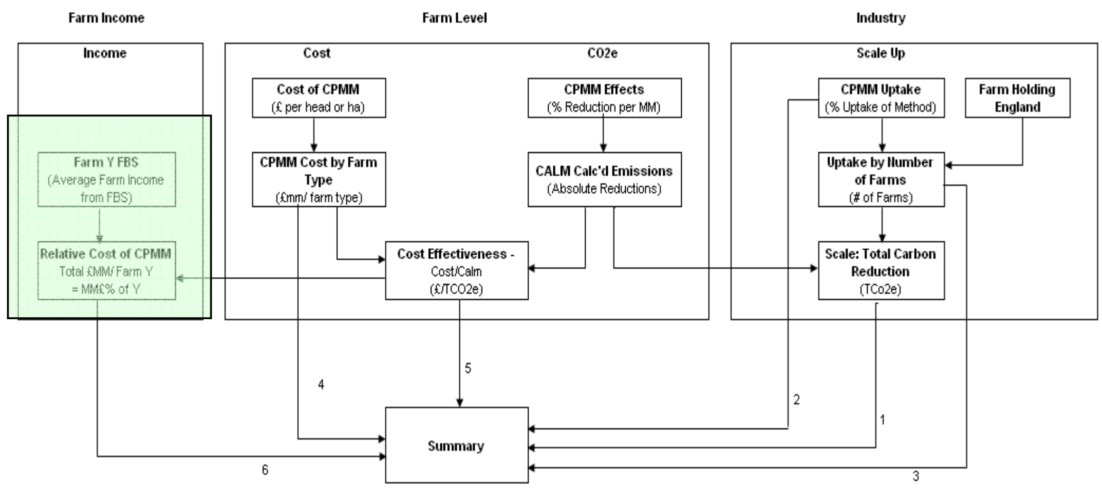
[33] UK Greenhouse Gas Inventory, 1990 to 2008: Annual Report for submission under the Framework Convention on Climate Change.
MacCarthy J, Thomas J, Choudrie S, Passant, N, Thistlethwaite G, Murrells T, Watterson J, Cardenas L, Thomson A (2010)

CALM farm emission output data (Table 6) to provide an absolute figure for the reduction in carbon equivalent emissions attributed to each MM, across all farms and farm sizes.

Model: Cost-effectiveness calculations

The final box in the farm level section of the model relates to estimating cost effectiveness. The sheet 'Cost effectiveness' calculations integrates the information in 'MM cost by farm type' and 'CALM Calc'd Emissions' to provide a cost per CO_2 equivalent per farm type per annum. It divides the calculated costs per farm (from 'CPMM cost by farm type') by the emissions per farm (from 'CALM Calc'd Emissions') to show the cost of each tonne of GHG abated. Negative values mean the farmer would make money from applying the method.

4.2.3 CPMM costs as a proportion of farm income



The costs of CPMM implementation need to be taken in conjunction with effects on income. Representative net farm income (NFI) and gross margin (GM) were calculated using a nine year average of income figures from 2000/01 to 2008/09 FBS data. Income figures from 1999/2000 were of insufficient quality to provide a standard 10 year average.

This provided a net cost of each CPMM for each farm type.

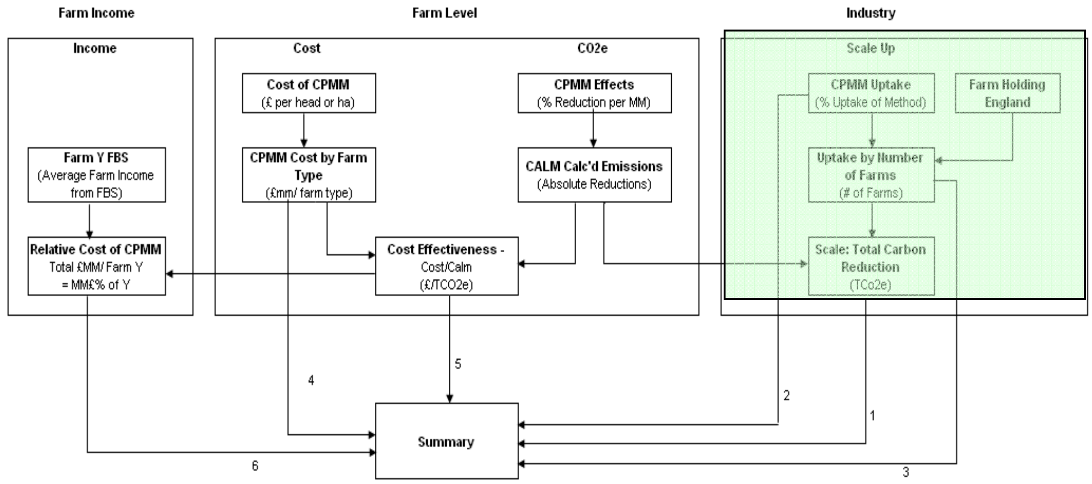
Detailed results of the relative costs by farm type, size and CPMM are presented in section 4.2.5.

Model: Calculation of relative cost impacts

Sheet 'Relative Cost of CPMM' presents the cost (or saving) associated with each mitigation measure, taken from 'CPMM Cost by Farm Type' as a percentage of the values in 'Farm Y FBS'.

These values should be interpreted with caution and compared alongside the cost effectiveness and income measures because a level of distortion exists due to some farms having very low incomes.

4.2.4 Industry - Scale Up



Farm level data derived from the model were scaled up to the industry level using the number of farms (from FBS Data Builder for 2008/09) and a level of uptake across the industry for each measure from the farmer survey as described in Section 3.0 and Appendix 3. These are combined to give an estimate of the number of farms in England undertaking a CPMM (accounting for those who do not always implement the CPMM). This is used with the calculated emissions per farm for each CPMM to produce an output indicating the likely reduction in CO_2e emissions for each mitigation measure.

The results of the industry scale up and detailed results by individual methods and farm types are presented in section 4.2.5.

Model: Calculation of potential increases in uptake and scale up

'CPMM Uptake' contains the survey-determined likely percentage uptake of each measure on each farm.

Sheet 'Number of Farms England' lists data compiled by Defra statistics from FBS data, of the total number of farms in England by farm type and by farm size.

Figures from 'CPMM Uptake' and 'Farm England' are combined in sheet 'Uptake by Number of Farms' to give an absolute value for number of farms in England undertaking a certain mitigation method.

This measure is then combined with data regarding the reduction in CO_2e emissions per farm from each individual mitigation measure (from 'CALM Calc'd Emissions').

Survey Uptake Rates

The lower and maximum potential increases in uptake for each method by farm type and size were calculated from the survey findings. The lower potential uptake (Table 8) excludes survey respondents who stated that they would not implement the method and in this sense shows the greatest potential for increased uptake without regulation. In general the potential for increased uptake on this basis is quite low with the majority of potential increased uptake percentages below 25%. The CPMMs 3, 4, 5, and 6 (all fertiliser application methods) are particularly low - all have average potential increase in uptake below 10%. The highest of the potential increases in uptake is for CPMM 8 (crops that need less N), with an average of over 40% of survey respondents that suggested they might be persuaded to take up this method, with the cereal sector over 50%. All the other methods are around the 20% level.

The averages across farm types and sizes show that there is very little difference in the potential for increased uptake e.g. the average potential increase in uptake for small dairy farms across all the CPMMs is 17%, the same as for mixed small farms, and the lowest average is 12% for large general cropping farms.

The maximum potential uptake (Table 9) is the increase in uptake that would result in all farmers implementing the method all of the time. The CPMMs 3, 4, 5, and 6 show the least potential increase in uptake. Another N related method, measure soil N (CPMM2) is the only other method below 50%. The CPMM8, grow crops that need less N, stands out as the MM with the greatest potential increase in uptake reflecting the relative low current planting of triticale.

In general, there is less potential for maximum increased uptake in cereal and general cropping farms reflecting the current high level of uptake for the fertiliser based methods as compared to the dairy, lowland, LFA and mixed farm types.

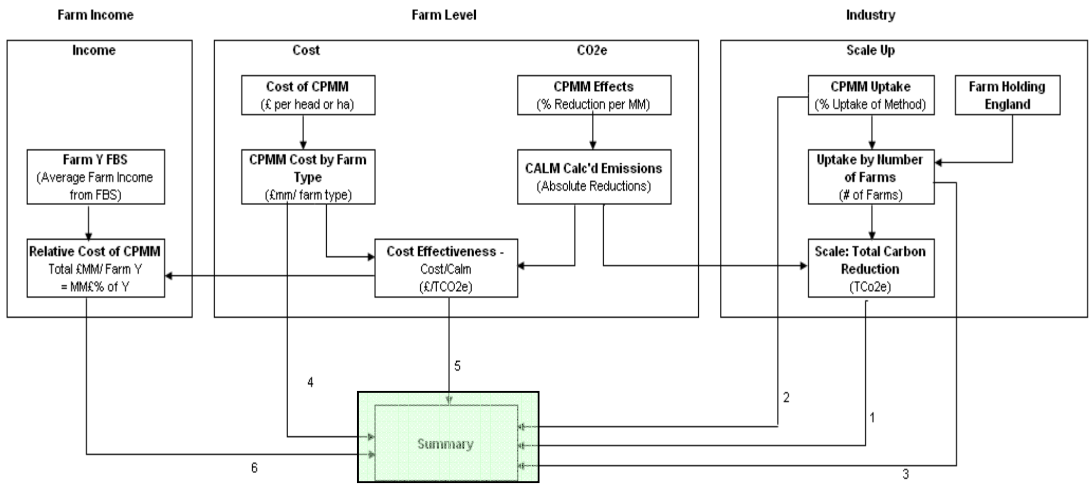
Table 7 CPMM lower potential uptake

Farm Type	Farm Size	Mitigation Methods									
		CPMM1 N Mng Plan: RB209	CPMM2 Measure soil N (SMN)	CPMM3 Fertiliser Spread calibration	CPMM4 Make Full Allowance for Manure N Supply	CPMM5 Improve Mineral N Timing	CPMM6 Manure Timing	CPMM7 Use Clover	CPMM8 Grow crops that need less N	CPMM9 Breeding for yield, fertility and health	CPMM10 Optimum Diet Formulation
Dairy	Small	42%	28%	14%	8%	11%	3%	30%		11%	13%
Dairy	Medium	37%	21%	8%	3%	9%	8%	25%		10%	7%
Dairy	Large	34%	14%	8%	2%	8%	4%	27%		8%	4%
Lowland B&S	Small	30%	23%	9%	10%	8%	6%	19%		18%	17%
Lowland B&S	Medium	28%	19%	11%	5%	6%	7%	21%		18%	14%
Lowland B&S	Large	26%	16%	10%	6%	7%	7%	21%		17%	13%
LFA B&S	Small	25%	26%	7%	6%	9%	0%	28%		23%	18%
LFA B&S	Medium	24%	30%	13%	5%	9%	0%	30%		22%	19%
LFA B&S	Large	26%	25%	9%	5%	9%	0%	29%		20%	17%
Mixed	Small	28%	25%	16%	7%	8%	4%	26%	26%	17%	16%
Mixed	Medium	26%	23%	17%	4%	7%	6%	26%	26%	16%	14%
Mixed	Large	23%	19%	15%	4%	8%	5%	26%	26%	15%	12%
Cereal	Small	17%	11%	0%	3%	4%	5%		55%		
Cereal	Medium	21%	15%	2%	0%	6%	6%		56%		
Cereal	Large	8%	12%	0%	2%	5%	7%		54%		
General Crop	Small	20%	18%	3%	4%	6%	7%		43%		
General Crop	Medium	11%	15%	0%	3%	5%	9%		42%		
General Crop	Large	9%	14%	8%	2%	3%	7%		43%		
Average Uptake Rate		24%	20%	8%	4%	7%	4%	24%	41%	16%	14%

Table 8 CPMM maximum potential uptake

		Mitigation Methods									
		CPMM1	CPMM2	CPMM3	CPMM4	CPMM5	CPMM6	CPMM7	CPMM8	CPMM9	CPMM10
Farm Type	Farm Size	N Mng Plan: RB209	Measure soil N (SMN)	Fertiliser Spread calibration	Make Full Allowance for Manure N Supply	Improve Mineral N Timing	Manure Timing	Use Clover	Grow crops that need less N	Breeding for yield, fertility and health	Optimum Diet Formulation
Dairy	Small	91%	68%	51%	26%	24%	20%	58%		50%	40%
Dairy	Medium	81%	50%	28%	9%	18%	59%	47%		47%	23%
Dairy	Large	74%	33%	27%	6%	16%	31%	53%		35%	13%
Lowland B&S	Small	94%	69%	29%	29%	33%	32%	49%		79%	68%
Lowland B&S	Medium	87%	56%	35%	13%	24%	35%	55%		76%	56%
Lowland B&S	Large	82%	49%	31%	20%	29%	39%	55%		72%	60%
LFA B&S	Small	92%	75%	23%	35%	30%	0%	68%		81%	65%
LFA B&S	Medium	90%	65%	41%	28%	30%	43%	73%		75%	70%
LFA B&S	Large	95%	73%	27%	26%	29%	25%	70%		71%	63%
Mixed	Small	72%	51%	19%	23%	22%	24%	58%	98%	70%	58%
Mixed	Medium	66%	47%	21%	13%	20%	37%	58%	98%	66%	50%
Mixed	Large	57%	38%	18%	13%	19%	32%	59%	97%	59%	42%
Cereal	Small	36%	20%	1%	10%	11%	24%		99%		
Cereal	Medium	45%	27%	8%	1%	14%	30%		100%		
Cereal	Large	17%	21%	1%	6%	13%	32%		96%		
General Crop	Small	44%	22%	3%	8%	15%	23%		100%		
General Crop	Medium	25%	18%	0%	6%	14%	32%		98%		
General Crop	Large	20%	17%	8%	3%	8%	27%		100%		
Average Uptake Rate		65%	44%	21%	15%	21%	30%	59%	98%	65%	51%

4.2.5 Model outputs at industry level



The summary sheet of the model brings together all the key values in the background sheets to provide a headline and detailed summary of the effectiveness, the total costs and the cost-effectiveness (Table 10). The traffic light style colouring in Table 10 differentiates the high potential mitigation/most cost effective methods.

Total emissions values from the model show a potential saving of 0.6M tCO_2e from the lower potential uptake model which equates to 2.2% of emissions from English agriculture. This is increased to 1.7M tCO_2e using the maximum model or 5.7% of English agriculture emissions. Of this clover and livestock breeding offer the greatest potential, although growing lower N crops, improving nitrogen use and optimal diet formulation have estimated contributions above 150,000 tonnes per annum.

A degree of caution on the total potential of all the methods should be noted since many of the methods may be substitutes and target the same source of emissions. Thus, whilst the methods can be applied concurrently, the savings from all methods together is unlikely to equal the sum of the parts. When methods interact their relative levels of abatement and therefore their cost effectiveness will change. This is a highly complex subject with very limited empirical data. The MACC 2 includes an analysis of the interactions of mitigation methods and the effects of interactions are represented within the estimates therein.

The farm level aggregated results (for the 36,000 farms considered) show that 6 of the 10 CPMMs have a saving for the farmer (-ve cost values), with relatively large savings from the use of clover and improving livestock breeding. Growing low nitrogen crops could also offer savings. Those that impose costs to the industry include estimating soil nitrogen, spreader calibration and managing nitrogen timing for manures.

In general the mitigation methods can be viewed in three groups:

- Mostly green group: CPMM7 Clover; CPMM9 Livestock breeding; (CPMM8 Triticale);
- Mostly amber group: (CPMM8 Triticale); CPMM10 Optimal diet formulation; CPMM1 RB209 – CPMM4 Manure nitrogen;
- Mostly red group: CPMM2 Soil nitrogen supply; CPMM3 Fertiliser calibration, CPMM5 Nitrogen timing and CPMM6 Manure timing.

Those MMs with more red cells in Table 10 might be considered least attractive methods for policy consideration.

Table 9 Summary of lower and maximum potential uptake mitigation potential and costs for the selected farm types at an industry level

CPMM	Total M tCO_2e Reduced		Total Cost		Cost per tCO_2e	
	Lower	Maximum	Lower	Maximum	Lower	Maximum
1: Fertiliser planning, RB209	0.052	0.123	-£0.6m	-£1.2m	-£14	-£11
2: Estimate Soil N	0.045	0.086	£10.8m	£23.6m	£259	£297
3: Spreader calibration	0.015	0.030	£2.9m	£7.2m	£231	£261
4: Manure N Supply	0.004	0.013	-£0.2m	-£0.7m	-£59	-£58
5: N Timing	0.084	0.220	£4.9m	£13.1m	£63	£64
6: Manure Timing	0.020	0.109	£1.2m	£7.2m	£66	£72
7: Clover	0.135	0.301	-£18.3m	-£40.1m	-£152	-£150
8: Grow triticale instead of feed wheat	0.075	0.151	-£8.3m	-£16.5m	-£114	-£115
9: Livestock Breeding	0.109	0.452	-£13.5m	-£63.7m	-£132	-£154
10: Optimal Diet	0.062	0.227	-£6.3m	-£23.0m	-£89	-£88
Total	**0.601**	**1.710**				

Green	Total CO_2 e reduced > 0.150M tpa, total costs > -£25m, cost effectiveness per tonne > -£100
Amber	Total CO_2 e reduced 0.050M – 0.150M tpa, total costs -£25m - £0m, cost effectiveness per tonne -£100 - £0
Red	Total CO_2 e reduced < 0.050M tpa, total costs > £0m, cost effectiveness per tonne > £53

In terms of the cost effectiveness of the mitigation potential (cost per tCO_2e reduced), approximately three quarters is estimated to be achieved at a level below zero (i.e. cost savings to the farmer). A further 20% is estimated to be achievable at a cost slightly above the DECC cost of carbon 2012 value of £53/tCO_2e (the two fertiliser timing methods). The rest is estimated to be achievable at cost well above the DECC cost of carbon i.e. not cost effective.

The cost per tCO_2e varies between the maximum and lower estimates, which is in line with findings in MACC 2. This effect originates because the relative[34] uptake rates between different farm types are different for the lower and maximum models.

Each CPMM is discussed in more detail below.

Mitigation theme: Avoid excess nitrogen

CPMM1: Nitrogen management plan: RB209

Using nitrogen management planning gives estimated farm level emissions reductions aggregated to the 36,000 farms covered by these farm types. Reductions range from 944 tCO_2e for medium lowland cattle and sheep farms to over 7,000 tCO_2e for large dairy farms for the lower potential uptake, and up to over 16,000 tCO_2e for large diary farms for the maximum potential uptake.

The cost of implementing this MM at a farm level is relatively small with overall costs in the lowland and LFA beef and sheep sectors, but an overall benefit for all other sectors, reflecting the different usage of fertiliser. Savings per farm are relatively modest with the largest savings (as shown by the negative sign[35]) of £705 for large cereal farms (Table 11).

The costs per tCO_2e are similar for mixed, cereal and general farms of all sizes with a saving of £17-24/t. Savings are lower for dairy farms at around £5-6/t, while there is an overall cost of £24-28/t CO_2e in beef and sheep farms.

Table 10 Model results CPMM1

		Total tCO_2e Reduced		Max cost of measure per farm	Cost as % of Net Farm Income	Cost as % of Gross Margin	Cost per farm per tCO_2e reduced
		Lower	Maximum				
Dairy	Small	1,013	2,194	-£9	-0.1%	0.0%	-£6
Dairy	Medium	1,914	4,191	-£13	-0.1%	0.0%	-£5
Dairy	Large	7,525	16,377	-£24	-0.1%	0.0%	-£5
Lowland B&S	Small	1,876	5,878	£48	0.9%	0.1%	£25
Lowland B&S	Medium	944	2,933	£76	0.8%	0.1%	£24
Lowland B&S	Large	1,383	4,361	£126	0.9%	0.2%	£24
LFA B&S	Small	842	3,099	£45	0.6%	0.1%	£28
LFA B&S	Medium	749	2,329	£68	0.5%	0.1%	£27
LFA B&S	Large	1,051	3,839	£133	0.7%	0.2%	£26
Mixed	Small	1,653	4,251	-£63	-0.6%	-0.1%	-£19
Mixed	Medium	1,415	3,591	-£100	-0.5%	-0.1%	-£17
Mixed	Large	4,533	11,235	-£212	-0.7%	-0.1%	-£17
Cereal	Small	7,016	14,858	-£193	-0.9%	-0.2%	-£22
Cereal	Medium	6,163	13,206	-£295	-0.9%	-0.2%	-£23
Cereal	Large	6,054	12,866	-£705	-1.7%	-0.3%	-£22
General Crop	Small	2,398	5,275	-£142	-0.7%	-0.2%	-£24
General Crop	Medium	1,004	2,282	-£230	-0.7%	-0.2%	-£23
General Crop	Large	4,562	10,138	-£566	-1.1%	-0.3%	-£23

[34] For example, for CPMM2 relative uptake rates for dairy small versus cereal small is 2.55 (28%:11%) for lower model and 3.4 (68%:20%) for the maximum model.
[35] In this and all the subsequent tables, negative numbers mean that the farm saves money by implementing the method and positive numbers mean that the method incurs additional costs. The signs follow into the relative savings or costs as a proportion of farm income or gross margin and the cost per tonne of CO_2e reduced.

CPMM2: Estimating soil nitrogen

The models show limited mitigation potential associated with lowland and LFA farms from measuring soil nitrogen supply. Cereal farms have the greatest potential mitigation by some margin. Dairy farms increase their share of potential mitigation in the maximum model as this excludes those who say they will not be persuaded to utilise the method.

The farm level costs of implementation are generally over £1,000 per farm with LFA and lowland farms having the highest relative costs. The cost per tonne of CO_2e saved is above £100 for all farm types making this one of the least cost effective methods.

Table 11 Model results CPMM2

		Total tCO_2e Reduced		Max cost of measure per farm	Cost as % of Net Farm Income	Cost as % of Gross Margin	Cost per farm per tCO_2e reduced
		Lower	Maximum				
Dairy	Small	675	1,639	£1,096	7.7%	2.1%	£766
Dairy	Medium	1,087	2,587	£1,668	7.0%	2.0%	£666
Dairy	Large	3,098	7,303	£3,009	8.4%	2.2%	£620
Lowland B&S	Small	1,438	4,315	£977	18.3%	2.4%	£515
Lowland B&S	Medium	640	1,888	£1,549	15.7%	2.8%	£482
Lowland B&S	Large	851	2,606	£2,556	19.1%	3.3%	£487
LFA B&S	Small	876	2,527	£661	8.5%	1.8%	£411
LFA B&S	Medium	668	1,893	£1,004	6.9%	1.9%	£393
LFA B&S	Large	1,010	2,950	£1,957	9.6%	2.6%	£387
Mixed	Small	1,476	3,011	£957	9.3%	1.6%	£294
Mixed	Medium	1,252	2,557	£1,516	8.3%	1.7%	£259
Mixed	Large	3,745	7,490	£3,221	11.2%	2.2%	£256
Cereal	Small	4,540	8,255	£915	4.1%	0.9%	£106
Cereal	Medium	4,402	7,924	£1,402	4.5%	0.9%	£108
Cereal	Large	9,082	15,893	£3,347	8.3%	1.5%	£104
General Crop	Small	2,158	2,637	£912	4.3%	1.1%	£154
General Crop	Medium	1,369	1,643	£1,474	4.3%	1.1%	£149
General Crop	Large	7,096	8,617	£3,620	7.3%	1.7%	£144

CPMM3: Fertiliser Spreader Calibration

Mitigation potential of fertiliser calibration appears comparatively limited with large dairy, large mixed and large general cropping farms providing around half of the total potential. These farms have the greatest potential to increase uptake and a large amount of current relevant emissions for the MM to act upon.

The total costs of implementing the CPMM to each farm are relatively similar across farm types and sizes, with the relative impact being greatest for lowland and LFA farms. In terms of cost per tonne, it is only for cereals that this moves towards the DECC 2012 cost of carbon of £53/tCO_2e.

The zero maximum potential for medium general farms reflects the survey where all respondents said they always calibrate their spreader. The zero values for small and large cereal farms reflect the responses of those that don't currently calibrate, who say they won't be persuaded to change.

Table 12 Model results CPMM3

		Total tCO_2e Reduced		Max cost of measure per farm	Cost as % of Net Farm Income	Cost as % of Gross Margin	Cost per farm per tCO_2e reduced
		Lower	Maximum				
Dairy	Small	338	1,229	£685	4.8%	1.4%	£479
Dairy	Medium	414	1,449	£1,043	4.4%	1.3%	£417
Dairy	Large	1,771	5,975	£1,881	5.2%	1.5%	£387
Lowland B&S	Small	563	1,813	£610	11.4%	2.4%	£322
Lowland B&S	Medium	371	1,180	£968	9.8%	2.8%	£301
Lowland B&S	Large	532	1,649	£1,598	11.9%	3.3%	£305
LFA B&S	Small	236	775	£413	5.3%	2.5%	£257
LFA B&S	Medium	290	913	£627	4.3%	2.7%	£246
LFA B&S	Large	364	1,091	£1,223	6.0%	3.5%	£242
Mixed	Small	945	1,122	£598	5.8%	1.8%	£184
Mixed	Medium	925	1,143	£948	5.2%	1.9%	£162
Mixed	Large	2,957	3,548	£2,013	7.0%	2.4%	£160
Cereal	Small	0	413	£572	2.5%	1.8%	£66
Cereal	Medium	587	2,348	£876	2.8%	1.8%	£68
Cereal	Large	0	757	£2,093	5.2%	2.8%	£65
General Crop	Small	360	360	£570	2.7%	1.6%	£96
General Crop	Medium	0	0	£921	2.7%	1.6%	£93
General Crop	Large	4,055	4,055	£2,263	4.6%	2.5%	£90

CPMM4: Allowance for Manure Supply

Whilst cost effective, the high current use and low willingness to expand the use of this method result in particularly low estimated potential. The total savings per farm are modest in absolute and relative terms. As with CPMM3 (spreader calibration), the zero in cereal medium for the lower model was due to zero potential increases in uptake due to the unwillingness of those not implementing the method to do so.

Table 13 Model results CPMM4

		Total tCO_2e Reduced		Max cost of measure per farm	Cost as % of Net Farm Income	Cost as % of Gross Margin	Cost per farm per tCO_2e reduced
		Lower	Maximum				
Dairy	Small	166	539	-£120	-0.8%	-0.2%	-£97
Dairy	Medium	117	350	-£171	-0.7%	-0.2%	-£91
Dairy	Large	309	927	-£294	-0.8%	-0.2%	-£87
Lowland B&S	Small	526	1,526	-£59	-1.1%	-0.1%	-£37
Lowland B&S	Medium	139	360	-£93	-0.9%	-0.2%	-£35
Lowland B&S	Large	250	832	-£151	-1.1%	-0.2%	-£37
LFA B&S	Small	177	1,030	-£56	-0.7%	-0.2%	-£40
LFA B&S	Medium	96	537	-£85	-0.6%	-0.2%	-£39
LFA B&S	Large	177	922	-£167	-0.8%	-0.2%	-£38
Mixed	Small	222	729	-£119	-1.2%	-0.2%	-£68
Mixed	Medium	102	331	-£171	-0.9%	-0.2%	-£62
Mixed	Large	351	1,142	-£351	-1.2%	-0.2%	-£63
Cereal	Small	377	1,256	-£130	-0.6%	-0.1%	-£49
Cereal	Medium	0	90	-£201	-0.6%	-0.1%	-£51
Cereal	Large	447	1,340	-£462	-1.1%	-0.2%	-£49
General Crop	Small	154	307	-£93	-0.4%	-0.1%	-£49
General Crop	Medium	86	173	-£147	-0.4%	-0.1%	-£47
General Crop	Large	315	473	-£351	-0.7%	-0.2%	-£45

Mitigation theme: Nitrogen timing

CPMM5: Improve mineral timing

The mitigation potential of this MM is restricted by the high levels of current uptake. However, the levels of potential mitigation are a function of the assumption on the effect of the method per hectare – a reduction of 25% per hectare, thus total potential for the maximum uptake is still over 200,000 tonnes.

The costs are mostly above £1,000 per farm but potential changes to yield have not been incorporated. In a number of cases the costs are greater than 10% of historic net income and it is only for mixed, cereal and general farms that the cost effectiveness approaches the DECC 2012 carbon value (£53/t CO_2e).

Table 14 Model results CPMM5

		Total tCO_2e Reduced		Max cost of measure per farm	Cost as % of Net Farm Income	Cost as % of Gross Margin	Cost per farm per tCO_2e reduced
		Lower	Maximum				
Dairy	Small	1,326	2,893	£742	5.2%	1.4%	£104
Dairy	Medium	2,328	4,657	£1,129	4.8%	1.3%	£90
Dairy	Large	8,853	17,705	£2,037	5.7%	1.5%	£84
Lowland B&S	Small	2,501	10,317	£982	18.4%	2.4%	£104
Lowland B&S	Medium	1,011	4,045	£1,558	15.8%	2.8%	£97
Lowland B&S	Large	1,861	7,712	£2,570	19.2%	3.3%	£98
LFA B&S	Small	1,516	5,054	£918	11.7%	2.5%	£114
LFA B&S	Medium	1,002	3,341	£1,393	9.6%	2.7%	£109
LFA B&S	Large	1,818	5,859	£2,715	13.3%	3.5%	£108
Mixed	Small	2,362	6,495	£1,048	10.2%	1.8%	£64
Mixed	Medium	1,904	5,441	£1,661	9.1%	1.9%	£57
Mixed	Large	7,884	18,725	£3,528	12.3%	2.4%	£56
Cereal	Small	8,255	22,700	£1,778	7.9%	1.8%	£41
Cereal	Medium	8,804	20,543	£2,723	8.7%	1.8%	£42
Cereal	Large	18,920	49,192	£6,505	16.1%	2.8%	£40
General Crop	Small	3,596	8,991	£1,314	6.2%	1.6%	£44
General Crop	Medium	2,282	6,389	£2,124	6.2%	1.6%	£43
General Crop	Large	7,603	20,276	£5,217	10.6%	2.5%	£42

CPMM6: Manure Timing

This method has been assumed to apply to those areas currently receiving organic manures as stated in the BSFP (2009). The difference between the lower and maximum estimates is quite large reflecting the higher proportion of respondents who say that they could not be persuaded to implement this method. This is particularly the case in the dairy sector.

Over half of the potential is within the cereal and general crop sectors which are also the only two sectors that have a cost effectiveness below the DECC 2012 cost of carbon.

Table 15 Model results CPMM6

		Total tCO_2e Reduced		Max cost of measure per farm	Cost as % of Net Farm Income	Cost as % of Gross Margin	Cost per farm per tCO_2e reduced
		Lower	Maximum				
Dairy	Small	183	1,221	£346	2.4%	0.7%	£96
Dairy	Medium	914	6,743	£494	2.1%	0.6%	£89
Dairy	Large	1,819	14,094	£852	2.4%	0.6%	£85
Lowland B&S	Small	928	4,951	£460	8.6%	1.1%	£98
Lowland B&S	Medium	570	2,852	£720	7.3%	1.3%	£93
Lowland B&S	Large	856	4,771	£1,175	8.8%	1.5%	£97
LFA B&S	Small	0	0	£438	5.6%	1.2%	£106
LFA B&S	Medium	0	2,427	£662	4.5%	1.3%	£102
LFA B&S	Large	0	2,607	£1,302	6.4%	1.7%	£100
Mixed	Small	373	2,238	£390	3.8%	0.7%	£76
Mixed	Medium	449	2,768	£558	3.1%	0.6%	£69
Mixed	Large	1,292	8,267	£1,148	4.0%	0.8%	£70
Cereal	Small	1,846	8,862	£377	1.7%	0.4%	£49
Cereal	Medium	1,585	7,923	£581	1.9%	0.4%	£50
Cereal	Large	4,599	21,026	£1,339	3.3%	0.6%	£48
General Crop	Small	791	2,599	£270	1.3%	0.3%	£48
General Crop	Medium	763	2,714	£427	1.3%	0.3%	£46
General Crop	Large	3,245	12,515	£1,018	2.1%	0.5%	£44

Mitigation theme: Crop choice

CPMM7: Clover instead of grass

The potential for increased levels of uptake in the lower and maximum models were fairly high and consistent within models across farm types resulting in a high absolute potential reduction from growing clover, across all farm types when compared to other methods. The CPMM was applied only to those systems with significant areas of grass, hence the apparent zero potential in cereals and general cropping.

Dairy farming accounts for around one third of potential reduction in CO_2e emissions in both models.

Savings per farm were similar and substantial across farm types, with lowland and LFA farms having the greatest relative savings. The high negative cost per farm per tonne of CO_2e reduced make this a win-win method.

Table 16 Model results CPMM7

		Total tCO_2e Reduced		Max cost of measure per farm	Cost as % of Net Farm Income	Cost as % of Gross Margin	Cost per farm per tCO_2e reduced
		Lower	Maximum				
Dairy	Small	6,756	13,062	-£2,150	-15.1%	-4.1%	-£161
Dairy	Medium	9,813	18,449	-£2,908	-12.3%	-3.4%	-£153
Dairy	Large	39,964	78,447	-£4,755	-13.2%	-3.4%	-£146
Lowland B&S	Small	10,830	27,929	-£1,895	-35.5%	-4.7%	-£110
Lowland B&S	Medium	6,176	16,174	-£2,931	-29.8%	-5.3%	-£105
Lowland B&S	Large	9,173	24,025	-£4,804	-35.9%	-6.2%	-£112
LFA B&S	Small	9,190	22,319	-£1,844	-23.6%	-5.0%	-£118
LFA B&S	Medium	6,340	15,426	-£2,775	-19.1%	-5.3%	-£115
LFA B&S	Large	11,504	27,768	-£5,506	-26.9%	-7.2%	-£111
Mixed	Small	6,463	14,418	-£2,104	-20.5%	-3.6%	-£153
Mixed	Medium	4,474	9,980	-£2,780	-15.3%	-3.1%	-£150
Mixed	Large	14,586	33,099	-£5,474	-19.1%	-3.8%	-£153
Cereal	Small	0	0	£0	0.0%	0.0%	£0
Cereal	Medium	0	0	£0	0.0%	0.0%	£0
Cereal	Large	0	0	£0	0.0%	0.0%	£0
General Crop	Small	0	0	£0	0.0%	0.0%	£0
General Crop	Medium	0	0	£0	0.0%	0.0%	£0
General Crop	Large	0	0	£0	0.0%	0.0%	£0

CPMM8 : Grow crops that need less nitrogen

The growing of crops that need less nitrogen (growing of triticale in place of some feed wheat in this project) was restricted to mixed, cereal and general cropping farms. In the lower and maximum models, cereal farms have the greatest potential. The high contribution to both models from the cereal sector is driven by the relatively high potential increase in uptake of this measure on these farms (55% and 98% in the lower and maximum model respectively). It should be noted that the total abatement potential is limited in the model in that it is assumed (as in AC0221) that the maximum extent of triticale as a crop is 24% of the winter wheat area. As such it should be viewed as indicative of the potential for growing low N crops.

The difference between the maximum and lower models are relatively greater for general cropping and mixed than for cereals reflecting the response in the survey – a greater proportion of mixed and general cropping farmers said they would never be persuaded to change as compared with cereal farmers.

Like the clover MM, this CPMM provides savings to the farmers and therefore very cost effective CO_2e reductions.

Table 17 Model results CPMM8

		Total tCO_2e Reduced		Max cost of measure per farm	Cost as % of Net Farm Income	Cost as % of Gross Margin	Cost per farm per tCO_2e reduced
		Lower	Maximum				
Dairy	Small	0	0	£0	0.0%	0.0%	£0
Dairy	Medium	0	0	£0	0.0%	0.0%	£0
Dairy	Large	0	0	£0	0.0%	0.0%	£0
Lowland B&S	Small	0	0	£0	0.0%	0.0%	£0
Lowland B&S	Medium	0	0	£0	0.0%	0.0%	£0
Lowland B&S	Large	0	0	£0	0.0%	0.0%	£0
LFA B&S	Small	0	0	£0	0.0%	0.0%	£0
LFA B&S	Medium	0	0	£0	0.0%	0.0%	£0
LFA B&S	Large	0	0	£0	0.0%	0.0%	£0
Mixed	Small	639	2,409	-£107	-1.0%	-0.2%	-£79
Mixed	Medium	621	2,341	-£204	-1.1%	-0.2%	-£79
Mixed	Large	2,590	9,664	-£504	-1.8%	-0.3%	-£79
Cereal	Small	15,988	28,779	-£687	-3.0%	-0.7%	-£113
Cereal	Medium	10,503	18,755	-£934	-3.0%	-0.6%	-£113
Cereal	Large	26,180	46,543	-£2,325	-5.7%	-1.0%	-£113
General Crop	Small	3,296	7,665	-£428	-2.0%	-0.5%	-£113
General Crop	Medium	2,073	4,836	-£602	-1.8%	-0.4%	-£113
General Crop	Large	12,812	29,795	-£1,662	-3.4%	-0.8%	-£113

Mitigation theme: Livestock breeding

Livestock Breeding: CPMM9

Livestock breeding has a high potential impact on GHG mitigation. Survey data showed a lower potential increase in uptake rate on dairy farms, because close to half of farmers interviewed stated that they always undertook this measure, whilst on other farms potential increases in uptake rates were generally twice as high.

This method provides substantial reductions in carbon equivalent emissions, given the large emissions from dairy herds with nearly one half of the total mitigation potential associated with this method attributed to dairy farms.

Absolute savings to each farm were highest for dairy across all sizes but lowland and LFA savings were greater.

Table 18 Model results CPMM9

		Total tCO_2e Reduced		Max cost of measure per farm	Cost as % of Net Farm Income	Cost as % of Gross Margin	Cost per farm per tCO_2e reduced
		Lower	Maximum				
Dairy	Small	5,600	25,455	-£3,520	-24.8%	-6.6%	-£117
Dairy	Medium	9,277	43,600	-£5,274	-22.2%	-6.2%	-£118
Dairy	Large	33,508	146,598	-£10,747	-29.9%	-7.7%	-£117
Lowland B&S	Small	8,662	38,018	-£2,509	-47.0%	-6.2%	-£172
Lowland B&S	Medium	4,117	17,381	-£3,748	-38.1%	-6.7%	-£172
Lowland B&S	Large	7,677	32,514	-£6,637	-49.6%	-8.5%	-£149
LFA B&S	Small	8,717	30,700	-£2,185	-27.9%	-6.0%	-£121
LFA B&S	Medium	5,591	19,062	-£3,330	-22.9%	-6.4%	-£114
LFA B&S	Large	10,124	35,939	-£7,008	-34.3%	-9.1%	-£111
Mixed	Small	2,912	11,992	-£1,575	-15.4%	-2.7%	-£167
Mixed	Medium	2,437	10,051	-£2,167	-11.9%	-2.4%	-£132
Mixed	Large	10,280	40,436	-£3,774	-13.2%	-2.6%	-£86
Cereal	Small	0	0	£0	0.0%	0.0%	£0
Cereal	Medium	0	0	£0	0.0%	0.0%	£0
Cereal	Large	0	0	£0	0.0%	0.0%	£0
General Crop	Small	0	0	£0	0.0%	0.0%	£0
General Crop	Medium	0	0	£0	0.0%	0.0%	£0
General Crop	Large	0	0	£0	0.0%	0.0%	£0

Mitigation theme: Livestock feeding

CPMM10: Optimum Diet Formulation

Potential appears fairly evenly spread across the farm types. Small lowland farms stand out as having potential which is partly a function of over 60% of lowland farms (>0.5 SLR) being classified as small. This is the largest proportion of small farm size of any of the farm types.

The potential uptake may be overstated. Many extensive systems are based around maintenance diets and standard rations provided by feed companies, and although formal rationing is possible it may not actually provide any further reduction in emissions as the benefits are already being realised.

Table 19 Model results CPMM10

		Total tCO_2e Reduced		Max cost of measure per farm	Cost as % of Net Farm Income	Cost as % of Gross Margin	Cost per farm per tCO_2e reduced
		Lower	Maximum				
Dairy	Small	4,364	13,428	-£1,778	-12.5%	-3.4%	-£89
Dairy	Medium	4,420	14,523	-£2,682	-11.3%	-3.2%	-£88
Dairy	Large	11,265	36,612	-£5,494	-15.3%	-4.0%	-£89
Lowland B&S	Small	7,806	31,225	-£1,239	-23.2%	-3.1%	-£89
Lowland B&S	Medium	3,062	12,248	-£1,945	-19.8%	-3.5%	-£93
Lowland B&S	Large	4,832	22,302	-£4,446	-33.2%	-5.7%	-£121
LFA B&S	Small	5,143	18,572	-£1,601	-20.5%	-4.4%	-£117
LFA B&S	Medium	3,512	12,939	-£2,689	-18.5%	-5.2%	-£127
LFA B&S	Large	5,826	21,590	-£5,868	-28.7%	-7.6%	-£137
Mixed	Small	3,460	12,542	-£880	-8.6%	-1.5%	-£74
Mixed	Medium	2,061	7,359	-£1,444	-7.9%	-1.6%	-£91
Mixed	Large	6,717	23,510	-£3,396	-11.8%	-2.3%	-£95
Cereal	Small	0	0	£0	0.0%	0.0%	£0
Cereal	Medium	0	0	£0	0.0%	0.0%	£0
Cereal	Large	0	0	£0	0.0%	0.0%	£0
General Crop	Small	0	0	£0	0.0%	0.0%	£0
General Crop	Medium	0	0	£0	0.0%	0.0%	£0
General Crop	Large	0	0	£0	0.0%	0.0%	£0

4.2.6 Anaerobic Digestion

Notes on costing analysis:

Those that required capital expenditure (e.g. AD) exhibit a step function in terms of costs when applied at different scales. However, for AD it was considered that this MM was only appropriate for larger farms and thus only large farms were considered.

Anaerobic digestion is very different from any other MM in that it requires major capital investment in the buildings and provision of a feedstock with high energy levels, since there is insufficient energy in animal slurry to justify the investment. On farm AD units using farm produced crops such as silage (grass, whole cereal or maize) by definition use a consistent feedstock and can be operated in house, whereas AD units utilising food waste require greater technical competence and expertise. On farm AD is more suited to larger farms. Unlike other MM outlined in this report, farmers who implement this method are likely to receive some kind of financial support/grant aid for its uptake. As AD has the potential to produce renewable energy (in the form of methane) its utilisation is very different to other MMs which do not receive subsidy or produce a marketable end product.

Anaerobic digestion has been costed on a per farm basis. It is unrealistic to model the potential for AD on the same basis as the other MMs since the use of uptake data would lead to the model showing the effect of an AD plant on almost all the 36,000 farms (since almost none of the survey respondents currently used AD).

The Agriculture GHG Action Plan targets 550,000-600,000 tCO_2e abatement from 1,000 farm based AD plants by 2020. Therefore the uptake/potential of this measure has been calculated on the basis of this target. Whilst this is only a figure based upon the likely up-scaling of AD as a new technology it is still unclear as to the relative size of the units. For example large units may exist on bigger livestock farms taking purely agricultural waste as well as more centralised units that receive feedstock from multiple sites (municipal food waste as well as agricultural). Based on expert opinion and review of Defra 2008 data, it has been assumed that 100 of the1,000 units would be based on pig and poultry farms and therefore not included in this analysis. The remaining 900 units have been apportioned at 500 to dairy, 200 to lowland, 190 to mixed and 5 to both cereal and general farms. However, at this stage only on-farm materials have been considered for feedstock, thus reducing the potential mitigation substantially as compared to centralised facilities.

Costs for cereal and general farms have been calculated at £54,460 per year and other farms at £28,200. These costs were considered too high for small or medium farms to be able to incur and therefore we have only attributed AD to large farms. This created five scenarios.

The costings for the AD units used the National Non-Food Crop Centre (NNFCC) model, to give an average cost for a generalised digester (http://www.biogas-info.co.uk/index.php/ad-calculator).

Cereal and General Cropping: The AD unit would utilise 100 ha of a suitable crop and import 250t of dairy slurry. The unit would have a capital cost of £435,000, incur an annual charge of some £35,000 for maintenance and other costs, including those of energy crops. Income from electricity sales, Renewable Obligation Certificates/Feed in Tariffs' (ROCs/FITs) of some £48,000 and savings in fertiliser costs of £135,000, took the net income to around £134,000.

Dairy, Lowland and Mixed: A smaller unit was assumed, using 30 ha of crops and manure from the livestock. Cropping was assumed to be 15 ha of wheat, 7 ha of maize and 7 ha of grass. The unit would have a capital cost of £210,000, incur an annual charge of £17,000 for maintenance and other costs including those of the energy crops. Similar fixed costs (though at a lower level) were assumed for the dairy unit as the arable unit. This unit would qualify for FIT due to a yield of <500kW electricity, added to electricity sales of some £44,000 and with fertiliser value of digestate this gives a total net income of £33,000.

Farm level effectiveness

CPMM11 mitigation potential is adapted using expert opinion from ACO206. It is given a high mitigation potential in AC0206, but this includes the methane generated from the AD unit, which would be far greater than if the slurry had been left in the slurry store. In AC0206, an estimate of 10% reduction in methane emissions from slurry is suggested.

Model outputs

Table 20 Summary of lower and maximum potential uptake mitigation potential and costs

	Total tCO_2e Reduced		Total Cost		Cost per tCO_2e	
CPMM	Lower	Maximum	Lower	Maximum	Lower	Maximum
11: Anaerobic Digestion	6,643	6,643	-£25.6m	-£25.6m	-£4,667	-£4,667

Anaerobic Digestion is estimated here to have a low mitigation potential at the farm level given the assumptions used. However, the NNFCC model does suggest that such investments provide good financial returns.. However, this outcome is the result of using the NNFCC model and is at odds with other estimates in terms of cost effectiveness (e.g. WQ0106).

In terms of costs per tCO_2e reduced, AD showed very large value for money in CO_2e terms but this result is not repeated in other studies. The high apparent cost effectiveness is also due to the cost savings being divided by a limited amount of mitigation. This also occurs in other CPMMs for certain farm types, most commonly LFA, that have low levels of potential mitigation

Table 21 Model results CPMM11

	Total tCO_2e Reduced	Total Cost	Cost per tCO_2e Reduced	Cost as % of Net Farm Income	Cost as % of Gross Margin
Dairy (Large)	3,950	-£14.100m	-£3,570	78.5%	20.3%
Lowland B&S (Large)	160	-£5.700m	-£35,250	210%	36.2%
Mixed (Large)	2,299	-£5.358m	-£2,331	98.3%	19.5%
Cereal (Large)	119	-£0.272m	-£2,288	134.7%	23.6%
General (Large)	115	-£0.272m	-£2,368	110.5%	26.0%
Total	6,643	-£25.642m	-£4,667	126.5%	25.1%

AD provides a good return on all farms tested, with upwards of 20% of gross margin being made by implementing AD and in some cases more that the entire net farm income for a year. In the case of lowland farms, the return as a percentage of NFI was double that of current NFI.

5. Discussion and conclusions

5.1 Mitigation potential of on farm methods

5.1.1 Emissions reductions targets

The Agriculture Industry GHG Action Plan[36] proposed an annual emission cut in England of 3M tCO_2e per year against a 2008 baseline. Of this, nutrient management contributes 0.9M tCO_2e with 2.15M tCO_2e from livestock. The Action Plan does include a separate section for energy from renewables and that used in fertiliser production but these were outside the scope of this project and are not included in the 3M tCO_2e target.

5.1.2 Mitigation methods

A large number of MMs have been suggested in the literature and those selected for this project were primarily on the basis of their practical implementation and the estimated scope for abatement. This has limited the number and scope of the MMs somewhat. Some methods such as drainage were omitted due to the high level of uncertainty but this method has been estimated by some to potentially provide high levels of abatement. Similarly probiotics use in feed rations have been estimated to significantly reduce GHGs but were excluded here because of low current uptake and the need for further research.

Some other methods not covered in this and previous projects were mentioned by farmers in the focus groups. These include:

- The use of mixer wagons for feeding cattle which provide a more homogenous food supply which improves gut efficiency and therefore improves growth rates and possibly direct methane emissions
- The use of GPS systems. There is quite widespread use on arable farms with the simplest systems allowing greater precision of tramlines and spraying. Cattle and sheep farms also identified a potential benefit especially on grassland where there were no tramlines and the systems led to more accurate fertiliser applications. It is useful to note that in this project GPS was somewhat outside the scope as it refers to mitigating emissions from direct fuel usage contributing CO_2 rather than methane and nitrous oxide emissions.

These and other mitigation methods can be included in a similar analysis at a later stage (and in the case of GPS systems one that focuses upon methods of improving fuel use and energy efficiency)

5.1.3 Estimated emissions reduction potential

The on farm methods reviewed in this study could contribute between 0.6M tCO_2e from the lower estimate (based on those that said in the survey that they might change) and 1.7M tCO_2e at the maximum uptake where all those currently not using the method adopt it. The size of the emission reduction is a factor of the mitigation potential of the method and the potential uptake. Comparing these figures to

36 http://www.agindustries.org.uk/documents/crossSector/GHG_Action_Plan_10_Feb_2010_as_presented_to_RCCF.pdf (accessed June 2010)

proposed emissions cuts outlined in the Agriculture Industry GHG Plan of 3M tCO_2e (see above) the contribution from the identified mitigation methods could account for 20% and 57% of required mitigation depending on future uptake. The MMs outlined in this report are only a selection of possible mitigation methods and over a limited range of farm types and thus a larger figure could realistically be possible.

Figure 2 shows that around one third of the emissions reductions come from the N management related methods (NB interactions between these methods will reduce the achievable total) with a further 20-25% coming from livestock breeding. The others contribute between 10 and 20% each.

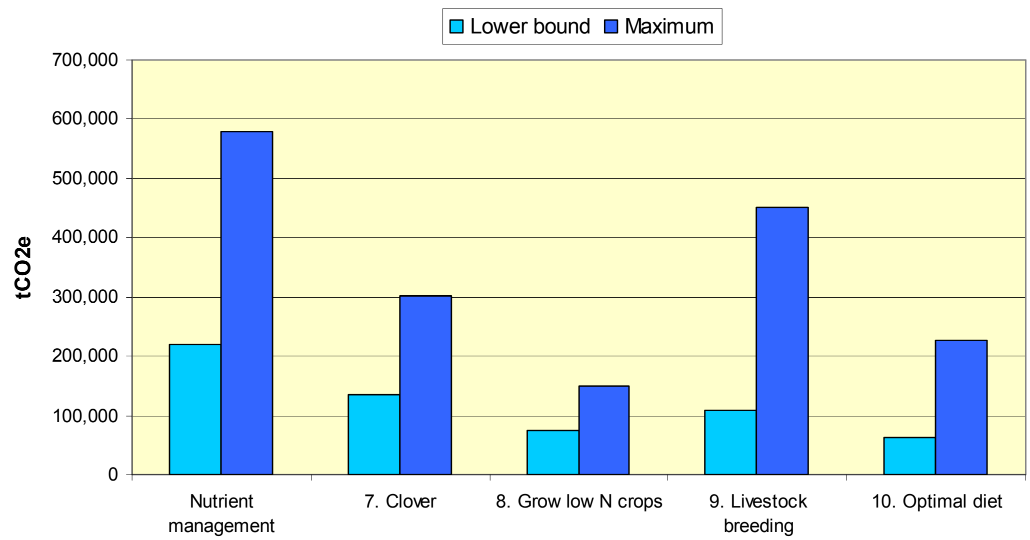


Figure 2 Contribution to potential CO_2e mitigation

5.1.4 Current levels of uptake

The telephone survey indicated fairly high levels of current uptake for many of the MMs. Given the estimated cost profile of many of these this may not be surprising since cost effective farming practices are often in line with GHG reduction methods. Uptake of some MMs are impacted by regulatory (e.g. timing of manure applications in NVZs) or farm assurance requirements (e.g. fertiliser calibration for arable crop assurance).

Mitigation theme	Practical mitigation method (PMM)	Uptake
Avoid excess nitrogen	a. Use N planning tool	34%
	b. Estimate soil mineral nitrogen levels	55%
	c. Calibrate fertiliser spreader every year	80%
	d. Take account of N from manures	87%
Nitrogen timing	e. Avoid N fertiliser before crops start growing	85%
	f. Avoid N fertiliser for 5 days after heavy rain	76%
	g. Avoid N fertiliser for 5 days after manure applications	86%
	h. Apply N fertiliser over 2 or 3 application timings	78%
Manure timing	i. Avoid manures before crops start growing	70%
Crop choice	j. Include clover in grassland mixes (Percentage based upon number of respondents rather than land area).	80%

	k. Grow triticale instead of feed wheat	3%
Livestock breeding	l. Dairy – use of bulls with high Profitable Lifetime Index (PLI)	56%
	m. Beef – use of bulls with high Estimated Breeding Value (EBV)	23%
Livestock feeding	n. Use ration planning system	50%
Anaerobic digestion (AD)	o. Use of anaerobic digestion facilities	0%

The focus groups highlighted the reliance on experience to undertake the MMs correctly. It was clear from the focus groups that farmers believed that their experience was more valuable than the use of tools for fertiliser application, ration formulation or selecting breeding stock. It is possible that other estimates of abatement potential are too high as farmers may well be achieving the emissions reductions without resort to formal indicators. The MACC studies suggest average abatement rates but acknowledge local variability make them very uncertain.

Whilst it is true that the farmers know their land the best, the survey and the focus groups also highlighted gaps in their knowledge as regards the relationship between how they manage the land and GHG emissions.

The lowest levels of current uptake relate to more forward looking MMs such as AD and growing crops such as triticale. Both exhibit perceptions of uncertain returns and are therefore currently viewed as risky. The potential benefits of these appear to require a stronger evidence base. In particular these findings highlight the lack of appropriate knowledge transfer in the industry, particularly with regard to new technologies and methods for mitigating GHG emissions.

These results concur with the findings in FFG0918 where it was clear that whilst farmers have a low understanding of agriculture in relation to GHGs, most MMs are widely taken up for economic reasons. Clearly there is a need for more effective education in the sector highlighting the impacts agriculture has upon climate change and why farmers should act upon it. Whilst the ‘business case’ for reducing GHG emissions may act as a more powerful incentive for the implementation of MMs, it is clear that more targeted GHG emissions advice should be included in the various suites of advisory services available to farmers. This is discussed in more detail in FF0201.

5.1.5 Drivers and barriers

There were a range of barriers and drivers to the uptake of greenhouse gas mitigation measures (MM) identified in this project. Many, either directly or indirectly, were finance-related, but often differed with farm type and size. Other drivers and barriers were related to knowledge and understanding, and legislative or market requirements.

Drivers

Of those who already implement a MM, cost or avoidance of waste or to saving money were key drivers for many of the nitrogen planning MMs including calibrating the fertiliser spreader., However, a significant proportion of farmers undertook the methods because they felt it was good agricultural practice, which could have been driven by their views on land management or requirements under cross compliance. Regulatory drivers were generally cited less frequently.

Few farmers surveyed already grew triticale and those who did, did so for a range of reasons including secondary uses such as bird feed, to avoid crop damage from rabbits or because the soil type was more suited to it.

Farmers who currently use ration formulation programmes or nutritional advice did so in order to maximise growth and income, although a high proportion also felt it was good farming practice.

Farmers who use high PLI or EBV bulls primarily did so to maximise productivity and income.

The reasons for use of clover in grass leys were more mixed with more emphasis on the fact that it produced nitrogen rather than the reductions in cost. Here the technical aspect seemed more important than the fact that there were potentially significant cost savings.

Another important category of driver to adopt MMs was regulation, and one which is not affected by farm size or type. Cross compliance and NVZ regulations were mentioned as a reason to avoid N fertiliser and manure/slurry applications before the crop starts growing:

> *"We are aware of where and when we can and can't apply, frosty, wet, dry, September to February due to regulations and good practice." Pig farmer*.

The NVZ regulation regarding storage requirements for slurry that need to be in place by 2012 will also help avoid manures being spread before crops start growing:

> *"I'll have to [build new storage] as if I have to cut my cow numbers down to be right for NVZs my farm won't be viable, so I've got no choice" Dairy farmer.*

Market drivers were also apparent, with high uptake of fertiliser calibration in the arable sector being driven by requirements of farm assurance schemes, and interestingly farmers perceived a benefit beyond the marketing of their grain in the use of fertiliser calibration with some citing savings in fertiliser and accurate applications.

Barriers

For those who currently do not undertake the MMs, the key finding was that a high proportion felt that there was nothing that could be done to encourage them to take up the practice (Table 23).

This may be a reflection of higher initial uptake than the formal indicators suggest. In the focus groups is was clear that many farmers felt their experience meant they new what they were doing without additional input from advisors or computer programmes.

Barriers to uptake that were directly financial included the cost of a soil mineral N test which was seen to be expensive when it was possible to use look-up tables in RB209:

> *"Yes just on the weather forecast on the winter rainfall, you can work it out with RB209 with the winter rainfall" Arable farmer*

also the cost of installing an AD plant on a farm:

> *"It's a massive capital cost" Dairy farmer*

and the cost of converting layer hen housing from deep pit to belt removal:

> *"It's an expense we just can't afford" Poultry farmer*

All of these examples of cost were seen by all sectors as barriers to uptake. However, there were other costs which were seen as reasonable by one sector or farm size but as a barrier by another. One example of this was the cost of regularly calibrating the farm fertiliser spreader. Arable and larger farms saw the calibration cost as justifiable, whereas livestock and smaller farmers felt it was not:

> *"So what you waste, (cost of calibration £200-300) for us you could go and buy another tonne of fertiliser" Cattle and sheep farmer*

Smaller cattle and sheep farmers also found that cost was a barrier to using a ration planning system:

> *"Perhaps they're on a bigger scale so they can justify better than us" Cattle and sheep farmer.*

It was found that financial drivers to the uptake of MMs were less frequently increases in outputs, as in the case of increasing yield through better N timing, although this was a consideration, but more often were increases in efficiency giving reductions in cost. Examples of this include avoiding N fertiliser for 5 days after manure application and avoiding applying N fertiliser and manure before crops start growing, all of which did not appear to differ with farm type or size:

> *"There's no point ... if it's not growing there's no crop to take it up so you don't do it" Dairy farmer*

and the use of ration planning systems for feeding livestock:

> *"I think sometimes your chucking too much energy at them which they can't absorb so it goes straight through them... you need to know roughly where you are and that's why you trust nutritionists who should know what they're doing" Cattle and sheep farmer*

Related to increased efficiency is reducing risk, a driver for applying fertiliser N in more than one application:

> *"The benefit of putting it on in 3 applications is putting it on a little bit rather than a lot so if you do get a massive weather event your chances of it leaching by diffuse pollution to the ground ..... you lose less" Arable farmer*

Farmers' reliance on previous experiences was sometimes found to be a barrier to the uptake of a number of MMs across all sectors. This was particularly the case when considering the use of a planning tool:

> *"It's not an exact science, you know your farm, the weather conditions, you can't take what they say is correct for each individual farm" Arable farmer*

and taking account of N from manures:

> *"We don't estimate we just do it, we know we need less N after we've applied the muck" Arable farmer*

It was also a barrier to using beef bulls with high Estimated Breeding Value, along with a mistrust of the system:

> *"The highest bull we ever bought served about 4 cows and then went wrong" Cattle and sheep farmer.*

Farmer experience was also a driver to uptake, for example in avoiding N fertiliser for 5 days after manure applications:

> *"If you put manure on you don't go and put fertiliser on perhaps for 3 weeks, you're making use if the nitrogen in the manure" Dairy farmer*

Additional barriers to uptake included a factor beyond their control – the weather. This was the case when considering avoiding N fertiliser for 5 days after heavy rain, and seemed a particular issue for livestock farmers. This may be because more of the livestock farmers are based in the West and North where there is higher rainfall, or may be because of the equipment they have available.

> *"You might not have a lot of choice in April sometimes... you might put it on 5 days after or two days before, you don't have a lot of choice" Dairy farmer*

Finally, the market could also be a barrier to uptake. This was given as the reason why triticale was not being grown more:

> *"You are not going to see a lot of triticale grown outside its normal areas unless the bio-fuels industry fully embraces it as a feedstock" Arable farmer*

> *"Well I looked into it last year... I was prepared to give it a go but no-body was prepared to sell me the seed" Dairy farmer*

5.1.6 Potential increase in PMM uptake

The lower estimate of potential increase in uptake varied significantly between MMs and farm type, although there was less variation between farm sizes for most MMs but generally there was slightly less potential for increased uptake on the larger farms.

In the lower model, the largest potential increase in uptake for nutrient management was in the livestock sector. The already high uptake in cereals and general cropping farms suggest limited scope for further increases. Using more clover had a potential uptake increase of 20-30%, with more in LFA beef and sheep farms. Using lower N crops (in this case triticale instead of wheat) had a 25-56% potential uptake with the highest in the cereals and general cropping farm types. However, there was considerable resistance to the crop expressed in the focus groups. Livestock breeding and feeding have a greater potential uptake in the beef and sheep sector compared to dairy, due to current lower uptake.

In all MMs, for those who did not implement an MM, or only relatively infrequently, there was a high percentage of farms that did not feel willing to change at all (Table 23). Farmers were more willing to be persuaded for anaerobic digestion with 54% of farmers saying nothing would make them change, but for all others those unwilling to change was over 60% and up to 80%.

Table 22 Survey: summary of farmer numbers who would not change practices

CPMM	Mitigation method		Total	Cereals	General Cropping	Dairy	Cattle & Sheep Upland	Cattle & Sheep Lowland	Small	Medium	Large
1	RB209	***Total***	***469***	***47***	***40***	***127***	***134***	***121***	***170***	***161***	***138***
		Nothing	63%	53%	55%	54%	73%	68%	64%	65%	60%
2	Estimate soil nitrogen	***Total***	***322***	***32***	***21***	***78***	***115***	***76***	***116***	***115***	***91***
		Nothing	59%	44%	19%	58%	65%	67%	59%	61%	55%
3	Calibrate fertiliser spreader	***Total***	***119***	***4***	***4***	***43***	***34***	***34***	***36***	***43***	***40***
		Nothing	67%	75%	0%	72%	68%	68%	78%	56%	70%
4	Take account of manure N	***Total***	***64***	***3***	***2***	***14***	***28***	***17***	***28***	***17***	***19***
		Nothing	73%	67%	50%	71%	82%	65%	75%	76%	68%
5	Avoid N before growth	***Total***	***57***	***18***	***10***	***14***	***2***	***13***	***17***	***26***	***14***
		Nothing	75%	67%	80%	71%	100%	85%	76%	73%	79%
5	Avoid N after heavy rain	***Total***	***147***	***28***	***23***	***39***	***23***	***34***	***38***	***56***	***53***
		Nothing	54%	43%	52%	33%	61%	82%	61%	43%	60%
5	Avoid N after manure	***Total***	***67***	***10***	***2***	***19***	***17***	***19***	***17***	***25***	***25***
		Nothing	75%	90%	50%	68%	65%	84%	65%	84%	72%
5	Increase application number	***Total***	***135***	***6***	***7***	***26***	***53***	***43***	***49***	***46***	***40***
		Nothing	69%	67%	71%	58%	75%	67%	67%	70%	70%
6	Avoid manure before growth	***Total***	***82***	***24***	***18***	***15***	***4***	***21***	***15***	***31***	***36***
		Nothing	80%	79%	72%	87%	100%	81%	80%	77%	83%
7	Include more clover	***Total***	***217***			***58***	***97***	***62***	***71***	***74***	***72***
		Nothing	57%			48%	59%	61%	51%	57%	63%
8	Grow triticale	***Total***	***734***	***147***	***149***	***142***	***147***	***149***	***246***	***246***	***242***
		Nothing	73%	44%	57%	90%	92%	83%	79%	73%	67%
9	Dairy PLI	***Total***	***67***			***67***			***26***	***24***	***17***
		Nothing	78%			78%			81%	71%	82%
9	Beef EBV	***Total***	***224***				***114***	***110***	***78***	***75***	***71***
		Nothing	74%				71%	77%	79%	65%	77%
10	Diet formulation	***Total***	***228***			***38***	***101***	***89***	***86***	***78***	***64***
		Nothing	73%			68%	73%	75%	67%	71%	84%
11	AD	***Total***	***449***			***150***	***148***	***151***	***150***	***150***	***149***
		Nothing	54%			36%	72%	54%	60%	52%	50%

Notes:

The ‘total’ line is the number of survey respondents who do not currently adopt the practice;

The ‘nothing’ line is the % of those who do not currently adopt the practice who would not be encouraged to do so

There are a number of reports that assess the mitigation potential of a wide range of methods and the latest MACC 2 report (unpublished) highlights the high degree of uncertainty with regard to many aspects of the information required to provide estimates of abatement potential. The uncertainty centres around the abatement achievable per unit applied to, the number of units that the MM can be applied to, and the degree to which farmers are already utilising them. However, in FFG0918, it was clear that whilst uptake is widespread, farmers are receptive to increasing implementation of a wide range of MMs.

5.2 Impact of MMs on farm economics and practical considerations

5.2.1 MM potential by farm type and size

Figure 3 shows graphically the contribution to mitigation potential by farm type and size. It illustrates the greater potential in dairy and the large range between the maximum potential and lower estimates for all farm types and sizes. It also shows that in many cases small and medium sized farms can contribute significant abatement (particularly lowland) and the distribution between small, medium and large farms is fairly evenly spread.

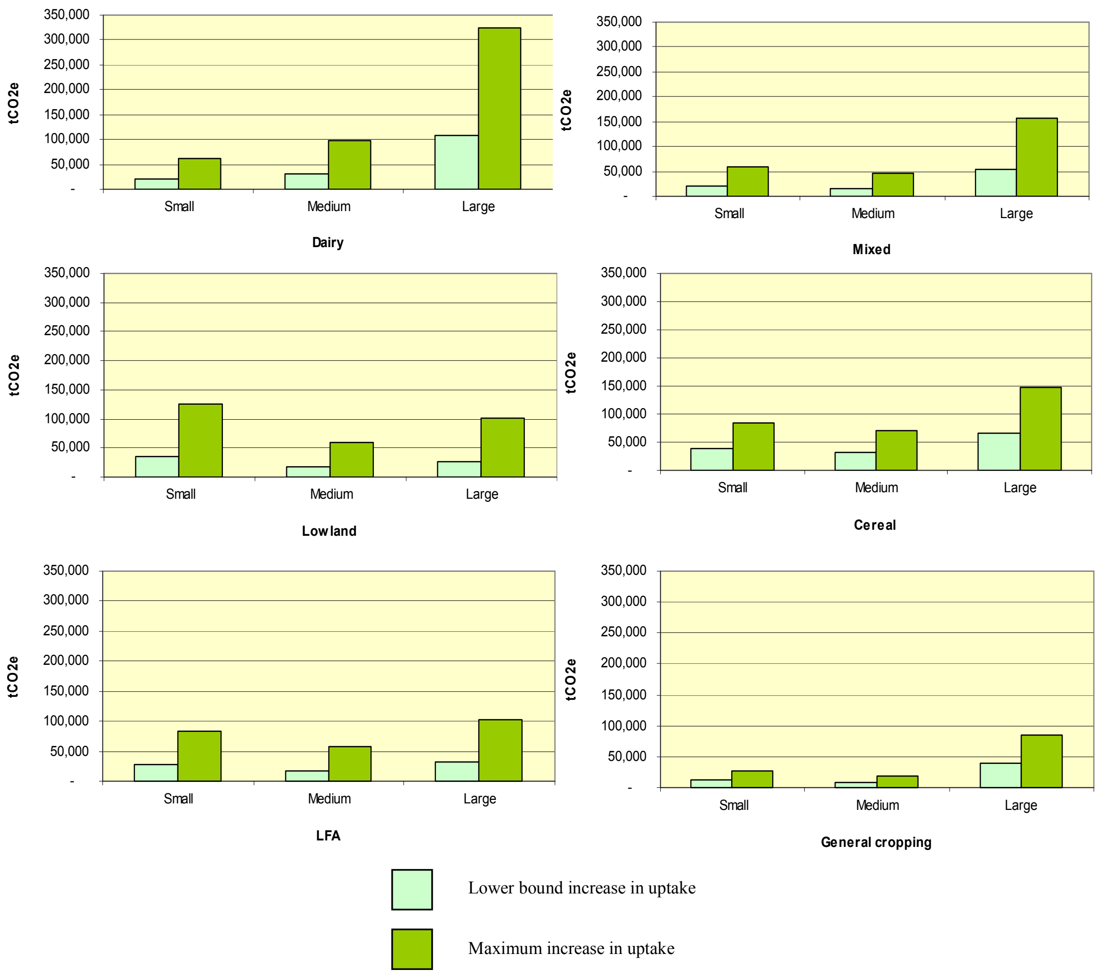


Figure 3 Estimated mitigation potential by farm type and size

Neither lowland beef and sheep and LFA beef and sheep are estimated to have significant mitigation potential with a combined 11% of the total under the lower uptake assumptions and 15% under the maximum. Mixed farms and general cropping farms are estimated to produce similar mitigation potential with the larger farms in both these types producing around 10% of total potential mitigation.

The cereal sector is estimated to produce the second largest potential by farm type with one quarter of the lower mitigation and close to 20% of the maximum.

5.2.2 MM costs and farm size

The tables in section 4.2.5 show the cost of the farm level implementation as a percentage of farm income and gross margin. A fairly consistent picture emerges of increasing costs by farm size both in absolute and relative terms. Increasing costs in absolute terms is to be expected for larger farms but the higher costs as a proportion of income or gross margin is less intuitive and requires some explanation.

Emissions per farm as calculated by CALM are linear in that each cow or each tonne of fertiliser emits the same amount on any farm type and size (with the size characteristics taken from the FBS 2008/09). Similarly, the costs of practical MMs are also linear and applied to the same FBS input data. However, gross margins and net income in the FBS data generally show declining returns per hectare from small to large farms. As a result the costs are proportionately higher for larger farms.

5.3 Understanding findings

5.3.1 MM selection

The MMs selected were based on previous work, but this covered most options for effective abatement. The project included only MMs associated with methane and nitrous oxide emissions, so those associated with carbon dioxide emissions or sequestration were not included. The MM selection criteria also excluded a range of MMs that are currently not an option due to EU regulation e.g. bovine somatotrophin (bST), ionophores or too uncertain, for example drainage.

The model can, however, be used for other MMs in the future.

5.3.2 Stakeholder consultation

The survey provides an estimate of the proportion of farmers who already implement particular MMs and how frequently they do them. It does not show whether they are implemented to maximum effect.

There is a risk that the survey results may generate a warm glow response, providing the answer the participants think we wanted. However, most farmers appeared to be focused on farming correctly rather than GHG mitigation and many were unaware of the connection between the MMs and GHG emissions. Because of the opportunity to opt out, there may be some bias to those with a more positive attitude compared with a random response.

5.3.3 Costs of MM implementation

MMs can be implemented in a variety of ways and the costs estimated here reflect just one of these. Amongst other things, implementation will reflect local conditions, the available capital and manpower, and the level of knowledge.

Little work has been carried out on actual costs of CPMMs so the costs were largely based on standard costs and personal communication with operatives in the field.

5.3.4 MM Abatement potential

Much of the unit abatement potential is a product of expert judgement with some experimental evidence (referenced in AC0206, RMP4950). Research is being considered by Defra into providing evidence of emissions locally in England rather than relying on IPCC standard data, but if this goes ahead, it will take some time to gather.

In line with variable costs of implementation, farms vary greatly in their physical characteristics, structure, and management. As such it can be expected that the effectiveness of the MM in reducing GHG emissions will similarly vary.

5.4 Findings in context with policy requirements

The estimated emissions reduction potential (0.6m – 1.7m tCO_2e) is relatively small when compared to the GHGAP (3m tCO_2e) targets and the estimates within MACC 2 (5.6m – 12.5m tCO_2e <£100/tCO_2e).

5.4.1 Comparison with MACC 2

There are two principal reasons for the generally lower estimates of abatement potential estimated in this project as compared to MACC 2. One is the direct result of the methodological approach and the other the result of the use of this project's finding relating to the current and potential uptake of the MMs.

The methodological approach used here utilised information from the FBS survey on the average farming attributes (hectares of crops and head of livestock) by farm type and size. The farm types selected accounted for 36,082 farms out of a total number of farms with more than 0.5 SLR estimated at 59,224 and the 120,000 or so total number of farms. The method used involved scaling up the averages in the FBS survey to the total number of farms for each farm type and size. MACC 2 used the business-as-usual figures produced in SFF061. When compared, the scaled up area and livestock totals for the 36,082 farms in this project accounted for around 80% of the area and livestock that the methods were applied to in MACC 2.

This underestimation is exacerbated somewhat by the fact that the FBS survey data provides average numbers of crop hectares and livestock for each farm type. Therefore, a proportion of the dairy cattle, for example, will be in non-dairy farm types and will not be included in the abatement potential if a relevant method is not applied to that sector. For example, optimum diet formulation is not applied to the general cropping sector but the average large general cropping farm has 6.4 dairy cows and heifers in milk. In this example, the optimum diet formulation is not applied to the scaled up number of dairy cows in large general cropping farms (12,866 cows). Furthermore, since pigs, poultry and horticulture sectors were omitted from this analysis, all emissions from these sectors were excluded.

The second reason is related to the survey conducted as part of this project. The survey asked respondents for each farm type and size whether they currently implemented the mitigation method and how frequently. Those who did not implement the method were asked whether they might be persuaded to implement. Using this information this project produced lower and maximum estimates of the potential increase in uptake of each method by farm type and size. One of the principle findings of the survey was the relatively high level of uptake of many of the methods.

N Timing example

MACC 2 presented pessimistic and optimistic estimates of abatement potential that reflected uncertainty in the abatement rate and the area (or head of livestock) to which the method could be applied). MACC 2 produced much reduced estimates for N timing from MACC 1. The range for the pessimistic and optimistic estimates for this method was based upon it being applicable to between 10% and 58% of grassland and 10% to 80% of cropland. The abatement rate was presented with a range of 0-

0.3 tCO_2e per hectare. This resulted in estimated abatement potential range of 239k[37] tCO_2e and 1,628 tCO_2e.

The maximum estimate for this method from this project was around 220k tCO_2e with the potential for increased uptake varying from as little as 11-14% in the cereal sector with the other sectors varying between 8% and 30%. In the lower model, the potential for increased uptake is below 10% for all farm sizes and types apart from small dairy.

AC0221 also produced an estimate for the potential for GHG reductions by adjusting N timing, of around 165k tCO_2e. The method is assumed to apply to the 62% of wheat crops that receive N in May or later.

Table 23 Comparison of findings from MACC 2 and project findings

	MACC 2	Project findings
Abatement rate	Tonnes CO_2e/unit (hectares or head)	% of farm emissions
Abatement scope	Relevant proportion of total land/head	Relevant farm types and size
Farmer uptake	Assumed 100% of the area applied to	From farmer survey
Baseline	Business as Usual 3[38]	FBS 2008-09

Generally, the potential abatement identified in this project will be lower than in MACC 2 since fewer MMs are assessed and these not applied to all farm types. This affects the AD MM in particular as all the AD MMs in MACC 2 are in the pigs and poultry sectors. The AD considered here also allows only for on-site feedstocks.

Another important difference is the level of uptake used. MACC 2 uses a high level of potential uptake that is applied to a defined proportion of the appropriate aggregate units (e.g. % of all grassland deemed applicable for a particular MM).

Conversely, MACC 2 utilises interactions factors that has the effect of lowering total abatement potential by realising that some MMs interact with each other to alter the effectiveness of abatement. Interactions are not applied in this project.

5.5 Policy implications – increasing uptake

- A moderate proportion of the respondents could be persuaded to take up the MM or do it more frequently.

[37] We believe this is an error in MACC2 and in fact should be zero as a lower abatement rate of 0 would produce a zero total

[38] Defra. (2007): Baseline Projections for Agriculture and Implications for Emissions to Air and Water

- The results also suggested that a large proportion of those who do not implement MMs or do so only occasionally would **not** be encouraged to increase uptake. However it may be that financial incentives would encourage some uptake of those MMs that place a financial burden on the farm. Others may be persuaded over time if the evidence base increases and the methods are gradually adopted.
- Financial benefit was a key driver for those who currently undertake the measures, although this may be indirectly through complying with market requirements. However for those that implement the MM less than always their reasons for not doing so were more related to knowledge and information which suggests that they perhaps do not see the potential financial benefit and could be persuaded with more information or advice.
- Those that say they will never implement the MM may require a regulatory approach but the results do suggest that even this group might be persuaded to may change their minds given local examples.
- The policy choice needs to be balanced against the potential for GHG mitigation potential. Perhaps a regulatory approach should be considered only for a MM with high abatement potential, low uptake and a high proportion saying they would never implement. The barriers to uptake will also inform the policy response.
- The dairy sector was estimated to have the greatest potential for GHG reductions primarily due to the potential identified in the livestock breeding MM. The other sectors had similar estimates of mitigation potential.
- After livestock breeding the MMs with more than 150k tCO2e of estimated savings (maximum potential) were CPMM5 (N timing), CPMM7 (Clover), CPMM 8 (Grow low N crops), and CPMM10 (Optimal diet).

These findings correlate well with FFG0918, where it was clear that:

- There is a range of current policies and schemes available through which to introduce MMs and secure early abatement at low cost;
- Farmers are keen to receive knowledge and advice about GHGs and MMs;
- Regulatory policy may be perceived negatively;
- Monitor and demonstration farms are cost effective methods to introduce abatement to the industry;
- The emphasis was on locally derived evidence to improve uptake of MMs.