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IMPLICATIONS OF FARM-SCALE METHANE MITIGATION MEASURES FOR UK METHANE EMISSIONS

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SUMMARY

Agriculture contributes ~40% of the total UK's emissions of methane (CH_4), mostly from enteric fermentation by ruminant livestock, with a smaller contribution associated with manure management. A number of CH_4 mitigation measures have been identified, but their effectiveness over broad spatial scales had not previously been investigated. Another question was whether widespread implementation would have consequences on production levels and emissions of other pollutants, such as ammonia (NH_3), nitrous oxide (N_2O), or leaching of nitrate (NO_3^-).

This project brought together models from rumen processes to the individual animal level, as well as at the herd, farm and national scale, for the first time (Chadwick *et al*., 2007). Emissions of CH_4, NH_3, N_2O, NO_x and NO_3^- leaching were quantitatively assessed for dairy cattle, beef cattle and sheep. Increasing milk yield in dairy cows (with associated reduction in numbers) results in the largest decrease in CH_4, with comparable decreases in N pollutants >20%. For beef cattle and sheep, the most effective CH_4 mitigation method is vaccination to reduce rumen methanogens by approx. 10%.

INTRODUCTION

Methane is the second most important greenhouse gas (GHG) after carbon dioxide (CO_2), contributing 20% to global warming. Agriculture accounts for ~40% of the UK's emissions of CH_4. In the UK GHG inventory, 85% of the agricultural CH_4 emissions are estimated to originate from enteric fermentation (39% dairy, 48% beef, 22% sheep), with the remaining 15% associated with manure management. Under the Kyoto Protocol the target is to reduce GHG emissions by 12.5% of the 1990 levels by 2008-2012, although this is now under re-negotiation.

A number of CH_4 mitigation measures has been identified for livestock sources, but there is a need to investigate their effectiveness over broad spatial scales, and whether widespread implementation would have other consequences, e.g. for production levels and emissions of other pollutants, such as ammonia (NH_3), nitrous oxide (N_2O), or leaching of nitrate (NO_3^-).

Potentially effective measures for reducing CH_4 emissions from ruminant livestock farming in the UK include:

- Increased productivity per dairy cow, i.e. increased milk production per kg CH_4 produced
- Increased fertility, i.e. reducing the number of followers required

- Improved forage composition and balanced energy/protein feeds
- Feed additives – to reduce rumen hydrogen production
- Vaccination – to reduce the rumen methanogens

In the modelling study presented here, the effectiveness of each of these methods is quantified at different scales, through spatial scenario exploration with a new modelling framework which links four existing models, at the rumen, herd/farm and national level.

METHODS

An overview of the modelling framework used in the study is represented in Figure 1, showing the links between the different models and scales. The rumen model of Reading University (e.g. Mills *et al*. 2001, 2003) generated CH_4 emissions from enteric fermentation for ruminant livestock under a range of intensities. Separate model estimates were obtained for three typical dairy farming typologies (extended grazing, conventional intensive and fully-housed intensive management), and upland and lowland farming systems for beef cattle and sheep, respectively (derived from IGER/ADAS, 2004a, 2004b, 2005; Defra, 2000; Smith *et al*., 2001). The effects of various mitigation strategies on CH_4 emissions were then predicted using a herd level model (Mottram and Mills, 2003), which allows herd management decisions and fertility factors to be incorporated.

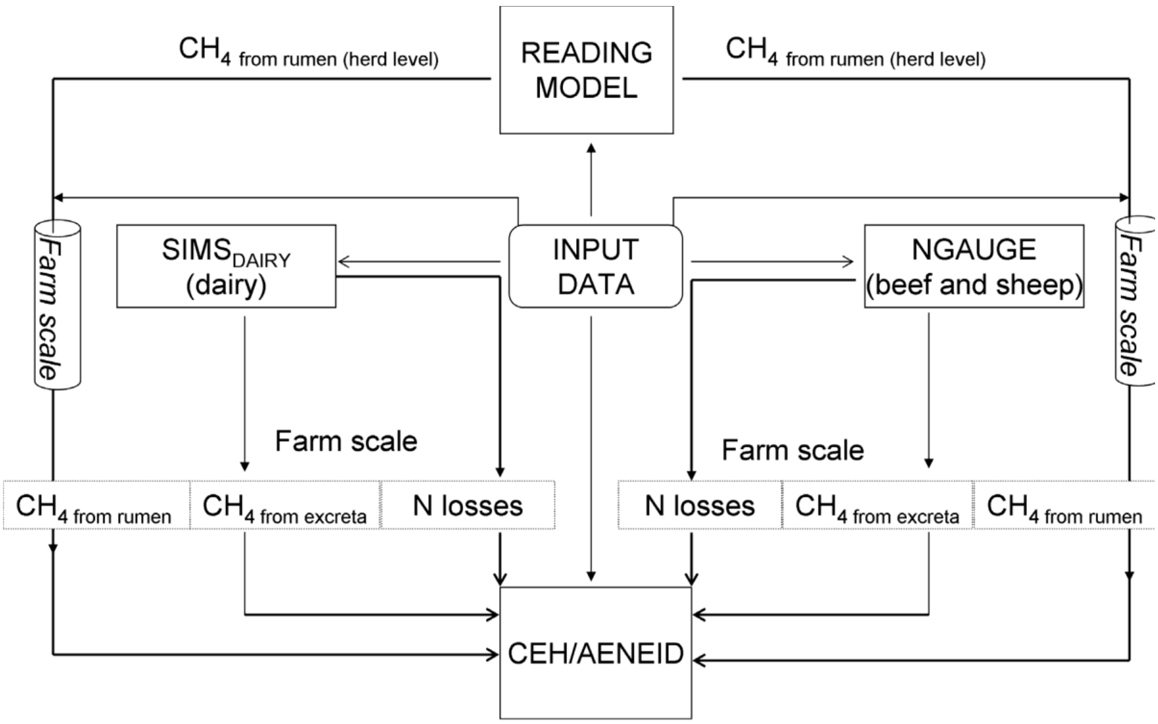
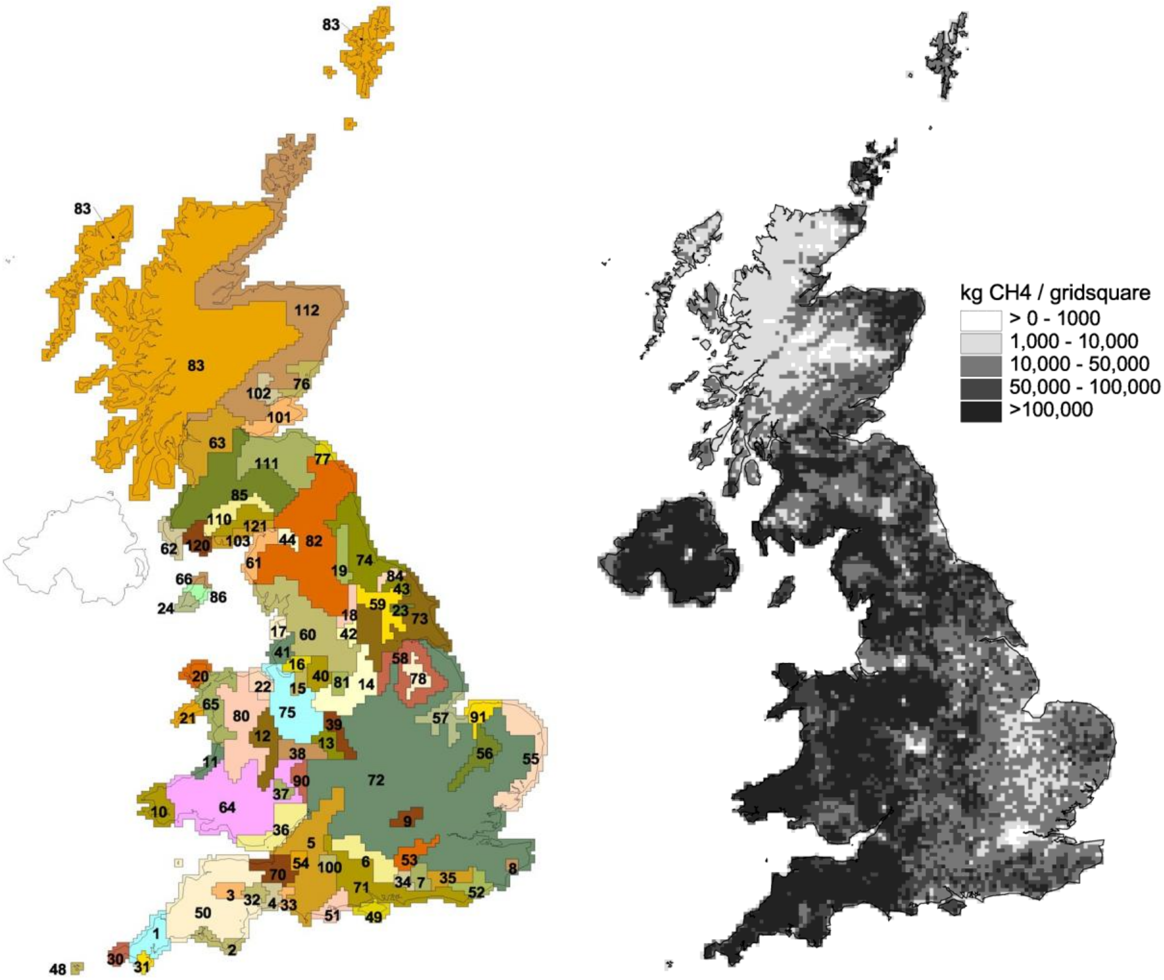


Figure 1: Schematic representation of the modelling system

In a second step, a single map was generated comprising a simplified overlay of climate, soil texture and altitude data, resulting in 121 zones (Figure 2a). Expert judgement was then used to apportion the dairy, beef and sheep typologies to these different zones. For example, it was assumed that 80% of dairy cows in the soil-climate zones in SW England and Wales were in the intensive conventional typology, 20% were in the extended grazing typology and 0% was in the fully housed intensive typology. The $SIMS_{DAIRY}$ (del Prado and Scholefield, 2006) and

NGAUGE (Brown *et al*., 2005) models were then used to simulate emissions of CH_4 from manure management as well as emissions of NH_3 and N_2O and NO_3^- leaching, according to soil, agro-climatic factors and farm management for each the typologies (as well as the mitigation options) for all zones. Although CH_4 emissions were not assumed to be influenced by soil or climate, it was necessary to take the spatial variability of soil/climate into account when modelling changes in N_2O emissions and NO_3^- leaching due to CH_4 mitigation measures.



a) b)

Figure 2: a) Soil/climate zones for farm scale and national scale modelling, b) baseline annual CH_4 emissions (2005) from UK agricultural sources, modelled using AENEID (5 km grid)

This information was fed through to the UK scale modelling, by applying the spatially varying emission estimates on a per-animal basis in the AENEID model (Dragosits *et al*., 1998; Sutton *et al*., 2004; 2006) for each mitigation scenario and zone. AENEID (Atmospheric Emissions for National Environmental Impacts Determination) was originally developed for the spatial distribution of NH_3 for the UK and is currently used for annual modelling and mapping of the distribution of NH_3, CH_4 and N_2O emissions in the National Atmospheric Emissions Inventory (NAEI, www.naei.org). In this study, AENEID was used both to estimate baseline emissions and to assess the impacts of CH_4 mitigation methods against these baseline emissions. Figure 2b illustrates the baseline spatial distribution of CH_4 emissions from agriculture in the UK.

RESULTS AND DISCUSSION

At a per-breeding animal level (Table 1), losses from dairy cows (including followers) varied between management, mitigation methods (not shown; see Table 2 for UK data) and forms of N lost. Nitrate leaching from intensive management was larger than from extended grazing management, partly due to the greater proportion of concentrates ingested per animal. Nitrous oxide emissions were largest from the conventional intensive pastoral system, while NH_3 emissions from fully housed intensive management were almost double those from the other two typologies. For beef cattle, emissions per breeding animal were much larger in upland than in lowland situations. This may appear counter-intuitive, but this is due to the longer reproductive cycle and the resulting larger number of followers. Differences in losses due to soil and climate conditions were largest for NO_3^-, N_2O and NO_x. However, animal type and management were estimated by the models to have a lesser effect on NH_3 emissions.

Table 1: Estimated baseline emissions of CH_4, NH_3, N_2O, NO_x and NO_3^- leaching (in kg per breeding animal*) from the herd/farm models

Animal type & management	**NO_3-N**	**CH_4**	**N_2O-N**	**NH_3-N**	**NO_x-N**
	emission kg (inc. followers)$^{-1}$ yr^{-1}*				
Dairy cows					
Extended Grazing	12-36	103.9-104.6	0.2-5	31-35	0.002-0.003
Conventional Intensive	16-70	113.9-115.2	0.4-12.2	31-35	0.001-0.001
Fully-housed Intensive	23-67	107.3-107.4	0.2-6.4	68-68	0.001-0.002
Beef cows					
Lowland	6-35	169.9-171.2	0.2-12	21-37	0.022-0.356
Upland	1-14	214-214.4	0.1-6	8-16	0.012-0.237
Sheep					
Lowland	0.2-2.1	25.1-25.1	0.02-0.7	0.8-1.4	0.001-0.028
Upland	0.2-1.9	20.2-20.2	0.02-0.4	0.7-0.9	0.001-0.028

* Emissions relate to one adult dairy cow, beef cow or breeding ewe + the associated number of youngstock as calculated by applying typology-specific annual replacement rates. Ranges reflect different soil-climatic zones.

At a UK level (Table 2), an increase in milk yield per dairy cow (by 30% in the modelled scenario), coupled with a reduction in dairy cow numbers to maintain current national milk production, resulted in the largest reduction in CH_4 emissions (-24%). The next most effective mitigation strategy was a high fat diet, which provides a 14% saving, followed by increased heat detection rate (HDR) of cows in oestrus at 7% and a high starch diet at 5%. Changes in diet by feeding high quality forage did not appear to result in large differences in the national emission of CH_4 (-3%), whereas scenarios modelling an increase in low quality forage or decreased HDR resulted in marginal increases. A reduction in the milk yield per dairy cow by 30%, coupled with an increase in the number of dairy cows (to maintain national milk production), resulted in an increase in CH_4 emissions by almost 15%. The most effective CH_4 mitigation measure for beef cattle and sheep was vaccination (-10%), while a diet high in starch also appeared effective at reducing emissions from beef cattle at the national level (-5%). Diets high in water soluble carbohydrates (WSC) appeared to be counter-productive and actually increased modelled national CH_4 emission estimates slightly.

Table 2: Relative impact of methane mitigation methods at the UK scale on CH_4, NH_3, N_2O and NO_3^- leaching (for year 2003)

	Mitigation scenario	UK 2003	comparison with base scenario (%)			
		kt CH_4	**CH_4**	**NH_3**	**N_2O**	**NO_3^-**
Dairy Herd	base	277.3	100	100	100	100
	milk yield decrease: 30%*	318.6	115	118	113	121
	milk yield increase: 30%*	211.0	76	73	79	78
	high fat	238.5	86	99	100	104
	HDR decreased	298.9	108	106	104	105
	HDR increased	257.1	93	89	93	91
	high quality forage	269.5	97	100	99	99
	low quality forage	282.0	102	100	100	100
	high starch	264.0	95	99	100	100
Beef herd	base	391.6	100	-	-	-
	high starch	372.8	95	-	-	-
	high WSC	401.0	102	-	-	-
	high fat	391.6	100	-	-	-
	vaccine	352.8	90	-	-	-
Sheep flock	base	176.3	100	-	-	-
	high starch	174.0	99	-	-	-
	high WSC	176.8	100	-	-	-
	vaccine	158.3	90	-	-	-

* numbers of dairy cows and associated followers increased/reduced to keep national milk yield constant

The effectiveness of increasing milk yield per cow to decrease CH_4 emissions was matched by similar decreases in emissions of NH_3 and N_2O and NO_3^- leaching. While high fat diets for dairy cows appeared to decrease CH_4 emissions by 14%, emissions of NH_3 and N_2O were only slightly decreased, but N_2O emissions and NO_3^- leaching showed a slight increase compared with the base scenario. Small decreases in CH_4 emissions through the introduction of high starch diets or high quality forage were not matched by similar decreases for the N compounds, which showed very marginal decreases.

In summary, the modelling framework provided a quantitative assessment of the effectiveness of selected CH_4 mitigation strategies, and the impacts of these on other forms of atmospheric (NH_3 and N_2O) and water pollution (NO_3^- leaching) at the farm scale, as well as nationally.

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