OPTIONS FOR GREENHOUSE GAS MITIGATION IN UK FARMING

A Study by
Chris Pollock

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1. INTRODUCTION

All human activity impacts upon the world around us. We have long recognised the negative impacts of such activity and, since the early part of the 20th century, have taken steps to mitigate many of the more severe effects of processes like mining, refining and manufacturing. More recently we have become aware of the dangers of unrestricted emissions of compounds that, whilst not directly poisonous to humans, have the capacity to affect our climate. These materials, referred to generically as greenhouse gases, affect the balance between incoming energy from the sun and the capacity of the earth to reflect some of this energy back into space. By absorbing and reflecting back to the earth's surface some of this re-emitted energy, greenhouse gases cause the surface of the globe to be warmer than it would otherwise be. A simple analogy is of the still air in a greenhouse that traps the heat of the sun and thus warms the soil to a greater degree than that outside.

Life on earth relies on the greenhouse effect to maintain global surface temperatures at a suitable level. The problem is that the amounts of greenhouse gases in the atmosphere have increased dramatically since the industrial revolution and there is now widespread agreement that they are driving a sustained increase in surface temperatures across the globe. The implications of that increase are complex and will vary across the globe but very few of them are positive and there is international agreement that strong measures will be needed both to mitigate future emissions and to adapt to a warmer world. There is also agreement that action is required in the very near future. As a result of meetings in Kyoto (1997) and Bali (2007), many countries are setting targets for reducing emissions. The UK Government has introduced a Climate Change Bill and has indicated that it expects all sectors of the economy to play a part in both mitigation and adaptation.

Against this background, agriculture occupies an interesting and distinctive position in the UK. Over 70% of the UK land area is farmed and almost 50% is as grassland. Despite this, primary production is a relatively small part of the UK economy (<1% of GDP) although it also delivers a wide range of non-value goods like clean air and water, biodiversity and landscape diversity. Across the UK economy as a whole, carbon dioxide (CO_2) is the most important greenhouse gas. Typically this would be produced by the combustion of fossil fuels and long-term carbon stores like timber, although this is only part of a much larger cycle of carbon within the natural world, with CO_2 being removed from the atmosphere by photosynthesis and returned by respiration and combustion.

Globally, the increase in combustion of fossil fuels has caused atmospheric CO_2 levels to increase by 20% since 1960. Agriculture, however, has a rather different pattern of emissions. As well as some CO_2, agriculture leads to significant emissions of methane (CH_4) and nitrous oxide (N_2O). Both of these gases are much more potent drivers of global warming than CO_2. Thus, even though the amounts of emissions are small, their contribution is much greater than the CO_2 that arises directly from agriculture. This is allowed for in calculations by converting emissions of other greenhouse gases into CO_2 equivalents based upon their potency as greenhouse gases relative to CO_2. Allowing for this, plus the fact that some land use elements (forestry and permanent grassland) sequester more carbon dioxide than they emit, then the net contribution of agriculture to GHG emissions is mainly attributable to CH_4 and N_2O, with N_2O having a slightly greater impact (Reference 1).

There are huge amounts of data on GHG emissions from various elements of the UK economy, and frequently there are overlaps between the different data sets. Emissions from liquid fuel use, for example, will contribute to agricultural emissions via cultivation, to Manufacturing emissions via transportation of food from farm to processor and from processor to retailer and finally to domestic emissions via trips to purchase food.

In another context these could all be viewed as emissions relating to the food chain. Effective comparisons are not always easy but an analysis of greenhouse gas production in the UK (Figures 1a and 1b) demonstrates two important facts. Firstly, the direct contribution of agriculture and land use to GHG emissions is significant but outweighed by a number of other sectors. Secondly, agriculture is a relatively small contributor of emissions when considered across the whole of the food chain. In my view, therefore, the challenge facing the primary production sector is to recognise the need to mitigate emissions of greenhouse gases, to identify clear priorities and to seek a proportionate response across the entire sector.

For convenience, I will concentrate on agriculture, recognising that primary production also involves other activities like forestry, horticulture, aquaculture etc where the balance in emissions will be somewhat different. The specific problems facing the sector are four-fold. Firstly effective mitigation options for methane and particularly for nitrous oxide are less clear-cut than for CO_2. Secondly, there are limits to the savings that can be made without significantly affecting productivity, thirdly, the basis for estimating emissions of methane and nitrous oxide is imperfect and finally increasing global population and prosperity and decreasing land and water resources will lead to increased emissions from the primary production sector worldwide no matter how effective are the implementation of mitigation measures.

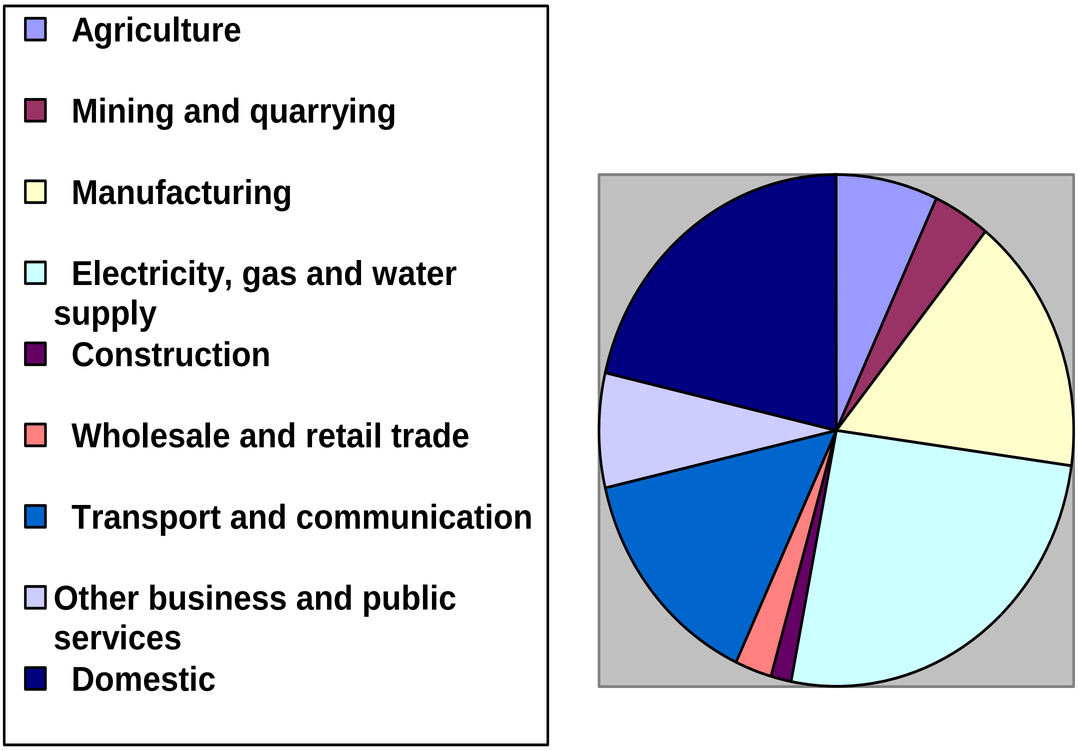

Figure 1a. GHG emissions from UK Industry expressed as a percentage of the total emissions for 2005 (733446 kT CO_2 e).

Data are from the UK office of National Statistics:http://www.statistics.gov.uk/STATBASE/ssdataset.asp?vlnk=5695

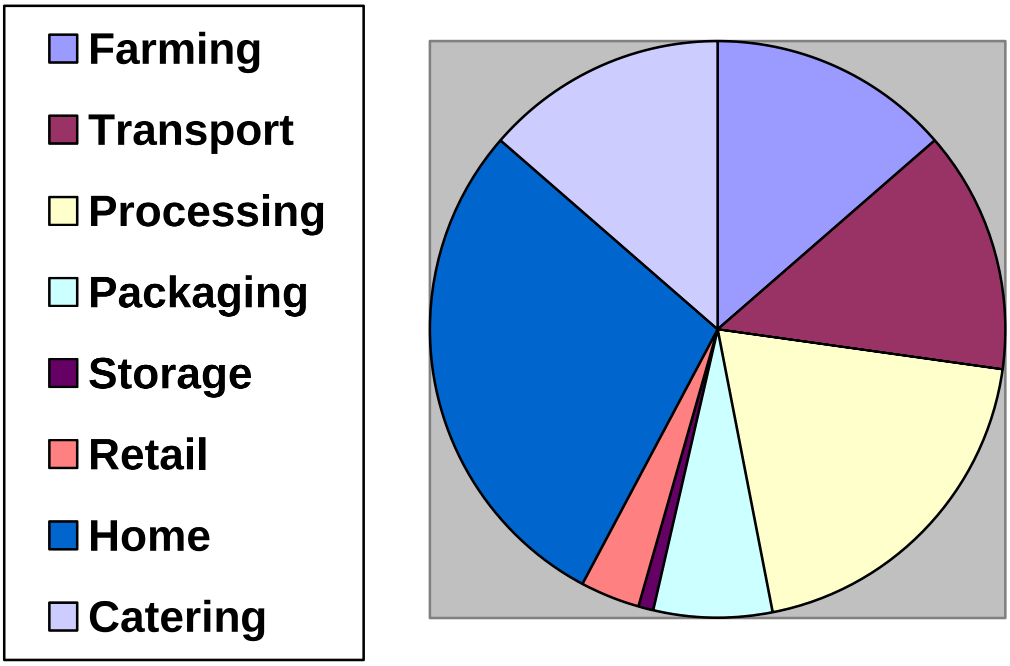

Fig 1B. Contribution of different elements of the food chain to GHG emissions in the UK expressed as a percentage of the total (70.1 kT CO_2 e). Data recalculated from http://www.eci.ox.ac.uk/research/energy/downloads/eceee07/white.pdf

Despite this somewhat down-beat analysis, I regard it as imperative that mitigation is taken seriously within the UK primary production sector. Not only are there the political pressures mentioned above but there are real opportunities associated with mitigation, both in terms of cost reductions and the generation of alternative income generation opportunities. In the body to this report, I will analyse in turn each of the major greenhouse gases associated with agriculture, focusing on the steps that farmers can take both within their own operations and more widely to reduce the impacts of other sectors. I will concentrate on options that are proven and that can be implemented now but will mention in passing longer-term options so that people are aware of how the position may change in the future. I will specifically highlight areas of uncertainty and the interactions that occur between different mitigation strategies. Some of these interactions go beyond emissions of greenhouse gases and link to other losses to the environment like nitrate and ammonia. I will attempt wherever possible to give some idea of the scope for savings and any up- or down-sides in terms of the economic performance of particular production systems. This piece of work draws heavily on other studies. In particular it builds on recent reports published by Defra (2) CLA/AIC/NFU (1) and St George's House (3). This report also links through to the more detailed considerations of key mitigation opportunities that were undertaken at the same time by the other recipients of the Frank Arden Award, the titles of which are given below.

Jiggy Lloyd	Carbon stewardship- some on farm case studies
Julian Morgan	Agriculture's role in energy production
David Hugill	Management of the uplands and climate change

2. CARBON DIOXIDE

2.1 Introduction

Although CO_2 is globally the most significant greenhouse gas, this is not true for agriculture. Direct emissions of CO_2 from heating, electrical power and combustion of liquid fuels associated with the agricultural sector only amount to some 0.3% of total UK emissions, a figure dwarfed by direct emissions elsewhere in the food production and distribution chain and more than counterbalanced by the net reduction of atmospheric CO_2 attributable to carbon sequestration in forests and grassland. There are also indirect carbon costs of agriculture such as the carbon costs of buildings, equipment and the production and distribution of inputs. The largest of these is nitrogen fertiliser, estimated at around 1% of total emissions including production losses of N_2O. However, this relatively modest contribution to total emissions does not mean that there are no mitigation options directly applicable to agriculture. Furthermore, this is also the area where agriculture has the opportunity to mitigate emissions from other sectors through improved carbon capture or the provision of renewable sources of fuel and power.

2.2 Evidence Base

The evidence base for calculating emissions of CO_2 is good. It is relatively simple to calculate carbon content and/or energy cost of production and convert this into overall GHG emissions. There are, however, uncertainties. Use of electricity produced from renewable resources significantly affects the CO_2 cost of fertilizer production, and the overall shift from coal/oil to gas has reduced the CO_2 cost of steel and concrete. Nevertheless, I believe that the figures presented here and cited in the three references quoted are accurate enough to provide the basis for a rational consideration of options.

2.3 Mitigation Options

2.3.1 On-Farm energy efficiency. Gains here will be small, but relatively easy to secure, will have a positive effect on enterprise costs and will be visible indications of commitment to GHG reductions. Many of these are similar to actions that consumers as a whole are being encouraged to carry out (accurate setting of thermostats, not leaving appliances and engines running when not in use, keeping equipment serviced, reducing heat losses etc) and will, consequently, be easily recognised.

The scale of gains will be very variable between enterprises depending upon actions taken to date, but there is a general estimate that some 10% of total distributed energy consumption across the UK could be saved by means like these at minimal cost or with payback times of 1-3 years. Looking beyond this, enterprises could consider options like increasing the renewable material content of new buildings, participation in machinery rings rather than going for outright purchase of new equipment and extending the life of capital assets by a rigorous programme of planned maintenance. As above, all these measures could also have a benefit in terms of longer-term enterprise costs but this would need to be assessed against any capital costs of implementation. Progressive incorporation of timber and other bio-products as structural materials also offers potential market opportunities for UK landowners.

Obviously, the magnitude of benefits that accrue is extremely dependent on the prevailing cost of energy, but this is expected to continue to rise in the face of supply constraints and international emission control agreements, so payback times are likely to

reduce rather than increase. The importance and value of individual on-farm audits will increase concomitantly as energy and input costs rise.
Maximising the efficiency of energy utilisation on-farm offers small but real savings in emissions and reductions in cost, and the scale of savings is likely to increase over time. Estimates of potential GHG savings are in the range of 3-5%.

2.3.2 On-farm input efficiency. I shall consider this in much greater detail when discussing N_20 below but the basic premise of ensuring that fertilisers and agrochemicals are applied in a way that minimises inputs without unduly constraining productivity is straightforward. There is broad evidence that European arable fertiliser application rates are approaching optimum efficiency but there remain considerable variations between different farming systems and the challenges of linking input optimisation with good manure management in the livestock sector are considerable**. Once again, economic benefits as well as environmental benefits will accrue and the scale of these will increase as energy-related input costs rise.**

2.3.3 On-farm energy production

2.3.3.1 Biomass. There are a range of by-products and secondary products from land that can be combusted directly and used to replace oil and gas. For example, dry straw has an energy content of around 15 GJ/tonne and wood chips around 10. Thus one tonne of straw is potentially capable of replacing 400 litres of heating oil or 400 m^3 of natural gas. Average yields of straw are around 3.5 tonnes/ha. To put this into context, average annual household energy use is around 90 GJ and would thus require the energy in straw from less than two Ha of land. There are a number of commercially-available boilers that can use different agricultural by-products and can supply heat to support a range of on-farm operations. There is, of course, a capital cost but payback times (currently >5 years) are likely to fall as fossil fuel prices rise. The efficiency of small on-farm units is fairly low but this is offset by relative simplicity, a guaranteed source of raw materials and short movement distances between the site of cultivation and the site of combustion.

In principle, small-scale production of liquid fuels (mainly bio-diesel from rape oil) is possible on farm and equipment to do this is available. However, this competes directly with food uses for the same crop and does not currently yield the same margins as small-scale treatment of waste oils. It would appear, currently, that centralised treatment, blending and marketing of biodiesel will be the norm, subject to some of the uncertainties discussed in 2.3.4 below.

2.3.3.2 Digesters. Anaerobic digestion (AD) of agricultural materials will generate a mixture of CH_4 and CO_2. This can be burnt to generate energy as heat. In Germany, this is seen as a renewable source of energy beyond the farm and dedicated biomass crops are grown for AD. In the UK, there is more of a view of AD as a way of minimising GHG emissions from agricultural wastes and also for processing other carbon-rich waste from off-farm where gate fees might be payable. AD of slurries also offers a mitigation option to reduce losses of CH_4 (see Section 3 below)

For all elements of on-farm energy production, the main barriers to uptake are the immediate direct cost-benefit analysis and the perverse incentives provided to other strands of the renewable energy market. The Country Land and Business Association (CLA) has discussed the regulatory changes that would be needed to overcome these problems and

these are summarised in reference 1. Any local generation of renewable energy will offset GHG emissions elsewhere in the generation system and there are examples of wind and water-powered electricity generation at a range of scales in use by a range of enterprises. https://www.renewablesandchp.ofgem.gov.uk/Default.aspx
Hosting larger-scale renewable projects like windfarms can also bring financial benefits to landowners.

2.3.4 Large-scale energy/biomass crops. There has been considerable interest in and controversy concerning the production of biomass and biomass products on a large scale as a way of reducing use of fossil fuels. In the UK, there are already co-firing arrangements using *Miscanthus* and short rotation willow that receive subsidy support under the non-fossil fuels obligation, and there are plans for bioethanol production from sugar beet and wheat that would receive similar support under the road transport obligation. Bio-diesel from oil-seed rape is also produced on a small scale. Large-scale production poses different challenges to on-farm production/utilisation in that issues of contract, transport, storage and security of provision all become significant. For *Miscanthus* and willow there are additional capital costs involved in growing a new crop, which makes some sort of secure supply contract even more important. However, these crops also generate some benefits in terms of increasing soil carbon and reducing N_20 emissions because of the reduced fertilizer requirement. However, in many cases, land used to produce these crops could also be used to grow food, and individual farmers will have to retain the ability to make business-focused decisions on the best way to exploit their own asset base. These decisions will obviously be conditioned by the prevailing price of food and if grain shortages persist, then large-scale biomass production will be less attractive. Further information on this topic can be found in the CLA discussion document cited in Section 8

2.3.5 Carbon Sequestration

2.3.5.1 Existing carbon-rich soils. Much of the detailed information on management options for such soils will be found in the report of David Hughill. Rates of microbial respiration of carbon in peaty soils will increase markedly if the soils dry out or new surfaces are exposed to the air by cutting or by erosion/damage. Peaty soils are very vulnerable to damage and there are added risks of such material being washed into surface waters. The UK has large areas of such soils in the hills and uplands and it is important that damage is minimised, and that, where possible, sequestration of atmospheric carbon dioxide increases. Such supportive managements will bring other benefits in terms of habitat preservation and reclamation, but will tend to reduce productivity. The steps that individual enterprises can take will have to be seen against a background of the topology and geology of the farm, the nature of the farming system and the availability of financial support for income foregone.

2.3.5.2 Improving carbon sequestration. Sequestered carbon in natural ecosystems will eventually reach a balance where the rate of fixation is equalled by the rate of respiration. However, the majority of agricultural systems are not in balance because of the provision of additional inputs, the removal of harvested products and, in arable systems, the periodic disturbance of the soil through ploughing which stimulates soil respiration and loss of CO_2. There are two distinctive approaches to increasing soil carbon content. Reduced and zero tillage as an alternative to ploughing maintains surface organic matter and can improve soil structure and reduce erosion. Potential to apply such techniques is fairly wide within the UK and some 1.5Mha are currently cultivated using discs or tines. Unfortunately, occasional ploughing (usually every 3-4 years) of minimum tillage land is common to relieve compaction and control grass weeds, and this will reduce the overall effectiveness of the system in sequestering carbon.

A further disadvantage is the potential for the increased water-holding capacity of such soils to lead to enhanced N_2O emissions, albeit at the expense of some reduction in nitrate leaching. I am not aware of studies that have measured the overall balance of GHG emissions under reduced or zero tillage in order to assess whether or not enhanced carbon sequestration is outweighed by increased N_2O emissions. Estimates of direct energy savings from reduced or zero tillage are in the range of 0.06-0.08 t CO_2e/ha/yr.

The other approach to increasing on-farm carbon sequestration is by changing land use. Replacing arable land with permanent grassland, woodland or perennial biomass crops increases soil carbon sequestration. Estimates of the magnitude of this process range from 2-7 t CO_2e/ha/yr, plus, in the case of uncropped woodland, 0.4-4 t CO_2e/ha/yr in the vegetation itself.

Further benefits accrue from lower inputs of N fertiliser, resulting in lower N_2O emissions. With perennial biomass crops, there is also the option for GHG mitigation through fossil fuel replacement (see 2.3.3.1 above). Once again, the applicability of these approaches will depend significantly on the nature of the individual enterprise, **but establishment of relatively small areas on farm of perennial biomass crops will bring positive benefits in terms of energy provision, soil carbon sequestration and reduction in N_2O emissions.**

Apart from infrastructure issues relating to the exploitation of on-farm energy (see below), there seems to be no down side to this approach, provided that changes in land use can be accommodated in an economically sustainable farming system. Changes in land use can also bring additional advantages in terms of habitat diversity, opportunities for field sports and promotion of farm tourism.

2.4. Sensitivities and uncertainties.

There are still considerable uncertainties relating to the interactions between soil carbon and the soil nitrogen cycle. This is discussed in more detail in sections 4 and 5 below, but it is very important to ensure that activities that lead to a positive effect on CO_2 emissions do not exacerbate emissions of CH_4 and N_2O. There are some uncertainties on the carbon costs of inputs and infrastructure which may introduce errors into life cycle analysis, but the steps discussed above will, if implemented, lead to improvements, even if there is some lack of clarity over their magnitude.

There are, however, two very significant uncertainties relating to implementation. The first relates to the economic value of any production losses associated (e.g.) with land use change. The current trend in global commodity prices is upward, and it is difficult to estimate with certainty whether the land needed to support on-farm energy production would bring a better economic return if used for food production.

There is a strong argument that reducing UK GHG emissions by reducing the scale of UK food production is an inappropriate response, since the problem is merely exported elsewhere, and individual landholders will have to balance likely changes in energy costs with likely increases in income from growing food.

This further underlines the value of on-farm audits.

The second major uncertainty is the extent to which government support to renewable energy production will promote a viable “small producer” sector. Combustion of biomass or methane from fermentation is a source of heat, but also potentially of electricity via combined heat and power (CHP) boilers. Small-scale CHP boilers exist currently and are being developed further using innovative technologies like Stirling engines, but the infrastructure and regulatory framework to allow small producers to sell surplus power back to the energy companies is not currently fit for purpose. In countries like Sweden, small scale CHP is a reality. In the UK it has the potential to play a significant role in areas of low population density and to link in to a sustainable approach to the management of biological waste (see section 3 below).

It is important that the support structure for renewable energy in the UK is consistent with the needs of small producers if agriculture is to make a proportionate contribution to reductions in net CO_2 emissions.

3. METHANE

3.1 Introduction

Methane (CH_4) is some 21 times more potent as a GHG than CO_2. Estimates of UK emissions are in the range of 50 kt CO_2e per annum, of which agriculture accounts for some 40%. The majority of this is released directly as a result of enteric fermentation, predominantly in ruminants, but about 13 % of total agricultural emissions come from manures and farm wastes during storage, processing and utilisation. CH_4 emissions represent about 47% of agricultural GHG emissions in the UK in terms of their effects on global warming CH_4 is a common product of biological activity in the absence of oxygen (anaerobic respiration).

Energy is released if carbon-containing molecules (like sugars) are split and part of the carbon oxidised to CO_2, whilst other carbon atoms are reduced to products like lactic acid (in your muscles during violent exercise), alcohol (in yeast-based fermentation) or CH_4 (in the case of enteric fermentation). The rumen of cows, sheep and goats is an exclusively anaerobic environment and about 10% of the feed intake would normally end up as CH_4. Anaerobic environments occur elsewhere in agriculture and in nature. Manure heaps and slurry tanks become substantially anaerobic because of the slow rate of diffusion of oxygen from the air, and the same is often true of swamps and marshlands, particularly in warmer climates where CH_4 release from rice paddies exceeds that from ruminants. **It is important to realise that CH_4 release is an inevitable product of agriculture in general and livestock agriculture in particular, but that some mitigation is feasible in many cases.**

3.2 Evidence base

Because direct measurement of CH_4 requires dedicated and fairly complex equipment, most national inventories are calculated on the basis of emission factors. These link an easily measured number to the extent of overall emissions. For direct emissions from livestock, calculations are based on census values for animal numbers multiplied by a factor that is UK-specific and species-specific.

For emissions from manures and slurries, calculations are based on some direct measurements of release, livestock numbers and assumptions about the mix of manure management systems for different livestock. This approach is accepted as being broadly accurate in the case of delivering a usable inventory of CH_4 emissions, but does have drawbacks in terms of delivering mitigation options. For example, a treatment that reduced CH_4 emissions per animal would not translate to mitigation in terms of the national inventory, even though it would deliver reduced overall emissions. Conversely, treatments that improved output per animal, allowing production to be maintained with a smaller herd, would show up as mitigation within the national inventory even if CH_4 emissions per animal increased as a result. **To avoid restricting viable mitigation options for farmers, it is important that there is agreement between farmers and policy makers that reductions in the national inventory should not be the sole target for GHG mitigation.**

3.3 Mitigation options

3.3.1 Ruminant systems

3.3.1.1 Diet. It is known that methane outputs from ruminants are sensitive to diet. There is a strong interaction between diet and N losses from ruminants that can also influence CH_4 emissions. In particular, appropriate use of maize silage to reduce the N content of diet can also reduce CH_4 emissions. Since higher N losses also feed through to increased GHG emissions be cause of the interactions with N_2O release (see section 4 below), there are some generic guidelines that can be given that will give some reductions in emissions of CH_4 and N_2O with negligible effects on growth rate or milk production.

These are discussed in detail in reference 2, but are based upon optimising protein and energy supply in a way that allows for the age, sex and production status of the animal. In some cases this can be linked to more efficient managements (like 3x daily milking) to reduce herd size accordingly. Estimates of potential CH_4 and N_2O reduction by such practices are modest (ca 600kt each; reference 2) but are feasible within current systems. **Farmers are already putting such approaches into practice for economic reasons, and widening adoption of practices that improve nutrient use efficiency must be a priority.**

3.3.1.2 Animal health and animal genetic improvement. The principle here is clear. Minimising the number of poorly-producing or non-producing individuals in a herd will maintain production and reduce emissions. It should reduce costs as well, in that overall feed efficiency will increase. In practice, significant progress is likely to be slow and variable. Development of intensive dairy systems has resulted in declines in fertility and increased incidence of conditions like mastitis, and much research is being undertaken worldwide to seek for solutions. **Currently, maintaining the highest possible standards of husbandry would seem to be justified in economic, welfare and environmental terms,** and it will be important to ensure that future advances are taken up widely and as rapidly as economics permit (see section 7).

3.3.2 Slurry and waste management. Reducing emissions from manure storage without generating other forms of pollution is complex. Anaerobic digestion (AD) seems a promising option when compared to composting in that it retains the nutrient value of the residue material and produces a useable source of energy in the form of a gas stream containing combustible concentrations of CH_4.
There are already small- and medium-scale plants in use in Europe and a much more detailed consideration of the economics and operational issues surrounding the technology is given in the report of Julian Morgan. Estimates of potential savings suggest that up to 75% of current CH_4 emissions from farm wastes could be prevented if the technology was introduced on a broad scale.

There are however, a number of challenges. Some of them relate to the regulatory framework that deals with small scale heat and energy generation and have already been discussed above. Additionally, there is a need for clarity about what individual AD plants are for. At one level, they can be considered as a way of turning a potent GHG (CH_4) into a less potent one (CO_2). Such a plant would have two desirable by-products in terms of useable energy and a better-defined residue that could be incorporated into a whole-farm N budget designed to minimise N_2O release.

However, it is not certain that the overall economics of such an enterprise would give acceptable pay-back times because of seasonality of production and the relatively low carbon content of some wastes. There are two other models that address these concerns. The first incorporates high-carbon products off the farm into the plant. This will emphasise renewable energy production as an output, but at the expense of reduced food production from the enterprise. Comments made above concerning the need for farmers to balance energy and food production based upon current global prices are relevant here, but I have concerns that small-scale energy generation from "food-grade" materials will neither be profitable nor publicly acceptable in the short- to medium-term.

Incorporation of non-farm wastes into AD plants overcomes this objection, and opens up the possibility of economic returns via gate fees. The challenges then become ones of scale (are bigger, area-based plants more appropriate) and any constraints on the use of residues as inputs in food-based production systems.
There is an urgent need to both raise awareness of AD technology and to ensure that the regulatory and support system acknowledges the range of benefits that could accrue and helps farmers to make the right choices for their enterprise.

3.4 Sensitivities and uncertainties

Many of these are similar to the issues raised in 2 above, in that the straightforward gains are likely to be modest, and there is lack of clarity regarding the future viability of more radical options. The conflict between maintaining production and reducing emissions is particularly stark in the case of ruminant emissions of CH_4, and in some cases, welfare-friendly "slow" production systems that emphasise product quality will increase emissions per unit of final product. The extent of use of AD to reduce manure emissions will be highly dependent upon the overall regulatory environment and upon the balance between energy costs, input costs and food prices. Although the method of calculating emissions is not perfect, I do not believe that this needs to constrain appropriate mitigation measures. In the longer term, there remains a pressing need to address some of the negative impacts of advances in animal productivity, so that efficiency can be increased accordingly. It cannot be stressed too strongly that, without the development of radical new technological advances (see 6 below), reductions in ruminant CH_4 emissions will be modest and, once achieved, cannot be improved upon significantly. **This puts real emphasis on the industry working to ensure maximum uptake of best practice across the full spectrum of GHG management if we are to avoid criticism.**

4. NITROUS OXIDE

4.1 Introduction

Nitrous Oxide (N_2O) is the most potent of the agriculturally-relevant greenhouse gases, with an emission factor of 310 compared to CO_2. This high factor results from a combination of its direct effect and its persistence in the atmosphere. Thus, although emissions from UK agriculture are small in mass terms (Defra estimates of 128 kt for 2005), they represent almost 60% of the total impact of agriculture. There are emissions of N_2O outside agriculture related to plastics manufacture and combustion of liquid fuels, but within agriculture, the predominant source of N_2O is from microbial activity in the soil.

The soil nitrogen cycle is complex and variable, but a variable proportion of the available ammonia, organic N and nitrate in soil is lost as free ammonia, free nitrogen, N_2O and leached nitrate that ends up in ground water. The absolute magnitude of total loss of N and the relative proportions of the different components are affected by a number of external factors including temperature, soil condition, water status and organic matter content.

Just to complicate the picture even further, emissions can also be affected by the means by which N inputs are applied and by the “natural” deposition of N onto land from atmospheric pollutants and via lightning. This variability of the magnitude of the soil N cycle both in time and in space has had a very significant impact upon consideration of appropriate mitigation strategies, but in general terms factors that will tend to favour high rates of N loss will be high input levels, elevated temperatures, wet soils and high levels of available soil carbon.

4.2 Evidence base

Direct measurements of N_2O emissions are complex, time-consuming and expensive, relying on analysis of the different gases liberated into the space above sealed chambers placed onto soil. As mentioned above, there are large spatial differences in emissions, particularly in pastured livestock systems where returns through dung and urine are highly discontinuous. In the absence of comprehensive direct measurements, the IPCC inventories of N_2O emissions are based upon a factor related wholly to the amount of artificial nitrogenous fertilizer that is used in agriculture. However relevant this estimate may or may not be for policy development, it has significant flaws in terms of pinpointing viable mitigation strategies. These are outlined briefly below:

- Legume N and organic returns are not accounted for. In livestock systems (both organic and conventional), significant N enters the system via biological N fixation and via externally purchased feed. N_2O emissions in the production of feed may have been incorporated into the inventory within the country of origin, but further UK emissions will result as this additional N is metabolised in the soil. There is no compelling evidence to suggest that legume or livestock return N is any less vulnerable to soil loss than fertilizer N.
- The complex relationship between the carbon and nitrogen cycles in soils means that N_2O release in arable systems will not be a simple function of available N content

The industry needs to accept, however, that mitigation actions will have to take place in the absence of good quantitative data to predict outcomes. By the same token, regulators will have to accept that these actions will deliver benefits that may not reduce the inventory figures and that will produce a variable range of benefits that include but are not restricted to N_2O.

4.3 Mitigation Options

Essentially most of the currently viable mitigation options revolve around the development of agricultural practices that will, over time and subject to other external factors, tend to reduce soil concentrations of ammonium and nitrate. These will also tend to reduce N losses by nitrate leaching and ammonia volatilization and will, at least in theory, reduce input costs. However, there is a strong, direct but non-linear relationship between input levels and overall production and consequently a real need to ensure that economic sustainability is not compromised. As with methane, reduced agricultural activity will reduce UK emissions, but only at the expense of exporting the problem elsewhere. Indeed, there is evidence to suggest that overall emissions could increase if production was exported to countries where agricultural production was less input-efficient. Within this overall envelope, mitigation can centre around the following actions:

4.3.1 Do not exceed crop N requirements. There are a number of existing schemes and regulatory instruments that assist farmers to link nutrient applications to crop requirements, soil type and growth stage. These are described in more detail in Reference 2, and estimates of savings achievable via such measures are in the range of 5% for N_2O, nitrate leaching and ammonia emissions. Availability of schemes like FACTS (Fertilizer Adviser Certification and Training Scheme) are absolutely crucial to the success of such an approach, as is ensuring that uptake within the industry is widespread.

4.3.2 Make full allowance for manure N in farm input budgets. Once again, a range of recognised approaches to managing total N inputs are available, but do require an understanding of the processes involved, the use of manure analysis and making full allowance for these nutrients in terms of calculating farm input budgets. There are also issues relating to the timings of applications when land receives both fertilizer and manure N. Once again these are discussed in more detail in reference 2, but estimates of savings of around 5% for both N_2O and nitrate leaching, with ammonia emissions also being reduced depending upon the manure or slurry application method. As with 4.3.1 above, success will depend on acceptance by the industry of the principles involved, the availability of good guidance and training and the widespread adoption of best practice.

4.3.3 Spread manures and slurry at appropriate times and under appropriate conditions. Effectively this is a further element of a “best practice” approach to managing inputs at the farm level to match as far as possible application to the demands of the crop to which it is being applied and to take into consideration the prevailing conditions at time of application. It is known, for example, that moving slurry applications from late autumn/winter to spring can reduce direct N_2O emissions by up to 50% on free-draining grassland soils. However, optimal benefits from this approach will depend on soil type and rainfall and are conditional on farms having sufficient storage capacity to allow choice as to when to apply slurry. Concomitant estimates of potential reductions in nitrate leaching are in the range of 5-15%, although ammonia emissions are likely to increase associated with spring application, and methane losses will increase slightly due to the extended period of slurry storage.

All the issues discussed above relating to training, advice and uptake are relevant to this approach, and it must be accepted that some farmers will find it difficult to achieve best practice consistently year upon year because of issues like exceptional rainfall that are beyond their control. However, minimising N losses will also help to reduce the need for fertilizer N if accurate on-farm budgets are available.

4.3.4 Increase livestock N use efficiency. Feeding excess N to livestock exacerbates the already low efficiency of N utilisation without producing significant increases in production. “Unnecessary” N returns land will stimulate N losses including to N_2O. Diet recommendations are available, but there is evidence of “over-feeding” of N as a safeguard against loss of production.

Once again, greater precision in terms of characterising all elements of the diet will allow optimal feeding practices to be developed that can reduce both feed costs and environmental impacts. There is, however, a need to update the detailed information on nutrient requirements for poultry, beef and sheep to reflect the level of information available for pigs and dairy cattle (Reference 2).

For grazed livestock, some improvement in the available carbohydrate to protein ration is available via new forage varieties and this in turn can improve N efficiency. It has been estimated that a 10% improvement in N efficiency would result in a 6% reduction in N_2O emissions and would also reduce nitrate losses via leaching and losses of ammonia from urine and manure management.

There is a significant challenge in improving the precision of livestock feeding in UK systems and once again the scale of benefits will depend upon the availability of advice and training and upon the extent of adoption of best practice. There have already been demonstrations within the dairy sector that input costs can be reduced via such an approach without reducing production.

4.3.5. Manage stock to protect nutrient-rich soils against compaction. This is the only mitigation option that seeks to alter the soil N cycle by management rather than by controlling inputs. It is known that anaerobic conditions in soils with high N and C contents do strongly favour N_2O production. Thus poaching associated with high livestock numbers and wet soils should be minimised wherever possible. N_2O and methane emissions and nitrate leaching will be reduced, and there would also be positive effects on water pollution from sediment runoff and P loss. There is a lack of good quantitative data to allow estimates of the extent of savings, and different farms will be more or less prone to such problems depending on soil type, topology and rainfall. Additionally, the capacity of different holdings to employ alternative approaches (such as more or longer winter housing) will vary considerably and, in the absence of hard data on savings, it will be a matter of judgement as to the importance and feasibility of this option. Any management change that created increased amounts of manure would also face problems of the kinds described in 4.3.2 and 4.3.3 above in terms of maintaining optimal input strategies for such material.

4.4 Sensitivities and Uncertainties

Sustained, consistent and quantifiable reduction in agricultural N_2O emissions will be very difficult to demonstrate because of the complexity of the soil carbon and nitrogen cycles. This poses problems for both practitioners and regulators. Additionally, the potential financial savings associated with optimal input management both require an improved level of precision across farm practice and, in some cases, will increase the risk of an occasional production penalty. I would argue that the key uncertainties here relate to gaining acceptance at the policy level that agreed standards for efficient input management will produce a basket of gains over time that will be accepted as evidence of mitigation.

It will be important to ensure that occasional and isolated problems do not call into question the long-term value of the approach.

If such agreement can be reached, the second uncertainty relates to the availability of the training and guidance infrastructure to ensure that best practice becomes widespread. I will discuss this further in section 7, but it would be wrong to imply that progress in this area can be generated easily by all farmers without changing their methods. It is also important to stress that, even under the most optimistic projections, N_2O emissions will remain the most significant element of agricultural GHG production and that only relatively modest savings are possible without paying a significant production penalty.

5. INTERACTIONS BETWEEN THE DIFFERENT MITIGATION OPTIONS

5.1 Introduction

Agricultural systems and the flows of materials within them are complex and interlocking, and changes in one element often produce effects elsewhere. The mitigation options discussed above are organised by the primary GHG that they are designed to mitigate, but very few of the options will not have either positive or negative impacts elsewhere. One of the real dangers inherent in the current discussions on GHG mitigation is the potential to cause adverse effects in other processes that may also be of considerable environmental significance. In the absence of an holistic way of accounting for the balance between benefits that will accrue in one area and disbenefits that accrue somewhere else, it is important that farmers should be aware of some of the key interactions so that they can be factored in to farm-level mitigation strategies.

5.2 AD and on-farm methane production

The debate about the value of AD is coloured by different views as to the primary output (see 3.3.2 above). For the purposes of this paper, it is viewed principally as a way of replacing an active GHG (CH_4) with a less active one (CO_2). Energy is a useful by-product, together with a tractable residue that can be better managed in terms of on-farm inputs of N, P and K. In some parts of Europe, AD is seen primarily as a way of generating renewable energy, but to do this, other inputs are needed.

Currently these inputs (e.g. forage maize) would also have value in terms of food production, and there is considerable disagreement about the long-term sustainability of such a system. Finally, incorporation of non-farm waste into AD can improve the efficiency of the system in terms of CH_4 production, can bring a financial return in terms of gate fees and could form part of a sustainable waste management strategy. However, its direct importance in terms of on-farm mitigation would be reduced, and concerns have been expressed concerning the subsequent use of residues.

We need to know a lot more about options to use such residues as inputs in non-food land use before it is possible to carry out a reliable assessment of benefits and disbenefits. There is a more detailed discussion of this in Julian Morgan's report.

5.3 Soil carbon sequestration and N_2O production

The microbial N cycle in soils consumes energy. The bulk of this energy comes from the aerobic and anaerobic metabolism of carbon compounds either coming directly from plant growth or indirectly via the intervention of above- and below-ground herbivores.
In principle rates of N_2O production will therefore be related to available soil carbon as a microbial substrate. However, the relationship is neither direct nor consistent.
There is some evidence that low- or zero-till can lead to enhanced N_2O emissions, but this may be because of indirect effects on the movement of water through such soils rather than an increase in available carbon. However, if there is to be encouragement given to carbon sequestration techniques, the subsequent input status of the land will be significant in determining once again the balance between benefits and disbenefits. **I have no doubt that we need more information on the interactions between the C and N cycles in soils and the possible impacts that carbon sequestration will have on N_2O release at high, low and medium levels of available soil C.**

5.4 Pollution-swapping within the soil N Cycle

Apart from dinitrogen, all the forms in which N is lost from soils (nitrate, N_2O and ammonia) have negative environmental effects. It has been known for many years that the balance between the three is complex and that it is possible to decrease emissions of one component at the expense of increasing emissions of another (pollution-swapping). For example, slurry management techniques involving subsurface incorporation are prone to reductions in ammonia emission at the expense of increases in nitrate leaching. Currently we lack broadly-applicable and well-validated models that can predict some of these interactions and we also have no good method (as discussed in 5.1 above) of evaluating the relative value of benefits and disbenefits across the sector as a whole. Environmental legislation tends to concentrate upon fairly narrow issues, whereas the debate about GHG mitigation requires, in my view, a much more holistic approach to setting targets and monitoring progress. **Developing the tools to promote such a debate should be a priority for regulators.**

5.5 Transformations during waste storage

Shifts towards slurry-based systems are likely to reduce N_2O emissions by up to 15% when compared to manure-based systems, since there is little possibility of ammonium oxidation until spreading occurs. However, it is not clear the extent to which this is offset by greater CH_4 emissions from slurry, and there may be increased losses as ammonia and via nitrate leaching. Given the costs of installing slurry-based systems, the balance of GHG emissions from slurry and straw-based manure management systems for both cattle and pigs need to be quantified

6 LONGER-TERM OPTIONS

6.1 Introduction

The mitigation options discussed above could be implemented now. In some cases, development or extension work would be needed to help individual farmers to decide whether they are applicable but the scientific basis for them is reasonable well understood in general terms. There are, however, a range of options that may become more attractive in the future. I have summarised what I believe to be the most feasible of these in terms of medium-term introduction into economically-viable farming systems. The first two represent potential developments of biomass production to improve the value of the product, the second two represent management options to reduce GHG emissions and the final two look at options for reducing inputs without compromising production.

6.2 Biofeedstocks

Plants produce a huge range of chemicals, usually in rather small quantities. There are high-value plant products (e.g. spices, flavours and prized woods) but in principle there are opportunities to breed plants to produce high value feedstocks that would replace products derived from oil. There is a considerable body of research ongoing into both modulating plant biochemistry to produce more of particular compounds and refining plant products to generate a range of product streams that could be used industrially in different ways. The challenges are considerable, and it seems likely that genetic manipulation would become an essential element in such an exploitation pathway, but there are considerable opportunities if we can obtain a better understanding of how plant secondary metabolism is regulated. The competition with food production and the price of oil will both be very important in determining at what point production in plants becomes more economically important than using products derived from oil, but it seems unlikely to me that significant acreages will be grown for biofeedstocks within the next decade.

6.3 Liquid fuel from wastes and/or low value lignocellulose

First generation liquid biofuels (ethanol, butanol and biodiesel) are produced by fermenting starch and sucrose or by refining and modifying plant oils. All of these are also food products and are very easy to degrade or modify. Ruminants and some insects (among other animals) can break down recalcitrant fibre to yield simple sugars that can also be fermented to ethanol or butanol, and there is considerable interest in developing chemical or biological treatments that would allow low-value fibre or waste fibre to become a liquid fuel feedstock. If this was successful, it would not impact significantly on primary agricultural production, but could impact on pastoral systems based on grazing, since these grasses would be potential feedstocks. The challenges of modifying recalcitrant fibre have not yet been overcome, but there is considerable research effort being directed to this goal, and when it is achieved, it will undoubtedly offer some farmers new options for mitigating GHG emissions across society

6.4 Methane inhibitors and related approaches

As discussed in 3.1 above, methane is the product of anaerobic fermentation. Other compounds can act as hydrogen acceptors in such fermentations and it may be possible to “divert” the path of rumen fermentation by modifying the flora and fauna of the rumen.

A range of approaches have been tried on a small scale, including vaccination against methanogenic bacteria, use of specific antibiotics and use of feed additives such as essential oils, yeast products and organic acids.

Significant reductions in methane emissions have been shown on a small scale but it remains to be established how effective these treatments are in the longer term and at the herd level. Once confirmatory data were provided, incorporation of additives into feed could occur quite rapidly, with the balance between costs and benefits determining uptake.

6.5 Nitrification inhibitors

Nitrification inhibitors are chemicals that reduce the rate of conversion of ammonium ions to nitrate. The rationale is that slowing this process improves uptake by the plant and reduces losses via nitrate leaching and N_2O emissions. Estimates of their effects vary considerably but reductions in both processes of around 30% have been reported under field conditions. There is active use of these inhibitors in pastoral agricultural systems in New Zealand, and this is discussed in reference 2. They are expensive, and significant reductions in mineral fertilizer requirements would be needed to make them cost effective. This may be easier in the New Zealand system where growing seasons are longer and soils more free-draining. There appears to be a need to measure effectiveness under UK systems. If this was demonstrated, then the technology could be introduced relatively quickly. It may be possible, over a longer time frame, to breed plants that contain such inhibitory chemicals

6.6 Improving animal performance

In the absence of direct options to mitigate CH_4 emissions from livestock and N_2O emissions from pasture, there will be continued pressure to improve animal performance so that the same amounts of product can be generated from fewer animals. The challenges of doing this in a way that is compatible with animal health and welfare have been discussed above and are not insignificant. It is, however, worth noting that the use of bovine somatotrophin allied to increased milking frequency is already in use in other countries with some success. Whilst this technique is not currently allowable under EU legislation, it is a concrete example of a technology that does bring benefits in terms of the rather intractable issues relating to GHG emissions from livestock

6.7 Improving plant performance

It is known that there are large differences between plant species in the efficiency with which they access and utilise nutrients such as N, P and K. In principle, therefore, it is possible to use selective breeding (and possibly GM technologies) to improve the nutrient use efficiency of crop plants. This would, if achieved, cut costs by reducing the need for inputs and reduce pollution caused by excess or unassimilated nutrients. There is also the option of increasing the range of plants that fix nitrogen, with potential concomitant gains in the reduced use of fossil fuels to fix nitrogen via the Haber process. There may well be considerable challenges to achieving these aims, since most crops are derived from ancestors that were strong competitors in disturbed habitats, showing a strong response to nutrient availability; rapid growth and seed set all allied with low efficiency of nutrient utilisation. To improve the latter without adverse effects on other important agronomic characteristics will be difficult and will take many years to come to market, but would be of very considerable value in reducing N_2O emissions.

7 CONCLUSIONS, IMPLEMENTATION AND IMPLICATIONS

I believe that the key strategic messages for both farmers and policy makers are relatively simple, and I have indicated these below in no particular priority.

- Mitigation of GHG emissions from UK agriculture is possible to an extent, but overall reductions using currently viable approaches are likely to be modest (maximally some 10-15% of current emissions assuming similar levels of production).
- There will come a point where further reductions in emissions will compromise outputs. Given the current concerns about global food supply both the industry and policy-makers need to be committed to maintaining economic competitiveness and the UK production base rather than moving the problem elsewhere in the world
- Many of the approaches that will generate these reductions are compatible with reductions in enterprise cost and are based around increasing the precision and efficiency of agricultural practice and making better use of waste materials.
- Many but not all of the techniques discussed above can be implemented with modest capital costs. However, there is a need for additional training and guidance
- Farmers should take GHG mitigation into account when carrying out forward planning. There may well be a better balance of risk and reward associated with more radical changes in farming systems
- There needs to be a clear recognition by policy-makers of the challenges of encouraging mitigation (particularly of CH_4 and N_2O emissions) against a background of inventory calculations that do not recognise many mitigation options
- The techniques of on-farm auditing and system models that are GHG compatible require continued investment in both financial and R&D terms
- New technologies will progressively expand the range of viable mitigation options, and both farmers and policy makers need to be aware of this and to maintain the flexibility needed to embrace new approaches
- The political implications of there being only modest achievable savings in the early stages requires the industry to encourage very wide uptake of the viable mitigation options and to engage with government and other stakeholders to demonstrate real commitment

The implementation of the fairly modest measures described above will send a positive signal that the industry is serious about GHG mitigation. However, there is a real need to ensure widespread take-up of appropriate options. In the current climate of economic strictures, the development of auditing and best-practice across the industry is a very tall order, and I am concerned that the challenges have been underestimated. I strongly welcome the development of the Farming Futures project (http://www.farmingfutures.co.uk/) and would urge all those concerned with the development of UK farming and Land Use to support this as an excellent example of how information and guidance can be made available as widely as possible.

I believe that now is exactly the right time for the industry to take stock and make a contribution that is proportionate, economically justified and effective. I have real concerns that growing global demand for food might jeopardise attempts to reduce the footprint of agriculture in general and we need to use the time available now to develop agricultural systems that are more sustainable and more efficient.

8 REFERENCES AND FURTHER READING

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