Part of the Solution

CLIMATE CHANGE, AGRICULTURE AND LAND MANAGEMENT

Country Land & Business Association
RURAL ECONOMY IS OUR BUSINESS

agricultural industries confederation

www.nfuonline.com

In October 2005 HSBC Bank became the first FTSE 100 Company (and the world's first major bank) to achieve Carbon Neutral status.

Some forty years earlier we were the first UK bank to establish a specialist Agriculture team.

Against this background it is highly appropriate for HSBC to support the launch of this report. We commit ourselves to working with the CLA/AIC/NFU and all UK farmers in achieving a better scientific understanding of the issues impacting on carbon balance in the countryside. Most important of all we wish to assist with the identification and implementation of practical steps that can be taken to lessen the Carbon Footprint of our great industry.

Steve Ellwood
Head of Agriculture
HSBC Bank plc

Supported by

HSBC
The world's local bank

Part of the Solution

Report of the joint NFU/CLA/AIC Climate Change Task Force

Contents

Foreword i

Executive summary and recommendations for action 1

Initiatives to be led by the agricultural and land management sector 5

Recommendations for government policy and intervention 5

1. Introduction 7

2. Describing the problem 9

2.1 The policy context 9

2.2 Key climate change concerns 9

2.3 UK greenhouse gas emissions from the land-based sector 10

3. Solutions – how the land-based industries can mitigate climate change 17

3.1 Energy and agricultural production 17

3.2 Other agricultural emissions 23

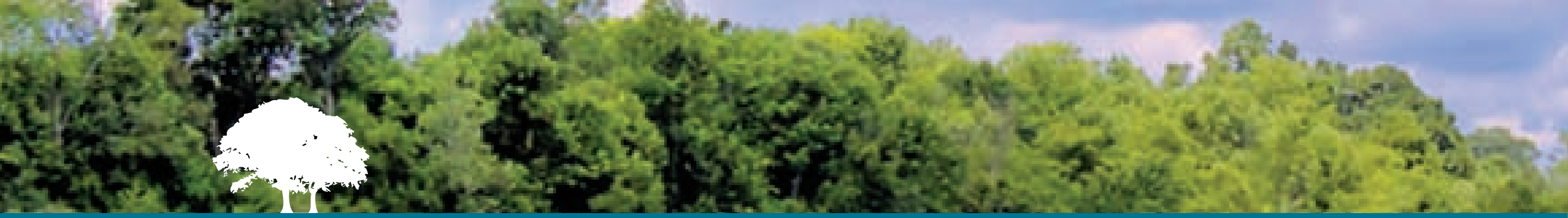
3.3 Land use, land-use change and forestry 30

3.4 Other options 36

Annex 1: Climate change impacts on UK agriculture and land management 39

References 41

Acknowledgements 43
(Sponsors, Stakeholders consulted, Reviewers, Sources of Information)



Foreword

Our sector, representing farmers, land managers and associated businesses, is a central part of the response to the growing threat posed by climate change. We recognise the role played by agriculture and rural land use in the wider context of global sustainable development. Managing the land is the most basic of human industries, without which we would not be able to sustain all others, including our own lives. Given that we all depend upon large areas of the land for our food and, increasingly, for other renewable resources, we accept our responsibility to use our finite resources wisely, and to mitigate unwanted impacts on air quality, soil, water, habitats and wildlife.

The National Farmers' Union (NFU), the Country Land and Business Association (CLA) and the Agricultural Industries Confederation (AIC) launched this joint Climate Change Task Force in January 2007 to present a united stance against the serious threat that climate change poses to agricultural production and the rural sector. By working together, we demonstrate here how our sector offers part of the solution to a major public problem.

This report represents the culmination of a great deal of study and sets out our recommendations for action. In order to address climate change in the agricultural and land management sector, we believe the future priorities of our industry should be:

- directed research on the UK greenhouse gas inventory, to include: breakdown of components and emission factors more representative of land use and management; soil carbon and N_2O balance; reduced or zero tillage systems; and integrated models of whole farming systems;
- delivery of best available practices for integrated nitrogen management to improve current nitrogen efficiency, with support from the fertiliser industry, agronomists, advisers and animal nutritionists;
- raising awareness of energy and carbon accounting, and promoting energy efficiency and carbon management by farmers, land managers and foresters through financial incentives;
- removing barriers to the uptake of anaerobic digestion in order to harness methane emissions from animal manures as a source of heat and power, through education, capital and revenue-based support, cost-effective electricity grid connections, and establishment of a digestate standard; and
- realising the wider potential for the land-based industries to supply renewable energy.

David Yiend Chairman AIC	Henry Aubrey-Fletcher President CLA	Peter Kendall President NFU

December 2007

Executive summary and recommendations for action

Shared responsibility and leadership

Together, the organisations representing the British agriculture, forestry and land management sector recognise that climate change is occurring and that our sector needs to address the issues raised by the Stern Review and the Intergovernmental Panel on Climate Change. Climate change is rarely out of the news, the scientific body of evidence for human impacts upon climate worldwide is growing steadily and policy measures to try to limit change, and adapt to it, are already being put in place at national, international and local level. As a sector of society uniquely exposed to the impacts of climate change, our three organisations believe leadership is not only vital for our businesses to survive, but also indicative of the importance we expect government and others to attach to this issue.

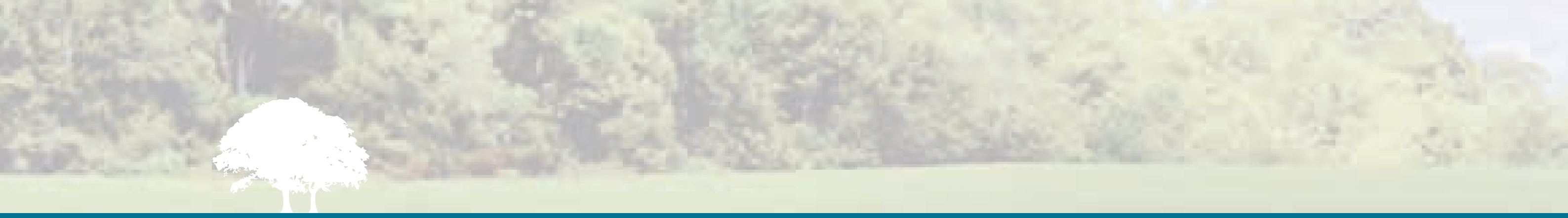
The NFU, the CLA and the AIC launched a joint Climate Change Task Force in January 2007 to present a united stance against the serious threat that climate change poses to agricultural production and the rural sector. Based upon a number of contributory science-based background papers, and with an emphasis on self-regulation, this report highlights best practice and identifies shortcomings and areas where we believe that research is needed to guide future development. We make a series of recommendations, emphasising what support we expect from government.

Early action

Our Task Force agrees that there are substantial economic, social and environmental benefits in taking action now in anticipation of climate change, to ensure that our sector remains economically and environmentally viable in the future. In presenting how land-based activities can offer part of the solution to this problem, we also show that the UK may benefit from its relatively stable, moderate climate. These characteristics may yet give Britain an edge in new 'low-carbon' food and energy products that address customer demands as well as emerging government policies. However, it is important that action on climate change should complement, and not conflict with, other environmental initiatives.

UK and worldwide challenge

At the outset, we acknowledge that Britain's GHG (greenhouse gas) emissions are relatively modest in the context of a global problem and that UK forestry and agriculture's share of national emissions (about 7%) is considerably lower than the share of agriculture worldwide (around 10-12%). We note that predicted physical impacts of climate change in the UK over this century include: milder, wetter winters; hotter, drier summers; and more extreme weather incidents. The effects of these changes on the land-based rural business sector are likely to be extremely complex and variable. Changing conditions are also likely to have significant economic impacts on agriculture and land management through markets, both at home and abroad.



"Within the UK, the total energy used in production of fertiliser contributes just 0.2% of total national CO_2 emissions."

Greenhouse gases

We have reviewed the evidence base for GHG emissions from agriculture and horticulture together with land use, land-use change and forestry, and we note that current methodologies are subject to a number of uncertainties. We note our contribution to climate change through emission of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) in the course of producing food and other land-based renewable commodities. The gradual fall in land-based emissions is explained partly by a reduction in the UK livestock population, as well as a decrease in nitrogen fertiliser use on grassland, and the gradual reduction in emissions from past conversion of permanent pasture to arable land. Carbon emissions from the land-based industries are balanced, in part, by their removal and storage of carbon from the atmosphere in soils and biomass, including trees. Our sector may also earn credit for its indirect contribution to emissions reductions in other sectors, through the supply of a wide range of renewable energy services.

Don't export the problem

The businesses in our sector depend upon a variety of inputs in order to produce food and land-based products in a manner which is both economically and environmentally sustainable. These inputs include the expenditure of energy for space and water heating, ventilation, field operations and initial processing of harvested products, as well as physical inputs such as fertilisers, pesticides and other agrochemicals. Reducing the level of UK farming activity and its associated emissions could actually have the perverse effect of increasing global GHG emissions. It is far better to set an example and export good agricultural practice.

Within the UK, the total energy used in production of fertiliser, including ammonia for both fertiliser and other uses, contributes just 0.2% of total national CO_2 emissions. N_2O emissions from fertiliser production facilities with nitric acid plants add 0.4% to the UK total (expressed as CO_2 equivalents) and the energy use in ammonia plants comprises a further 0.3% - together, a modest proportion of the total GHG emissions from agriculture. Expressed as the resulting increase in crop yield, investment of energy in nitrogen fertiliser typically yields a six-fold return, i.e. an energy balance of 6:1.

Carbon neutral agriculture?

Rising energy prices combined with a rising level of environmental awareness have led to significant energy savings in recent years. Through accelerated uptake of energy efficiency and a range of renewable energy technologies, there is potential for agriculture ultimately to become almost carbon neutral. Significant government support or outside investment would be required to achieve this goal.

The challenge of methane

Agriculture is a substantial source of methane (CH_4) emissions, making up about one third of the UK total. Measures to reduce CH_4 emissions from enteric fermentation are aimed either at lowering CH_4 production per animal or reducing animal numbers by increasing the productivity of livestock within the system. Studies confirm that diet, nutrition and level of food intake all have a significant effect on CH_4 production from ruminants, which could be reduced by 10-40%, depending on the nature of the intervention.

Although dietary manipulations can and do reduce methane emissions by livestock, the most widely recommended strategy for reducing methane emission by ruminants is by indirect means, through increased productivity per animal and the related improvement in feed utilisation efficiency. Anaerobic digestion, i.e. controlled production of biogas, looks to be the most promising mitigation option and is widely used elsewhere in Europe. Research suggests that by stimulating both on-farm and centralised anaerobic digestion facilities, up to 75% of UK methane emissions could be prevented from current manure management practices in dairy, cattle and fattening pig enterprises.

Nitrous oxide and nutrient management

Every process or activity that returns or adds nitrate or ammonium to the soil increases the likelihood and extent of N_2O formation. Mineralisation of soil organic matter, decomposition of crop residues, biological nitrogen fixation, deposition of fixed nitrogen from the atmosphere, and application of both manures and fertiliser, all contribute to ammonium and nitrate supplies in the soil. Different agricultural situations vary in their typical rates of N_2O emission, as a function of a number of risk factors – which may increase if the projections of warmer temperatures and higher precipitation coincide in some parts of the UK.

The most significant scope for reducing N_2O emissions is offered by increasing the efficiency of nitrogen management, integrating organic nitrogen sources with mineral fertilisers on fields which receive both sources. For arable crops, timing of nitrogen application and variable rate strategies can fine-tune nutrient management. For pastures, there is more to be gained from basic measurement and application techniques, but also in timing strategies on heavy soils. It will be very difficult to specify outcomes that result in lower N_2O emissions, but combined improvements in livestock and crop nitrogen efficiencies could mitigate emissions by up to 20%.

Carbon in trees and soils

The total emissions from our sector are offset by carbon removal and storage through land use change and forestry, on balance resulting in a modest net removal of carbon from the atmosphere. Forests and woodlands have the capacity to sequester carbon in biomass and soils, whilst at the same time providing a sustainable renewable resource for both material substitution and renewable fuels. Forestry policy and management decision-making might be transformed if carbon had a more significant tradable value. Timber, timber products and products from agricultural crops, such as hemp, have a significant part to play in

climate change mitigation by their substitution for brick, concrete and steel, all of which have high "embedded" CO_2 emissions.

Research on land management and soil carbon points to the modest, relatively long-term, but complementary role that soil carbon sequestration can play in reducing atmospheric GHG emissions, and the additional benefits that can be gained from increased soil carbon – improved productivity, resilience to erosion and biodiversity. Land use change is, therefore, one way to build up soil carbon, although there is a risk that leakage will occur if crop production is simply displaced to other areas. The main climate change benefits of soil carbon sequestration mitigation actions taken now will emerge only over decades as the soil carbon builds up in the soil, but where the drivers achieve other policy objectives - for example, to meet water or air quality standards - there may also be short-term benefits.

Carbon accounting

There has been considerable interest recently in carbon trading or carbon offsetting schemes, which pay a modest incentive towards carbon sequestration or sustainable energy projects that displace fossil fuel emissions. The land-based sector needs to be certain that carbon trading is based upon sound science. A growing number of Internet-based carbon calculators already exist, mostly for the domestic market, but others intended for farm use are under development. Many stakeholders agree on the need for a universally accepted and commonly understood measure of the carbon footprint of individual consumer products, looking at the complete life cycle from production to final consumption. Success of the agricultural Climate Change Levy Agreements demonstrates the action that individual farmers and growers are taking already to reduce their carbon emissions. In the future, those whose customers require additional information in order to estimate their carbon footprint may need to keep records of fuel use in field operations, and farm-based renewable energy may become an important permitted mechanism for reducing the net GHG emissions from food production.

Recommendations

In this report we identify the need to encourage best practice across a range of activities on the land, in order to better address the threat of climate change. Some are recommendations for action (immediately, or by 2010); others are proposals for future work to be carried forward by this Task Force and members of our organisations. Specific recommendations and follow-up work fall in two main categories:

1. those where our sector should take a lead (e.g. educational measures and voluntary agreements); and
2. those where we suggest that government leads (financial incentives and research).

Recommendations

1 Initiatives to be led by the agricultural and land management sector

1a Advisory, awareness-raising and skills

- Including climate change awareness and mitigating actions in agronomist, adviser and practitioner training – through systematic upgrades of the Fertiliser Advisers Certification and Training Scheme (FACTS) and Continuing Professional Development (CPD), and a proposed register for accredited animal nutritionists.
- Illustrating better the carbon cycle in agriculture and positive energy balance of fertilisers and other inputs.
- Developing case studies/models of GHG balances across various sub-sectors, e.g.: biofuel feedstock grower; biogas from livestock/silage maize; hill farm grazing with wind power; estate management with wood fuel supply.
- Promoting sustainable on-farm energy use, through increased uptake of energy audits, broader range of energy efficiency and renewable energy measures.
- Raising awareness urgently (2008-2010) of anaerobic digestion (biogas), across all agricultural sectors and the food chain; also with local government and regulators.
- Improving the flow of information on vehicle compatibility in order to encourage use of biofuels, including in agricultural vehicles.
- Increasing knowledge and skills in productive forest management, in particular the dissemination of advice to small woodland owners.
- Expansion of advice on utilisation of wood fuel from thinnings, emphasising local medium-sized heating systems that return significant income to the grower.
- Promoting economic agronomic practices that remove carbon from the atmosphere, including improved crop varieties and incorporation of manure/compost.
- Developing further and deploying carbon calculators, e.g. CLA's Carbon Accounting for Land Managers (CALM) due in 2008, and participating in emerging carbon labelling standards.
- Continuing successful industry-led communications projects on climate change in 2008 and beyond (further to the joint Farming Futures project: www.farmingfutures.org.uk).

1b Voluntary agreements

- Ensuring tools of delivery (e.g. Nutrient Management Plans) build on existing commitments and joint agricultural industry communications.
- Supporting adoption of sustainable, integrated and best-practice options, to increase uptake of integrated farm management as a central decision-making process for achieving nitrogen efficiency while managing environmental impacts.
- Development of a template for carbon trading schemes based on afforestation in the UK with robust science-based processes for verification, monitoring and permanence.

2 Recommendations for government policy and intervention

2a Financial mechanisms/incentives

- Incorporate climate change objectives into agri-environment schemes by 2008, to complement present emphasis on biodiversity and ecosystem services; and award greater credit where agri-environment options yield multiple benefits (climate change, resource protection and biodiversity).
- Initiate new and imaginative approaches for financing ecosystem services such as carbon management through land-use change options, e.g. restoration of peat.
- Implement tax allowances and/or better allocated funding for on-farm skills training.

- Enhanced Capital Allowances must support and incentivise take-up of latest sustainable energy options in agricultural and horticultural buildings, as well as in-field precision technologies.
- Stronger support for renewable heat, through a Renewable Heat Obligation or other obligations on existing heat energy suppliers.
- Encourage greater agricultural contribution towards UK and EU renewable energy targets, through differential rates of biofuel duty, tax incentives for biofuel-compatible vehicles, revision of the Renewables Obligation, stronger planning guidance, and reform of Ofgem to improve grid access for small generators.
- Provide a range of incentives for anaerobic digestion: revenue-based (enhanced Renewables Obligation banding); capital grants to encourage project development; development of market infrastructure (electricity network access, sale or disposal of digestate).
- Develop policy recognising the value of productively managed woods and forests and the timber they can provide for material substitution.
- Implement policy measures to deliver the Forestry Commission Woodfuel Strategy for England by 2010, supplying an extra 2 million green tonnes of wood fuel from currently unmanaged woodlands.
- Rationalise current support mechanisms for woodfuel, to become either entirely national or entirely regional with strong national guidance, with support for wood-fired boiler installation and the supply chain to be delivered by one co-ordinating organisation.
- Recognise a carbon trading scheme for afforestation in the UK.
- Amend planning guidelines to emphasise carbon savings achieved through material substitution and further develop policies that promote greater use of low-carbon renewable resources in construction (through Building Regulations, Building Inspectorate, and the architectural profession).

2b Research and development

- Refine the UK national GHG inventory/measurement by 2010, to more accurately reflect emissions from agriculture: currently emissions are estimated using general methodology with too many default factors, which do not allow for many mitigation responses to be reported.
- Drive nitrogen efficiency for N_2O savings from soils on all farms, particularly in relation to the efficiency of nitrogen utilisation by livestock and the recycling of organic nitrogen.
- Develop the basis of animal feeding changes for reducing methane emissions, with consideration given to current regulatory constraints.
- Improve knowledge on use of digestate from anaerobic digestion as a fertiliser, including its effects on all GHG emissions, environment impacts, etc.
- Faster transfer of methane mitigation knowledge from other countries, especially work done on-farm in the EU.
- Develop the measuring and monitoring of soil carbon, to allow stronger and more reliable estimates of soil carbon storage to be estimated.
- Improve knowledge on soil management, such as minimum tillage, and its possible contribution to reducing carbon emissions; also on the state of UK peatlands, their carbon budgets and timeline for restoration.

1. Introduction

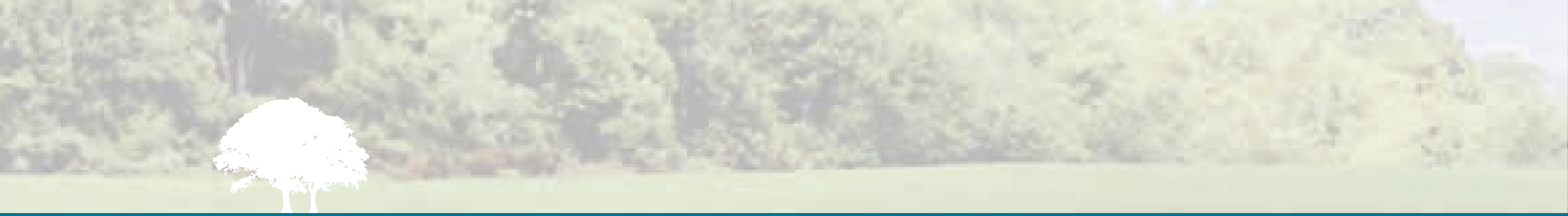
The agricultural and land management industries recognise that climate change is occurring, that human activities are having a significant impact upon our economy, society and environment, and that our sector needs to address the issues raised by the Stern Review and the Intergovernmental Panel on Climate Change. The NFU, the CLA and the AIC launched a joint Climate Change Task Force in January 2007 to present a united approach to the serious threat this poses to agricultural production and the rural sector. Collectively, we have risen to the challenge of ensuring continued production of food and other renewable resources while managing GHG emissions from the rural sector. The emphasis of this Task Force is on mitigation of climate change (how to reduce the severity of its impacts), within the context of likely adaptations to the changing climate.

Together, the NFU, CLA and AIC agree that there are substantial economic, social and environmental benefits in taking action now in response to climate change, to ensure that our sector remains economically and environmentally viable in the future. Our key aims are as follows:

- to demonstrate responsibility within agriculture and the rural sector;
- to contribute to the climate change debate;
- to promote action for change within our sector;
- to anticipate future needs, both within and outside our sector; and
- to recommend roles for government.

This report sets out what farmers and growers can do (and are already doing) to combat climate change, across the full range of GHG (greenhouse gas) emissions. We demonstrate herein how our organisations, through communication with our members, are promoting the positive opportunity presented by climate change - an opportunity to demonstrate how agriculture and land management is part of the solution. (An example of such joint industry working is the Farming Futures project, www.farmingfutures.org.uk, in which the CLA and NFU collaborated with the Applied Research Forum and Forum for the Future).

Our policy advisers and office holders have explored the boundaries of the problem, through mutual discussion and reviews of current knowledge and scientific evidence.



We have also held bilateral meetings with other stakeholders from the agricultural, food distribution and service industries, and from the environmental sector and government. This report summarises a range of contributory technical background papers, based upon sound science, which have been prepared as part of the work of the Climate Change Task Force.

"The UK agriculture and forestry sector contributes about 7% of UK greenhouse gas emissions."

We acknowledge that Britain's GHG emissions are relatively modest in the context of a global problem, that UK forestry and agriculture's share of national emissions (about 7%) is considerably lower than the share of agriculture worldwide (around 10-12% of total global anthropogenic emissions; IPCC, 2007b), and that estimates of national agricultural GHGs need to be refined by the use of improved emission factors. We also reflect upon how climate change impacts on agriculture elsewhere in the world, manifest through input costs and product markets, could have a greater indirect impact on British growers, agricultural suppliers and consumers than any of the direct effects of climate change. Yet the UK may also benefit from the advantage of its relatively stable, moderate climate. These characteristics may yet give British agriculture, horticulture and land management an edge in new 'low-carbon' food and energy products that address climate change-driven customer demands as well as emerging government policies.

2. Describing the problem

2.1 The policy context

For much of 2007, the subject of climate change has rarely been out of the news. The scientific body of evidence for human impacts upon climate worldwide is growing steadily, and policy measures to try to limit change (and adapt to it) are being put in place at national, international and local level. The latest scientific consensus report from the Inter-Governmental Panel on Climate Change (IPCC, 2007) states that global GHG emissions must start to fall within 15 years, and be cut to half of 1990 levels by 2050, if the world is to avoid irreversible and possibly catastrophic climate change. It agrees that the technologies and potential to reduce emissions already exist across all sectors, including agriculture and land management, but incentives are needed to further develop and deploy them.

Targets for limiting GHG emissions, and related measures and targets designed to promote sustainable energy use, will have a profound effect throughout the global economy. The Stern Review on the economics of climate change (Stern, 2006) suggests that the likely impacts of GHG emissions represent a colossal market failure and that urgent action by governments and industries alike is needed to avoid the worst effects of climate change on the global economy. The costs of taking action over the next 10-20 years are considered to be much lower than the estimated costs of climate-related disruption to economic and social activity. Indeed, it is in this spirit that our Climate Change Task Force undertook this work – in anticipation of potential change, to size up the problem and to identify early action that we and others can take. However, it is most important that action on climate change should complement, and not conflict with, other environmental initiatives such as the Voluntary Initiative on pesticides, Catchment Sensitive Farming, Joint Professional Nutrient Management, the Environmental Plan for Dairy Farming, support for Integrated Farm Management and Continuing Professional Development (CPD) schemes.

"The Inter-Governmental Panel on Climate Change agrees that the technologies and potential to reduce emissions already exist across all sectors but incentives are needed to further develop and deploy them."

In the context of international negotiations on a successor to the worldwide Kyoto Protocol, the UK Government has launched a draft Climate Change Bill which would put Britain in the forefront of policy response, by requiring this and future governments to audit their own progress towards reductions in GHG emissions, with an initial focus on carbon dioxide emissions. In addition, the European Union has its own aspirations for both GHG emissions (at least a 20% reduction on 1990 levels) and targets for sustainable energy by the year 2020 – a 20% improvement in energy efficiency, coupled to an overall 20% contribution of renewable energy to energy use across the economy (including electricity, heat and transport). Britain will be under pressure to achieve its own contribution to these EU targets, and the measures announced in the recent Energy White Paper, as well as related proposals on planning and waste management, indicate that the next 13 years will be a period of substantial change in the structure of our economy. Carbon trading, carbon taxes, carbon "foot-printing" and carbon labelling of consumer products are all likely to play some role.

2.2 Key climate change concerns

The predicted physical impacts of climate change in the UK over the 21st century include: milder, wetter winters; hotter, drier summers; and more extreme weather incidents (Hulme et al., 2002). The effects of these changes on the land-based rural business sector (agriculture, horticulture, forestry) are likely to be extremely complex and variable -

recent concerns about insect-borne disease being a case in point (NFU, 2005). Further details are provided in Annex 1 below.

Changing conditions are also likely to have significant economic impacts on agriculture and land management through markets, both at home and abroad. A change in the production of certain outputs from other countries may have considerable effects on the global market and, in turn, the prices offered for UK products. In general, the impacts of climate change are likely to be more severe in southern than northern Europe. Wealthier regions and sectors will be less adversely affected than more marginal and poorer ones.

Overall, climate change is likely to have a major effect upon UK agriculture, horticulture and forestry, with both negative and positive outcomes. However, when compared to other parts of the world, the UK is likely to experience less extreme impacts and it is unlikely that agri-climatological conditions will move into a range that could be described as dangerous or even 'un-adaptable' for crops, livestock and land use in Britain in the short- to medium-term. Nevertheless, it is vital that adaptation and mitigation options are considered to alleviate these effects and to make best use of any consequent advantages and opportunities.

These climate change impacts must be considered not only in relation to their direct impacts on land management industries, but also on GHG emissions from these industries. For example, increasing temperatures may alter the fluxes of CO_2 from vegetation, changing how much is stored or released. Likewise, factors such as warmer temperatures and higher precipitation may lead to increased N_2O emissions from soils. Furthermore, the prevalence of more variable and extreme weather conditions will increase the uncertainties in the planning of fertiliser and pesticide inputs. These consequent changes could offset some or all of the reductions that may be achieved by adoption of best practices. It is highly uncertain how soils will behave and, for example, how temperature will affect the carbon storage capacity of soils and vegetation. This issue may be more significant globally than within the UK, but it cannot be discounted. Many of these interrelationships between expected climate change impacts and GHG emissions are still not fully understood and this must be considered when developing mitigation strategies. Paradoxically, the ability of our sector to mitigate its GHG emissions may be heavily dependent on these climate change impacts.

2.3 UK GHG emissions from the land-based sector

We have reviewed the evidence base for GHG emissions from agriculture (including arable, livestock farming and horticulture) together with land use, land-use change and forestry (LULUCF) – sometimes also referred to collectively as the agriculture, forestry and land management (AFLM) sector. Current methodologies for calculating the GHG emissions from agriculture are outlined in the UK Greenhouse Gas Inventory 1990-2005 (AEA, 2007), and are subject to a number of uncertainties. These are the official government figures compiled by a number of organisations, under contract to Defra, in order to fulfil national obligations under the UN Framework Convention on Climate Change (UNFCCC), following guidelines established by the UN Intergovernmental Panel on Climate Change (IPCC).

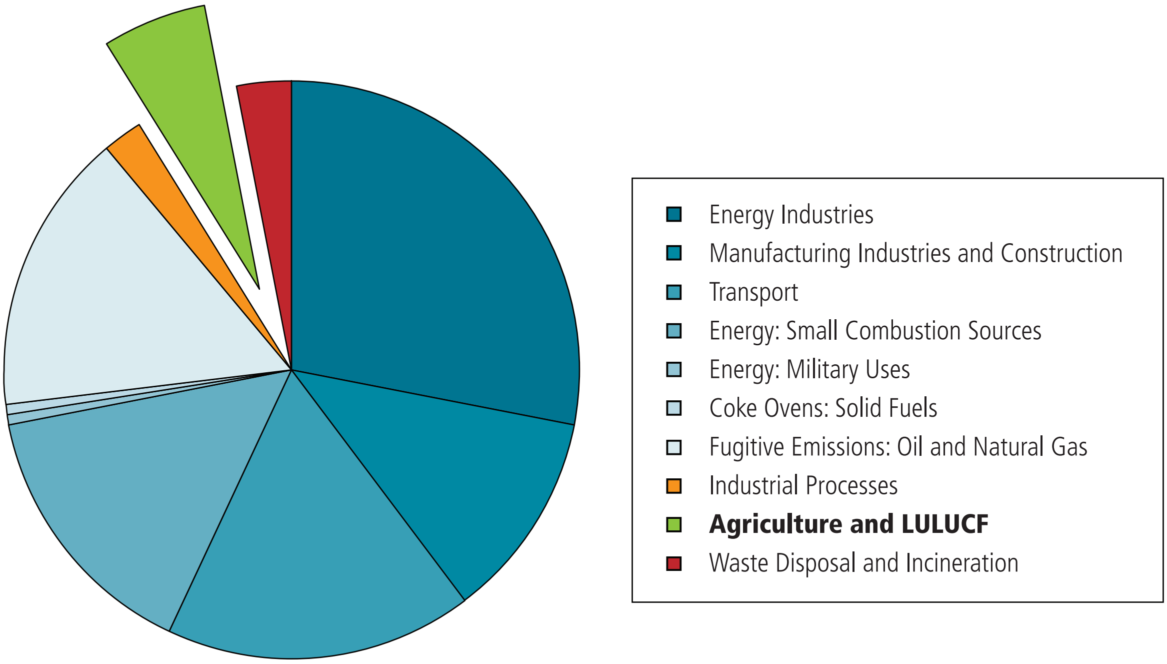


Figure 1. Relative contributions to UK GHG emissions by sector for 2005, as CO_2 equivalents. Emissions from various types of energy use are shown as shades of blue, with agriculture and land use highlighted in green.

Both direct and indirect GHGs are estimated across seven sectors, as follows:

1. Energy - including fuel combustion (energy industries, manufacturing industries and construction, transport, other sectors and other) and fugitive emissions from fuels (solid fuels and oil and natural gas).
2. Industrial processes.
3. Solvents and other product use.
4. Agriculture.
5. Land use change and forestry.
6. Waste.
7. Other.

There are six distinct GHGs: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride.

Note that Sector 3 produces only indirect GHGs, and Sector 5 is responsible for some carbon dioxide removals as well as emissions, resulting in only modest net emissions. A breakdown of UK GHGs by sector is shown in Figure 1 below. The energy sector accounts for the vast majority (87%) of net direct GHG, with agriculture and LULUCF trailing in second place at 6.8%. Waste is the third largest source of GHG at 3.8% and industrial processes are responsible for 2.5%, but this does include the manufacture of ammonia (some for the fertiliser industry) as well as food industries like brewing and baking.

UK GHG emissions have decreased since 1990, falling by 15.5% to 2005, and the net emissions from Agriculture/ Land Use and Land-Use Change have declined even further, by 24% (Figure 2). Thus the share of the land-based sectors actually fell over this period, from 7.3% to 6.8%. Table 1 and Figure 3 below show the 2005 breakdown of GHG emissions for the land-based sectors, as presented in Table A9.1.16 of the UK Inventory (AEA, 2007). We note that these estimates are subject to a great many

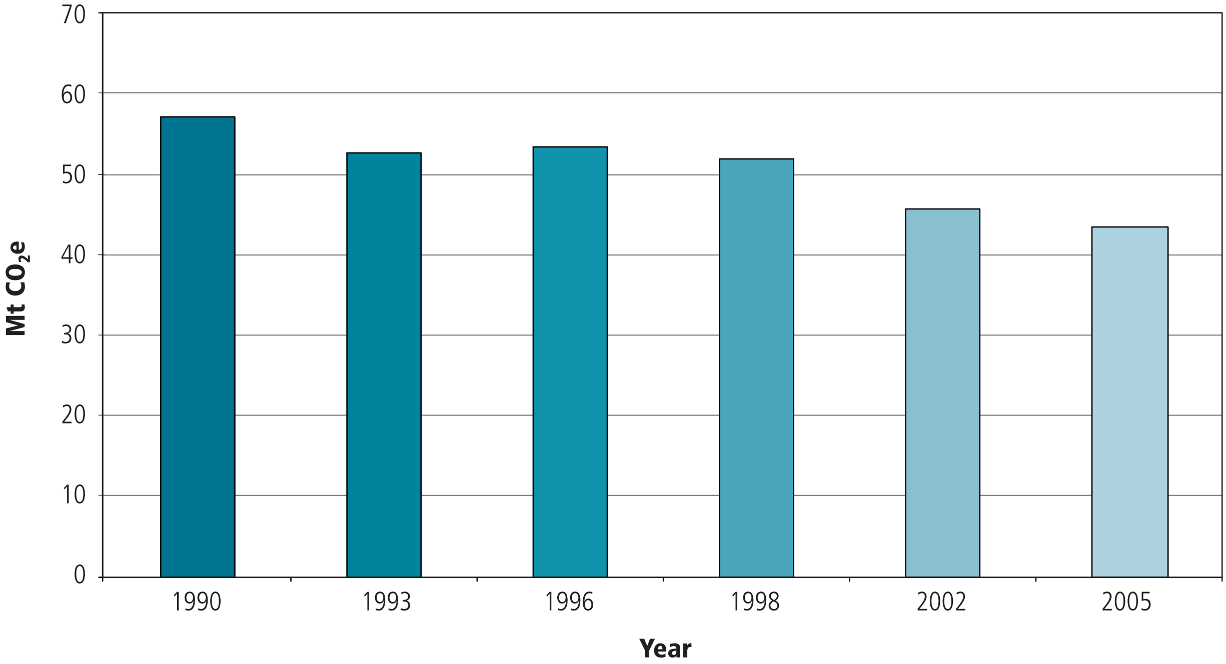


Figure 2. Trend in GHG emissions (million tonnes of CO_2 equivalent) from agriculture, land use and land-use change from 1990 to 2005.

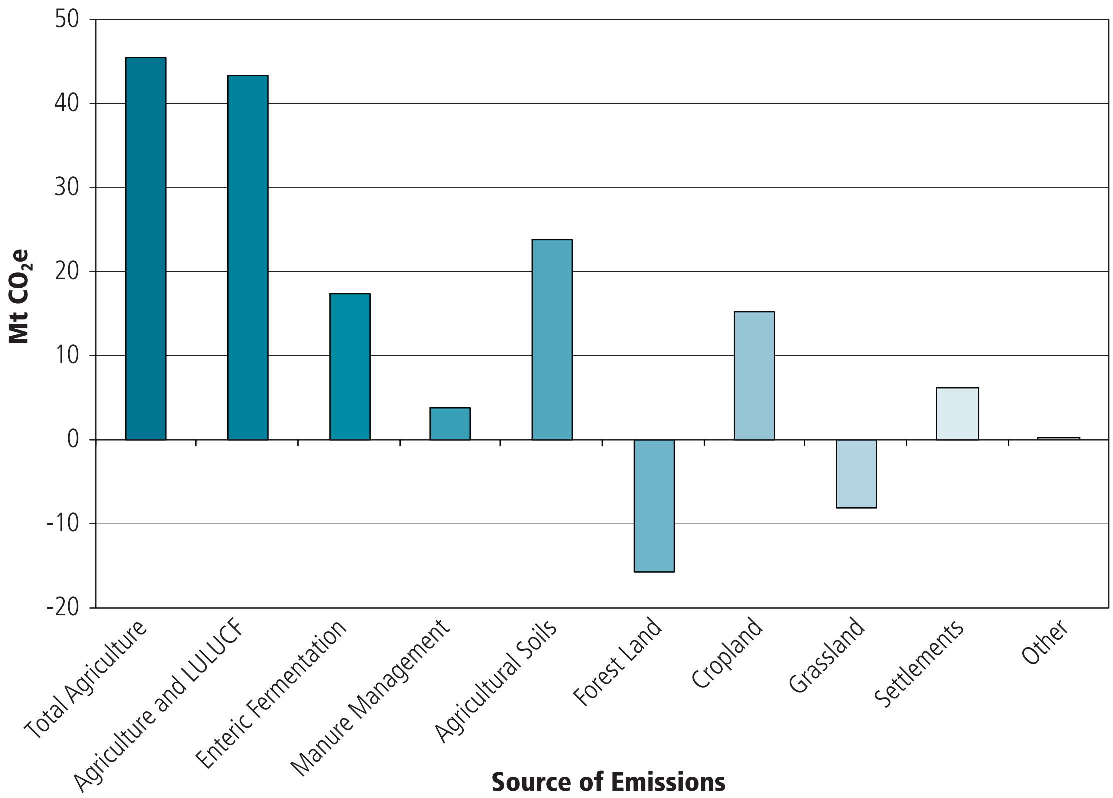


Figure 3. GHG emissions and removals (million tonnes of CO_2 equivalent) from agriculture, land use change and forestry in 2005.

Year 2005 except where specified	CO_2 only: emissions and removals (kt)	CH_4 emissions (kt)	N_2O emissions (kt)	Total CO_2 equivalents (Mt)	% of total for Sectors 4 & 5
UK all emissions	554,200	2348	128	656.2	
Direct energy use in agriculture (2002)	1,799	0.96	0.40	1.9	
Sector 4 - Agriculture		878.3	85.3	45.5	105.0
A Enteric Fermentation		759.8		17.4	40.0
B Manure Management		119.5	4.1	4.0	9.0
D Agricultural Soils			81.0	24.0	55.0
F Field Burning of Agricultural Residues				0.0	0.0
Sector 5 – Land Use, Land-Use Change and Forestry (LULUCF)	-2,056.1	0.9	0.0	-2.0	-5.0
A Forest Land	-15,738.0			-15.7	-36.0
B Crop Land	15,258.3			15.3	35.0
C Grassland	-7,934.0	0.6		-7.9	-18.0
E Settlements	6,261.6	0.4		6.3	14.0
G Other	96.3				0.1
Agriculture and LULUCF (net)	-2,056.0	879.2	85.3	43.4	100.0
in Mt CO_2 equivalents	-2.1	20.2	25.3	43.4	
% of total net emissions	-4.8	46.5	58.3	100.0	

Table 1. UK GHG accounts for Agriculture plus Land Use Change and Forestry. Units are given as thousands of tonnes (kt) or millions of tonnes (Mt). Total UK GHG emissions and direct energy use in agriculture are included for the purpose of comparison.

Footnote to Table 1: explanation of inventory methodology

Sector 4, Agriculture, is divided into: A, Enteric Fermentation; B, Manure Management; D, Agricultural Soils; and F, Field Burning of Agricultural Residues (although that practice has no emissions now due to new regulations).

Category A (Enteric Fermentation from Livestock) includes mostly ruminants. Emissions are calculated using animal population data (based on Agricultural Census data) and appropriate emissions factors (based on IPCC methodology). Some animals (cattle, lambs and deer) have 'Tier 2' emissions factors, which are UK specific, based on experimental research. Only mitigation measures, therefore, that involve a reduction in the number of animals would currently register as a reduction in the enteric fermentation inventory.

Category B (Manure Management) covers methane from uncontrolled anaerobic decomposition of liquid and solid manures, and some N_2O from this source. Calculations are based on livestock numbers and complex assumptions about the mix of manure management systems for different livestock.

Category D (Agricultural Soils) is based on IPCC methodology, but incorporates some UK-specific factors, covering inorganic fertilisers, biological fixation, ploughing-in, cultivation and manure spreading and dropping. This is recognised in the IPCC (IPCC 1997) where a single default emission factor of 0.0125 (1.25%) is used to estimate N_2O emission from soil nitrogen supplied by fertilisers, manures, crop residues and biological fixation. IPCC methodology does not take into account nitrogen fixed by pasture legumes due to the difficulty in estimating the extent of fixation. However, as the fixed nitrogen is mineralised on the death of clover roots, it will add to the pool of ammonium and nitrate from which N_2O can form. Originally the UK inventory used only the IPCC methodology (IPCC 1997) with default values for emission factors: 0.0125kg N_2O/kg N added for nitrogen additions to the soil and 5kg N_2O/ha/year for the cultivation of organic soils. Additions of nitrogen comprise fertilisers and manures applied (net of any losses of ammonia and NOx), biological nitrogen fixation and crop residues returned. Annual improvements are made to methodology for the UK and the previous time series is then recalculated. A model, UK-DNDC (Denitrification and Decomposition) originally developed in the USA, has been adapted for UK conditions and is used to estimate N_2O emissions on field, county and regional scales (Brown and Jarvis, 2001). Development of inventory methodologies for the UK is ongoing (Defra 2005). Further support for research in this area is required to account for regional variability.

Sector 5, LULUCF, is sub-divided into five categories: Forest Land; Crop Land; Grassland; Wetlands; Settlements; Other Land; and Other. Each category measures emissions from those areas remaining under the same land use and from those being converted from another land use to that land use. Emissions occur when a rich carbon land use is converted to a poorer carbon land use – e.g. grassland to crop land, and vice versa.

Category A (Forest Land) is divided into 'forest remaining forest land and land converted to forest land'. Only forest stocks established since 1921 on land that had not been forested for many decades are counted - those planted earlier are considered to be in equilibrium – i.e. not emitting or removing carbon. The carbon uptake by the forests planted since 1920 is calculated by a carbon accounting model, C-flow, as the net change in the pools of carbon in trees, litter, soil and products from harvested material for conifer and broadleaf forests.

Category B (Crop Land) is divided into 'crop land remaining crop land and land converted to crop land'. The former is calculated by considering the effect on non-forest biomass due to crop yield improvements (from improved species strains and management), the effect of fenland drainage on soil carbon stocks (these areas were drained decades ago and are still emitting CO_2) and CO_2 emissions from lime applications. The latter calculates the change in soil carbon stocks due to land use change to crop land.

Category C (Grassland) is divided into 'grassland remaining grassland and land converted to grassland'. Emissions from biomass burning due to the conversion of forest land to grassland is reported for all of the UK in two time periods, 1950-1989 and 1990 onwards. 'Grassland remaining grassland' includes emissions related with peat extraction for use in horticulture and application of lime on grassland. 'Land converted to grassland' measures the annual change in soil stocks due to land use change to grassland. Wetlands are included in the Grassland category if they are saturated lands (such as bogs and marsh) or 'Other Land' if open water. The category 'Other' measures the changes in stocks of carbon in harvested wood products.

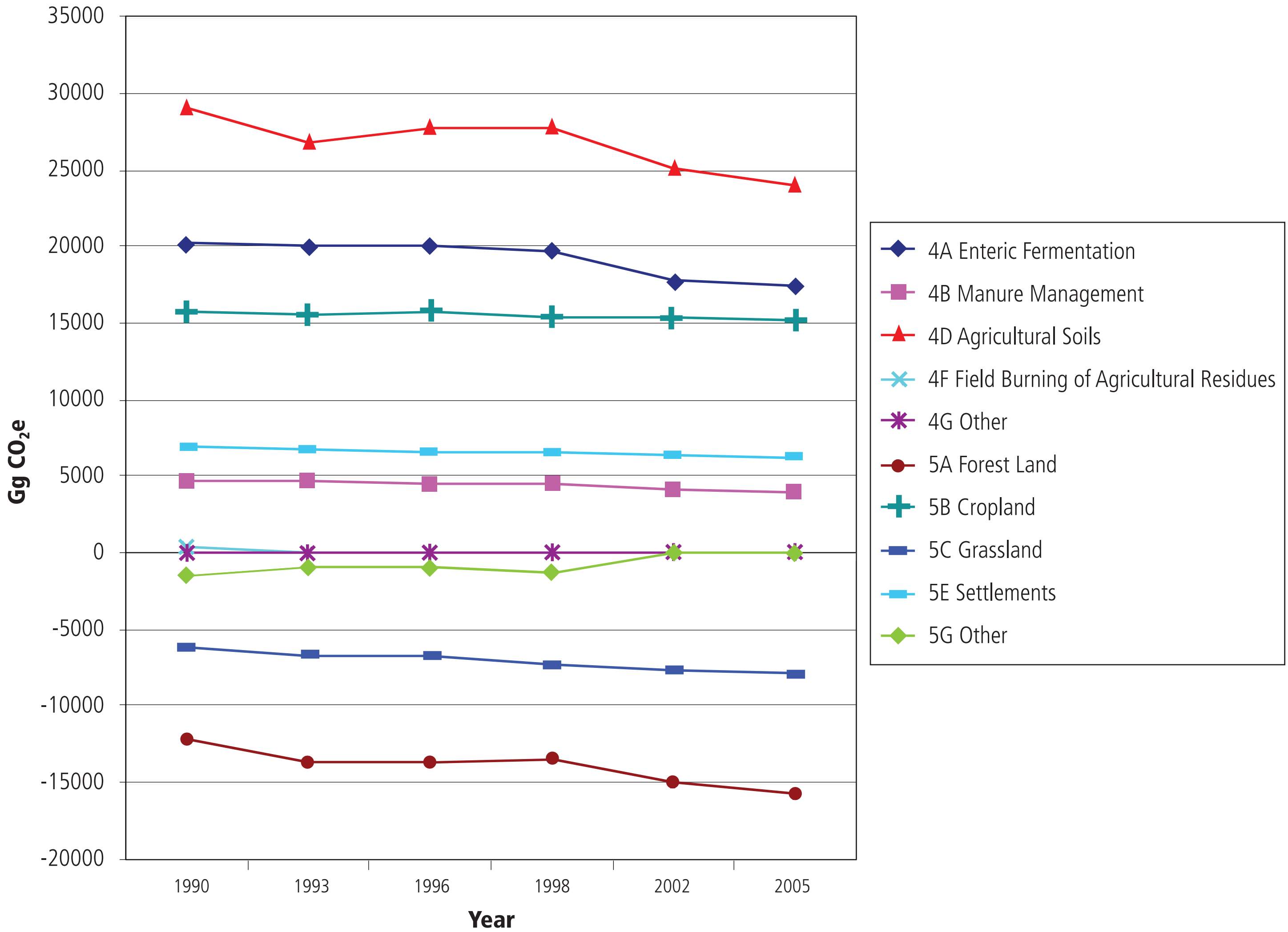


Figure 4. Time series of all land-based components of the UK greenhouse gas inventory for the years 1990 to 2005. Note the gradual overall decline.

uncertainties. Many assumptions are made which are then extrapolated to national level by multiplying by some broad data on livestock numbers and crop and forest areas. We hope, and expect, that these calculations and the data on which they are based will be refined over time (for example via the ongoing Defra science project AC0101: 'An improved inventory of greenhouse gases from agriculture'). It is clear that there is more uncertainty over agricultural methane and nitrous oxide emissions than any other part of the UK GHG inventory.

The only direct GHG emissions from Sector 4, Agriculture, are methane (CH_4) and nitrous oxide (N_2O). CO_2 emissions from use of fuels (heating buildings, field operations, ventilation, etc.) are accounted for separately as part of Sector 1, Energy, but can be disaggregated for Agriculture.

Carbon dioxide uptake through forest growth and grassland almost balances emissions from Crop Land, Settlements and Other (harvested wood products), so there is a modest net removal of CO_2. As a proportion of the total emissions from the land-based sectors, CO_2 from land management comprises - 4.8% of emissions, methane 46.5% and nitrous oxide 58.3%. As noted above, the contribution of land-based GHGs has been falling steadily at just under 2% per annum (AEA 2007). Figure 4 shows a breakdown of all land-based GHG components for the years 1990 to 2005. Over this period, net emissions from agricultural soils have dropped by 17.4%, enteric fermentation is down 13.5%, and land-use related soil emissions have fallen 24%.

Discussion

The gradual fall in land-based GHG emissions is explained partly by a reduction in the UK livestock population, as well as a decrease in nitrogen fertiliser use on grassland, and the gradual reduction in emissions from past conversion of permanent pasture to arable between the 1940s and 1980s. Also noteworthy is the significant difference between modelled UK land use change emissions and the IPCC default 'Tier 1' methodology (Netcen, 2004; p3), with the UK figure accepted as more accurate. There is more refinement on-going in the Agriculture section and some small projects in the LULUCF section which could supply sufficient justification to move away from the default approach to calculating emissions, however, both need more resources as these areas are amongst the most uncertain. Other more detailed soil management practices are not included in the UK inventory due to lack of convincing evidence; however, work continues on a number of projects, e.g. on emissions from peat. Recent evidence also suggests that some soils may be losing carbon by as much as 2% annually, irrespective of land use and possibly linked to climate change (Bellamy et al., 2005). This is clearly a research area that deserves further work, given the substantial reserves of carbon that are held in soils.

Although national GHG inventories are in need of revision and reassessment, we should not expect every refinement to methodologies to favour our sector; estimates of emissions may be revised upwards as well as down. Likewise, the downward trend in many land-based emissions should not be expected to continue, since it is associated with a reduction in economic activity as well as a likely increase in efficiency. These data and accounting methodologies have important implications for our sector, since only certain kinds of change in land-based GHG emissions will be detectable, and it may be anticipated that any formal carbon (or GHG) trading and its associated verification will have to be based upon internationally accepted GHG accounting conventions. However, for the purpose of general awareness-raising, and for business-based behavioural change to reduce emissions, a broader analysis of all direct and indirect GHG emissions may be needed.

Likewise, progress towards national climate change targets (initially CO_2 only in the draft Climate Change Bill) may use different approaches. It is presently hard to imagine how emission caps will be implemented by business, allowing individual enterprises to trade carbon allowances. Making the monitoring and verification procedures workable for this highly fragmented and complex sector poses severe challenges. However, having attained a 24% reduction over 15 years from the 1990 baseline (AEA 2007), more ambitious targets for reduction in CO_2 emissions by 2050 may not appear unrealistic. In addition, the land-based sector offers the potential of earning credit for its contribution to emissions reductions in other sectors, through all types of renewable energy supply, as energy commodities, supply of biomass fuels, or export of heat and electricity.

3. Solutions – how the land-based industries can mitigate climate change

In presenting how the land-based industries (agriculture, including horticulture; and land management, including forestry) can offer part of the solution to the problem of climate change, we have followed broadly the categories laid out in the UK national GHG inventory (AEA 2007), which places agricultural business under one sector and groups forests and estate management together with land use change in another.

3.1 Energy and agricultural production

Reducing agricultural production?

The businesses in our sector depend upon a variety of inputs in order to produce food, animal feed, fibre and other land-based products in a manner which is both economically and environmentally sustainable. These inputs include the expenditure of energy for space and water heating, ventilation, field operations and initial processing of harvested products – as well as physical inputs such as fertilisers, pesticides and other agrochemicals.

Since the emissions from these land-based activities are a direct function of the level of output, it is common to hear calls for a reduction in the intensity or the total output of our sector, in order to moderate its emissions. This argument is not tenable for a number of reasons. The British agriculture and land management sector encompasses a diversity of different production methods and products, from organic to intensive, from high-technology to traditional. In general, the average efficiency of UK production is greater than the world average – as measured in terms of specific energy consumption per unit of output, or as specific rates of emission of all GHGs. Reducing the intensity of production would firstly reduce the overall level of output – requiring increased imports of food from abroad, mostly beyond the influence of domestic climate change policy and likely to entail increased GHG emissions. In the absence of a robust global regulatory regime or set of agreements governing emissions from agriculture, it is not clear that reducing UK output would lead to any significant emissions benefit (NERA, 2007).

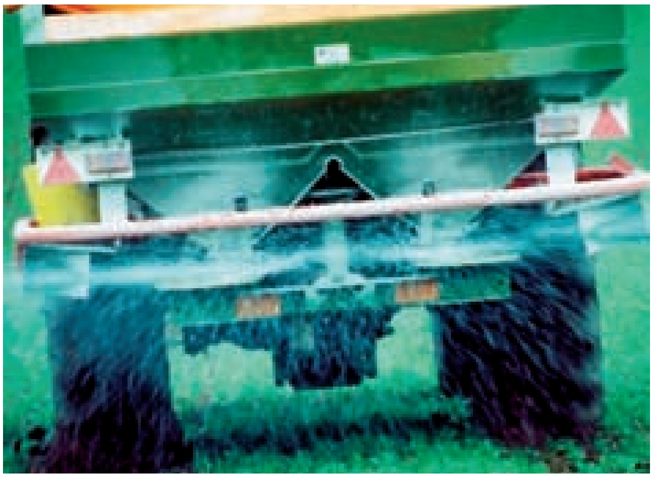
This is particularly the case for the livestock sector, where specific rates of GHG emissions in many developing countries (notably methane emissions) are much higher due to poor animal diet and low productivity.

Secondly, less intensive domestic production would itself entail higher specific energy consumption and emissions – manifest, for example, as lower rates of livestock production per unit area of land, or reduced conversion efficiency of animal feed into animal products. Unlike imported foodstuffs (for which GHG emissions would be attributed to consumption), these increased emissions would be directly attributable to the UK agricultural sector.

Lastly, a number of pressure groups routinely advocate not only a reduction in domestic livestock production but also management of the demand for livestock products. Laying aside the arguments about freedom of consumer choice, and the preference for gradual shifts in dietary preference over mandates or "choice editing", there would be climate change implications in the conversion of pasture land into arable cropping, through the loss of significant reserves of stored soil carbon (see Table 2 below). Furthermore, some parts of our agricultural land area are suitable only for grass and grazing. Leaving these areas under-utilised or idle would reduce further the overall efficiency of the agricultural sector, increasing the specific rate of GHG emissions.

Overall, it is, therefore, critically important to maintain UK production of land-based goods, and to continue to improve upon our land management techniques, not only to meet domestic demand, but also as a basis from which to export our best practice to the rest of the world. Extensification only shifts production and emissions somewhere else on Earth, in effect exporting the problem rather than the solution.

These arguments are entirely consistent with the overall international objectives of "Sustainable Consumption and Production" (SCP), which is about achieving economic growth whilst respecting environmental limits. SCP requires that the life cycles of products and services reduce their environmental impacts across a wide range of areas, driven by shifts in consumption patterns. However, demand for land-based products is growing. The issue of food security is once again increasing in importance, as consumption levels and diets grow and change throughout the world. Energy security is also becoming a significant driver of demand for products and services, both for energy efficiency and for renewable energy resources (see below). Taken together, these growing needs cannot be provided without significant inputs such as nitrogen fertiliser. It is estimated that 60% of the protein content of the current world diet relies upon nutrient sources other than the natural fixation of nitrogen.



Energy and fertilisers

Within the UK, the total energy used in production of fertiliser, including ammonia for both fertiliser and other uses, contributes only 0.2% of total national CO_2 emissions. By comparison, electricity generation and passenger cars contribute 30% and 13% respectively. Although it is the single largest use of energy in the agricultural sector, the energy required for fertiliser production is an insignificant proportion of total UK energy use, and the energy input to the essential primary production of food is also very modest.

The total agricultural contribution to CO_2 equivalent GHG emissions per annum in the UK is estimated to be about 7%, including the N_2O emissions from fertiliser production facilities with nitric acid plants (0.4%) and energy (raw material) use in ammonia plants (0.3%). Eliminating N_2O emissions at the site of fertiliser manufacture would reduce this figure by about 0.4%. By comparison, the total annual sequestration of CO_2 in UK agricultural products may be estimated as equivalent to about 9% of UK CO_2 emissions.

The total energy consumption for the production, packaging and distribution of fertiliser used in the UK in 2005 (Defra, 2007) was 46.5 petajoules (PJ), of which 31 PJ comprised the raw material feedstock to ammonia plants (average European figures; Jensen and Kongshaug, 2003).

The energy efficiency of European ammonia plants has improved significantly over the last 30 years, with actual consumption in 2003 being 25% less than the theoretical best available technology in 1973. European plants in

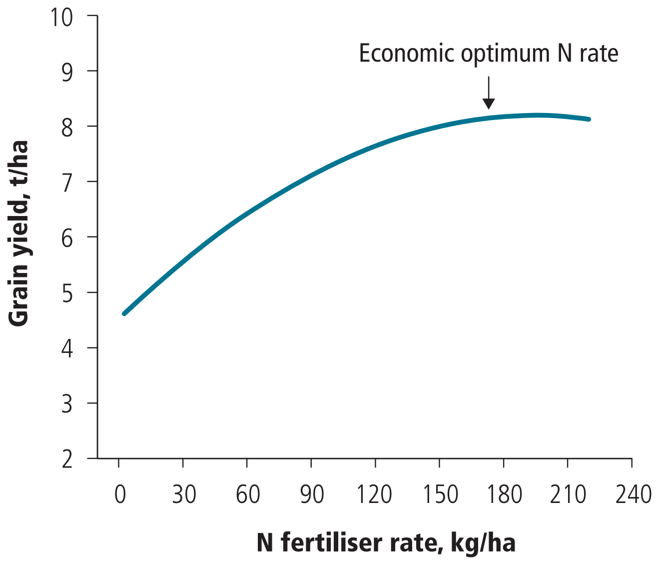


Figure 5. Effect of increasing N fertiliser rates on the grain yield of winter wheat (Kusters, 1999).

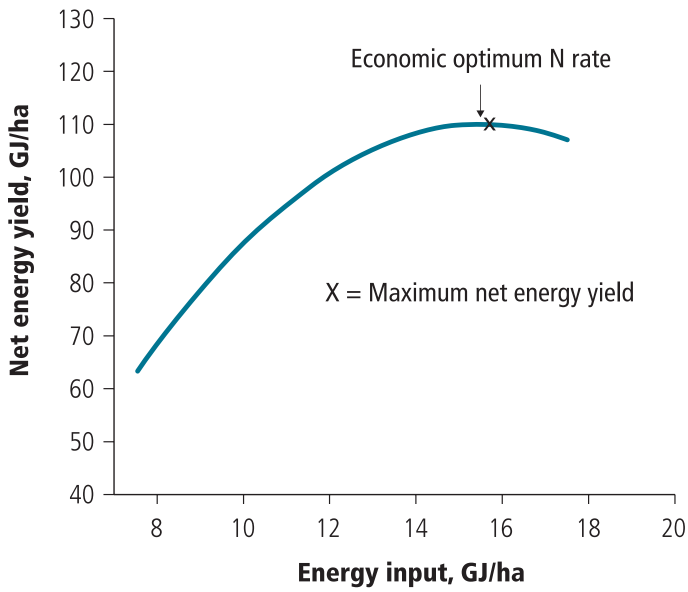


Figure 6. Net energy yield at different energy input levels in production of winter wheat (Kusters, 1999).

2003 had approximately 15% lower specific energy consumption than the world average. A further 25% reduction should be theoretically possible by renewing the bulk of the plants, using the latest technologies. The continuing process of refurbishment and updating of plants is driven by economics as well as environmental benefits.

The total direct and indirect energy used in British agricultural production (up to the farm gate) was some 131 PJ in 2005, of which 36% comprised fertiliser production, packaging and distribution (Defra, 2007). This is equivalent to 5.9 megajoules (MJ) per day for every member of the population (or in other words, less than two kilowatt-hour standard energy units), to provide all the food, animal feed and fibre grown in the UK, as well as the management of the countryside. On average, the daily energy content (calorific value) of the food consumed by the British public is 9.5 MJ per person. The UK is about 58% self-sufficient in food production, so it may be estimated that food from home-grown sources provides around 5.5 MJ per person per day. Taking into account the substantial UK exports of meat, grain and other agricultural products (about 43% of the level of imported foods), it is clear that the energy used in British agricultural production is transformed into a greater quantity of edible food energy.

The positive energy balance of fertiliser application to crops is illustrated by the relationship between the net energy output (yield) of a fertilised crop of wheat and the energy input to fertiliser production up to the point of application (Figures 5 & 6). Note that the maximum net energy balance (typically 6 to 1) is obtained at close to the typical economic optimum fertiliser application rate for European winter wheat (about 170 kg N per hectare). This suggests that fertiliser use by many European arable farmers is already highly efficient (Kusters, 1999). There is a similar relationship in the production of increased crop residues from higher yields, which buffers soil carbon loss (see also section below on carbon removals). Much of this carbon removal is of short duration (less than a year): as the grain is consumed for food, the carbon will be returned to the atmosphere by respiration as CO_2. Carbon stored as straw, where used for animal bedding or directly returned to the soil, will be oxidised by soil microbes in the medium term (one to five years) and also returned to the atmosphere. A fraction of this sequestered carbon will be retained in the soil on a longer timescale, but this process may only be considered as a medium to long-term system of sequestration (5-10 years or more) if the soil organic matter content increases. Long term data sets at Rothamsted Research are helping to further develop predictive models of the dynamics of soil carbon.

The UK enjoys some of the highest agricultural productivity in the world and continues to set standards for best practice, for example in the emerging assurance schemes for reporting the sustainability and carbon balance (or total GHG balance) of bioenergy feedstocks. However, it is important that these new reporting schemes recognise that up to 15% less energy is used in European nitrogen fertiliser manufacture than elsewhere in the world. About one-third of fertiliser used in the UK is imported, and these data need to be reflected in the default values for reporting of carbon intensity, for example under the UK Renewable Transport Fuel Obligation (RTFO). When making comparisons between different fertiliser nitrogen types, it should be noted that overall emissions can vary as much within a fertiliser type as between fertiliser types. Furthermore, the UK emissions ceiling targets for ammonia depend on the current balance between urea and ammonium nitrate use. It is clear that government policy on ammonia emissions needs to be integrated with that for CO_2 and other GHGs.

Energy efficiency

Energy efficiency within the agricultural community is becoming an increasingly important issue. Escalating energy prices combined with a rising level of environmental awareness have led to significant energy savings being made in recent years, especially in the more intensive sub-sectors. Climate Change Agreements (operated under schemes for horticulture, pigs and poultry – as well as for animal feed and nitrogen fertiliser production) have stimulated these energy savings, with considerable reductions being made in both emissions and expenditure. For example, between 2006 and 2007, businesses in the horticultural scheme reduced their CO_2 emissions by 4%, or 50,000 tonnes, saving a total of £6.5 million on fuel bills and the Climate Change Levy discount. Moreover, the pig, poultry meat and egg sectors gained three of the top 10 places out of 45 industry sectors participating in Climate Change Agreements at the 'Milestone 3' stage in 2006 - all delivering energy efficiency improvements averaging better than 4% per year over six years. Overall, potential energy savings in agriculture and horticulture of 15-20% by 2015 are achievable, particularly with regards to heat use (HRI/FEC, 2007). With respect to Climate Change Agreements for the animal feed sector and for nitrogen fertiliser production these have resulted in overall CO_2 savings of 10% since 1999, and 23% since 2000 respectively (AIC/CIA 2007).

Energy efficiency may also be tackled more generally through outreach and information services within the agricultural and land management sector. The NFU Energy Service and, to an extent limited by EU state aid rules, the Carbon Trust, provide advice and help to farmers wishing to reduce their energy costs or diversify their energy supply. Reduction in energy use is focused not only on farm buildings and processing, but also in other areas of farm activity such as field operations. For example, precision agriculture using modern field equipment with satellite navigation, alongside other best application practices, can significantly reduce consumption of fuel and other inputs, leading to a reduction in GHG emissions from multiple sources.

However, we should add one cautionary note. There is a risk that over-ambitious or prohibitively expensive energy efficiency targets, in the absence of suitable resources and incentives, may result in "export" of the industry. The UK stands to gain little, and lose a lot, if its agricultural businesses are driven abroad to countries with less stringent environmental controls.

Renewable energy

A contemporary report on reducing fossil fuel emissions from agriculture (HRI/FEC, 2007) notes that the bulk of energy used is in the form of petroleum fuels and electricity. Energy-related CO_2 emissions from agriculture are modest (0.8% of the national total) compared to other

sectors and the food chain as a whole. Heating, field operations and ventilation are the largest uses of energy. Insulation of agricultural buildings and the use of biomass heating have the greatest potential for reducing energy-related carbon emissions. Renewable energy currently provides disproportionately little direct energy supply to the sector (only 0.1% of the total), but, ultimately, there is potential for agriculture to become almost carbon neutral (HRI/FEC, 2007). However, significant government support or outside investment would be required to approach this goal.

The CLA report "Renewable Energy - more than wind?" (CLA, 2007) assesses the relative costs and benefits of the main available renewable technologies for the rural sector, identifying hidden costs in the electricity system and the significant mis-allocation of resources that is likely to result. It notes that carbon savings available from renewable heat supply may be more cost-effective than for renewable electricity, but that policy has so far failed to recognise this. In 2004, an independent report for Defra by Ilex Energy Consulting evaluated a range of possible support measures and concluded that a renewable heat obligation (RHO) offered the best way forward. This would oblige gas, oil and coal suppliers to provide an increasing proportion of their business from renewable heating sources. The 2007 Manifesto for Sustainable Heat, supported by a coalition of UK trade associations and non-governmental organisations, further underlines this recommendation.

Government targets for GHG emissions reductions from the energy sector require a step change in the take-up of renewables, as described in the Energy White Papers of 2003 and 2007, in addition to efforts to increase energy efficiency. It is recommended that the planning system should treat all renewable generation proposals as individual generators, thus ensuring that they engage in the local planning process (CLA, 2007). Assessment of renewable energy proposals should consider any adverse impacts on tourism, including impacts of associated transmission capacity, and planning guidance should favour small to medium-scale farm and village-based developments except in urban and peri-urban locations. Stronger requirements for the use of renewable energy, including district heating, should be factored into new housing developments, and development rights should include exhaust stacks for small-scale biomass boilers and farm-scale wind turbines. Notwithstanding government policy on renewable energy, the energy regulator Ofgem still focuses more on competition between suppliers, instead of supporting access to the electricity grid by small renewable generators, who often face unreasonable charges from Distributed Network Operators.

Farm waste grants should be reintroduced and upgraded to cover capital investment in anaerobic digestion plant, renewable combined heat and power technologies, and associated equipment (e.g. processing digestate into fertiliser). The waste hierarchy should be amended to recognise energy recovery using AD and use of digestate for land improvement as a better option than simple composting, which releases GHGs. Integrated farm management offers the opportunity for the co-production of food and decentralised energy with reference to nitrogen and methane management.

Biofuels have an important strategic role to play, but they must be produced from sustainable resources, and not where their production may result in damage to the natural environment. We note that the emerging biofuels industry is in the process of establishing and participating in new standards for reporting carbon savings and sustainability of supply chains. Measures to encourage the use of renewable resources for fuel or power generation should

FAI Farms, Oxford

also guard against possible adverse impacts, for example competition for resources and their by-products with the animal feed and livestock industries. To complement the large-scale prospects presented by the RTFO, opportunities for small-scale production and use of biofuels and vegetable oils, which degrade with reduced harm to the environment, should be mandated in sensitive areas, particularly inland waterways. The recently-introduced tax exemption by Her Majesty's Revenue & Customs for very small-scale producers (less than 2500 litres/year) is helpful, but should be revised to a more appropriate single-farm level, around 5000-10000 litres. Previous levels of support for perennial energy crops, such as short rotation coppice and miscanthus, should be maintained under the Rural Development Programme and extended to single-stem energy crops, and the Government should ensure that UK growers are not disadvantaged in the terms of international trade in biomass feedstocks.

Research is needed on a full comparison of the current and projected relative costs and benefits, including cost of carbon savings, of various renewable energy technologies under UK conditions. This would assist with the provision of low and zero carbon energy under the forthcoming Code for Sustainable Homes. Increased support is needed for training heating engineers and plumbers in biomass boiler installation, as well as resources for education of the wider public on the available technologies, such as the former Community Renewables Initiative.

Recommendations

1 Initiatives to be led by the agricultural and land management sector

- Illustrating better the carbon cycle in agriculture and positive energy balance of fertilisers and other inputs.
- Developing case studies/models of GHG balances across various sub-sectors, e.g.: biofuel feedstock grower; biogas from livestock/silage maize; hill farm grazing with wind power; estate management with wood fuel supply.
- Promoting sustainable on-farm energy use, through increased uptake of energy audits, broader range of energy efficiency and renewable energy measures.
- Improving the flow of information on vehicle compatibility in order to encourage use of biofuels, including in agricultural vehicles.

2 Recommendations for government policy and intervention

- Encourage greater agricultural contribution towards UK and EU renewable energy targets, through differential rates of biofuel duty, tax incentives for biofuel-compatible vehicles, revision of the Renewables Obligation, stronger planning guidance and reform of Ofgem to improve grid access for small generators.
- Enhanced Capital Allowances must support and incentivise take-up of latest sustainable energy options in agricultural and horticultural buildings, as well as precision farming techniques.
- Stronger support for renewable heat, through a Renewable Heat Obligation or other obligations on existing heat energy suppliers.

3.2 Other agricultural emissions

Enteric Fermentation and Manure Management (see Table 1, Sector 4, A and B)

Issues

Methane (CH_4) emissions from British agriculture are significant, making up one third of UK total methane emissions. This comes predominantly (90%) from enteric fermentation in livestock, mostly cattle, although this figure has declined in recent years due to a reduction in livestock numbers. Emissions of methane and nitrous oxide from manure management are also significant.

Measures to reduce methane emissions as a result of enteric fermentation are generally aimed either at lowering methane production per animal (direct emission reductions) or at reducing animal numbers by increasing the productivity of livestock within the system (indirect emission reductions) (IGER, 2001). Many studies have confirmed that diet type, nutritional nature and level of food intake have a significant effect on methane production from ruminants, and furthermore, depending on the nature of the intervention, that methane production can be reduced by 10-40%. A number of studies have examined not only changing diet, but also the potential of feed and microbial additives (e.g. lipids or ionophores in the diet) as a way of manipulating rumen fermentation and microflora to reduce methane production (ADAS, 2006; Silsoe, 2003). These types of options not only reduce methane emissions, but also lead to associated increases in yield through more efficient use of the energy intake (IGER, 2001).

However, any application of these techniques must take into account the economics of the feeds, the efficiency of the entire rumen system, and the impact of their long-term, large-scale use. They would need to be piloted under field conditions, particularly as there is evidence that under some circumstances, methane production can vary between animals receiving the same diet (ADAS, 2003). Further work is warranted, with some studies suggesting this work should be directed at methods for enhancing the efficiency of rumen microbial growth, or the addition of fumaric acid and methane oxidisers to ruminant diets, which offers to reduce methane production by up to 20% (ADAS, 2001).

Although dietary manipulations can and do reduce methane emissions by livestock, the most widely recommended strategy for reducing methane emission by ruminants is by indirect means, through increased productivity per animal and the related improvement in feed utilisation efficiency. Enhancing productivity generally requires simultaneous improvements in nutrition, genetics and management. However, often these methods are not economically viable and would require an additional driving policy or incentive to encourage their use. The UK also risks exporting the industry and its associated emissions if we are over-zealous with regulation – see 3.1 above.

Emissions of methane and nitrous oxide from soils amended with organic fertilisers are uncertain and difficult to measure. However, the contribution of these effects is very small when compared with the potential generation of methane directly or indirectly by grazing animals. Further research on this is needed. The spreading of manures and slurries to land are also significant sources of GHGs, and can be reduced by a number of management measures, including shallow injection or rapid incorporation of land-spread material.

Reducing emissions from manure storage is a complicated process, since often decreasing one type of gaseous emission will increase another. Anaerobic digestion, i.e. controlled production of biogas (methane and CO_2) within a gas-tight digester vessel, appears to be the most promising mitigation option for reducing net methane emissions from manures. This is, arguably, both more energy-efficient and economic than composting of residues, since it yields a source of income from energy recovery, while retaining the nutrient value of the digestate or 'biofertiliser' by-product. Small-scale on-farm AD (biogas) plants may be simpler to build than larger centralised units, do not require long distance transport of wastes, and require less coordination between different stakeholders. However, most single-farm plants will require co-digestion of manures with high gas-yielding feedstocks such as silage maize in order to be economic, and many smaller units are likely to require additional financial support (e.g. soft loans, capital grants). Centralised AD plants may be economic where local and market conditions combine positively, through gate fees and sale of electricity at enhanced rates (Renewables Obligation Certificates).

Holsworthy Biogas Plant

Technologically, there is no reason why AD should not succeed in the UK as it has in Germany, where 3500 single-farm units have been installed with a combined capacity of 1100 MW. Government proposals to provide enhanced tariffs for electricity from anaerobic digestion from April 2009 (through banding of the Renewables Obligation), and a protocol under development for disposal of digestate as a biofertiliser rather than under waste management licence exemptions, will help make the prospects for anaerobic digestion favourable. However, there are still barriers to be overcome in public understanding of the technology, not least with local planners, and with the cost of electricity connection to the local network.

Research suggests that by stimulating both on-farm and centralised anaerobic digestion facilities, up to 75% of UK methane emissions could be prevented from current manure management practices in dairy, cattle and fattening pig enterprises. With capital grant support from Government, it is suggested that GHG emissions equivalent to up to 0.03 Mt of carbon could be saved annually in the UK at a cost of £60/tC, if 20 centralised anaerobic digestion plants were built (Mistry and Misselbrook, 2005). However, without careful design and operation, some of this environmental advantage could be lost through problems such as pollution swapping.

A study of the feasibility and economic potential of mitigation measures suggested that total agricultural methane emissions could potentially be reduced by 17.3% (maximum feasible reduction), while emissions from the dairy, non-dairy and pig sectors could be reduced by 22%, 11% and 7%, respectively (IGER, 2001). However, such reductions would have a cumulative cost of £700 billion, far in excess of these sectors' contribution to gross domestic product. The cost-effective reduction potential is about 12%, with total on-farm savings of £128 million, and a 15% reduction in emissions may be achieved with negligible net costs.

"Anaerobic digestion appears to be the best method for reducing GHG emissions from manures and slurries."

Solutions

Options for reducing emissions from enteric fermentation include changing dietary formation and introducing supplements. Changes to methane production based on specific dietary manipulations (including the use of additives or technologies designed to modify the diet) cannot reasonably be considered as a basis for policy until measurement-based UK emission factors have been developed and the inventory calculations revised. However, the most appropriate abatement measures are likely to be those that encompass a reduction in emissions alongside increases in efficiency, productivity and, therefore, profitability. Such options should be the targets of future research. From an assessment of options, anaerobic digestion appears to be the most suitable method for reducing GHG emissions from manures and slurries.

There must also be a consideration of wider related matters, such as pollution and 'emission swapping' issues. There may also be problems associated with issues like animal welfare or profitability, with some mitigation measures conflicting with environmental and economic objectives. Furthermore, many of the mitigation measures discussed may be much easier to apply to housed or yarded livestock, rather than animals out to grass. From a review of the data and research available, it has been found that there is a significant amount of research and information in this area, although gaps still remain. Economics must also be incorporated into all science-based policy and future work.

Recommendations

1 Initiatives to be led by the agricultural and land management sector

- Raising awareness urgently (2008-2010) of anaerobic digestion (biogas), across all agricultural sectors and the food chain; also with local government and regulators.
- Including climate change awareness and mitigating actions in agronomist, adviser and practitioner training – through systematic upgrades of FACTS and CPD, and a proposed register for accredited animal nutritionists.

2 Recommendations for government policy and intervention

- Provide a range of incentives for anaerobic digestion: revenue-based (enhanced Renewables Obligation banding); capital grants to encourage project development; and development of market infrastructure (electricity network access, sale or disposal of digestate).
- Improve knowledge on use of digestate from anaerobic digestion as a fertiliser, including its effects on all GHG emissions, environment impacts, etc.
- Faster transfer of methane mitigation knowledge from other countries, especially work done on-farm in the EU.
- Develop the basis of animal feeding changes for reducing methane emissions, with consideration given to current regulatory constraints.

Agricultural Soils (see Table 1, Sector 4, D)

Issues

Every process or activity that returns or adds nitrate or ammonium to the soil increases the likelihood and extent of N_2O formation. Mineralisation of soil organic matter, decomposition of crop residues, biological nitrogen fixation, deposition of fixed nitrogen from the atmosphere, and application of both manures and fertiliser all contribute to ammonium and nitrate supplies in the soil. Various soil conditions affect the rates of nitrification and denitrification, the ratio of formation of N_2O to main reaction products (nitrate and N_2 for nitrification and denitrification respectively), and the proportion of N_2O formed that escapes to the atmosphere.

Conditions that favour microbial activity in the soil will tend to promote nitrification and denitrification. Adequate water, warm temperature and a good supply of easily degradable carbon promote both processes. High soil organic matter content, incorporation of crop residues and application of organic manures – all features of good agricultural practice - are also sources of degradable carbon, and thus associated with enhanced N_2O formation. Consequently, emission of N_2O tends to be greatest where aeration is such that both aerobic and anaerobic micro-sites are present in the soil, and both nitrification and denitrification can occur. Rates of both nitrification and denitrification increase with pH from acidic conditions to neutral or slightly alkaline conditions.

Different agricultural situations vary in their typical rates of N_2O emission, as a function of a number of risk factors – which may increase if the projections of warmer temperatures and higher precipitation coincide in some parts of the UK. Relatively high N_2O emissions are associated with grassland, especially intensively managed grazed grass, fine textured soils, organic and peat soils. In grazed grassland, the very high ammonium concentrations that occur within urine patches can result in elevated N_2O emission. Grassland soils tend to be heavy, often wet, acidic, and subject to surface compaction through livestock treading. N_2O emissions from grassland dominate total emissions from agricultural soils in the UK, due to the substantial grassland area as well as the high rate of emission per unit area. However, between 1990 and 2005, the overall average fertiliser nitrogen rate for all grass in England and Wales decreased from 132 kg N/ha to 72 kg N/ha (BSFP 2006).

It has been established for some time that N_2O emission tends to be greater where direct drilling or minimum cultivations are practiced than where soil is ploughed. Emission may be high immediately after ploughing due to release of N_2O-enriched air from the soil. However, ploughed and less disturbed soils can differ in water content, porosity, organic matter content and nitrate concentration, all of which can affect the rate of denitrification.

Comparison of N_2O emission rates between conventional and organic farming systems is difficult as there are differences in many interacting factors. Nitrogen supply, crop yields and stocking rates tend to be lower in organic farming, and this may be associated with reduced N_2O emission per unit area (but not necessarily per unit of crop or livestock output). However, greater dependence on manures may be associated with increased emissions.

General conclusions from UK research on N_2O emissions have been summarised (Defra 2006a):

i. there is wide spatial and temporal variability in emissions from soil;

ii. there are wide variations in emissions for each cropping type;

iii. management/weather conditions play a very large part in determining day-to-day emissions;

iv. excreta, manures and slurries can be substantial sources; and

v. there are considerable variations from standard emission factors.

The full impact of some practices on N_2O emission from soil may extend over weeks or several months, so it is

important that long-term monitoring is carried out over an appropriate period. In addition, emission of N_2O tends to be episodic, occurring when several favourable conditions coincide. Problems of scaling up from measurement day to whole year, and from chamber area to field area, have been pointed out (Defra 2005). Site-by-site and year-on-year variations, and the inter-relations between them, are still imperfectly understood due to the interrelationship between the carbon and nitrogen cycles in the soil.

Solutions

The most effective options to reduce N_2O emissions are those that minimise soil ammonium and nitrate concentrations. This can be done by:

a. limiting nitrogen applications;

b. adjusting nitrogen inputs from whatever source to ensure that additions of ammonium and nitrate are optimised and closely match crop demand; and

c. increasing nitrogen removal by the crop.

a) Limiting nitrogen inputs from fertilisers, manures and biological fixation to levels below the economic optimum for crop output would reduce agricultural production and, therefore, farm incomes. It would also encourage imports of animal feed and would simply export rather than reduce worldwide N_2O emissions.

b) Matching nitrogen inputs to crop demand is required to minimise N loss from soils by leaching as well as by emission of N_2O, bearing in mind that the greatest area of uncertainty in getting fertiliser applications right lies in predicting soil nitrogen supply. Low soil nitrate concentrations outside the growing season are needed to minimise losses by both of these routes. Consequently, drivers already in place, e.g. through the Nitrates Directive in specific respect to accounting for manure nitrogen in calculating total crop nitrogen requirements, through nutrient and manure management plans under Entry Level Stewardship, and through actions undertaken in farm assurance schemes, will assist in minimising N_2O emission. This option benefits farm economics and need not introduce overly-onerous demands on the farmer. Universal adherence to the latest recognised nitrogen recommendation systems and related tools, taking account of soil analysis, the nutrient value of organic manures and attention to the maintenance, calibration and operation of fertiliser and manure spreaders, would have a significant positive impact. The main agricultural organisations are already committed to jointly addressing current shortcomings in nutrient management. Central to united communications will be a universal guide on nutrient management planning, which includes all of the key actions outlined in this section, and is likely to increase fertiliser nitrogen use efficiency and the best available practices of integrated farming. The guide will direct readers to latest information sources and continued professional development, with support from accredited advisers, agronomists and animal nutritionists. The role of farm business advisers will also be investigated.

c) There may be some scope for increasing the effectiveness of nitrogen uptake through plant breeding. It has been indicated that improved genetic resources could potentially reduce fertiliser nitrogen requirement over 15-20 years.

Mitigation measures applicable at farm scale other than control of nitrogen supply have also been proposed. These include: i) reduction in livestock stocking rates, closely linked to limiting nitrogen input; ii) management of soils to avoid conditions that encourage denitrification; iii) management of manure/slurry applications; and iv) changes to the form of fertiliser nitrogen applied and use of nitrification inhibitors.

i) It seems unlikely that UK cattle numbers will increase in the foreseeable future, and a further decline is possible.

ii) Improvements could be made by alleviation of soil conditions that favour N_2O emission. In grassland areas, rainfall tends to be high and soils heavy, conditions that favour denitrification. Prevention of soil compaction by grazing animals or by vehicles should help minimise N_2O emission. This could involve shortening the grazing season, so reducing the risk of compaction and poaching to the soil surface in wet weather. Improved drainage, particularly of grassland, could reduce the occurrence, duration or extent of anaerobic conditions, thus reducing N_2O emission but increasing leaching of nitrate.

iii) Shallow injection of slurry, or use of trailing hose equipment, has been associated with greater N_2O emission than has surface application (Defra 2006a). Broadcast application results in smaller N_2O but greater ammonia emission than does injection – an example of pollution swapping.

iv) Direct comparisons of different fertiliser types on N_2O emission from soil show no significant differences (Defra, 2006b) and confirm the previous decision not to cater for different fertiliser materials in Pollution Prevention and Control methodology. The quantitative benefits of nitrification inhibitors added to manures and mineral fertilisers are not substantiated by UK practice, and further assessment of the potential benefits in terms of increased nitrogen use efficiency from UK farming systems is required (Chadwick et al., 2007).

Some potential options, for example reduced cultivation of organic and peat soils, would no doubt be effective but costly. Some, such as reductions in fertiliser nitrogen use and livestock numbers, have already occurred for other reasons. Others, such as a change to fertiliser form or broadcast application of slurry, could have unpredictable secondary effects or could exacerbate other problems such as ammonia emission. The most attractive option, to improve nitrogen use efficiency, is common to all shortlists and offers several advantages. It:

- addresses several problems – N_2O emission, nitrate leaching and ammonia emission – without pollution swapping;
- has no secondary or knock-on effects;
- offers significant scope for improvement;
- does not increase farm costs, and may lead to cost reductions; and
- consistent with existing advisory and regulatory initiatives.

Within this option, efforts can be directed to developing and implementing nitrogen recommendation services, improving the maintenance, calibration and operation of fertiliser and manure spreaders, ensuring full account is taken of nitrogen applied in manures, improving manure application strategies and promoting understanding and uptake of integrated nutrient management practices amongst advisers and farmers. Relevant ongoing initiatives are Environmental Stewardship, Nitrate Vulnerable Zone action programmes, updating of national guidance on fertiliser recommendations ('RB209') and supplementary guidance, and CPD in nutrient management through FACTS.

On a national scale there is little evidence to suggest widespread overuse of nitrogen fertiliser on arable crops, with usage broadly in line with national guidance 'RB209' (BSFP, 2006). Nitrogen efficiency has significantly improved since the peak in fertiliser use in the mid-1980s, with farm outputs being maintained or rising despite lower nitrogen inputs. However, phosphate and potassium reserves, which took decades to build up to non-limiting levels, are once again deficient in some areas and, overall, a negative balance is shown for the main arable crops. In some situations, these nutrients (plus sulphur and lime) may be limiting factors in crop performance, with a consequential knock-on effect for nitrogen efficiency. This trend is a cause for concern; balanced fertilisation is the key to the maximisation of crop uptake.

On grassland, due to the lack of confidence in nitrogen availability from manures, farmers tend to "play it safe" and potential savings in inorganic fertiliser nitrogen may not be fully achieved in practice, when used in conjunction with manures. Creating the right drivers and support for farmers to utilise more of the potentially available manure nutrients and make the appropriate adjustments for additional fertiliser requirements is a challenge, and the primary reason for error which can result in an overall lowering of nitrogen efficiencies.

However, over recent years there has been a continuing improvement in nitrogen use efficiency. Crop and grass production has been maintained with savings in application of nitrogen of 21% overall since 1995. Similarly, nitrogen savings in animal feeds of 10% since 1999 have been demonstrated. Therefore, a significant proportion of the resulting benefit in terms of reduced N_2O emissions is now likely to be realised, especially on the most efficient arable farms. Further savings of crop and livestock nitrogen may be possible through further uptake of integrated crop and livestock nitrogen best practices, with estimated potential reductions in N_2O emissions of 2-20% (Chadwick et al., 2007).

Data from Defra and the British Survey of Fertiliser Practice show no relationship between major changes in price on the rate of use of nitrogen fertiliser on winter wheat in England and Wales. It may be concluded that the imposition of a tax on N fertiliser would not have an effect on application rates on major arable crops, even with a 200% increase in fertiliser price relative to grain prices.

In the absence of the availability of organic manures, an enforced reduction by 30% in the application rate of N fertiliser would have a major effect on farm profitability. N_2O models suggest that this could theoretically lead to a reduction in emissions of about 12%, but this is uncertain and the timescale is unknown. It would result in a fall in output, which would have to be made up for by increased imports. Product quality would decline, but this would also depend on the requirements for the reduction - 30% less on all land, or zero application on 30% of the land? This is not considered a realistic option, but calculations of the possible outcomes would be useful.

Recommendations

1 Initiatives to be led by the agricultural and land management sector

- Inclusion of climate change awareness and mitigating actions in agronomist and practitioner training – through systematic upgrades of FACTS and CPD, and a proposed register for accredited animal nutritionists.
- Ensuring tools of delivery (e.g. Nutrient Management Plans) build on existing commitments and joint agricultural industry communications.
- Supporting adoption of sustainable, integrated and best-practice options, to increase uptake of integrated farm management as a central decision-making process for achieving nitrogen efficiency while managing environmental impacts.

2 Recommendations for government policy and intervention

- Refine the UK national GHG inventory/measurement by 2010, to more accurately reflect emissions from agriculture: currently, emissions are estimated using general methodology with too many default factors, which do not allow for many mitigation responses to be reported.
- Drive nitrogen efficiency for N_2O savings from soils on all farms, particularly in relation to the efficiency of nitrogen utilisation by livestock and the recycling of organic nitrogen.
- Implement tax allowances and/or better allocated funding for on-farm skills training.

3.3 Land Use, Land-Use Change and Forestry

The total emissions from this sector are offset by carbon removals, so there is a small net removal from land use change and forestry of -2.1 million tonnes CO_2. Land management is one of the few industries which can actually remove CO_2 from the atmosphere, thereby mitigating emissions by means other than improving efficiency.

Forest Land (see Table 1, Sector 5, A)

Issues

Forests and woodlands have the capacity to sequester carbon in biomass and soils, whilst at the same time providing a sustainable renewable resource for both material substitution and renewable fuels. There is scope to increase these savings in carbon emissions by planting more new woodland, improving the management of existing forests and increasing timber production. Over 50% of the forest land in Britain is currently not productively managed, and there is considerable potential to improve the carbon sequestration capacity of these forests and, more importantly, their ability to produce timber for material substitution and renewable energy.

A recent Forestry Commission comparison between Kielder Forest, Northumberland, and the East Anglian District Forest, Thetford, assessed annual GHG emissions from operations, personnel travel, road maintenance, administration and recreational visitors at 57 kg/ha carbon equivalent (Grieg, 2007). Annual carbon storage in trees (roughly equivalent to harvest rate) was about 2000 kg/ha at Kielder and 1000 kg/ha at Thetford, around 20 to 40 times greater than total emissions. Car-borne visitors, deer (ruminants), harvesting operations and timber transport were the largest sources of emissions, suggesting a number of areas where the carbon balance could be further improved.

Solutions

Forestry policy and management decision-making might be transformed if carbon had a more significant tradable value. Options to increase carbon sequestration include:

- Increased forestry area (plant new more productive forests and farm woodlands with higher yielding species, long-lived products that lock up carbon, avoiding planting on organic peaty soils, planting closer to the markets and population centres to reduce transport needs for timber, wood fuel, recreation, etc.).
- Optimised forest management (maximise timber potential, minimise losses by fire, windblow and pests, manage deer populations to improve natural regeneration).
- Increased productivity (improved thinning, use of thinnings for energy, minimise fuel use in harvesting, minimise soil disturbance).
- New kinds of forest management (continuous cover instead of plantation clear-cut, more natural and complex ecosystems which better adapt to climate change). Forests managed by continuous cover rely

almost entirely upon natural regeneration to provide succession. This dramatically reduces the carbon inputs associated with the growing, transportation and planting of the young trees compared with a clear-fell system. Naturally regenerated trees require no herbicide or fertiliser inputs; however, control of deer populations may be necessary. Fewer interventions are required compared with clear-fell management, typically once every 10 years rather than once every five, which brings carbon savings in the use of harvesting equipment, as well as savings in carbon emissions from reduced soil disturbance at harvest. Trees managed by continuous cover create an improved micro-climate, and are therefore more robust and better able to adapt to climate change.

Recommendations

1 Initiatives to be led by the agricultural and land management sector

- Increasing knowledge and skills in productive forest management, in particular the dissemination of advice to small woodland owners.
- Expansion of advice on utilisation of wood fuel from thinnings, emphasising local medium-sized heating systems that return significant income to the grower.
- Development of a template for carbon trading schemes based on afforestation in the UK with robust science-based processes for verification, monitoring and permanence.

2 Recommendations for government policy and intervention

- Develop policy recognising the value of productively managed woods and forests and the timber they can provide for material substitution.
- Implement policy measures to deliver the Forestry Commission Woodfuel Strategy for England by 2010, supplying an extra two million green tonnes of wood fuel from currently unmanaged woodlands.
- Rationalise current support mechanisms for woodfuel, to become either entirely national or entirely regional with strong national guidance, with support for wood-fired boiler installation and the supply chain to be delivered by one co-ordinating organisation.
- Recognition of a carbon trading scheme based upon afforestation in the UK.
- Stronger support for renewable heat, through a Renewable Heat Obligation or other obligations on existing heat energy suppliers.

Material substitution

Issues

Climate change and the need to mitigate its effects are driving a renaissance in the use of timber for renewable energy and material substitution. Whilst forests provide opportunities for carbon sequestration it is in the use of the timber produced by these forests where the most impressive gains are to be made. The combined value of the carbon store, material substitution and energy substitution of one cubic metre of wood has been estimated at two tonnes of CO_2, making this an effective tool in climate change mitigation (Frühwald, 2002).

Timber, timber products, and products from agricultural crops such as hemp, have a significant part to play in climate change mitigation by their substitution for brick, concrete and steel, all of which have high levels of "embedded" CO_2 emissions. For example, substituting one cubic metre of heavy concrete blocks or brick with timber results in savings of 1013 kg and 922 kg CO_2 equivalent, respectively (Reid et al 2004). On average, building a house with timber instead of brick reduces carbon emissions by 10 tonnes (Frühwald, 2002). If an additional 10% of all houses in Europe were built with wood, carbon emissions would be reduced by 1.8 million tonnes (2% of all European carbon emissions).

In Scotland 50% of new homes are now timber-framed, but there is considerable potential to improve this proportion in

England, where it is only 10%. Whilst only a small percentage of the timber in currently unmanaged woodlands is of sufficient quality to be used in house building, improved forest management and advances in the technology of timber products will allow more of this timber to enter this high value market, increasing the amount of CO_2 sequestered through material substitution.

Solutions

Use more low-carbon renewable resources to substitute for carbon-rich materials such as brick, concrete and steel in all new building projects. We should improve the understanding of the end-users' requirements for timber and timber products, and encourage owners to grow what the market requires.

Recommendations

1 Initiatives to be led by the agricultural and land management sector

- Amend planning guidelines to emphasise carbon savings achieved through material substitution, and further develop policies that promote greater use of low-carbon renewable resources in construction (through Building Regulations, Building Inspectorate and the architectural profession).

Crop Land and Grassland (see Table 1, Sector 5, B and C)

Issues

Soils are major players in the carbon cycle. Globally they store the equivalent of about 300 times the carbon now released annually through the burning of fossil fuels (Schulze and Freibauer, 2005). In England and Wales the total amount of carbon in the soils is estimated to be 2890 x 1012 g, with peat soils containing the majority (Dawson and Smith, 2007). Carbon is stored within soils in the organic matter – which is of great importance in the formation and stabilisation of soil structure. It has a number of key properties, such as water holding capacity, supply of nutrients, binding the soil together and, therefore, reducing erosion, all of which are essential for good agricultural production. The organic matter of a soil reflects the balance between gains of carbon from plant residues and organic inputs and the loss of carbon through decomposition by soil organisms (White, 1987). Compared to organic carbon contents of 5-10% in pasture soils, arable soils often contain no more than 1-2%, which is principally due to removal of organic residues, as well as tillage and weight of root systems (Briggs and Courtney, 1991). Activities which build up the organic matter in soil have a dual outcome: they build up soil carbon, thereby reducing the atmospheric carbon, and also improve the soil quality – crucial for food production.

Research on land management and soil carbon points to the modest, relatively long-term, but complementary role that soil carbon sequestration can play in reducing atmospheric GHG emissions, and the additional benefits that can be gained from increased soil carbon – improved productivity, resilience to erosion, and biodiversity (Dawson and Smith, 2007; Smith et al., 2007). Historically, agricultural ecosystems have lost carbon, but with improved management practices or land use change this can be recovered thereby withdrawing atmospheric CO_2. Any practice that increases the photosynthetic input of carbon or slows the return of stored carbon via respiration or fire will increase stored carbon, thereby sequestering carbon or building carbon sinks. Many studies world-wide have now shown that significant amounts of soil carbon can be stored in this way through a range of practices suited to local conditions (Smith et al., 2007).

Evidence suggests, therefore, that there is significant potential for agriculture to mitigate carbon emissions, in particular through changing land use, improved crop land and grazing land management, and restoration of degraded land and cultivated agricultural soils. The principal approaches to increasing carbon in the soil are described below.

Solutions

Land use change/restoration

We know that conversion from land uses with low carbon stocks and low inputs to the soil (e.g. crop lands) to those with higher carbon stocks and inputs to the soils (e.g. grassland and forestry) will increase soil carbon stocks overall, removing CO_2 from the atmosphere. Land use change is, therefore, one way to build up soil carbon, although there is a risk that leakage ("exporting emissions") will occur if crop production is simply displaced to other areas.

Land use changes that lead to an increase in soil carbon include:

- Reversion of crop land to native vegetation/wetlands – this may be most practicable for localised patches of land of low productivity, such as grass waterways, field margins and shelter belts. Such an approach would minimise any tendency towards extensification, which would export the emissions (leakage). More fundamental land use change such as conversion of drained crop lands back to wetlands is unlikely for economic reasons.
- Restoration of peatlands – peatlands are the UK's largest terrestrial carbon store with more carbon than all the forests of Britain and France (F. Worrall, pers.comm., Dept. of Geological Sciences, Durham University). Currently, peat deposits in England and Wales could store up to 41,000 tonnes of carbon per year if they were in pristine condition, but erosion and damage could mean that peatlands are actually releasing carbon into the atmosphere at a rate of 381,000 tonnes of carbon annually (F. Worrall, pers.comm., Dept. of Geological Sciences, Durham University). Restoring this damaged and eroded peatland could significantly increase the amount of stored carbon – equivalent to 2% of car traffic in England and Wales per year or 0.4 Mt C/yr.

Table 2 sets out measures for increasing soil carbon stocks in productive soils (Freibauer et al., 2004).

Measure	Potential soil carbon sequestration rate (tonnes C /ha/year)
Zero-tillage	0.4
Reduced tillage	<0.4
Perennial grasses and permanent crops	0.6
Animal manure	0.4
Crop residues	0.7
Sewage sludge	0.3
Convert arable to grassland	1.2 to 1.7
Convert arable to woodland	0.3 to 0.6
Convert grassland to arable	–1.0 to –1.7
Convert woodland to arable	–0.6
Protection and restoration of farmed organic soils	Up to 4.6
Avoid deep ploughing of farmed organic soils	1.4 to 4.1
Sheep grazing on undrained peatland	>2.2

Table 2. Potential soil carbon sequestration rates of various management measures

Improved agronomic practices

- Practices that increase yield and generate greater crop residues which are returned to the soil can increase the amount of carbon sequestered (Follet, 2001). For example, using improved crop varieties to increase yield, extending crop rotations, retaining crop residues, avoiding or reducing use of bare ground by planting cover crops (this also takes up residual nitrogen in the soil, potentially reducing N_2O emissions), and introducing grass species with high productivity or carbon allocation to deeper roots, are all practices which will sequester soil carbon (Smith et al., 2007).

- Minimum tillage – reduced-till or no-till (NT) management, involving negligible amounts of soil disturbance, is likely to bring soil carbon gains but not always - it is dependent on soil and climate conditions. There is conflicting evidence on the benefits of NT. Some figures suggest that NT has a small part to play and could offset approximately 3-4% of anthropogenic CO_2 in Europe if 100% of arable land was converted to no-till. More practically, although still challenging, 50% NT would halve the mitigation ability (Smith et al., 1998). Another study shows that in humid climates such as Britain, NT can sequester 222 kgC/ha/yr over the first 20 years, even when factoring in N_2O emissions (Six et al., 2004). In addition to this, changes in agricultural inputs under NT can lead to ancillary emission reductions of as much as 31 kgC/ha/yr. However, recent research suggests NT has little or no impact on total soil carbon, once the carbon in soils greater than 30 cm depth is taken into account (Baker et al., 2007). It is clear that there is much uncertainty surrounding this potential solution.

- Addition of organic manures and straw to the soil, e.g. animal manures, sewage sludge and green waste composts, will maintain and potentially build up soil carbon. If these practices are to sequester additional atmospheric carbon they will have to take the form of increased levels of application, not just a continuation of current practices. Research suggests that this approach could sequester between 300 – 1600 kgC/ha/yr (ADAS, unpublished, 2007). The balance between soil carbon levels and N_2O emissions on different soil types needs further research.

The main climate change benefits of soil carbon sequestration mitigation actions taken now will emerge only over decades as the soil carbon builds up in the soil, but where the drivers achieve other policy objectives - for example, to meet water or air quality standards - there may also be short-term benefits. Figure 7 gives an idea of the potential for soil carbon sequestration with different management practices. Measures which raise awareness and build capacity about soil carbon, mitigation of climate change and the potential opportunities to motivate this change are vital. Good technology transfer to help land managers to understand technologies, their application and costs and benefits is key to them taking any mitigating action, e.g. to increase soil organic matter.

Carbon management by land managers is a valid climate mitigation measure that should be promoted through innovative financial mechanisms as part of the overall response needed to reduce GHG emissions. It is one of a range of public goods and ecosystem services that land managers can provide - a form of 'carbon stewardship'. However, it is important that carbon management is set in the context of wider environmental management as too

narrow a focus could result in policies that have adverse environmental consequences. Carbon management practices include increased organic additions to soil, minimum tillage where the conditions are favourable, growing cover crops to protect bare soil and taking marginal land out of production to leave grass waterways, field margins and shelter belts. Where these are covered by an agri-environment scheme, extra points could be awarded for having a climate change benefit.

Land use changes which involve larger soil carbon increases, such as restoration of peatlands, may impact on the economic return of a business and will, therefore, require greater financial incentives e.g. through carbon trading or rewarding land managers for delivering a public good in the form of carbon removal. The main climate change benefits of soil carbon sequestration mitigation actions taken now will emerge only over decades as the soil carbon builds up in the soil, but where the drivers achieve other policy objectives, for example to meet water or air quality standards, there may also be short-term benefits.

Soil, by its very nature is heterogeneous. One agricultural field can contain a number of different soil types, and the accumulation of soil carbon is a very slow process, so trends in carbon storage may take decades to become apparent. Measuring soil carbon is challenging, but a crucial area, especially as there are reports that we are already losing soil carbon as a result of climate change. We need continued and increased research in this area, e.g. on improving the precision of estimation of the soil carbon pool, improved understanding of soil processes, improved assessment of the impact of land use change and land management on soil organic matter, and the prediction of future threats to the soil organic carbon reserve due to land use and climate change. There are many unanswered questions about the state of Britain's peatlands, their carbon budgets, and their prospects for restoration. Further work is also needed on improving the LULUCF section of the UK GHG inventory in order that more detailed practices that sequester carbon, such as minimum tillage and peat management, may be detected and recorded at the national scale.

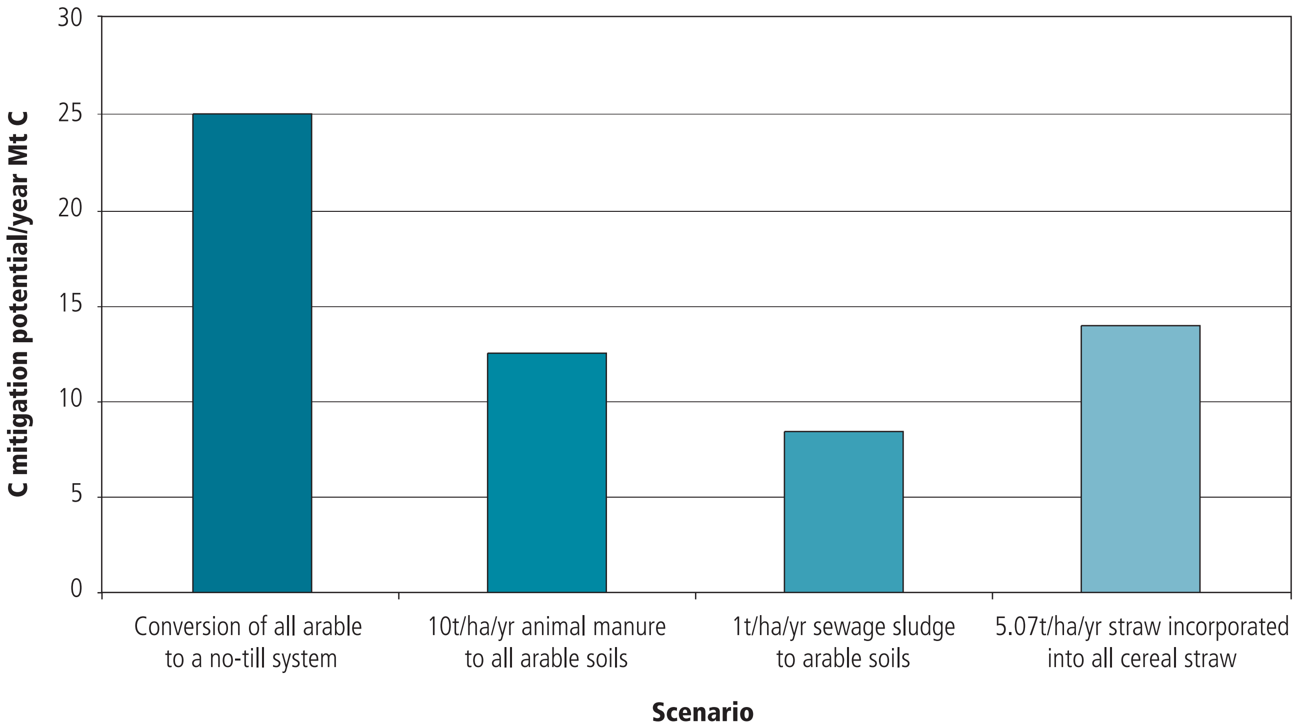


Figure 7. Soil carbon mitigation potential from organic additions in Europe (EU-15). Taken from figures in Smith et al. (1998)

Recommendations

1 **Initiatives to be led by the agricultural and land management sector**

- Promoting economic agronomic practices that remove carbon from the atmosphere, including improved crop varieties and incorporation of manure/compost.

2 **Recommendations for government policy and intervention**

- Incorporate climate change objectives into agri-environment schemes by 2008, to complement present emphasis on biodiversity and ecosystem services; and award greater credit where agri-environment options yield multiple benefits (climate change, resource protection and biodiversity).
- Initiate new and imaginative approaches for financing ecosystem services such as carbon management through land-use change options, e.g. restoration of peat.
- Development of the measuring and monitoring of soil carbon, to allow stronger and more reliable estimates of soil carbon storage to be estimated.
- Improve knowledge on soil management such as minimum tillage, and its possible contribution to reducing carbon emissions; also on the state of UK peatlands, their carbon budgets and timeline for restoration.

3.4 Other options

Emissions trading

There has been considerable interest lately in carbon trading or carbon offsetting schemes, which pay a modest incentive towards carbon sequestration or sustainable energy projects that displace fossil fuel emissions. The worldwide market for carbon offsetting has grown substantially (from £3m in 2004 to £55m in 2006), and representatives of some offsetting organisations, such as the Chicago Climate Exchange (CCX), have been indirectly approaching farmers. However, while the more rigorously-monitored carbon trading schemes appear to have merit, we have some concerns that public and scientific confidence in carbon offsetting is declining, at least in part due to the absence of independent standards. For example, Defra's position is to support mostly sustainable energy projects, rather than ecosystem-based offsets such as carbon storage in woodland or soils, and they are developing a code of best practice for offsetting.

The land-based sector needs to be certain that carbon trading is based upon sound science. Independent monitoring and verification of offsets is rarely the case for more than a small sample of traded offsets. It is noteworthy that forest carbon sink credits have been excluded so far from the EU emissions trading scheme, because of concerns about the accuracy of sequestration estimates as well as of the permanence of the sequestration (NERA, 2007). Furthermore, trading of carbon stored in existing woodland or grassland is fraught with difficulty in proving "additionality", as indeed are the carbon offsets from energy projects that may have gone ahead anyway, in the absence of any income from traded carbon rights. It has been argued that only newly-created (additional i.e. post-1990 new afforestation) long-term carbon sinks, or sustainable energy measures that are not otherwise incentivised, may be construed as high-quality carbon offsets. The internationally traded value of carbon (presently about US$4.00 per tonne of CO_2) is unlikely to be worth more than a simple top-up grant towards land-use change such as woodland planting. Individual businesses in our sector tend to be relatively small, with modest emissions compared to participants in other trading schemes. Weighed against the cost of monitoring and reporting emissions, it may not be worth the effort of the average enterprise to participate at this level (equivalent to perhaps £10-11 per hectare), at least until there is a substantial increase in the price of traded carbon.

Nevertheless, some parts of the forestry sector are currently making the case for such schemes, and looking at ways to ensure their credibility through certification, appropriate species choice and management regimes. Since there is an appetite for carbon trading from landowners and potential investors, this could result directly in carbon sequestered in timber and forest soils, and indirectly in more timber becoming available for renewable energy use and material substitution. The provision of an additional and complementary income stream could reduce the pressure on current government incentives for afforestation, with its biodiversity benefits and opportunities for improved recreational enterprises.

Carbon auditing and carbon labelling

A growing number of Internet-based carbon calculators already exist, mostly for the domestic market. The CLA is developing such a carbon calculator, Carbon Accounting for Land Managers (CALM) that farm and land managers will be able to use, to calculate their GHG emissions (CH_4, N_2O, CO_2) and removals (carbon sequestered in soils and timber) annually from individual farms. Based around the IPCC methodology for recording GHG inventories (IPCC, 1997), it will measure only changes in land management practices which would be recorded in the UK national inventory. The main objective of the CALM carbon calculator is to raise awareness of emissions/removals amongst land managers and to set a benchmark against which annual improvements can be made, as new investment takes place and new management practices are adopted. It also holds the key to be able to trade carbon in the future if that becomes possible, e.g. through carbon sequestration. Advice and sign-posting will back up the CALM tool to ensure that land managers have sufficient advice on which to base management changes and reduce their carbon balance in the future.

A growing number of food and other retailers in Britain are expressing an interest in helping customers understand the GHG emissions embodied in the products they buy. Manufacturers, producers and processors are all looking into the "carbon footprint" or "carbon life cycle" of their products, with the term "carbon labelling" being used broadly to describe this process. Many stakeholders, including the agricultural industries, agree on the need for a universally accepted and commonly understood measure of the carbon footprint of individual consumer products,

looking at the complete life cycle from production, through distribution to final consumption. However, it is yet unclear whether retailers will actually label individual products so that customers can compare their carbon footprint in the same way they compare price or nutritional profile. "Carbon labelling" should, therefore, be placed in the context of wider consumer communication about the need to reduce GHG emissions from production and consumption.

Key issues for food producers include:

- establishing a baseline against which to measure carbon footprint (presumably starting with land that has already been tilled or converted to agricultural use);
- defining the boundaries (as noted above) within the UK GHG inventory, the energy of fertiliser production

is accounted for within the industrial sector, not agriculture – and does carbon labelling stop at the supermarket cash till? – or is consumer food wastage also estimated?; and

- possible future consideration of non-CO_2 GHGs, assuming that reliable data on N_2O and CH_4 emissions are available at local level.

Defra has already funded a number of life cycle analyses of key agricultural and horticultural commodities, and consultation is continuing upon suitable methodologies. The Nuffield Farming Scholarships Trust is also supporting work on the carbon footprint of British agriculture. The NFU, the CLA and other food chain stakeholders are fully engaged, in order to avoid the confusion that would result if different key players adopted different carbon labelling standards. It is most important that factors such as seasonality of supply and year-to-year variation in climate are taken into account in the agreed methodologies, and that any reference database of emissions factors is overseen by a trusted and independent body.

Those growers participating in Climate Change Levy Agreements already get help with recording energy use in agricultural buildings and processing. This audited scheme, endorsed by government, demonstrates the action that individual farmers and growers are taking already to reduce their carbon emissions. In the future, those whose customers require such information may need to keep records of tractor fuel usage, in order to estimate their carbon footprint. Farm-based on-site generation of renewable energy may become an important permitted mechanism for reducing the net GHG emissions from food production, by making farms 'net exporters' of energy services. Other possible carbon offsets on the farm or elsewhere in the supply chain (tree planting, land use conversion) would be very modest in comparison to reducing fossil fuel energy use, on-site or elsewhere in the UK economy, through renewable energy or energy efficiency.

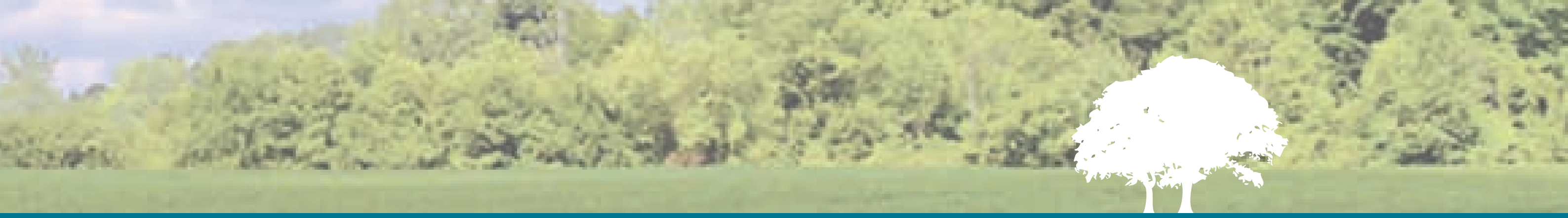
Recommendations

1 Initiatives to be led by the agricultural and land management sector

- Developing further and deploying carbon calculators, e.g. CLA's CALM (due in 2008), and participating in emerging carbon labelling standards.
- Development of a template for carbon trading schemes based on afforestation in the UK with robust processes for verification, monitoring and permanence.

2 Recommendations for government policy and intervention

- Recognise a carbon trading scheme for afforestation in the UK.



ANNEX 1: Climate change impacts on UK agriculture and land management

Carbon dioxide

Carbon dioxide (CO_2) levels in the atmosphere are rising and will continue to increase. Elevated CO_2 is known to stimulate plant growth (primary production) and increase the efficiency of water use in the absence of other limiting factors, but this could lead to changes in leaf/sheath ratio, reduced nitrogen and increased fibre contents. Some increase in yields is expected in Europe for mid and high latitudes with a local mean temperature increase of 1 to 3 degrees, depending on the crop (IPCC , 2007a). Coupled with other climate change factors, such as water availability, the overall impact of CO_2 is difficult to predict (NFU, 2005).

Temperature

Average annual temperature in Britain is expected to rise by between 0.1 and 0.5°C per decade. These warmer temperatures may provide opportunities for diversification into new varieties and types of crops, and an extension of the range and yields of some crops northward. However, increasing temperatures, particularly in the summer, may have a detrimental effect on some crops, with timing of maturity, crop uniformity and product quality all affected by temperature changes, (MAFF, 2000). Warmer summers may also result in heat stress effects on livestock, increasing ventilation and shade needs. On the contrary, warming winters will decrease frost damage, allowing earlier sowing, a longer growing season, double cropping and prolonged outdoor grazing for livestock. Protected crops or housed livestock may benefit from reduced energy costs in the winter, but will be impacted with a greater need to cool in the summer. Rising temperatures are expected to reduce the capacity of soils to store carbon, and after 2050 this is likely to outweigh the effects of increased afforestation in Europe. Peat sinks, with their higher volumes of carbon, are likely to be particularly susceptible to drying out and consequent fire risk. There are concerns that soil carbon is already reducing by up to 2% a year due to climate change (Bellamy et al., 2005).

Water

Precipitation is likely to increase in winter and decrease in summer, with the greatest changes and extremes occurring in the south east. The need for irrigation will increase, with water scarcity issues may arising, leading to associated problems for abstraction licensing. Lack of water is likely to impact upon both crop quality and variability. Drought resistant varieties may need to be developed to adapt to decreased water availability (Defra, 2002). Some wetter parts of the UK may become more suitable for arable crops, and less prone to waterlogging and poaching. However, an increase in winter rainfall could increase problems such as waterlogging and flooding, particularly on poorly drained soils. Livestock may need to be housed earlier and for longer to avoid poaching of the land. The effects of longer growing seasons and increased run-off and erosion are likely to be negative for groundwater recharge.

Weather extremes

A rise in variability with climate change (suggesting more damaging weather events such as heatwaves, storms and heavy rainfall) is likely to increase crop damage or loss, as well as soil erosion. Extreme events may lead to more variability in yield, increasing the need to plan and extend the range of crops (European Commission, 1997). Farmers and growers are likely to need to increase their investment in infrastructure (e.g. drainage systems) and modify building maintenance regimes, in the light of more intense weather events. Greater storm frequency is likely to lead to a rise in livestock stress levels and an increase in housing, impacting on stocking rates where housing space is limited. Storm winds and snow, together with fire, which already occurs annually in woodlands in almost all European countries, are all significant sources of climate-related loss and damage to woodlands.

Growing season

Increases in average temperature will lengthen the growing season for plants. For example, for each 1°C increase, the growing season can increase by approximately three weeks in the south east and by about 10 days in northern areas (Figure 8 below).

Pests and diseases

The range and types of UK pests, diseases and weeds is likely to significantly change. There could also be greater problems with pesticide resistance, through both the increased number of generations per year (allowing time for resistance build-up) and the warmer winters improving the survival of any resistant pests. A key example of this can be seen with the emergence of Bluetongue disease in northern Europe. This is likely to have been caused by increased virus persistence during winter and an enlargement of the range of the midge vector. In the future, increased surveillance and eradication procedures will be needed (Rothamsted Research, 2005).

Sea level rise

This is likely to become an increasingly severe problem, with net sea level changes by the 2080s ranging from 0 to 60 cm in Scotland, and 15-85 cm over much of England. Current relative sea level rise due to isostatic land movements is already having an impact on sea defences, and predicted changes in mean sea level will exacerbate this, increasing the risk of flooding and salt intrusion into aquifers. About 57% of Grade 1 agricultural land lies below the five-metre contour, where it may be subject to flooding, inundation, erosion and salinisation of fresh water and, therefore, a loss of our most productive land, thereby reducing our capacity to produce food.

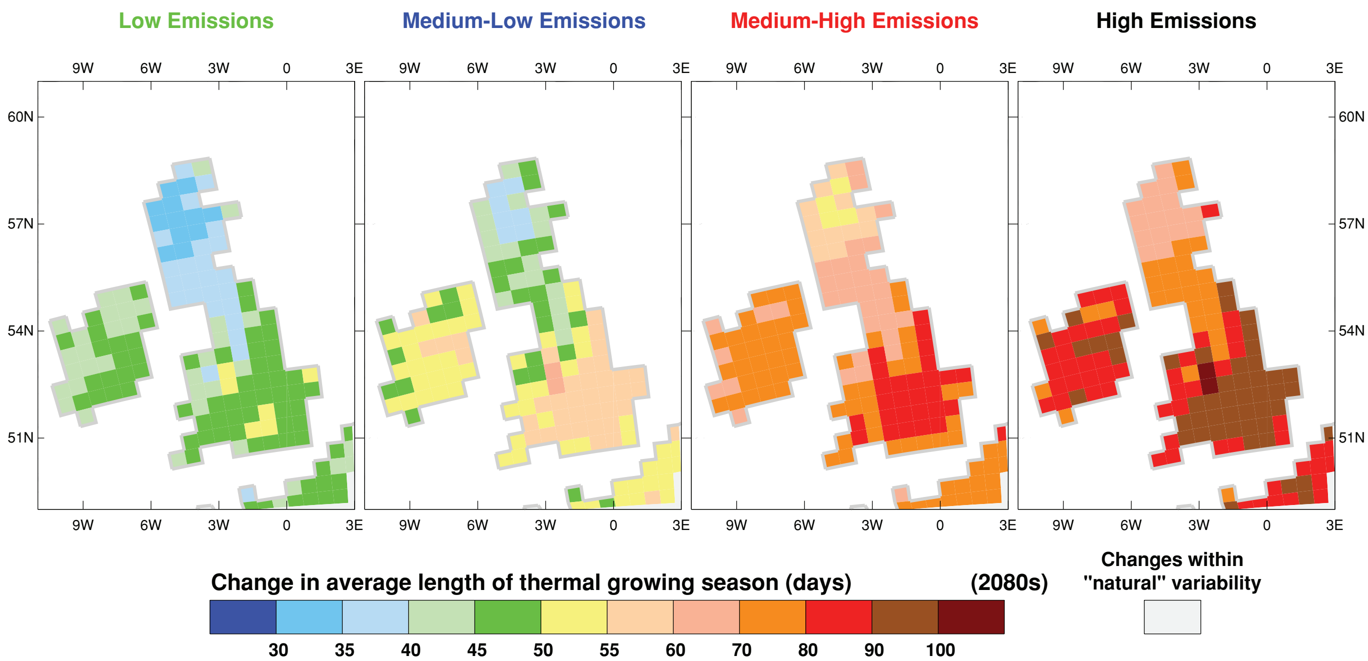


Figure 8. Change in the average thermal growing season by the 2080s, with respect to the 1961-1990 baseline period.

Source: UKCIP02 Climate Change Scenarios (funded by DEFRA, produced by Tyndall and Hadley Centres for UKCIP).

References

ADAS (2001) Novel feed additives for decreasing methane emissions from ruminants, Defra Project Code CSA 4320.

ADAS (2003) Meeting on Methods of reducing Greenhouse Gas from Agriculture, Defra Project Code CC0260.

ADAS (2006) Defra Research in Agriculture and Environmental Protection between 1990 and 2005: Summary and Analysis, Defra Project Code ES0127.

AEA (2007) UK Greenhouse Gas Inventory: 1990-2005. AEA Energy and Environment, Harwell.

AIC/CIA data sources (2007).

Baker, J.M., T.E. Ochsner, R.T. Venterea and T.J. Griffis (2007) Tillage and soil carbon sequestration – what do we really know? Agriculture, Ecosystems and Environment 118, 1-5.

Bellamy, P.H. et al. (2005) Carbon losses from all soils across England and Wales 1978-2003. Nature Vol 437/8 (September 2005).

Bradley R.I. et al. (2005) A soil carbon and land use database for the United Kingdom. Soil Use and Management 21, 363-369.

Briggs, D. and F. Courtney (1991) Agriculture and Environment - the physical geography of temperate agricultural systems (p.58). Longman Scientific and Technical.

Brown, L. and S.C. Jarvis (2001) Estimation of nitrous oxide emissions from UK agriculture. IGER Innovations, 2001. Institute of Environmental and Grassland Research.

BSFP (2006) The British Survey of Fertiliser Practice. Fertiliser Use on Farm Crops for Crop Years 1998-2006. Defra, London.

Chadwick, D.R. et al. (2007) A Review of Best Practice for Reducing Greenhouse Gases from Agriculture. Defra Project AC0206, ADAS/IGER (in press).

CEI-Bois in cooperation with European Wood Councils, European Wood Factsheets 3. Wood Products as Carbon Stores 4. Wood Products and Climate Change. CEI-Bois/European Confederation of woodworking industries, Brussels, Belgium. http://www.cei-bois.org/prowood/argumentsprowood.html

CLA (2001) Climate Change and the Rural Economy. Country Land and Business Association, London.

CLA (2007) Renewable Energy - more than wind? Country Land and Business Association, London. 79 pp. (originally published 2005; updated May 2007).

Cruickshank, M.M., R.W. Tomlinson, P.M. Devine and R. Milne (1998) Carbon in the vegetation and soils of Northern Ireland. Proceedings of the Royal Irish Academy 98B, 9-21.

Dawson, J. and P. Smith (2007) Carbon losses from soil and its consequences for land-use management, Science of the Total Environment.

Defra (2002) Maintaining UK wheat performance through improved exploitation of drought-resistance traits (Project Review CCO370).

Defra (2005) Synopsis and review of relevant projects to assess mitigation options for nitrous oxide and methane to inform the climate change program. Final Report, Project CC0272.

Defra (2006a) Defra Research in Agriculture and Environmental Protection Between 1990 and 2005: Summary and Analysis (Project ES0127).

Defra (2006b) NT26 Research Programme.

Defra (2007) Agriculture in the UK 2006. TSO, London. ISBN 978-0-11-243095-7.

Defra Project AC0101 An improved inventory of greenhouse gases from agriculture.

DETR (1998) Climate Change Impacts in the UK: the Agenda for Assessment and Action. Department of the Environment, Transport and the Regions, London.

European Commission (1997) Assessment and adaptations: a summary report, Climate change and agriculture in Europe.

Follett, R.F. (2001) Organic carbon pools in grazing land soils. In: The potential of U.S grazing lands to sequester carbon and mitigate the greenhouse effect (eds R.F. Follett, J.M. Kimble & R.Lal), pp 65-86 Boca Raton, FL: Lewis Publishers.

Freibauer, A., M.D.A. Rounsevell, P. Smith and J. Verhagen (2004) Carbon sequestration in the agricultural soils of Europe. Geoderma 122, 1–23.

Frühwald, A. (2002) The Miracle of the Carbon Cycle, University of Hamburg.

Greig. S. (2007) Carbon Issues in UK Forestry, Quarterly Journal of Forestry.

HRI/FEC (2007) Direct energy use in agriculture: opportunities for reducing fossil fuel inputs, 57 pp. Defra project report AC0401, HRI, University of Warwick / FEC Services Ltd., Stoneleigh Park, Warwickshire.

Hulme, M., Turnpenny, J.R., Jenkins, G.J. (2002) Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report. Tyndall Centre, University of East Anglia.

IGER (2001) Cost curve assessment of mitigation options in greenhouse gas emissions from agriculture. Defra Project Code CC0229.

IPCC (1997) Greenhouse gas emissions from agricultural soils. In: Houghton J T et al. (Eds), Greenhouse Gas Inventory reference Manual. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories.

IPCC (2007a) Climate Change 2007: impacts, adaptation and vulnerability. Fourth Assessment Report, Working Group II.

IPCC (2007b) Climate Change 2007: mitigation of climate change. Fourth Assessment Report, Working Group III, chapter 8 Agriculture.

Jensen T.K. and G. Kongshaug, (2003) International Fertiliser Society, Proceeding No. 509.

Kusters, J. (1999) Life cycle approach to nutrient and energy efficiency in European agriculture. International Fertiliser Society, Proc 438, York, UK. ISBN 978-0-85310-073-7.

MAFF (2000) Climate Change and Agriculture in the UK. Defra, London.

Milne, R. and T.A. Brown (1997) Carbon in the vegetation and soils of Great Britain. Journal of Environmental Management, 49, 413-433.

Mistry, P. and T. Misselbrook (2005) Assessment of methane management and recovery options for livestock manures and slurries. Report for Sustainable Agriculture Strategy Divisions, Defra, London. 58 pages.

Natural England (2007) Potential for carbon offsetting from the restoration of peatlands (workshop proceedings).

NERA (2007) Market Mechanisms for Reducing Greenhouse Gas Emissions from Agriculture, Forestry and Land Management. Final draft report for Defra, 18-Sep-07. NERA Economic Consulting, London. 151 pp.

Netcen (2004) Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland: 1990-2002. NETCEN, AEA Technology, Harwell.

NFU (2005) Agriculture and Climate Change. National Farmers' Union, Stoneleigh Park, Warwicks. 48 pp.

Penman, J. et al, (2000). Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. IPCC.

Penman, J. et al, (2004). Good Practice Guidance for Land Use, Land-use Change and Forestry. IPCC.

Paustian, K. et al (2006) Agriculture's role in greenhouse gas mitigation. Pew Center on Global Climate Change.

Reid, H., et al. (2004) Using wood products to mitigate climate change: a review of evidence and key issues for sustainable development. International Institute for Environment and Development, London/Edinburgh Centre for Carbon Management. 90 pp.

Rothamsted Research (2005) Climate Change and Land Management, Harpenden, Herts.

Schulze, E.D., and A. Freibauer (2005) Environmental science: carbon unlocked from soils. Nature Vol 437.

Silsoe (2003) Environmental and Welfare Benefits of IMS for Dairy Cows, Defra Project Code IS0102.

Six, J., S M. Ogle, F J. Breidt, R T. Conant, A R. Mosier, and K. Paustian (2004) The potential to mitigate global warming with no-tillage management is only realized when practised in the long term. Global Change Biology 10, 155-160.

Smith, P. et al (1998) Preliminary estimates of the potential for carbon mitigation in European soils through no-till farming.

Smith, P. et al (2007) Greenhouse gas mitigation in agriculture Phil Trans. Roy. Soc. B.

Stern, N. (2006) The Economics of Climate Change: the Stern Review. Cambridge University Press, Cambridge. 692 pp.

Viner, D., M. Sayer. M. Calvo Uyarra and N. Hodgson (2006) Climate Change and the European Countryside: Impacts on Land Management and Response Strategies. Climatic Research Unit, University of East Anglia, Country Land and Business Association, and European Landowners Organisation.

White, R.E. (1987) Introduction to the Principles and Practice of Soil Science. Blackwell Scientific Publications, 2nd edition.

Acknowledgements

(Sponsors, Stakeholders consulted, Reviewers, Sources of Information)

Steve Ellwood, HSBC Bank plc, London

Francis Sullivan, HSBC Holdings plc, London

Jeremy Eppel and Victoria Turner, Farming for the Future Programme, Food and Farming Group, Defra

David Scholefield and Laura Cardenas, Institute of Grassland and Environmental Research (IGER), Okehampton, Devon

Rhian Kelly, CBI Task Force on Climate Change, London

Andrew Smith and Ellen Gladders, Tesco plc., Hertfordshire

Professor Chris Pollock CBE, Chief Scientific Adviser to the Welsh Assembly

Dr. Jeremy Woods, Imperial College London

Jim Godfrey OBE

Dr. Amanda Thomson, Centre for Ecology and Hydrology, Edinburgh

Prof. Peter Smith, School of Biological Sciences, Aberdeen University

Jonathon Porritt, Forum for the Future, Cheltenham naturallyresponsible

Printed by Seacourt to the most stringent environmental systems using **Waterless** Offset (0% water and 0% Isopropyl alcohol or harmful substitutes), 100% renewable energy and vegetable oil based inks on paper with 100% recycled content. **Seacourt** is registered to EMAS and ISO 14001, is a CarbonNeutral® company and FSC certified TT-COC-2132.

THE QUEEN'S AWARDS FOR ENTERPRISE: SUSTAINABLE DEVELOPMENT 2007

Country Land & Business Association
RURAL ECONOMY IS OUR BUSINESS

aic agricultural industries confederation

NFU www.nfuonline.com