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POSTNOTE

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Emissions from Crops

Agriculture contributes 9% of the UK's greenhouse-gas (GHG) emissions burden and 10-12% globally.[7,8] Although there is a long-term declining trend from UK agriculture,[9] the sector may account for a larger share of overall emissions in the future as other sectors reduce emissions.[10] This POSTnote focuses on reducing GHG emissions from growing and storing arable and horticultural crops.

Overview

- Climate change mitigation and food security present challenges to agricultural systems.
- Nitrogen management has the greatest potential for reducing greenhouse-gas emissions from farming crops.
- Research suggests increasing stocks of carbon in soil can reduce emissions and improve soil fertility,[1-4] but other studies indicate that the UK's capacity to increase soil carbon stocks through cropland management may be limited.[5,6]
- Mitigation options need to be evaluated as part of the global food system in order to avoid exchanging one form of pollution for another.
- Improving farm efficiency alone will not be enough to ensure reductions in greenhouse-gas emissions and food security; diet change and food waste reduction will also need to be considered.

Agricultural Emissions and Sources

The 2008 Climate Change Act aims to reduce the UK's GHG emissions by at least 80% (from 1990 levels) by 2050. For agriculture in England, a reduction objective of 3 million tonnes of carbon dioxide equivalent ($MtCO_2e$) per annum is set for the period 2018-2022, an 11% reduction on 2008 emissions levels. Similar reductions are required for Scotland (1.3), Wales (0.6) and Northern Ireland (0.276).

Nitrous oxide (N_2O) contributes more to global warming than any other gas emitted from agriculture (Table 1). Soils are the main source of agricultural nitrous oxide emissions (90%);[9] which arise from microbial activity following application of man-made nitrogen fertilisers, farmyard manures and slurries and re-deposition of airborne nitrogen pollution to land (POSTnote 458). Nitrous oxide is also emitted from nitrogen leached into water bodies (POSTnote 478). The main sources of agricultural CO_2 emissions are on-farm energy use and crop storage. The majority of methane (CH_4) emitted from agriculture is from fermentation by livestock digestive systems (POSTnote 453) and the anaerobic break-down of stored farmyard manures and slurries (POSTnote 387). Methane is also produced as a by-product of the decomposition of organic matter in low oxygen environments, such as flooded rice paddies and wet grassland.[8,11]

Globally, agricultural expansion is a major driver of land use change and associated GHG emissions. Livestock farming and cultivating soya for animal feed are the main drivers (POSTnote 466).[12] The sector emits 30% of global GHG emissions, when all agricultural and land use change emissions are included,[13] and it is estimated that deforestation and forest degradation are responsible for 11% of these emissions.[16] Palm oil and pulpwood

Table 1. UK Agricultural GHG Emissions

GHG	Global Warming Potential (GWP)[a]	MtCO2e[14,b]	% agriculture's contribution to emissions[14]
N_2O	310	30.3	84
CH_4	21	22.3	44
CO_2	1	6.6	1

[a] GHGs vary in the extent to which they contribute to the greenhouse warming effect. GWPs assigned relative to CO2 are expressed over a period of 100 years (POSTnote 428).

[b] CO2e is calculated by multiplying the weight of gas emitted by the gas's GWP. There is uncertainty in calculating emissions (Box 1).

Box 1. Agricultural GHGs and Emissions Reporting
The UK is obligated to provide an inventory of its GHG emissions to the United Nations Framework Convention on Climate Change (UNFCCC) and the European Monitoring Mechanism (EUMM). Defra and the Devolved Administrations are funding a £12.6 million project which will enable the UK to submit agricultural emissions figures with reduced levels of uncertainty.[15] A major outcome will be refined emissions factors for nitrous oxide and methane from the range of agricultural sources. An emission factor is the rate of GHG emission per unit of activity, output or input. For example, the emission of nitrous oxide is expressed as a percentage of nitrogen input to the soil. The factors will be region-specific and will take into account different nitrogen sources (fertiliser type, livestock slurries and manures, and urine and dung deposition by outdoor livestock), as well as soil type and weather conditions. These refined factors will be used with improved regional farm practice data in a new reporting tool.

production is another major driver; in recent decades over 10 million hectares of peat swamp-forest in South East Asia has been drained for agriculture, leading to rapid peat degradation and large CO_2 emissions.[17]

Mitigation Options

This POSTnote focuses on mitigating GHG emissions from growing and storing crops through improved 'emissions efficiency' (minimising GHG emissions produced per unit of agricultural output). The following key issues are dealt with:

- improving nitrogen management
- soil carbon storage
- water and crop residue management for flooded rice
- improvements in on-farm energy efficiency (Box 2).

Options for emissions mitigation need to be considered with food security and adaptation to climate change in mind.[18] Climate change is predicted to have profound effects on global food production via temperature change, altered water availability, and changing patterns in crop pests and diseases, among other things.

Mitigating Nitrous Oxide Emissions

On-Farm Nitrogen Management
The addition of synthetic nitrogen fertiliser to land leads to increases in crop yield but also to large amounts of reactive nitrogen being added to soils (Box 4). Under most conditions, the more nitrogen added to soil the greater the nitrous oxide emissions.[19] A desired balance is to supply adequate nitrogen to maximise crop yield while reducing the release of excess nitrogen into the surrounding environment (nitrogen pollution). However, in England, 40% of farms have no nitrogen management plan (accounting for 26% of the farmed area) and Scotland reports similar figures.[20,21] Defra provides guidance on application levels for different crops under a range of conditions,[22] but the Agriculture and Horticultural Development Board is concerned that much of this information is out of date.[23,24]

Box 2. On-Farm Energy Management
Some examples of on-farm energy-efficiency measures:

- The Potato Council has identified energy costs associated with potato storage as a sector focus and has launched the Storage 2020 project to assist growers.[25]
- In horticulture, use of LEDs, improved design, and consideration of alternative energy sources for lighting and heating can improve greenhouse energy-efficiency.
- The UK tomato industry uses atmospheric CO_2-enrichment to improve yields. Using waste-CO_2 improves energy efficiency, for example Cornerways Nursery uses waste-CO_2 from British Sugar.[26]

Good nitrogen management requires the farmer to know how much nitrogen is in the soil and other relevant soil properties, such as pH, as well as the quantity of farmyard manure and slurry (FYMS) available for addition to land and how much nitrogen it contains. Weather conditions play an important role, as nitrous oxide emissions tend to be associated with warm and wet top soils (as well as with high soil nitrogen levels).[27] Careful timing of fertiliser applications, on the basis of medium-range weather forecasting and crop requirement, can reduce both direct emissions of nitrous oxide and leaching of nitrogen into water bodies.[11] Appropriate FYMS application techniques, storage capacity and management will also help to minimise nitrogen pollution (POSTnote 453). Managing land to reduce levels of nitrogen in water bodies also has the benefit of reducing nitrous oxide emissions.

Precision Farming to Optimise Nitrogen Management
Precision farming uses technology, agricultural engineering and data to help farmers apply treatments efficiently through the 4Rs: "right intervention, right time, right place, and right amount" (Box 3). In 2012, 22% of English farms used Global Positioning Systems and 20% used soil mapping to optimise treatments. Larger farms are more likely to take up the technology with almost half of farmers who do not use any precision farming techniques stating that they are not cost effective or the initial setup costs are too high.[28] The recently launched £160 million Agricultural Technology Strategy, co-funded with industry, includes funding for the translation of precision farming research.

Plant Breeding to Optimise Nitrogen Management
Most commercial plant breeding focuses on maximising crop yields under optimal plant growth conditions. Focusing breeding programmes on optimising yields under lower nitrogen conditions would take account of the link between soil nitrogen levels and pollution.[29] A large body of research highlights the importance of plant root and soil interactions in affecting plant growth and GHG emissions from soils.[30-33] Plants are influenced by the soil environment but they can, in turn, affect the communities of soil microbes that produce GHG emissions (Box 4).

Agroecology to Optimise Nitrogen Management
Agroecology emphasises ecological principles in the design and management of agriculture and explicitly integrates the protection of natural resources into food production.[34] For example, organic farms rely on biological nitrogen fixation by legumes, such as clover, to supply nitrogen, instead of artificial fertiliser (Box 4). These farms avoid GHG emissions from fertiliser manufacture and some studies have shown less nitrous oxide emissions from soil per unit of land.[35,36] However, there are often lower yields which offset these reductions.[35,36] Some studies have found the cropping system and site characteristics are more important than any organic/non-organic distinction.[37-39] For example, many non-

Box 3. Precision Farming and The Internet of Things
Fertilisers are usually applied at uniform rates across a field. However, using a precision farming approach creates soil property and crop growth maps through manual sampling, in-field or vehicle-mounted sensors or by aerial or satellite imaging. Software then predicts the level of inputs for each part of the field that will produce the greatest yield increases with the lowest costs. As machinery passes through the field, variable-rate application devices automatically adjust the delivery of seeds, fertiliser or plant-protecting chemicals to distribute them optimally.

The Internet of Things (POSTnote 423) connects devices, such as in-field sensors with previously isolated data sets, such as farm fertiliser records and meteorological information; this enables better management decisions based on more comprehensive information.

organic farms are also making use of legumes within crop rotations to supply nitrogen to the system.[40]

Agroforestry is an agroecological land-use system that integrates trees and shrubs with crops and/or livestock production. It is used in the production of global commodities such as coconut, coffee, tea, cocoa, rubber and gum.[41] Agroforestry systems require less fertiliser inputs as less nitrogen leaches out of the soil and recycled nitrogen from leaf litter provides a source for adjacent crops.[42] It is not clear how nitrous oxide emissions from soil are affected.[43] Increasing tree cover on agricultural lands reduces atmospheric carbon by increasing terrestrial carbon storage. A review of tropical agricultural systems highlights the potential of agroforestry to mitigate GHG emissions.[44] Agroforestry's potential for mitigating GHG emissions in temperate systems has been less well studied.[43,45]

Improving Global Use of Fertiliser
Large parts of the world – and sub-Saharan Africa in particular – suffer from low production efficiencies due to poor soils and low fertiliser application rates. The Alliance for a Green Revolution in Africa (AGRA) has enrolled 1.75 million small-holder farmers in a programme to increase yields through monitoring soil health and providing access to fertiliser, legume seeds and microfinance. AGRA farmers now use 10-50 kg of fertiliser per hectare, and although just a tenth of what farmers use in richer countries, this has helped contribute to an average doubling of yields.[46] Proponents of an agroecological approach highlight the potential for adopting alternative management practices sensitive to local conditions, such as optimising planting and weeding dates, erosion control and water harvesting.[47,48] As the largest producer and consumer of nitrogen fertiliser, China's participation is critical to global efforts to reduce nitrogen-related GHG emissions. The use of nitrogen fertiliser has helped double crop yields in China during the past three decades. However, recent studies have highlighted gross over-application with a nationwide application rate of 30-60% above optimum.[49,50]

Mitigating Carbon Dioxide Emissions

Maintaining Soil Organic Carbon Stocks
Soil contains organic material, some of which is carbon. Soil organic material is composed of soil microbes, decaying plant and animal tissues, faecal material and products formed from their decomposition. Soil microbes can make carbon and nitrogen available to plants, immobilize carbon and nitrogen in soil, and also decompose organic material to CO_2. Soil organic carbon is in a dynamic balance between the addition of carbon via routes such as manure inputs, returning crop residues (such as straw) into the soil, root growth and root exudates and emissions of CO_2 via decomposition of organic matter by soil microbes.

Box 4. Potential Nitrogen Management Biotechnology Solutions
Nitrogen is an essential element for life. It occurs predominantly as an unreactive gas in air; which means that only a few organisms can utilise it directly. This ability is only available to a select group of plants, including legumes (e.g. alfalfa and clover). These plants form a mutually-beneficial association with bacteria which can convert unreactive nitrogen from the air into a reactive form of nitrogen which is available to the plant. Scientists at the John Innes Centre in Norwich are in the early stages of a project that aims to transfer this capability into cereal crops.[51,52]

Industrial-fixation of nitrogen from the air creates reactive nitrogen (synthetic fertiliser) which can be added to soils in a form available to plants. The large amount of synthetic fertiliser added to agricultural systems has led to nitrogen cycles dominated by processes called nitrification and denitrification. These processes lead to enhanced nitrous oxide production by soil microbes; which reduces the amount of nitrogen in the soil available to plants. To address this issue there has been research conducted into the inhibition of these processes:
- Chemical nitrification inhibitors have shown potential in arable and grassland trials, however cost-effectiveness remains uncertain.
- Some varieties of crop plants naturally inhibit nitrification and reduce nitrous oxide release from denitrification: 'biological inhibition'. Research carried out at the James Hutton Institute in Dundee has highlighted the potential of high-yielding spring barley varieties to limit nitrogen losses. It is thought that varieties from other crop species may hold the same potential.[53]

Modification of agricultural practices is a recognized method of carbon sequestration, as soil can act as a carbon store.[1,2] It has previously been proposed that no- and reduced-tillage (ploughing) practices increase organic carbon stocks. However, evidence published in 2014 suggests that this is not the case and stocks remain the same but are distributed differently in the soil profile.[54] Long-term studies have shown that increasing manure inputs and the amount of crop residue left in the soil can increase total soil organic carbon stocks.[55,56] A review examining datasets from 74 studies in (mainly temperate) climatic zones across the globe found higher carbon stocks on organically-managed farms.[57] Soil organic carbon accumulation will not occur indefinitely: evidence from modelling studies demonstrates that the amount accumulated will reduce (and eventually stop) as a new steady-state is reached[3,5] and accumulation may be reversed if land management practices change.[58]

Defra's interpretation of the available evidence is that soil carbon storage is not an effective mitigation option in the UK.[5,6] Benefits of storage may be insignificant or outweighed by increases in nitrous oxide emissions, the risk of nitrogen run-off into water and short-term elevated CO_2 emissions.[59]

Maintaining carbon stocks in cultivated soils is important for sustaining yields and preventing soil degradation.[3,4] Soil degradation can lead directly to GHG emissions (Box 5).

There has been an overall loss of soil carbon from the UK's intensively-managed agricultural soils since the 1970s.[60]

Mitigating Methane Emissions from Rice Cropping

Rice feeds almost half of humanity.[61] Flooded rice contributes approximately 10% of global agricultural GHG emissions, with methane as the primary GHG emitted.[62] There is evidence that including a dry period leads to an average 48% reduction in methane emissions, without yield reductions. Approximately 40% of rice farmers in China and more than 80% in north-western India and Japan are applying a dry rotation as part of water-saving practices.[62] Composting rice straw before incorporating it back into the soil reduces methane emissions, as the act of composting reduces available carbon for the methane-emitting soil microbes.[63,64]

Using Policy to Reduce GHG Emissions

In the UK there is no specific legislation addressing agricultural emissions reductions. Instead, a voluntary industry-led approach has been adopted. Organisations from the sector in England have developed the Agricultural Industry GHG Action Plan[65] and the cereals and oilseed industry has a 'Roadmap' to assist with emissions reduction.[66] In the UK, cereals cover 51% of croppable land, with oilseeds and other arable making up 20%. Horticulture and potatoes cover 5% by area.[67] The Government is also supporting scientific and technological advances in 'sustainable intensification'; whereby yields are increased without damaging the environment including the cultivation of additional land.[68] In 2016, the Government plans to bring forward legislation for the Fifth Carbon Budget (which covers the period 2028-2032). The Committee on Climate Change (CCC) has recommended that Government ensures the agricultural sector monitors the effectiveness of the Industry Action Plan. They highlighted the need for quantifiable targets and evidence of buy-in from farmers, to allow effective evaluation in the Government's 2016 review.

The Scottish Government has developed the Farming for a Better Climate website which is designed to encourage voluntary uptake through the provision of information on win-win actions in five key areas, one of which is optimal application of fertilisers and manures.[69] It plans to introduce regulation if sufficient progress is not made to increase nitrogen use efficiency.

The Welsh and Northern Ireland Administrations have also established plans to consider how agriculture can reduce emissions.[70,71] One of the aims of the 'greening' component in the latest set of Common Agricultural Policy reforms is to support climate-beneficial agricultural practices.[72] However, the CCC has stated they are unlikely to reduce GHG emissions significantly.[9]

Box 5. Soil Degradation in England

Areas of lowland peat, such as the Fens and the Lancashire Coastal Plain produce 40% of the vegetables grown in England.[73] Once wetlands, these areas were drained for agriculture. Drainage of carbon-rich soils leads to soil degradation as microbes decompose the organic material and CO_2 is emitted. The top soil has disappeared completely in some areas and climate change could lead to complete loss from remaining areas in 30 to 60 years.[74]

The Natural Environment White Paper sets out the Government's responsibility to manage lowland peat soils in a way that supports efforts to tackle climate change. Suggestions to prevent the continued loss of these soils include re-wetting areas for low-intensity livestock grazing on wet grassland, wet agriculture (such as sphagnum moss farming and reed bed creation) and restoration of wetland habitats. (Some of these options take the land out of food production). These mitigation options can support other benefits such as water quality, flood management and biodiversity improvements.

What Works Where

To establish which mitigation mechanisms are most effective they need to be considered as part of a wider system. Systems assessments can take into account all inputs (e.g. imported feed and synthetic fertiliser) and outputs (e.g. pollutants and crop yields) and costs that fall outside farming, such as additional drinking water treatment. Applying this approach when evaluating options helps avoid:

- 'pollution-swapping' (when a mitigation option introduced to reduce one pollutant results in an increase in another)
- 'exporting emissions' (e.g. domestic GHG emission reductions being offset by increased emissions abroad).

Such assessments can use production efficiency calculations, such as how much GHG is emitted relative to a unit of agricultural production. There are different ways of calculating this, such as emissions per dry weight of crop, per area of land cultivated or per nutrient consumed, or other assessment approaches based on economics and pollution-swapping modelled using nitrogen budgets.[75] Debates continue over appropriate models and metrics, relevant time-frames, inputs and outputs.[76-79]

Recent studies predict that efficiency measures alone will not ensure environmentally-sustainable food security.[13,80-84] The food system is global: the UK imports 40% of total food consumed,[85] so international agricultural emissions need to be included through systems assessments. Demand-restraint measures, which focus on dietary change (e.g. eating less livestock products) and reducing food waste (POSTnote 453), need to be considered alongside issues such as affordability and access to adequate nutrition that are affected by social and cultural factors.[76,86-90]

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