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POSTNOTE

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Climate Change and Agriculture

Agriculture is highly vulnerable to climate change impacts, which has implications for food security. This POSTnote examines measures to reduce the impacts of food production and agricultural land use on climate change (mitigation) and to adapt agricultural land use to that change (adaptation).

Overview

- Agriculture is one of the most vulnerable sectors to the impacts of climate change, as well as the fourth highest greenhouse gas emitting sector globally.[1]
- Changes in temperature and rainfall, shifting pests and diseases, and increasingly frequent extreme weather events will affect food production and security globally.
- Emissions from food production could be reduced by encouraging healthier diets, reducing food waste, and changing farming and land management practices.
- Agriculture could be more resilient to climate change impacts through new technology or by diversifying crops on farms.
- Changes in food demand and farming practices may enable land to be taken out of agricultural use for land uses that deliver climate change mitigation and adaptation.

Background

Agriculture is responsible for a substantial proportion of UK (10%) and global (10–12%) greenhouse gas (GHG) emissions that cause climate change.[2,3] In the UK, climate change is projected to result in warmer, wetter winters and hotter, drier summers.[4] Globally, climate change is projected to increase temperatures and change rainfall patterns; increasing the frequency of extreme events, such as droughts and floods.[5] Resulting impacts on food production come at a time when there is increasing pressure from population and consumption growth.[6] Impacts of climate change on agriculture across the globe will have direct implications for UK food security (PN 556),[7] as the UK imports 40% of the food it consumes.[8]

The Climate Change Act 2008 requires UK GHG emissions to be reduced by at least 80%, compared with 1990 levels, by 2050.[9] Current national emission reduction commitments are not sufficient to meet the Paris Agreement to limit global temperature increase to "well below 2°C".[10,11,12] The UK Government has requested advice from the Committee on Climate Change (CCC) on setting a 'net-zero' GHG emissions target in line with the Paris Agreement.[13]

This POSTnote considers the impacts of climate change on food production globally and the implications for the UK, as well as options for reducing emissions, and approaches for adapting agriculture to climatic changes.

Potential Climate Impacts on Agriculture

Agriculture is highly vulnerable to climate impacts as it is based on biological systems dependent on weather and climatic conditions. Impacts will vary by location, socio-economic setting,[14] and level of future global warming (PN 594).[15] Impacts are discussed below for 2°C of warming.

Global Impacts

Any level of climate change will affect growing conditions for fruit, vegetables, cereals and livestock, including changes to temperature and availability of water. Temperature rises of 2°C will have a negative impact on production of major cereal crops in tropical regions. In temperate regions the impacts may be positive or negative.[16] Globally, it is estimated that each 1°C rise in mean temperature will reduce yields of wheat by 6.0%, rice by 3.2% and maize by 7.4%.[17] Higher temperature increases will cause heat stress in livestock, leading to reduced welfare, health and productivity.[18,19] A key constraint on crop and fodder production will be water availability,[20,21] which will decline in key crop-producing regions such as southern Europe, China and the USA,[22] affecting irrigation systems and food production. The current risk of simultaneous crop failures due to water shortages in the US and China is already estimated to be 6% per decade and may increase with climate change.[23] The increasing frequency of extreme weather events, such as drought and floods, will damage crop and livestock populations, as well as farming infrastructure and livelihoods.[24,25]

Further pressure will be placed on food production by increases in pests, weeds and diseases.[25] Warmer temperatures increase winter survival of existing insect pests, leading to increases in crop damage and pesticide use.[26] Changing temperatures may shift the ranges of pests and diseases to new areas where crops lack resistance.[27]

Impacts on Food Security
The Food and Agricultural Organization of the United Nations states that, "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food".[5] Climate shocks were one of the leading causes of food crises in 2017.[24] Climate variability impacts food security by making production less reliable, which increases food price volatility and reduces access to food.[20] The production of cereal crops, which provide most of the world's calories, and vegetable crops, which provide important nutrients, are projected to decline, particularly in tropical regions.[16,28] Although increased atmospheric carbon dioxide (CO_2) may promote growth in some plants, this can lead to the dilution of protein and mineral content in crops. As a result, projected increases in CO_2 are expected to put hundreds of millions of people, mostly in Africa and South Asia, at risk of zinc, iron or protein deficiencies.[20,29–31] In addition, the projected increase in frequency of extreme weather events may lead to increases in human displacement and migration.[20,32,33]

UK Impacts
More frequent extreme temperatures and changes to rainfall patterns will lead to overall negative impacts on production in the UK, even if a warmer UK climate may improve growing conditions for some crops.[34] For example, livestock are vulnerable to the migration of diseases with climate change. Bluetongue disease has appeared in sheep in northern Europe, possibly because of temperature-driven shifts in the range of disease-carrying midges.[35] Crop production is already being impacted by the availability of water resources. For example, the 2018 UK heatwave led to low yields of most UK crops, such as cereals, carrots, potatoes and livestock fodder.[34,36] In addition, the 2011 Government Foresight report on International Dimensions of Climate Change and the CCC's Risk Assessment 2017 highlighted the importance of global climate change impacts affecting the UK through trade networks.[7,37] For example, the UK imports 3.8% of fruit and vegetables from highly climate vulnerable countries such as Belize and India, and a further 13.8% from moderately vulnerable countries such as South Africa and Brazil.[38] Reductions in fruit and vegetable availability in the UK will have negative impacts on health.[28,39]

Emissions from Agricultural Production
To meet rising food demand while reducing the environmental impacts of food production, more food will need to be produced using less land and emitting less GHGs (PN 589).[40] Unintended increases in GHG emissions may occur if trade-offs with increased food production are not considered.[32] For example, increasing food production through expansion of agricultural land rather than increasing yields from existing agricultural areas may increase emissions, particularly when it results in deforestation in tropical countries.[41,42] Such changes in land use and vegetation returns carbon stored in trees and soils to the atmosphere (PN 466). However, using higher levels of inputs, such as fertiliser, to increase yields on existing agricultural land could also raise GHG emissions.[43]

It will not be possible to meet international climate change targets without reducing emissions from agriculture and land use.[44,45] However, as demand for food production is increasing globally and emissions from this sector are the result of biological processes essential for food production, such as livestock digestion, reductions will be challenging.[46,47] There are also time lags in emissions reductions from land use changes. For example, it can take decades for GHG emissions reductions from restoring peat-lands to be observed.[48] Progress in reducing emissions from agriculture has been slow in the UK, EU and globally.[3,34,49] In the UK, agriculture may become the second highest emitting sector by 2050 if emissions reductions in other sectors, such as energy, continue at current rates.[34]

GHGs emitted by agriculture include nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2). Different GHGs vary in their contribution to the greenhouse effect. N_2O and CH_4 have stronger warming potentials than CO_2 (PN 594). The main agricultural sources of GHGs are:

- **N_2O**: released by microorganisms in soils when fertilisers (synthetic, manure or slurries) are applied to land and through the deposition of ammonia (PN 453).
- **CH_4**: released by fermentation in the digestive systems of ruminant livestock, such as cattle and sheep, anaerobic breakdown of stored manure and slurry, and decomposition of organic matter in flooded agricultural lands such as rice paddies (PN 486).
- **CO_2**: released by land use change, such as draining peat-land for agriculture and deforestation for agricultural expansion,[3] on-farm energy use from non-renewable sources, and through crop storage.

Globally, the main sources of on-farm GHG emissions are N_2O from soils (38%), CH_4 from ruminant fermentation (32%), CH_4 from rice paddies (11%), and N_2O and CH_4 from manure management (7%).[50] The remaining 12% of GHG emissions arise from biomass burning.[50] In addition to on-farm GHG emissions, deforestation for agricultural expansion is estimated to add a further 20–50% to these emissions.[51,52]

Reducing Emissions from Agriculture
Mitigation of emissions from food production can be achieved by changing the demand for food production and adoption of best farming and land management practices.[53–56] Different agricultural products vary in their emissions

intensity (GHGs per unit of production) and land use by up to 50-fold.[51] Reducing demand for, and production of, products with high GHG emissions and high land use would be an effective mitigation option. Between farms producing the same product, emissions intensity can vary up to 12-fold,[51] so adhering to best practice on-farm could reduce emissions.[57,58] Analyses by the EAT-Lancet Commission and others suggest that to meet the Paris Agreement goal,[10] demand for high-GHG products will need to be reduced, in addition to changes in farming practices.[53–56]

Changing Demand for Food Production

Reducing demand for high-GHG foods by switching to healthier diets and tackling food waste are two possible mitigation options. The emissions reduction potential of population level dietary change has been estimated to be two to threefold greater than that of food waste reduction or changes to farming practice.[53–55]

Global Dietary Change

In developed countries, tackling overconsumption of calories would bring benefits for health and GHG emissions.[39] In particular, reducing production and consumption of high-GHG foods, such as meat and dairy (Box 1),[3,51,59] and substituting them for lower-GHG foods, such as cereals, legumes and vegetables, would reduce GHG emissions as well as having benefits for health.[32,52,54,60–62] However, globally, meat demand is rising with increasing wealth and consumption growth.[63] Modelling suggests that changing global diets to meet World Health Organization (WHO) diet guidelines[64] could reduce global mortality by 6% and food production GHG emissions by 29% by 2050.[53,60] Further reductions in red meat consumption, as suggested by the EAT-Lancet commission, could reduce global adult mortality by 19–24% and emissions by 49%.[54] In the UK, changing diets to meet government 'Eatwell' guidelines could reduce UK food production emissions by 18%,[65] while meeting WHO guidelines could reduce them by 17% and increase average life expectancy by 8 months.[66,67] Policy approaches to encourage dietary change range from fiscal incentives and subsidies,[68,69] to improving awareness and education through food labelling.[70] These policies may adversely impact vulnerable groups that are already malnourished.[39]

Reducing Food Waste

An estimated 30% of food produced globally for human consumption is wasted or lost.[71] In mid- and high-income countries, most food is wasted by the consumer, whereas in lower-income countries most wastage occurs earlier in the supply chain, such as during crop transport.[71] Overall, the GHG emissions associated with the full life cycle of wasted food is estimated to be equivalent to 4.4 billion tonnes of CO_2 annually.[72] This is roughly equal to the total emissions of the EU.[73] Reducing food loss and waste by half, in line with Sustainable Development Goal target 12.3, could reduce food system GHG emissions by 6–12%.[53,54,65] Approaches to tackle food waste in the UK include the Courtauld Commitment, a voluntary agreement for food producers, suppliers and retailers, which aims to reduce per capita food waste by 20% by 2025. Policy approaches include Defra's 2018 Resources and Waste Strategy for England that announced £15 million to reduce food waste, and consultations on annual reporting and mandatory targets on food waste for food businesses.[77]

Box 1: Variation in Emissions from Beef Production

The global average emissions intensity of beef production is ~50-fold greater per 100g protein than from peas, nuts or other pulses and ~tenfold greater than for poultry meat or fish. However, the emissions intensity of beef varies depending on the mode of production: the average emissions intensity of beef from a beef herd is double that of beef from a dairy herd.[51] GHG emissions from ruminant fermentation and manure management contribute 40–60% of emissions from beef production, and land use change up to 20%.[3,51] Cattle herds are also vulnerable to climate change impacts, such as heat stress and shifting pests and diseases.[18,74] Approaches to beef production range from intensive indoor production to extensive outdoor grazing, and can include aspects of both:

Intensive, largely-indoor beef production

- Benefits: can control indoor environment to prevent heat stress and feeds to reduce methane emissions.[18,75] Greater efficiency of manure collection for anaerobic digesters.
- Challenges: requires additional land to grow cereal crops for cattle feed,[59] and potential animal welfare issues (PN 588).

Extensive, largely-outdoor beef production

- Benefits: grazing land can sometimes improve soil carbon storage[41] and be an important part of a mixed farming (crops and livestock) approach, such as rewilding or agroforestry. This can mitigate emissions and improve the resilience of the landscape to climate change (PN 537).[75]
- Challenges: grass-only diets are a less efficient feed than those that incorporate other crops, such as maize.[76] Competition for land may arise with arable crop production in lowland areas or afforestation on marginal lands.[34]

Changing Agricultural Practices

Global agricultural GHG emissions could be reduced by 10–20% through changes in land management or farming practices to decrease GHGs per unit of production.[50,53,54] Key approaches include improving:[3,50]

- **Cropland management**, including through fertiliser management,[43,78] increasing leguminous and cover crops,[79] and improving rice management.[80]
- **Grazing land management**, including through fire management, nutrient management,[78,81] and introducing deep-rooting species (PN 453).[82]
- **Agricultural peat-land management and restoration**, by raising water levels and either taking them out of production[34] or growing wetland crops such as black alder or reed grasses for biofuel or construction.[83]
- **Livestock management**, including using novel feeds and additives (PN 499),[84] improving herd health,[85] and breeding varieties that produce less methane (PN 453).[86]
- **Manure management**, including good slurry storage, managing ammonia emissions and use of anaerobic digestion to capture methane.[87,88]
- **Integrated systems**, for example agroforestry (see Diversifying Production, and UK Land Use for Adaptation and Mitigation).[34,89,90]

The applicability and mitigation potential of these measures depends on context, including climate, soils, historical land management and the social setting.[91] Approaches that seek to sequester more carbon in soils may have less mitigation potential than improved management of nitrogen in many contexts.[92,93] Voluntary initiatives to reduce emissions from agriculture in the UK include the Linking Environment and

Farming Marque Standard and the industry-led GHG Action Plan.[94,95] However, in 2018 the UK Committee on Climate Change stated that the GHG Action Plan would not deliver sufficient emissions reductions to meet the UK Climate Change Act target.[34]

Adapting Agriculture to Climate Change

Adapting agriculture to climate change requires adapting the ecosystems that underpin it. The most suitable adaptation measures will depend on local context.[14] Ultimately, crop and livestock production may need to migrate to areas of suitable climate.[20] Adaptation options include use of new technologies and diversifying production on-farm.

Technologies for Adaptation

- **Breeding new crop varieties,** through gene editing (PN 541) and other approaches, that are more resilient to changing environmental conditions, such as reduced water availability or increased salinity (Box 2).[96]
- **Breeding new livestock varieties** that are more resilient to heat stress or diseases,[74] and adoption of heat stress abatement measures, such as improved ventilation in livestock housing.[97]
- **Controlled-environment farming (CEF)**, where heat, light, water and CO_2 can be optimised for crop growth in enclosed environments. However, CEF requires high energy inputs. Using low-carbon electricity, waste heat or CO_2 from industrial processes can alleviate this (PN 499).

Diversifying Production

In principle, a high diversity of crops and mixed land uses such as the integration of livestock increases the resilience of farm productivity to climatic changes.[98–100] High diversity, low-input approaches have been broadly defined as agroecological farming.[98,101] One approach is to plant trees in crop- or pasture-land (agroforestry) to increase carbon storage in trees and soils,[89] and support water and nutrient cycling.[34,90,102,103] For example, increases in temperature and reductions in rainfall reduce yields of arabica coffee.[104] Under these conditions, coffee yields can be improved by planting shade trees,[105,106] which buffer temperature extremes by up to 5°C.[107] Economic returns can be increased by choosing shade trees that produce high value crops, such as macadamia nuts.[108]. While agroecological practices can increase yields in tropical countries, they are not likely to increase yields in Europe as production is already highly intensive.[109] Scenario modelling suggests that if European diets shifted to meet WHO guidelines,[64] reducing demand, then food requirements could be met by agroecological farming in Europe.[110]

UK Land Use for Adaptation and Mitigation

Reducing demand for food and changing farming practices can release agricultural land for other uses that have benefits for mitigation and adaptation.[34,40] For example, afforestation (planting forests) and peat-land restoration improve the resilience of the landscape to climate impacts, while also increasing carbon storage in soils and vegetation.[34,93,111–113] Afforestation has been estimated to be the most cost- effective land use mitigation option in the UK.[75] However, competition for land between food or biofuel production, nature, housing and other uses may lead to perverse outcomes if not considered simultaneously. For example, high biofuel production has been projected to lead to increased food prices and food insecurity.[118]

Scenario modelling by the CCC suggests that the UK could reduce emissions from land use by 35–80% by 2050, compared with 2016 levels, by reducing grassland by 26–36%, increasing forest cover from 13% to 19%, restoring 55–70% of peat-lands and growing energy crops on 5% of UK land.[34] This scenario assumes significant changes in diet alters the proportion of food types produced, but maintains overall UK per capita food production.[34] This approach will only deliver mitigation at the global level if there is not a rise in embedded emissions in food imports to the UK.[52]

In 2018, the CCC suggested that more ‘transformational’ change in land use is needed to meet climate risks than the options outlined in the UK National Adaptation Programme.[119] For example, ‘transformational’ adaptation to flood risk would involve replacing arable cropland with grazing marshland.[34] However, Defra statistics suggest that only 35% of land is suitable for arable crops in the UK.[120] These land use changes bring higher net economic benefits if applied prior to climate impacts, rather than in reaction to them, and achieve multiple environmental outcomes, including biodiversity and water resource management.[34] The 2010 Government Foresight report on land use in the UK suggests that achieving large-scale land use changes would require an integrated land use planning system.[121] However, the UK Government currently does not have an integrated approach to food and health,[122] or land use policy (Box 3).[121,123]

Box 2: Genetic Conservation for Adaptation

Developing new crop varieties that are resilient to changing climatic conditions can help adapt food production to climate change.[114,115] For example, a historical bean variety from Bermuda has been re-discovered whose deep root systems make it resilient to tropical storms.[116] However, populations of wild relatives of crop plants are threatened by climate change and habitat fragmentation.[96] The genetic resources that plant breeders use to create new crop varieties are conserved in seed banks, such as the Millennium Seed Bank in Kew Gardens, as well as *in situ* in nature reserves or on farms.[96] In the UK, genetic diversity in seed banks rose by 15% between 2013 and 2018.[117] International agreements for conservation of genetic resources for food security include: the Second Global Plan of Action for Plant Genetic Resources for Food and Agriculture, and the Convention on Biological Diversity Strategic Plan for Biodiversity 2011–2020.

Box 3: Proposed Payments for Environmental Outcomes

The Agriculture Bill 2017–19 outlines a “public payments for public goods” mechanism.[124] This mechanism will be used to offer financial incentives to farmers for achieving environmental outcomes, including mitigation of climate change. Defra’s Environmental Land Management Scheme, introduced in the 25 Year Environment Plan,[125] may lead to marginal lands being taken out of agricultural use to deliver such environmental outcomes. This approach has been acknowledged by the National Farmers Union, whose Future of Food 2040 report suggests that “conservation will become the ‘crop’ for some farming areas”.[126]

Endnotes

POST is an office of both Houses of Parliament, charged with providing independent and balanced analysis of policy issues that have a basis in science and technology. POST is grateful to Dr Heather Plumpton for researching this briefing, to the British Ecological Society for funding her parliamentary fellowship, and to all contributors and reviewers. For further information on this subject, please contact the co-author, Dr Jonathan Wentworth.

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