Identifying future risks to UK agricultural crop production

Putting climate change in context

Jerry Knox, Joe Morris and Tim Hess

Abstract: *Internationally, agriculture is widely regarded as one of the sectors at most risk from a changing climate. This is due to the impact of increased temperatures, reduced rainfall and increased frequency of extreme events, not only in the tropics but also in temperate environments. In the UK, growers also face a range of 'non-climate' risks, which, it is often argued, present a potentially greater and more immediate threat to sustainable food production than climate change. This paper highlights the climate and non-climate impacts on crop production, the adaptation options and the institutional and regulatory barriers to their uptake by farmers. It concludes that there are likely to be both positive impacts (for example, yield gains) and negative impacts (for example, increased water stress). Either way, there will be a need for new investments in adaptive management and technology, including new collaborations between the public and private sectors, to enable UK agriculture to respond to the potential effects of climate change.*

Keywords: *adaptation; crop; food security; impact; rainfall; policy; yield; UK*

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Although UK agriculture accounts for a relatively small proportion of the national economy and employment, it occupies almost 75% of the total land area (Angus *et al*, 2009). It is strategically important in the provision of food – including both cropping (arable, horticulture) and livestock (beef, dairying, pigs, poultry) – and provides over half of all food consumed in the UK (Defra, 2010a). As in many countries, UK agriculture has a multifunctional role, sitting at the interface between the natural environment and society, whilst also contributing to a range of environmental services including landscape enhancement, leisure and recreation and the provision of non-food raw materials. As agriculture involves the manipulation of natural ecosystems, it is particularly vulnerable to climate change. But because of the interactions and feedbacks that exist between agriculture, the environment and society, any risk assessments of agriculture are notoriously difficult. In the future, producing food sustainably in a changing and uncertain climate will clearly be a high priority (Defra, 2010b), but climate change is just one of a number of stresses on agriculture, and responses to the threat of climate change need to be sensitive to ecosystems and to the diversity of benefits that agriculture provides, and not just to food production.

Recent concerns regarding future global food shortages have raised questions about food security at global and national scales (IAASTD, 2009a). The UK government seeks to achieve 'food security' by guaranteeing households access to affordable, nutritious food (Defra, 2010b). UK agriculture, along with the food industry as a whole, is charged with 'ensuring food security through a strong

UK agriculture and international trade links with EU and global partners which support developing economies' (Defra, 2010b). In this regard, it is required to be internationally competitive, whether it is delivering to domestic or international food markets. Climate change could affect not only the relative productivity of UK agriculture, but also its competitive position in international markets.

The aim of this paper is to highlight the potential impacts of climate change and other exogenous factors on UK crop production, including the most important environmental, economic, technological and societal impacts, both negative and positive. The range of adaptations available to growers and the barriers to their uptake are then briefly described. Because of the diverse composition of agriculture, we are concerned here with the sectors that relate only to food crop production, including arable, field vegetables (including root crops) and horticultural cropping. The 'non-food' production elements, namely forestry, fibre and biofuels, and the specific case of livestock, are excluded, but readers interested in these sectors are referred to assessments by Read *et al* (2009) and Moran *et al* (2009) respectively.

Climate risks to crop production

Internationally, agriculture is widely regarded as one of the sectors likely to be most impacted by climate change (Falloon and Betts, 2009), and UK agriculture is no exception. As a biological system, the driving force in crop production is photosynthesis, which is primarily dependent on the levels of incoming solar radiation. However, the production potential set by radiation is also influenced by temperature and water availability, technology, fertilizer and crop losses (Olesen and Bindi, 2002). Outdoor crops grown in the UK are particularly sensitive to changes in climate, both directly from changes in rainfall and temperature and indirectly, since any changes in climate will also impact on the agricultural potential of soils by modifying soil water balances. This affects the availability of water to plants and impacts on other land management practices (for example, trafficability for seedbed preparation, spraying, harvesting). The projected increases in atmospheric CO_2 concentration (Jenkins *et al*, 2009) will also have direct impacts on crop growth by increasing the resource efficiencies for radiation, water and nitrogen (Kang *et al*, 2009; Daccache *et al*, 2010). As a consequence, for most crops grown in northern Europe, the impacts of climate change with warmer temperatures and elevated CO_2 levels are expected to result in more favourable growing conditions (Olesen and Bindi, 2002), although of course there will also be negative consequences, which will vary spatially and temporally.

Agroclimate impacts

Information on the latest projections of climate change has been produced by the UK Climate Impacts Programme (UKCIP) using an ensemble of general circulation models (GCM) and emissions scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) (Jenkins *et al*, 2009). Using this climatology, the projected changes in summer (April to September) rainfall and reference evapotranspiration (ETo) – the main climate drivers of production – and potential soil moisture deficit (PSMD), a useful aridity index, for England and Wales for the 2050s (high emissions scenario) have been modelled and mapped (Figure 1). The maps show that for large tracts of eastern, central and southern England, where agricultural cropping is concentrated, summer rainfall is expected to reduce by between 10 and 15%. Assuming current average summer evapotranspiration (ET) rates of 3 mm/day, the projected future increases in ETo are also around 10–15%. By combining these two variables, increases in aridity from the current baseline of 20–30% are expected. This could drive production from the water-stressed areas of east and south-east England towards the north and west where growing conditions will be less constrained by soil moisture.

Crop yield and quality impacts

The changes in agroclimate could directly impact on the way UK agricultural crops develop, grow and yield. There could also be many indirect effects on production, such as changes in the distribution of pests and diseases and even the loss of agricultural land in some parts of the UK due to saltwater intrusion and flooding from sea level rise (for example, the Washlands, East Suffolk). Climate change could thus aggravate the effects on crops of stresses such as heat, drought, salinity and submergence in water (IPCC, 2007).

In the UK, the two most important impacts are likely to be changes in productivity (yield and quality) and land suitability, which will affect the viability of existing rainfed crops and create opportunities for new crop types. A summary of reported impacts on potential yields for selected crops is given in Table 1. Of course, these assume optimal production with non-limiting conditions relating to fertilizer and water availability, which themselves could constrain future production due to increased energy costs and demand for water resources. Although the data are based on different GCMs and emissions scenarios, they all demonstrate a positive impact of climate change on potential yields, varying from 13–16% for potatoes to 15–23% for wheat. It is also important to remember that for crops such as wheat, technological improvements alone have the potential to deliver significant yield increases over the next century, irrespective of climate change (Silvester-Bradley *et al*, 2005).

Table 1. Summary of reported changes in potential yield for selected UK crops in the arable and field-scale sectors.

Crop type	Projected changes in potential yield	Emissions scenario and time slice	Source
Wheat	+15 to +23%	HadCM2 2050s medium high	Richter and Semenov (2005)
Sugar beet	+1.4 to +2.0 t/ha	UKCIP02 HadRM3 2050s low and high	Richter *et al* (2006)
Potatoes	+13 to +16%	UKCP09 HadCM3 2050s low and high	Daccache *et al* (2010)

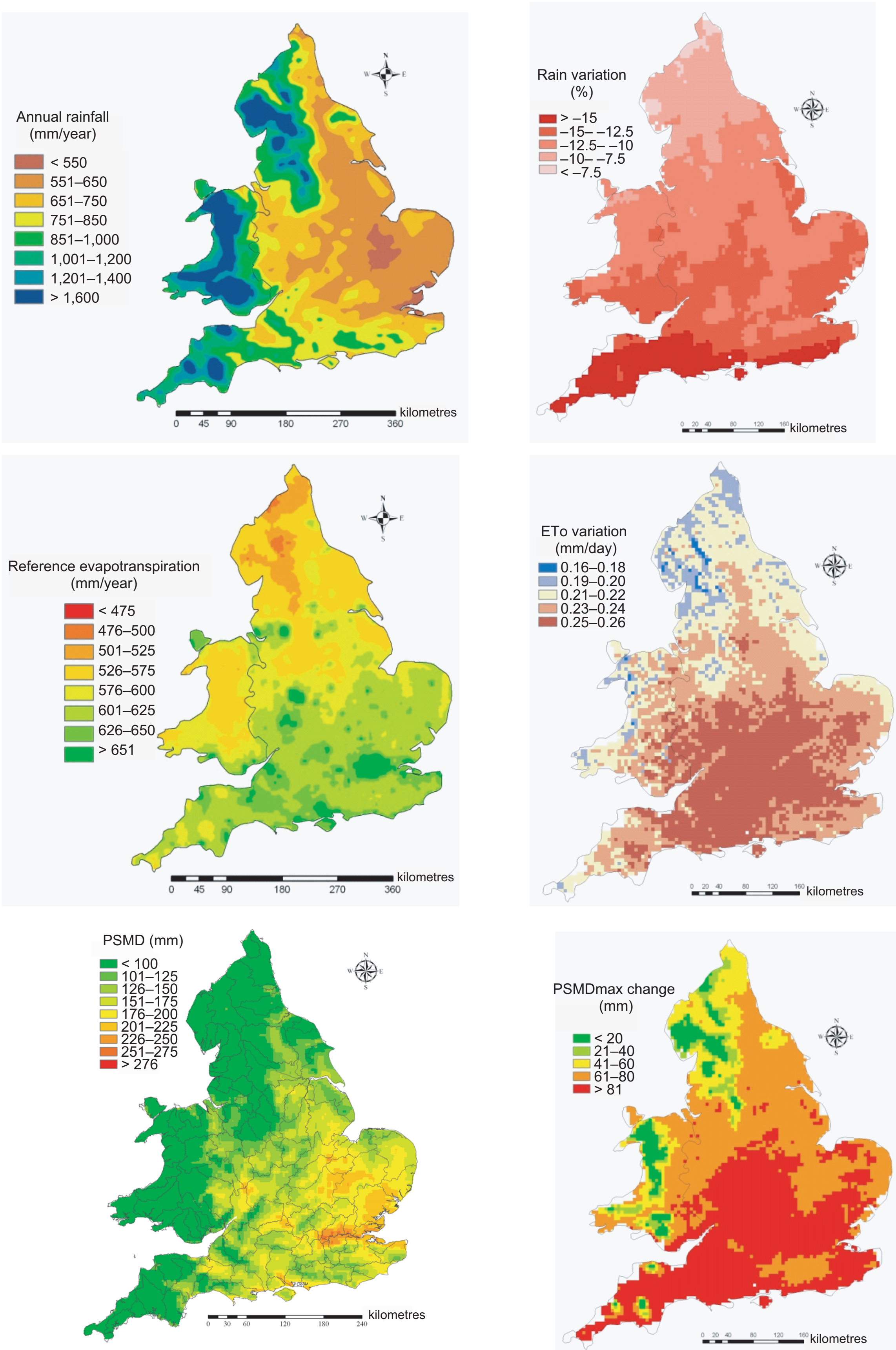

Figure 1. Projected future changes in rainfall (%), evapotranspiration (ETo, mm) and potential soil moisture deficit (mm) in England and Wales from the baseline (1961–90) to the 2050s for a high UKCP09 emissions scenario. Change data (%) relate to the summer period (April to Sept).

The projected warmer temperatures would generally allow crops to be grown further north, or at higher altitudes and for longer periods in the same location. However, an increase in summer temperature would influence a host of other factors, including the range of native/alien pests and diseases with which farmers might have to contend. It would increase the probability of damage to vulnerable crops (for example, wheat and salads) at extreme temperatures, enable greater crop diversification and result in a general lengthening of the growing season. A longer growing season in southern England may also lead to increased cultivation of continental crops such as maize, sunflowers, navy beans, soya, lupins and grapevines. High summer temperatures at critical growth stages could also have a major impact on yield, especially if they occur around flowering and seed development stages when their effect is translated into crop quality losses. Research suggests that the response to increased temperatures in field vegetable crops is likely to be positive, whilst salad and calabrese crops may suffer (Collier *et al*, 2008). Reductions in winter chilling, essential for inducing bud break, could also affect the viability of top fruit production, whilst the increased risk of water stress will impact on the yield and quality of soft fruit (Else and Atkinson, 2010).

Irrigation is thus likely to become more important, both on existing irrigated crops and on other historically rainfed crops such as wheat, in which growth is likely to be affected by increasing levels of water stress and the greater inter-annual variability in climate (Richter and Semeneov, 2005; Knox *et al*, 2010). Fifty-five per cent of potato and vegetable production is currently in catchments defined by the Environment Agency as being 'over-abstracted' (Hess *et al*, 2011). In order to maintain the premium-quality supplies demanded by supermarkets, those crops that are currently irrigated may require greater irrigation depths; and those that were previously rainfed are likely to need irrigating for quality assurance (Knox *et al*, 2009). With the increased likelihood of abstraction restrictions in dry summers in east and south-east England, there may be a gradual northward shift in production of water-intensive crops such as potatoes and field-scale vegetables to areas with suitable land and available water supplies. Irrigation of grass, which had been declining fast (Weatherhead, 2006), may become more viable to sustain livestock stocking levels, although where water is available, arable crops are likely to take priority, especially in lowland areas (Rounsevell and Reay, 2009). The economics of irrigation will depend, however, on the value and hence 'price' of water in other uses, which could increase if climate change affects the balance of water demand and supply.

It is also important to remember that changes in climate could impact not only on summer growing conditions – but increases in winter rainfall could also create new problems for managing soils and waterlogging. Excess soil water could reduce the load-bearing strength of soils to carry heavy machinery, restricting the period for harvesting and cultivations in late summer. New investments may also be required for upgrading drainage systems to cope with higher rainfall intensities. But for most crops, it will not be the gradual change in climate that causes problems, but rather the unexpected, extreme events that result in most crop and financial damage.

Extreme events

By definition, the impacts of changes in 'average' climate will be more gradual and growers will adapt autonomously, but the consequences of extreme weather on crop production will be much more unpredictable and damaging. Evidence from the 1995 drought showed that most crop sectors in the UK fared well, despite widespread negative media reports (Subak *et al*, 2000). Where not constrained by water availability cereals and field vegetables flourished in the warmer, drier weather. But consumers were impacted because lower yields led to higher prices, so consumers (rather than producers) absorbed much of the negative impact of the warm, dry year on agriculture (Subak *et al*, 2000).

A recent example of the economic impacts of extreme events on agriculture is provided by Posthumus *et al* (2009), who investigated the impacts of the summer 2007 floods, when a series of exceptional rainfall events caused extensive flooding in South and East Yorkshire, Worcestershire, Gloucestershire and Oxfordshire. They estimated the total agricultural flood damage to be £50 million based on analyses from farm visits and interviews with flooded farm owners in the regions affected. The average flood damage cost was £1,150 per flooded hectare when weighted by land use, which was then multiplied by the total flooded area (42,000 ha) reported by the Environment Agency. The analysis reported that > 90% of flood damage costs were associated with losses of farm output and additional production costs. The remainder involved damage to farm assets such as machinery, property and infrastructure. Only about 5% of agricultural damage costs were insured, compared with (typically) 80% in other sectors. The summer 2007 floods did not have a major impact on UK food supply, possibly because much of the high-value agriculture in East Anglia was unaffected; however, they probably contributed to further price increases during a year of general commodity deficit at the global scale. As 57% of grade 1 agricultural land in England is on floodplains (Morris *et al*, 2009), there is potential for increased flooding to have significant impacts on UK food production.

In summary, the impacts of a more unpredictable and warming climate on UK cropping are likely to result in a range of threats and opportunities. Increases in temperature and radiation coupled with elevated levels of CO_2 could increase crop yields, but only to a point at which other management factors, including water and nitrogen availability, are not limiting. But it will not be the gradual change in climate that will impact on growers, but rather the greater annual variability of climate and frequency of extreme events (flooding, droughts, heatwaves). Any increase in the frequency of such events will have both an agronomic and economic impact on agriculture. In this context, climate change is likely to exacerbate production fluctuations and lead to the return of buffer stocks and intervention buying – there are signs that this phenomenon, which was last seen in the 1930s, is reoccurring. Growers will also need to deal with an

Table 2. Summary of 'non-climate' risks to UK crop production, grouped according to whether they are economic, technological or environmental, and off- or on-farm.

Economic risks	Environmental risks	Technological risks
	Off-farm	
Impacts of European agro-economic policy and CAP reform on business viability. Impacts of instability in commodity markets at global and European levels on UK crop prices. Foreign exchange rates, especially £:Euro and £:US$ ratios. Supermarket pressures on the food supply chain. Cheap overseas food imports. High costs of borrowing limiting investment in new technologies and mechanization. Reduced availability of loans and finance reduce investment and promote risk avoidance in decision making. Higher UK taxes deter on-farm investment. Rising environmental costs associated with charges for water and pollution.	Low river flows limiting availability and reliability of water for irrigation abstraction. Environmental regulation (for example, Birds and Habitats Directives) constraining agricultural production. Imported, or mutated indigenous plant diseases. Monoculture reduces biodiversity (increases epidemic risks). Fear of GMOs and novel technology. Actual damage caused by GMOs and novel technology. Unidentified tipping points that lead to catastrophic failure of ecosystems, such as rapid soil loss, disease epidemics.	Inadequate research and development of new technologies appropriate to UK farming conditions. Adoption and uptake of technological advances lag behind European competitors. Improved storage and transport technologies remove barriers to imports. Cross-contamination of genetically modified plant material. Lack of investment in new research and technology (resulting in reduced competitiveness). Reduced number of people employed in the agricultural sector with a risk of dislocation to urban areas.
	On-farm	
Energy costs for crop production. Rising labour costs and labour supply problems. Rising environmental costs relating to meeting supermarket grower protocols. Rising costs of fertilizer (linked to energy costs) and seed. Reduced expenditure on flood defence and land drainage infrastructure.	Soil degradation: compaction (heavy machinery, inappropriate management)/salinity build-up (excessive use of fertilizers). Excessive use of pesticides and herbicides (risks of soil, air and water pollution affecting human and animal health and disrupting the prey–predator equilibrium). New diseases.	Reduced standards of land drainage (including flood defence). Inadequate knowledge transfer and understanding of new technologies that limit technology uptake. Rising cost of energy on which technology is dependent (affecting irrigation abstraction and machinery used in agriculture/food processing).

increasing number of 'non-climate' risks, both on- and off-farm, as these may pose a much greater degree of uncertainty for crop production.

Non-climate risks to crop production

A summary of the main 'non-climate' risks are given in Table 2, grouped according to whether they are economic, environmental or technological in nature, recognizing that there will be overlaps. These were identified via discussions with key informants in the agri-food industry, including policy advisers, practitioners (farmers), industry representatives (levy boards) and researchers. The majority occur 'off-farm' and impact on growers via various national and European agroeconomic policy interventions: these include the increasing burden of environmental regulations; limitations in the availability of finance; fluctuating exchange rates; and the relative power of supermarkets as these affect the operation of markets, including requirements for auditing and traceability. The most significant economic impacts on-farm relate to Common Agricultural Policy (CAP) reform, as it could affect farm income support, compliance requirements and incentives for environmentally sensitive farming. Rising production costs for water, energy, labour and fertilizer, coupled with increasing risks associated with infrastructure damage due to flooding, are other sources of economic risk. Much depends on whether these increased costs are offset by higher commodity prices arising from strong global demand – the latest OECD–FAO (2010) forecast is that average crop prices over the next 10 years will be 15–40% higher in real terms relative to 1997–2006. The main environmental impacts off-farm relate to changes in water availability due to low surface water flows and groundwater levels, increasing demands for water from other sectors, increasing environmental regulation and abstraction control, and the risks associated with genetically modified organism (GMO) cultivation.

The on-farm risks relate mainly to the control of the use of pesticides and fertilizers and their consequent impacts on local environments via diffuse water pollution, plus the risks of new disease and poor soil management. The main technological risks off-farm are related to insufficient R&D investment in agriculture (Royal Society, 2009), coupled with a lag in technological uptake compared with the UK's European neighbours. A decline in the capacity of skills in UK agriculture, as well as the number of people willing to work on the land are also constraints (Spedding, 2009) common to other parts of Europe and North America (IAASTD, 2009b). On-farm technological risks relate to the observed widespread deterioration in maintenance of land drains, inadequate staff training and the rising costs of energy on which new technologies are dependent.

In addition, there is a raft of international drivers that will affect UK agriculture, including the consequences for world trade, affecting both demand for, and supply and prices of agricultural commodities in global and regional markets and an increased volatility of market conditions. There are also the actions being taken by governments (including protectionism) to address climate change effects – with consequences for agricultural markets. There is likely to be greater instability in international food and energy prices, affecting fuel costs and fertilizer use, plus greater global water scarcity with consequent impacts on food production, especially in relation to food exports to the UK from southern Europe (Yang *et al*, 2007). Other international risks include:

- Agri-support funds for competitors: for example, European funds for the modernization of southern European irrigation schemes could provide competitive advantage over UK growers.
- The conversion of agricultural land from food production to production of biofuel and raw materials: the use of agricultural food commodities (such as wheat or sugarcane) for biofuels rather than for human consumption could impact on UK food imports and prices.
- Internationally agreed greenhouse gas (GHG) mitigation policies may inadvertently affect agriculture through, for example, policies to reduce energy use, which will impact on fertilizer production.
- Migration: climate change could increase the inward flux of migrants from drought-affected areas in North Africa and southern Europe northwards towards climatically 'safe havens' such as the UK, with possible impacts on local demand for land for housing, food and natural resources.

There are also likely to be societal factors, such as public and political resistance to the use of GMOs that could help to adapt to environmental change; changing dietary preferences towards healthy eating via, for example, the Food Standards Agency 'Eatwell Plate' campaign; increasing demand for year-round fresh supplies favouring food imports; and competition for land and water for development and non-agricultural uses such as nature conservation and recreation.

Farmer responses and adaptation

It may be possible to increase production under climate change if farmers can exploit longer growing seasons through the use of longer duration varieties or sequential planting. Such production opportunities may decline as climate change becomes more extreme, requiring adaptation to more prolonged and frequent droughts, changes in rainfall distribution, more storms and other extreme weather events, increased and changing pest loads and changes in soil water balances (Sugden *et al*, 2008). A selection of the most feasible adaptation measures for UK growers includes:

- changing sowing and harvest dates to cope with warmer springs and higher temperatures – for example, earlier sowing and later harvest to compensate for drought-related losses on light soils (Richter *et al*, 2006);
- improvements in seed and crop storage to deal with changes in moisture and temperature;
- switching from spring to winter cereal production;
- plant breeding for increased drought and flood tolerance and pest resistance;
- building high-flow/winter storage reservoirs to cope with reduced availability and reliability of summer river flows;
- investments in new technologies to improve water and energy efficiency;
- soil index mapping and precision farming to apply variable N, P and K to fields to reduce diffuse pollution;
- diversification of landholdings to extend crop rotations and to work towards more geographically spread cropping schedules;
- upgrading drainage systems to cope with higher rainfall intensities;
- adopting rainwater harvesting, water recycling and organic and artificial mulching to reduce water use;
- changing crop scheduling programmes, with multiple cropping (for example, of salads) to utilize extended growing seasons;
- developing international links in the food supply chain – many agribusinesses now have a European presence to provide greater flexibility and an extended season for food supply; and
- individual and collaborative actions working locally to protect natural resources (Leathes *et al*, 2008).

Small businesses and family farms with limited capacity to adapt will be most vulnerable. Conversely, large horticultural agribusinesses with high investment capital at stake may select risk-averse options that minimize the 'regret' under a range of possible future outcomes (for example, high-flow storage reservoirs). Whilst such investments may be marginally beneficial now, they become more attractive if the value of longer-term resilience and security is taken into account. Some crop sectors, such as salad and soft fruit production, may be more vulnerable since they are highly seasonal and dependent on consumer demands and the weather. Other crops such as potatoes and field vegetables may be less vulnerable, as their consumption patterns are less sensitive to the ambient weather. Given the uncertainty and long time scales, most responses to climate change will require combinations of adaptive management and technology. Developing this adaptive capacity will involve a commitment of resources now, by both the private and public sectors, in order to enhance future ability to cope with the uncertain impacts of future climate change. But for all these coping strategies, there are both barriers and enablers to adaptation, as highlighted below.

Adaptation barriers

Adaptation barriers include the following:

- a very high degree of short- to medium-term uncertainty in agricultural policy and markets, including speculative agricultural commodity trading;
- negative impacts of adaptation in other sectors – for example, the implementation of adaptation measures to

address the increased risks to urban areas from river flooding using agricultural floodplain land for attenuation could impact on crop productivity and land value;
- land use restrictions, for example, due to EU regulations and/or agri-environmental support schemes, could hamper crop diversification;
- inflexibility in the abstraction licensing regime may limit the potential for water trading and allocation of water to high-value cropping;
- poor availability of finance and investment in research and technology development;
- restrictions from planning regulations and development control;
- attempts to preserve 'existing' environments;
- the negative impact of energy policies on food production; and
- risk of overseas food suppliers failing due to extreme events: for example, food imports from southern Europe at risk.

Adaptation enablers

Enablers include:

- mechanisms and initiatives to promote improved resource efficiency; the converse of the above, including supporting education and knowledge transfer, investments, incentives, property rights, building capacity in the agriculture sector and governance systems;
- collaborative funding of science and technology to enhance adaptability to climate change;
- addressing market, institutional and regulatory failure: for example, by payments for environmental services and conservation of natural resources;
- water user associations providing opportunities for collective action in natural resource management;
- tax breaks: for example, capital allowance schemes to invest in adaptation measures; and
- legislative enablers, such as the Flood and Water Act 2010, which help promote adaptation by providing more flexible regulation for abstraction licensing.

Conclusion

The UK agricultural cropping sector faces a challenging period ahead, balancing the need to increase productivity whilst controlling spiralling farm costs, particularly in relation to energy. Growers also need to demonstrate compliance with regulations associated with environmental protection, food safety and biosecurity. In this context, coping with immediate economic, environmental and technological pressures means that farmers are less inclined to give climate change the priority it deserves as a key business risk. Climate change, however, is likely to exacerbate many of the current challenges already facing the agri-food sector. Clearly, it presents both threats and opportunities to UK crop production, but the key to tackling climate change will be in adaptation – securing access to the relevant skills, resources and knowledge to increase production efficiency, improve management and embrace new technology.

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