

Economics of Climate Resilience Agriculture and Forestry Theme: Agriculture CA0401

**A REPORT PREPARED FOR DEFRA AND THE DEVOLVED
ADMINISTRATIONS**

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Economics of Climate Resilience Agriculture and Forestry Theme: Agriculture

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Context of this report

The Economics of Climate Resilience (ECR) has been commissioned by Defra and the Devolved Administrations (DAs) to develop evidence to inform the National Adaptation Programme and the adaptation plans of the DAs. The report should be read in the context of other programmes of work on adaptation being taken forward separately.

The scope of the ECR

The ECR follows the publication of the UK Climate Change Risk Assessment (CCRA) in January 2012 and differs in scope from work envisaged prior to that date. While its original aim was to consider individual climate change risk metrics from the CCRA and specific adaptation options, this evolved as the project was considered across government departments. The current ECR therefore focuses on broader policy questions, with each report covering multiple climate risks and CCRA risk metrics. In this context, the economic assessment is broader than a quantitative assessment of costs and benefits – it concerns identifying and assessing market failures and other barriers to effective adaptation action, seeking to understand drivers of behaviour which hinder or promote the adoption of adaptation actions. The framework for assessing the costs and benefits of adaptation actions is considered in a separate phase of the ECR.

Questions addressed

The questions addressed by the ECR were chosen following cross-government engagement by Defra. They ask whether there is a case for further intervention to deliver effective adaptation given the current context – i.e. the current adaptive capacity of those involved and the policy framework. Criteria for the choice of questions by policy officials include: the current and projected degree of the climate change risk; priorities for additional evidence gathering beyond that already being considered in other work-streams, and the data and evidence currently available. Questions were deliberately broad to allow the wider context to be considered, rather than just individual climate metrics. However, this approach prevents a detailed evaluation of individual risks or localised issues being made. Detailed assessments of climate thresholds and the limits of specific adaptation options have also not been possible.

Analysis undertaken

The analysis has sought to build on existing assessments of current and projected climate change risks (such as the CCRA). The context in which sectors operate has been assessed, including the current adaptive capacity of relevant actors and the policy framework in which those actors function. Categories of actions currently being taken to adapt to climate change have been explored, including those which build adaptive capacity where it is currently low, and those which limit the adverse impacts or maximise opportunities, allowing identification of barriers to effective adaptation. The case for intervention is then presented.

The degree to which an adaptation action is likely to be cost-effective requires more detailed assessment, reflecting the particular context in which adaptation is being considered.

This report is underpinned by stakeholder engagement, comprising a series of semi-structured interviews with sector experts and a range of other stakeholders. This has enabled the experiences of those who undertake adaptation actions on the ground to be better understood. We are grateful to all those who have given their time.

1 Executive summary

How exposed is UK agriculture to climate change?

Key climate risks facing the sector are changes in average climate conditions, changes to the inherent variability of weather, and the increased frequency and severity of extreme weather events. Changes to extreme events, such as floods and drought are a potentially greater threat to agriculture than changing average conditions (Knox *et al.*, 2012).

Impacts of climate change on projected yields are subject to uncertainty. Based on projections from the International Food Policy Research Institute (IFPRI), across a range of climate change and socio-economic scenarios, yields in 2050¹ could be lower by 0.03-0.8 t/ha for wheat, 0.4 to 5.7 t/ha for sugar beet and yields could increase by 1.3 t/ha or decrease by 2.6 t/ha for potatoes, than under the current climate in that year (based on Nelson *et al.*, 2010).

Increasing CO₂ concentrations (not reflected in these projections) could however increase yields by perhaps 15% higher than without the climate change effect (assuming adequate water and nutrients), according to field research (Semenov and Shewry, 2011). However, the impacts of pests and diseases or other extreme events, such as drought, (none of which is reflected in the projections), could all act significantly in the opposite direction.

In response to these challenges, this report addresses the question set by Defra:

“Given projected climate change and current or likely adaptation, what is the case for further intervention in relation to climate change adaptation for agricultural productivity (crop yields) and production?”

Defra has requested that this work focuses on: wheat yield; sugar beet yield; potato yield, grassland yield (as a key input for livestock productivity); and, that additional commentary is provided on wider horticulture, pigs and poultry.

Context for adaptation and adaptation actions

The **adaptive capacity of the sector is in general terms relatively high** owing to the regular and short-term decisions that are required (the choice of crops, land management practices, etc.). However, **a necessary focus on the short-term coupled with the tight profit margins faced by many small farmers, (particularly of livestock), limits adaptive capacity** and longer term adaptation investment and planning.

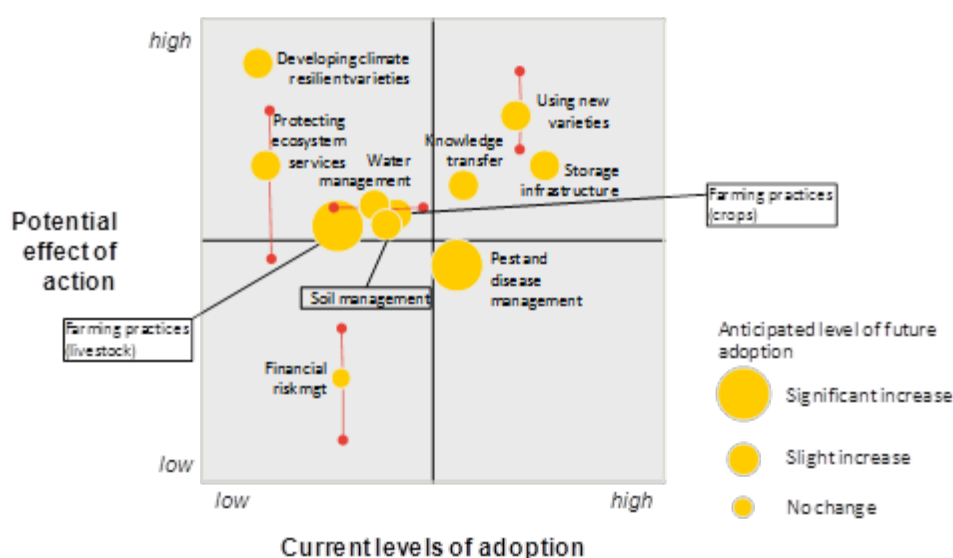
The **UK agriculture sector is heavily influenced by the policy landscape** at national, EU and international levels. At the UK and EU levels, most policies (often in the form of regulations) relate to environmental protection and

¹ Shown as the illustrative year in the modelling.

sustainability, while others – notably the Common Agricultural Policy (CAP) – relate to the operation and performance of the sector. Some policies facilitate effective adaptation (such as the Soil Protection Review and Catchment Sensitive Farming). However, the large number of policy objectives can create tensions that reduce the capacity to adapt, with environmental regulations particularly restricting genetically modified (GM) based adaptation options.

Adaptation actions are already being taken across the sector. **Figure 1** summarises the evidence on the range of the adaptation actions discussed in this report, as suggested by experts or identified in published literature. It presents the extent to which actions are likely to be effective in addressing a climate change risk, the degree to which they are currently being implemented and the anticipated level of adoption in the near-term (to 2020).

Figure 1: Summary of current and anticipated effects of different adaptation actions



Note: Scales are qualitative and relative to the sectors included. The **current levels of adoption** include decisions that are infrequent (e.g. purchase of storage infrastructure) as well as common practice (such as framing practices). **Effectiveness** varies from limited scope due to impact on yield productivity, time frames or effort involved (e.g. capacity building among individual suppliers) to major changes in risk management. Increases in future adoption reflects expected levels under current incentives, essentially over the next 10 years or so. The position of each measure is based on the classification used within this chapter, but could vary considerably depending on sector and company.

The yellow dots positioning the adaptation actions in **Figure 1** are scaled according to the extent to which an increase in uptake in the future is expected (without further intervention). The red lines illustrate variation in the levels of adoption and effectiveness of actions across different farmers.

Where actions are effective but not widely implemented – those in the top-left of **Figure 1** – barriers potentially hinder effective adaptation (cost-benefit analysis would be needed to determine the degree of appropriate implementation). Where

actions are being taken but their effectiveness is relatively low, barriers could be preventing greater effectiveness.

Barriers have been identified in terms of market failures, policy failures, behavioural constraints and governance constraints.

Barriers to effective adaptation and the case for intervention

Market failures

Dependencies are an important factor because they imply the presence of external costs or benefits imposed on another party, without those costs or benefits being accounted for in decision-making. In the case of agriculture, these arise as a result of:

- **Value-chain² dependencies:** The actions by some in the value chain can affect the resilience of others to climate change threats. For example, farmers cannot grow climate resilient varieties unless the research to develop those varieties has been undertaken, and that research has been translated into commercial products. Consumer demands may also lower the incentive to develop climate-resilient breeds.
- **Cross-sector dependencies:** Agricultural activities are inherently linked with the natural environment. Therefore, the resilience of the agriculture system and its adaptation actions can impact on the natural environment, and vice versa.

Information failures are identifiable in terms of:

- **Uncertainty** over climate change impacts which creates particular problems for planning large, high-cost adaptation options with long lifetimes.
- **Lack of tailored, practical information relating to risks and appropriate actions to manage them, targeted at those who need it most:** Although steps are being taken to share information with farmers (through extension services, for example), stakeholders have suggested that the information is, in some cases, overwhelming for farmers.

Missing markets for ecosystems services: this is a well-researched area and arises as a result of externalities – there are wider costs and benefits that are not accounted for in decision-making processes.

² This refers to the range of activities that a business or organisation undertakes to add value and deliver the product or service.

Policy failures

There are several examples where the policy framework is specifically likely to hinder effective adaptation action. Barriers include:

- The time taken to gain planning permission approvals for large investments (such as reservoirs) can cause unnecessary costs and extended delays; and
- Particular regulations can hinder the flexibility to develop and implement plant protection sprays. The latter largely stems from competing policy objectives.

Behavioural constraints

Small farms often lack adaptive capacity: Tight profit margins mean that small farms are not able to invest time and resources into adaptation which other, larger organisations may be able to. They often focus on the short-term. Others may be resistant to change familiar farming practices and to embrace new technologies.

Governance

A lack of co-ordination of parties in a particular area where there may be common benefit from an intervention, such as a reservoir, could lead to missed opportunities to enhance resilience.

Identification of these barriers, along with scenario analysis in this report, supports the case for intervention.

Recommended interventions

- **Develop adaptation roadmaps at the appropriate scale to identify effective adaptation strategies to manage climate change risks to agriculture.** Undertake research to develop a better understanding of the dependencies across agriculture and the natural environment and other sectors, and ensure the roadmaps account for these. Roadmaps should incorporate packages of actions; review points to allow learning and modifications to take place over time; incremental changes to existing processes (sharing information, etc.), and the potential for transformational actions (e.g. developing integrated pest management).
- Build adaptive capacity in relation to:
 - **Breeding activities by ensuring climate change adaptation is embedded within research programmes.** This is likely to require expertise to be integrated across the value chain.
 - **Undertaking case study research involving cost-benefit analysis of a range of adaptation actions** implemented across a range of contexts to understand the conditions under which they are likely to be effective.

Executive summary

- **Identify and empower appropriate bodies to be accountable for overseeing and advising on the translation of academic research into UK products, services and actions.** This would allow a greater level of understanding at the farm-level to help overcome behavioural barriers to adapting to climate change and breeding to develop climate-resilient traits specific to the UK. A national extension service, if appropriately designed to communicate practical, timely and easily accessible information, could offer significant benefits through disseminating and translating applicable research for farmers.
- **Identify and empower appropriate local champions to co-ordinate actions to facilitate the delivery of cost-sharing practices across catchments.** This could be appropriate where smaller farms are currently constrained by low incomes, particularly in relation to large infrastructure, such as that for water or storage.
- **Identify appropriate existing communication channels and farmer support networks to deliver practical knowledge and best practice in relation to the management of pests and diseases and water constraints, in particular.** Behavioural barriers in relation to the uptake of new technologies or perceptions of longer term uncertainties could therefore be addressed.

2 Introduction

2.1 Approach

Analysis in this report, as with each of the theme reports, is focused on a particular question set by Defra and the Devolved Administrations (DA), detailed below.

Agriculture theme question

Given projected climate change and current or likely adaptation, what is the case for further intervention in relation to climate change adaptation for agricultural productivity (crop yields) and production?

Defra has requested that this work focuses on:

- ▣ **Wheat yield**
- ▣ **Sugar beet yield**
- ▣ **Potato yield**
- ▣ **Grassland yield (as a key input for livestock productivity)**

and that additional commentary is provided on wider horticulture, pigs and poultry.

Productivity is defined as projected average annual yield (tonnes per hectare) and production in terms of volume produced. The work takes a pragmatic approach, exploring the four characteristic agricultural outputs assessed by the CCRA (Knox *et al.*, 2012) – wheat, sugar beet, potatoes and grassland – that provide an illustration of the wider sector. It is clear that other elements of the agriculture sector will also be affected by climate change, and that the issues highlighted in the box above are not of the same significance across the UK. The nature of agriculture is different in Devolved Administrations, for example, as livestock is much more prevalent. The analysis covers these wider activities, where possible.

2.1.1 Overview of approach

This work takes the CCRA (Knox *et al.*, 2012) as its starting point. That work provides an assessment of the nature and scale of individual climate change threats and opportunities projected for the UK to the 2080s. The ECR analysis was undertaken over a period of two months and draws on a wide published evidence-base and evidence from stakeholder engagement.

Agriculture theme

2.1.2 Stakeholder engagement

The work has benefited from the input of expert advisors from Rothamsted Research, the James Hutton Institute, a former Chief Scientist of the Environment Agency, and, in relation to methodology and general points, a range of other experts. In addition, the team has undertaken an extensive programme of stakeholder engagement. This includes approximately 40 in-depth semi-structured interviews with experts across the whole sector and its value chain, including researchers, academics, breeders, trade associations, sector specialists, retailers, farmers, policy makers and producers (Annex 1). In addition, a one-day agricultural adaptation forum was held, attended by 20 agricultural stakeholders, to discuss key issues related to the question set for this study.

2.1.3 Analysis

The framework for analysis to address the question involves a series of steps:

- **Understanding the scale of the challenge:** this involves exploring the evidence on the current scale of risks posed by climate change (including extreme weather events) and understanding the potential magnitude of associated impacts;
- **Understanding the context in which adaptation is considered:** this includes identifying the relevant actors and their adaptive capacity, as well as identifying relevant policies that are likely to facilitate or hinder effective adaptation;
- **Identifying and assessing adaptation actions currently being implemented by some in the sector, and considering their adoption and relative effectiveness:** These actions include building adaptive capacity and implementing action to limit damage or make the most of an opportunity. Barriers are then identified in terms of where uptake or effectiveness (or both) is constrained. Barriers are explored in the following categories:
 - **Market failures:** the degree to which there are market failures relating to pricing signals; externalities³; public goods, and where information may not be timely, accurate, relevant or complete;
 - **Policy:** the framework of regulation and policy incentives;
 - **Governance:** institutional decision-making processes; and,

³ Where there are costs or benefits imposed on others that are not accounted for in individual decision making.

- **Behavioural: factors such as short-sightedness and willingness to act.**

The case for intervention to address those barriers is then explored through the consideration of adaptive management – illustrated through roadmaps – and ‘what-if?’ scenario analysis to demonstrate the potential effectiveness of actions if barriers are overcome.

The ECR has drawn on substantial evidence from a wide range of sources. These include:

- The CCRA (Knox *et al.*, 2012) complemented by other evidence on climate change risks, where appropriate;
- Published literature from the UK and overseas;
- Data and quantitative evidence including published data, statistics and wider information from published sources;
- Stakeholder evidence, including information gathered through interviews with key stakeholders; and
- Expert testimony provided by this project’s expert advisors.

Building on the CCRA (Knox *et al.*, 2012), it is clear that in practice, threats and opportunities are not likely to occur in isolation of one another. They will interact and deliver different outcomes together than if considered separately. Capturing these interactions is therefore very important.

Projections of the impacts of climate change in this report draw on a range of sources, but the primary projections are based on those of the International Food Policy Research Institute (IFPRI) (Nelson *et al.*, 2010). The reason for not simply relying on the CCRA (Knox *et al.*, 2012), as explained in Section 3, is that IFPRI projections allow global markets to be reflected (outputs are shown at the UK level) and climate variables to interact. However, as with all modelling, there are recognised limitations, so alternative projections and analyses, such as those by Rothamsted Research, are presented for context.

2.2 Limitations

Understanding the economics of adaptation is a complex process. There are many challenges defining the context within which this work is carried out. First, the **timeframes being considered are long** - this report looks to the 2050s and beyond. This introduces **uncertainty** in terms of both future impacts of climate change (see Annex 2), and the possible socio-economic characteristics of the UK, behaviours, cultural norms and the policy context of the UK (and internationally)

over that period. In addition, the pace and scale of technological development is rapid and continually evolving.

Second, **analysis must work with currently available information** – in some areas, there are substantial gaps (as will be noted). Although significant advances have been made in recent years, for example through the development of detailed UK Climate Projections in 2009 (UKCP09) and the CCRA (Knox *et al.*, 2012), adaptation economics is a developing field of analysis. It will be important to update and monitor the analysis over time to ensure practices remain current and guided by the best available evidence.

Third, **analytical tools have limitations**. Managing uncertainty requires assumptions and scenarios to be used. Clearly, these have significant value in guiding actions and policy, but they can never provide certainty over future outcomes. Uncertainty creates particular problems for planning large, high-cost adaptation options with long lifetimes. A pragmatic and evidence-based approach to decision making is **adaptive management**. This approach is described later in this report.

Analysis has been carried out and presented for the UK as a whole, providing commentary on how this may vary across English regions and the Devolved Administrations.

2.2.1 Structure of the report

This report covers:

- **Section 3** describes the scale of the challenge given projected climate change;
- **Section 4** discusses the context for adaptation in terms of the adaptive capacity of relevant actors in the sector and the policy framework;
- **Section 5** explores the categories of adaptation actions currently being taken, and those likely, and associated barriers to taking effective action; and,
- **Section 6** discusses the case for intervention including illustrative adaptation roadmaps and ‘what-if?’ scenarios.

3 The scale of the challenge

Key messages

- Key climate risks facing the sector are long term climate change, the variability of weather, and the increased incidence of extreme weather events. Changes to extreme events, such as floods and drought, are a potentially greater threat to agriculture than changing average conditions (Knox *et al.*, 2012).
- Evidence suggests key threats affecting the sector are drought and water shortages, rising temperatures, greater diversity in pests and diseases and extreme weather events, and a key opportunity is increased CO₂ concentrations.
- Not only is crop yield likely to be affected, but production would be expected to shift across the country in response to climate change. However, the suitability of soils and terrain could cause challenges in some areas.
- There are many projections of what these impacts are likely to mean for productivity (crop yield) and production (overall tonnage and value). Projections in this analysis are mainly based on those of IFPRI (Nelson *et al.*, 2010) which illustrate that in 2050, climate change could reduce yields of wheat and sugar beet by up to around 10%; potatoes could increase or decrease by approximately 5%, relative to the current climate in that year.
- Simplistically, assuming land per crop does not change, the value of production in 2050 (relative to no climate change) could fall marginally for wheat and sugar beet but rise by almost 50% for potatoes (driven by rising prices). Livestock production could stay relatively constant (for pork) or fall by up to around 10% (for poultry).

3.1 Introduction

UK agriculture uses 17.2 million hectares, 71 % of the total UK land area. Almost all (17 million hectares) of that land is in agricultural holdings (the rest being common rough grazing) (Defra, 2011a).

UK agricultural activity sits within a global market. For example, out of a total annual wheat production in 2010 of 14.9 million tonnes, over 2.1 million tonnes were exported over July 2010 to June 2011 (HGCA, 2012). 86% of this went to the European Union (EU).

The scale of the challenge

Agriculture is a small part of the UK economy, contributing £7.4 billion, equivalent to 0.55 % of total UK output (measured as Gross Value Added). The contribution of the sector to the economies of England and Wales are broadly similar, at around 0.52 – 0.53 %, with Scotland slightly higher at 0.6 %, and Northern Ireland the highest at some 1.0 % (Defra, 2011a); although the food industry as a whole, of which agriculture is a critical part, is the largest manufacturing sector in the UK.

Agriculture accounts for 1.5 % of UK employment with a total labour force of 281,000 (Defra, 2011a). As a share of regional employment, there are substantial variations across countries in the UK, with the sector accounting for 1.1% of employment in England, but a more significant share in the Devolved Administrations: Wales (4.3%), Scotland (2.7%) and Northern Ireland (5.6%) (Defra, 2011a).

The sector is very segmented - by farm size, product type, and farmer business type. Average annual farm income in the UK is £38,800 per farm but this varies substantially across each country. England's farms have the highest income at £43,300 per farm, followed by Wales (£36,200), Scotland (£34,400) and Northern Ireland (£21,600) (Defra, 2011a).

Agriculture is a multifunctional sector providing food and non-food crops, supplying some 50% of UK food consumption (Knox *et al.*, 2012) but also ecosystem services, such as water cycling, climate regulation (through carbon sequestration) and cultural services (e.g. land for recreation, landscapes and rural livelihoods). It relies heavily on water (rain, and in some limited cases, irrigation).

The multi-functional nature of the sector therefore suggests that where adaptation actions may be required, there are likely to be important **dependencies** across functions. Despite these broad functions, this analysis focuses on productivity and production.

3.2 Focus of analysis

The choice of the four outputs selected for the purposes of this analysis is in part driven by the availability of data, but also, importantly, the extensive analysis of climate risks facing them, as presented in the CCRA (Knox *et al.*, 2012).

Table 1 presents the key statistics for the various factors on which this analysis focuses. Further detail on each is presented in Annex 4.

Table 1. Key statistics for focus of analysis

	Wheat (44% of UK arable crop land)	Sugar beet (3% UK arable cropland)	Potatoes (3% of UK arable crop land)	Grassland
Area occupied (thousand hectares)	1,939	118	138	10,000
Productivity (tonnes per hectare)	7.7	54	44	-
Volume of harvested production (million tonnes)	14.9	6.9	6.0	-
Value of production (£ billion)	1.69	0.197	0.78	-

Source: *Agriculture in the UK*, Defra, 2011a

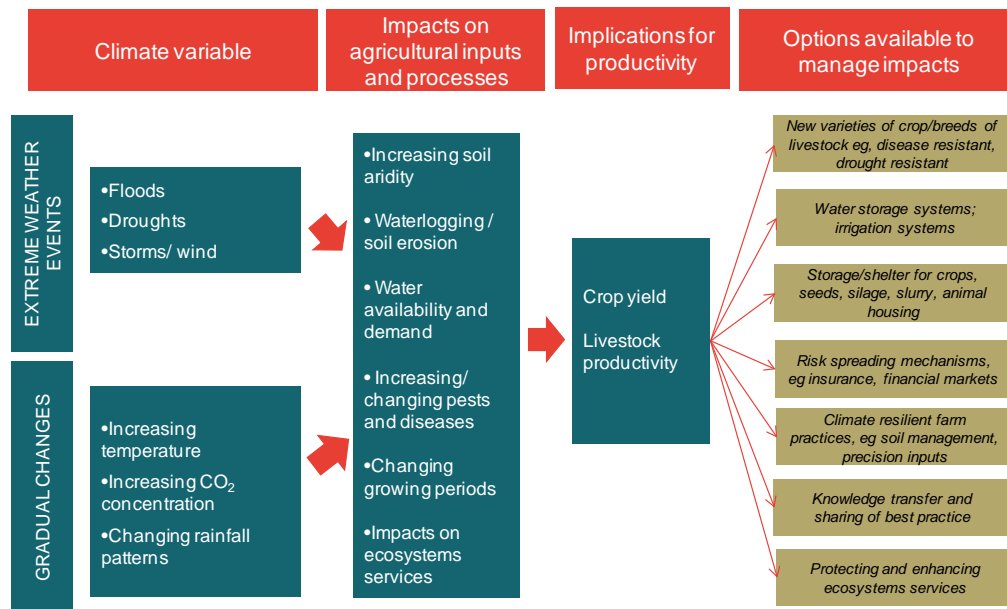
3.3 Climate change impacts on agriculture

This Section illustrates the potential impact of climate change on the selected agricultural aspects, drawing largely on the work of the CCRA (Knox *et al.*, 2012) but complementing this where appropriate (such as for the discussion of pests, diseases and heat stress in livestock).

Agriculture relies heavily on weather and the climate. Climate change is expected to influence yields, livestock productivity and health, with potential impacts also affecting farming systems. **Figure 2** shows how climate variables affect agricultural productivity and indicates some of the options farmers could explore to manage those effects.

The scale of the challenge

Figure 2. Simplified illustration of impacts of climate on agricultural productivity and examples of the available management options



3.3.1 Key biophysical factors affecting productivity and production in agriculture

Key biophysical drivers and inputs in agriculture include:

- **Land:** the amount used, its geographical location, land management practices and access to land;
- **Climate:** temperature, humidity, insolation, daylight, rainfall, wind, extreme weather events;
- **Nutrients and water:** atmospheric concentration of carbon dioxide, quality of soil, including soil structure, nutrients (naturally within the soil and with added fertilisers) and hydration (including soil water balances); and,
- **Pests and diseases:** emergence of new strains and changing distributions of existing ones.

Many of these factors are inextricably linked and, although there may be evidence of the effect of climate change on them individually, there is far less evidence on the effect of climate change on them in combination. Much of the literature appears to be inconclusive on the overall outcomes of interactions on yields. For example, for many crops in the UK, the projected increases in temperature and

The scale of the challenge

CO₂ concentration should provide more favourable conditions for crop growth and development. However, projections show these productivity gains only where the growing conditions are not constrained by factors such as water availability, nutrient availability, and increased incidences of pests and diseases (Tubiello *et al.*, 2007). In some cases, for example in legume cultivation, crop yields are reduced by warmer periods early in the growing season.

3.3.2 Direct climate impacts

Climate change is projected to impact on these biophysical factors through extreme weather events (those which are less predictable yet more extreme in their impacts), long term climate change (changes which occur as part of a longer term trend) and indirect effects via interactions of different factors. These are summarised below (further detail is provided in Annex 3).

Extreme weather events

While changes in long-term mean climate will have significance for food production, greater risks are expected from extreme weather events, with the most significant events set out below.

(a) Flood Risk

Agricultural land is at risk from flooding from rivers, coasts and estuaries. Flooding may increase due to increases of severity and frequency of extreme rainfall events in the short-term, and to sea level rise in the longer term. The severity of flooding will also be affected by climate-driven drying and compaction of soils making land more impermeable. The CCRA (Knox *et al.*, 2012) projects⁴ the area of agricultural land in England and Wales at frequent risk of tidal and river flooding to double by the 2050s, and rise by more than 150 % by the 2080s under the p50 medium emissions scenario, relative to baseline levels (1961-1990 and 2008 for tidal flooding) (Knox *et al.*, 2012)⁵.

(b) Droughts and heat waves

The CCRA did not assess droughts or heat-waves though several studies identify a rising trend of heat-waves and droughts with consequences for crop production (e.g. Luterbacher *et al.*, 2004; Schar and Jendritzky, 2004). **Expert interviews undertaken for this study provided an indicative yield loss of 1% for degree days greater than 30 degrees.**

⁴ The CCRA projections are based on GIS analysis of flood risk combined with spatial assessments of land suitability using the Agricultural Land Classification (ALC) to estimate areas of agricultural land flooded with return periods of less than 1 in 3 years, 3-5 years, and 5-10 years, for ALC 1-3 (horticulture/arable), and ALC 4-5 (grassland/grazing).

⁵ Areas at risk of flooding reported for medium emissions scenarios only in the CCRA.

The scale of the challenge

Evidence from field experiments suggests that droughts could reduce average wheat yields by 1-2 tonnes/hectare (Foulkes *et al.*, 2002) and sugar beet by about 24% (Qi and Jaggard, 2008). These experiments were undertaken for current conditions but they are indicative of the potential scale of impact.

(c) Storms/wind

Modelled climate projections do not give a clear picture of future changes to storm tracks (Jenkins *et al.*, 2009). However, it is clear that damage from storms (particularly from hail) and high winds can be severe through increasing livestock mortality, ruining crops entirely or so they cannot be sold, as well as impacting buildings and soils.

Long-term change in climate variables

(a) Rising temperatures

Crop growth cycles are related to temperature. **In general, increased temperature alone is projected to reduce the yield of cereals and annual crops** such as grassland (Thomas *et al.*, 2008; Knox *et al.*, 2012), although other crops (e.g. fruit and forage) may benefit. **The negative effects of temperature may be offset by increased levels of CO₂** if, for example, the changes in temperature are modest (e.g. Thomas *et al.*, 2008; Wheeler *et al.*, 1996).

(b) Effect of elevated carbon dioxide on crops

Rising CO₂ concentration has positive physiological effects, increasing the rate of photosynthesis (fertilisation effect), particularly in “C3” crops (e.g. wheat) which are more susceptible to CO₂ shortages than “C4” crops⁶ (e.g. maize). It can also lead to the development of fewer stomata on plants and can therefore reduce water usage (Wheeler *et al.*, 1996). Studies have suggested that there is **potential for improved production at leaf level being carried through to cropping systems over a growing season** (HRI, 2008).

(c) Changes in rainfall

Increased winter rainfall is projected, together with an increase in periods of heavy rainfall. This has the potential to increase soil erosion (Knox *et al.*, 2012), as well as cause waterlogging and crop damage.

3.3.3 Indirect climate change risks

Climate change is projected to have a significant impact on crop and livestock production through indirect effects. These are summarised below and detailed in Annex 3.

⁶ C3 and C4 refer to two different forms of carbon fixation within photosynthesis. C3 is significantly more common, but C4 plants have an advantage over C3 under conditions of drought, high temperatures and limited CO₂, and they are more efficient.

(a) Aridity

Combined reduction in rainfall and increase in evapotranspiration increases aridity, leading to higher summer soil moisture deficits. The CCRA (Knox *et al.*, 2012) found that changes in aridity using Potential Soil Moisture Deficit (PSMD) as an agro-climate index suggest central projected increases of 38% in the 2020s (medium emissions scenario p50; range -33% low emissions scenario p10 to +116% high p90) approximately 40% by the 2050s, rising to 118% by the 2080s (medium emissions scenario, p50; range 4% to 277%, for low emissions scenario p10 to high p90), with significant spatial variability. This is expected to be a particular problem in the already water scarce areas of Eastern England.

(b) Waterlogging

The CCRA (Knox *et al.*, 2012) acknowledged that waterlogging and surface water flooding can have a severe impact on agricultural land and production, through reducing productivity due to reduced respiration, leaching of salts, poaching and reducing land workability.

(c) Water availability and demand

Reduced summer rainfall, increased demand (including by other users) and the need to address unsustainable abstraction may cause increased competition for water resources in the summer. The CCRA (Knox *et al.*, 2012) estimated agricultural water demand in England and Wales for spray irrigation by combining historical abstraction data with data on aridity (PSMD). The research projected a 34% increase by the 2050s (medium emissions scenario, p50; range -9% to +75%, low p10 to high p90) and 45% by the 2080s (medium, p50; range -4% to +108%, range low p10 to high p90) against a 1990-2003 baseline. Other studies have reported increases of water demand for between 22 – 180% (Weatherhead and Knox, 2008).

(d) Pests and diseases

Climate change affects the ecology and proliferation of pests and diseases, such that some will spread into the UK from Europe and beyond. Inevitably, resistance to pesticides/fungicides are expected to increase and new strains are expected to emerge (Gregory *et al.*, 2009). The CCRA considered various marker diseases (yellow rust for wheat; beet mild yellow virus for sugar beet and blight for potatoes) and found no significant relationships between incidence and climate variability - largely due to treatment methods and improved crop agronomy significantly reducing disease expression. The interactions between crops, pests and pathogens are complex, non-linear and poorly understood in the context of climate change, making the effects on crop productivity difficult to predict (Butterworth *et al.*, 2010).

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(e) Impacts on ecosystem services

The recent UK National Ecosystems Assessment (2011) assessed pressures on broad habitats, including the impacts of farming on them. Agricultural pressures on ecosystem services (e.g. provisioning, regulating, supporting) are also projected to increase with climate change, given the reliance of the sector on the natural environment.

3.4 Projecting climate change impacts on annual average crop yields and production

3.4.1 Introduction

Understanding the impacts of climate change requires us to understand projected annual average crop yields with and without the effects of climate change. Although the CCRA (Knox *et al.*, 2012) has recently published projections for wheat, sugar beet, potatoes and grassland, it only looked at the effects on one variable at a time and not in combination. For example, it explored climate change's impact on soil moisture but did not then feed this through into the consequent impacts on crop yield. To allow these effects to be accounted for, alternative projections have been used for the main analysis in this report.

The main analysis draws on projections of the International Food Policy Research Institute (IFPRI) (Nelson *et al.*, 2010). Results are also reported for the CCRA (Knox *et al.*, 2012) and a range of research studies from Rothamsted Research and others. **As with all projections, they are subject to uncertainty.**

Projections shown are annual averages of yields (tonnes per hectare, t/ha). Those shown do not illustrate the degree of variability in yields around the longer-term projected trends. In addition, some climate change effects are not directly reflected. For example, the impacts of pests and diseases or rising CO₂ concentrations – the IFPRI authors (Nelson *et al.*, 2010) suggest these effects could broadly balance out on average over the long-term as they move in opposite directions. CO₂ concentrations would be expected to increase yields, whereas pests and diseases would be expected to reduce yields (in many cases substantially). This limitation should be noted.

Projections also assume that actions and behaviours are taken as rational responses to market signals. This may not be the case in practice; and indeed signals may not always lead to the best outcomes (where there are market failures, for example). Again, this limitation should be noted, but is not particular to IFPRI, but is a general modelling issue.

IFPRI⁷ is a global model with national outputs⁸. This allows global market activity (and associated impacts of market forces on behaviour) to be reflected in the results. It takes into account the complex factors which drive crop yields such as demand, supply, international trade, agronomic inputs and water availability, in addition to climate effects and interactions between these factors. An important limitation of this work is that atmospheric CO₂ concentrations are held at 369 ppm in 2050⁹. The model is described in more detail in Annex 4.

Rothamsted Research's analysis draws on field experiments to develop projections of the potential impacts of climate change on the characteristics of crops and their development to provide projections to the 2050s.

3.4.2 Accounting for uncertainty

Accounting for uncertainty is a core part of the approach. Both the CCRA (Knox *et al.*, 2012) and IFPRI (Nelson *et al.*, 2010) have considered such uncertainties through the use of scenarios reflecting socio-economic factors and climate change (see Annex 2). The latter have been explored using assumptions consistent with the scenarios of the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) (IPCC, 2001). These are also the scenarios that underpin the projections of UK climate in UK Climate Projections 2009 (UKCP09). To explore the impacts of climate change in this report we explore alternative socio-economic conditions, and SRES scenarios, as shown in **Table 2**.

⁷ Defra suggests that IFPRI assumes relatively pessimistic underlying technological growth which affects grain prices. In addition, specific UK policies are not directly modelled, though are generically represented.

⁸ The results of the IFPRI model are for the British Isles. These are minimally adjusted to reflect the yields for the UK by comparing actual yields in 2010 with the (projected) 2010 IFPRI result and using an adjustment factor c.3-5% in most cases. We assume this difference remains the same across scenarios for a given crop, and that it does not change over time.

⁹ This is substantially lower than other climate models project but the authors assume that the positive impacts on yields of CO₂ concentrations are uncertain and, in particular, the extent to which findings of such effects in laboratory field experiments would translate to field results. They also argue that the CO₂ effects would be lower if nitrogen is limiting, and some crops may be more susceptible to pests. The authors conclude that because they do not model the impacts of ozone damage or increased competition from pests and diseases, 369 ppm could be an imperfect mechanism to capture these effects (Nelson *et al.*, 2010).

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Table 2. Scenarios to account for uncertainty

Accounting for socio-economic factors	Accounting for climate change uncertainty
Low population growth and high GDP growth (equivalent to the IFPRI optimistic scenario).	What if there was no further climate change beyond current levels? - this reflects a situation of perfect mitigation.
High population growth and low GDP growth (equivalent to the IFPRI pessimistic scenario).	What if climate conditions are those consistent with SRES A1B? - this reflects a situation of relatively rapid and successful economic growth. ¹⁰
Medium population and GDP growth.	What if climate conditions are those consistent with SRES B1? - this reflects a high level of environmental and social consciousness.
	What if climate conditions are those consistent with SRESA2? - this reflects a low level of international trade or co-ordination and slower technological change.

Source: IFPRI modelling, Nelson *et al.*, (2010)

Underpinning each climate scenario is projected climate change (A1B experiencing the highest rise in temperatures and precipitation, and B1 the lowest).

The IFPRI (Nelson *et al.*, 2010) results incorporate farmers' responses to market prices and costs. They are therefore assumed to undertake some level of adaptation to climate change – that which is market-driven. For example, to maximise opportunities from a grain price rise, they can change land management practices or production inputs. Their underlying productivity is also improved by their choice of cultivars.

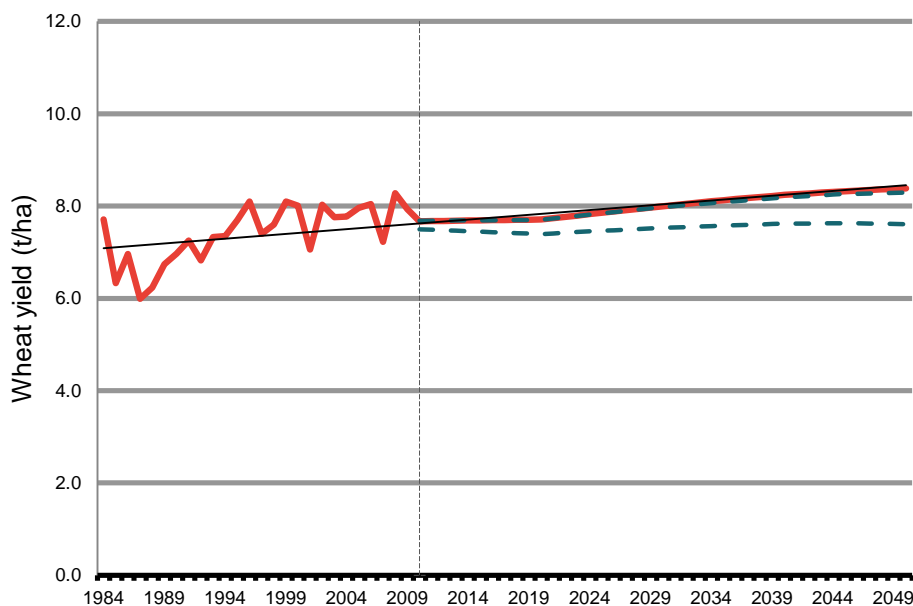
For the purposes of illustration, IFPRI (Nelson *et al.*, 2010) projections are shown relative to the medium socioeconomic scenario with perfect climate change mitigation (the solid red line) – this is equivalent to exploring “what if there was no *further* climate change?” Although the impacts of this scenario are in themselves subject to uncertainty, it is shown to allow relative effects to be illustrated. The dotted lines show the projections with climate change (the upper and lower bound of all combinations of socio-economic and climatic assumptions).

¹⁰ A1B reflects rapid economic growth but is not the highest SRES scenario. A1FI is the highest emissions scenario.

3.4.3 Wheat yield projections

IFPRI projections

Figure 3. Historic wheat yields and range of wheat yield projections (t/ha) for the UK - with climate change (dotted line with climate change, solid red line if there was perfect climate change mitigation, the straight line illustrates the trend through the data points)



Historic data source: Defra (2011a), Table 5.2

Projections source: Based on IFPRI (Nelson *et al.*, 2010)

IFPRI projections for wheat yields suggest that climate change is projected to have a negative impact on yields in the UK relative to the ‘no further climate change’ case¹¹. **Figure 3** shows that across scenarios, wheat yields are projected to be lower (as shown by the dotted lines) than if current climatic conditions were to continue (the red line which assumes perfect climate change mitigation). The average annual yields are projected to vary between 7.6 t/ha and 8.3 t/ha in 2050¹², compared to the ‘what if?’ there was no further climate change scenario (which was around 8.4 t/ha).

¹¹ Note that the effects of CO₂ concentrations on yields are not accounted for in these results.

¹² Shown as the illustrative year in the modelling using projections of climate change to the 2050s.

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The higher end of the projection range reflects the case in which we explore “what if socio-economic conditions were optimistic and climate change was consistent with SRES B1?” The lower projection reflects the case which explores “what if socioeconomic conditions were pessimistic and climate change was consistent with SRES A1B?”

The range implies a reduction in wheat yield ranging from -0.4 % to -9.9 % as a result of climate change, relative to what might otherwise be expected without the effects of climate change i.e. assuming perfect mitigation¹³.

CCRA projections

The CCRA (Knox *et al.*, 2012) also developed projections for wheat yield using the linear approach described above. In contrast with the IFPRI projections, these suggest a positive impact on yields overall from climate change.

Increases in wheat yields are described by the CCRA (Knox *et al.*, 2012) as very likely to result from increases in **mean growing season temperature, assuming other factors do not become limiting**. The CCRA (Knox *et al.*, 2012) highlighted potentially significant gains in yields of wheat in most regions of the UK, with some experiencing over a 100% gain in the 2080s relative to the 1960-90 baseline. Yields are described as likely to increase even further with improvements in wheat varieties and some gains due to higher CO₂ concentrations. **Table 3** shows the CCRA projections.

Table 3. Projected changes in wheat yield in the UK relative to a 1961-90 baseline assuming a medium emissions climate change scenario.

	2020s	2050s	2080s
Wheat yield	47% (p50 Medium) (Range 22% to 76%, Medium p10 to Medium p90)	79% (p50, Medium) (Range 36% to 137% for Low p10 to High p90)	111% (p50 Medium) (Range 46% to 212% for Low p10 to High p90)

Source: CCRA (Knox *et al.*, 2012)

Other literature

The impacts of climate change on wheat yield were explored on the basis of simulated experiments at Rothamsted Research (Semenov and Shewry, 2011). These studies established that CO₂ concentrations have a significant effect on

¹³ These results are from a global model. Some EC funded studies, such as Supit *et al* (2012), show the opposite.

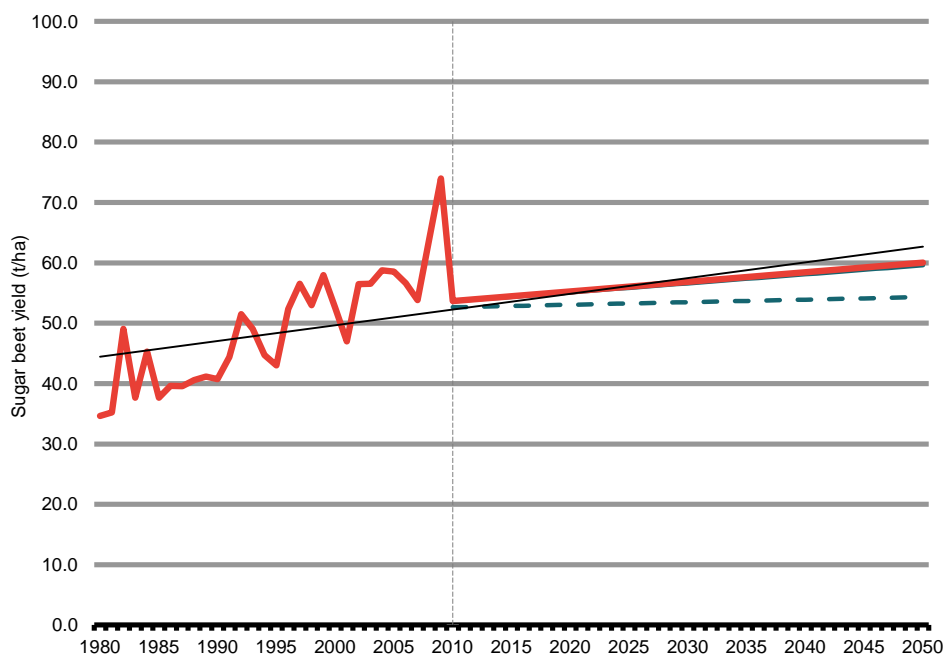
yields. In 2055 (A1B climate change scenario), yields are projected to increase by around 14.9% on average (compared to a reduction in yield without the CO₂ effect).

Many studies project wheat yields to rise (IGER, 2004; Iglesias and Rosenzweig, 2009; Ferrara *et al.*, 2010)). In contrast, others suggest a decline in yields owing to climate change (Tatsumi *et al.*, 2011). Some studies that have reviewed literature have found inconclusive results (Met Office, 2011; Lobell *et al.*, 2011).

3.4.4 Sugar beet yield projections

IFPRI projections

Figure 4. Historic sugar beet yields and range of sugar beet yield projections (t/ha) for the UK - with climate change (dotted line with climate change, solid red line assumes perfect climate change mitigation; the black line shows the trend through past data points)



Historic data source: Defra (2011a), Table 5.7,
Projections source: Based on IFPRI (Nelson *et al.*, 2010)

Figure 4 illustrates that with climate change, the projected sugar beet productivity in 2050 is in the range from 54 t/ha to 60 t/ha in 2050¹⁴. The lower

¹⁴ Shown as the illustrative year in the modelling using climate projections to the 2050s.

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bound reflects the case exploring “what if there was medium socio-economic change and climate change was consistent with SRES A1B?” The upper bound explores “what if there was no further climate change?”

Climate change drives a reduction in sugar beet yield ranging from -0.7 % to -9.5% relative to the “no further climate change” or perfect mitigation scenario.

CCRA projections

The CCRA (Knox *et al.*, 2012) projected national sugar beet yield (**Table 4**). Soil variability is projected to have a major impact on yields regionally, with increases on loamy soils being substantial. Earlier sowing and harvest dates are expected to compensate for any losses on sandy soils (Richter and Semenov, 2005).

Higher mean growing season temperatures are found to be very likely to benefit yields but technological developments in the sugar beet industry are more significant; yields have already outstripped the gains expected due to climate change. In the future, water availability may become a limiting factor (Knox *et al.*, 2012).

Table 4. Projected changes in sugar beet yield in the UK from a 1961-90 baseline assuming a medium emissions climate change scenario

Yields	2020s	2050s	2080s
Sugar beet yield	23% (Medium, p50) (Range 11% to 37%, Medium p10 to Medium p90)	39% (Medium, p50) (Range 18% to 68%, Low p10 to High p90)	55% (Medium, p50) (Range 23% to 105% for Low p10 to High p90)

Source: Knox *et al.*, 2012

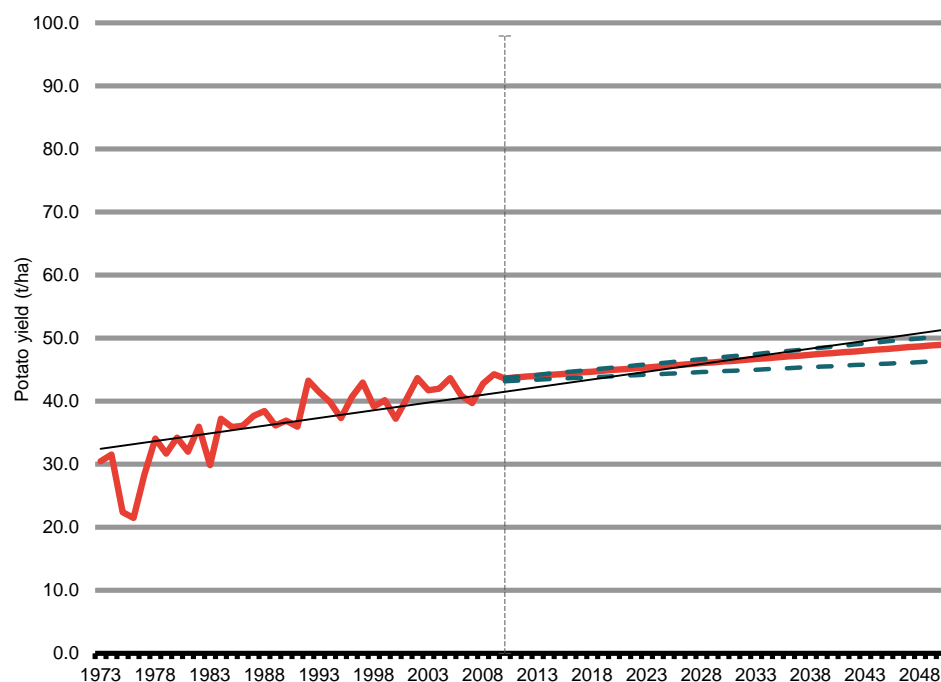
Other projections

Rothamsted research (2002; 2004) projects a modest increase of 1.4-2 t/ha by the 2050s depending on the emissions scenario. Jaggard *et al.*, (2007) analysed weather and sugar beet yield data for the 1976-2004 and estimated annual yield gains attributable to climate change at 0.14 t/ha.

3.4.5 Potato yield projections

IFPRI projections

Figure 5. Historic potato yields and range of potato yield projections (t/ha) for the UK - with climate change (dotted line with climate change, solid line assumes perfect climate change mitigation, the black line is the trend through past data points)



Historic data source: Defra (2011a), Table 5.11
Projections source: Based on IFPRI (Nelson *et al.*, 2010)

Figure 5 indicates that with climate change, the projected yield for potatoes is expected to be in the range from 46 t/ha to 50 t/ha in 2050 in the UK (as compared to 49 t/ha under ‘perfect mitigation’). The upper bound reflects the case indicated by “what if socio-economic growth was pessimistic and climate change was consistent with SRES B1?” The lower bound reflects the “what if there was pessimistic socio-economic change and climate change was consistent with SRES A1?” case.

This implies a change in potato yield from -5.3% to 2.7% relative to the scenario which explores “what if there was perfect climate change mitigation”, i.e. no further climate change.

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CCRA projections

The CCRA considered the impact of rainfall on potatoes, and developed a response function combining national rain-fed yields and national mean summer rainfall variability. This approach led to a projected **downward pressure on yields due to lower summer rainfall** but biophysical modelling indicates yield gains due to higher CO₂ concentrations. Lower summer rainfall indicates lower crop yield, but these findings are not consistent with biophysical modelling studies that consider CO₂ fertilisation and temperature (e.g. Wolf and van Oijen (2003) which report an increase of 2-4 t/ha in 2050s due to CO₂).

Other literature

Crops such as potatoes, sugar beet and vegetables, which require adequate soil moisture in summer, are more prone to drought effects. In future, the areas where these crops are grown could change, for example from East Anglia towards the Midlands and western Britain (IGER, 2004).

In Ireland, an increase in drought potential resulting from climate change could threaten the viability of non-irrigated potato production (Holden *et al.*, 2003). The importance of water for potatoes has been widely noted. With binding constraints, farm yields showed only marginal increases of 3 to 6% due to climate change, but future potential yields, without restrictions in water or fertiliser availability, were reported to increase by 13-16%. These increases are principally due to increased radiation and temperature levels and elevated CO₂ concentration effects (Daccache *et al.*, 2011; CCRA: Knox *et al.*, 2012; Knox *et al.*, 2010).

Summary of productivity effects based on IFPRI

The productivity effects described in the main analysis above are summarised in **Table 5**. These show the potential impacts of climate change relative to the projected situation in 2050, if there was perfect climate change mitigation and a medium level of socio-economic change was experienced.

Table 5. Agricultural productivity projections to 2050 (t/ha)

Crop	Current yield (t/ha)	2050 (t/ha): perfect climate change mitigation	2050 (t/ha): lower bound with climate change	Implied loss of productivity (t/ha)
Wheat	7.7	8.4	7.6 – 8.4	-0.8 to -0.03
Sugar beet	54.4	60.0	54.3 – 59.6	-5.7 to -0.4
Potatoes	43.7	48.9	46.3 – 50.3	-2.6 to 1.3

Source: Based on Nelson *et al.*(2010)

3.4.6 Grassland yield projections

The CCRA assessed grassland productivity based on four UK sites (West Wales, Central Devon, Gloucestershire and Cumbria) and projected an increase. This suggests a 15 % increase in yield per degree of warming for conditions with adequate water and nitrogen (Knox *et al.*, 2012).

Table 6 illustrates projections for grassland yield in the UK; data for Scotland and NI have been estimated from data for England and Wales as similar changes in Scotland and Northern Ireland are likely, although increases in yield may exceed those in England where water stress becomes a limiting factor.

Table 6. Projected climate change yields for grassland under in the UK only (baseline 1970s to 1990s)

	2020s	2050s	2080s
Average grass yield with moderate inputs are 6-8 t/ha under grazing, and 8-10 t/ha under management	20% (Medium, p50) (Range 11% to 31%, Medium p10 to Medium p90)	35% (Range 18% to 53%, Medium p10 to Medium p90)	49% (Range 24% to 54%, Medium p10 to Medium p90)

Source: Knox *et al.*, 2012

Note: Range here is from lowest to highest projected results which may not necessarily be Low p10 to High p90

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The effect of climate change on pasture is notably different than on other crops, with pasture maintaining an increase in yield (Metroeconomica, 2006). The potential consequences of the effects of future climate change on grassland-based livestock production are complex. Grassland agriculture is practised on a wide range of soil types. Sites have different growing conditions and there are variations in sward botanical composition and productivity – all of these factors mean the effects will vary accordingly. Projected yields in summer could increase but will be dependent on nitrogen use and possibly irrigation, noting summer drought affects grass most acutely (IGER, 2004).

In areas most suited to grass growth, such as lowland western Britain, on soils with a good depth, structure and soil available water capacity, annual dry matter production of 15-20 t/ha is achievable under silage cutting, given adequate supplies of nitrogen and supporting nutrients. In contrast, upland pastures in northern Britain, where there is a short growing season due to low temperatures in spring and autumn, and where there are leached and shallow soils on slopes, typically provide around 2-5 t/ha of forage, mainly for grazing.

3.4.7 Livestock and dairy productivity

Climate change is projected to have a direct impact on animal productivity, well-being and health. Indirect impacts on the animal are also projected, through feed availability and competition for land use. The impacts associated with increasing temperatures are likely to have the greatest effect on the welfare of dairy cattle.

Table 7 illustrates livestock production for the British Isles¹⁵ (IFPRI). Climate change could increase or decrease the production of beef, but this effect relative to the “what if there was perfect climate change mitigation?” case is less than a 7% reduction or a 3.6% increase. For pork, the projected impact of climate change is negative with the impact relative to the “what if there was no further climate change?” case indicating a reduction no greater than around 4%. For poultry, the effect of climate change relative to the case under “what if there was perfect climate change mitigation?” suggests a projected reduction in production of up to around 12% reflecting “what if there was pessimistic economic growth, high population and a relatively strong change in climate?”¹⁶

¹⁵ Note this is British Isles (including the Republic of Ireland) and not the UK.

¹⁶ This is consistent with the SRES A1B scenario.

Table 7. Range of livestock production projections (thousand tonnes) to 2050 - with climate change

	2050 (million tonnes): with perfect climate change mitigation	2050 (million tonnes) – with climate change
Beef	1.7	1.6 -1.7
Pork	1.0	0.9 -1.0
Poultry	1.9	1.7 – 2.0

Source: Based on IFPRI projections (Nelson *et al.*, 2010)

Currently the UK climate is not projected to result in losses from dairy system production or to pose a major risk to dairy production in the short term (to the 2020s). Heat stress losses are only projected to become relevant in the 2050s (Knox *et al.*, 2012). Small and largely insignificant increases in the number of days of heat stress for typical dairy herds are indicated in the CCRA, so that the number of deaths from heat stress is considered negligible.

Dairy cattle are projected to be most affected by an increase in temperature. Heat stress during summer months when cattle graze on pasture could be an increasing concern, owing to the unfavourable effect on livestock survival. Beef cattle are projected to be spared the major effects of heat stress, as the majority are reared in geographical areas where significant temperature increases are not likely to be felt for some time. As pigs and poultry are usually reared in intensive, indoor systems, the impacts of climate change are expected to depend on the capacity and efficiency of the environmental control systems. Increased temperatures and extreme events will place demands on environmental control.

The CCRA did not cover pigs and poultry yet the impact of heat stress on these animals could be greater, as they are frequently intensively produced in indoor housing (Haskell *et al.*, 2011).

The indirect impacts of climate change are projected to affect both endemic diseases (Haskell *et al.*, 2011) and the emergence of new diseases, such as blowfly strike, where high blowfly abundance is linked to higher maximum temperatures and higher rainfall. The emergence of vector-borne diseases, such as Bluetongue in Northern Europe, can be partially explained by climate change, although other factors, such as increased international transport, can also influence the frequency of introduction of new diseases into the region.

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3.4.8 Production projections with climate change

Productivity projections allow an overall value to be placed on the amount of output that would be possible for the given levels of projected productivity.

For illustration, **Table 8** shows production projections assuming the IFPRI levels of productivity described above combined with the assumption that the land space for each crop in 2050 remains the same as today. This simplistic assumption, combined with the projected commodity price change over 2010 to 2050 within the IFPRI framework, allows an illustrative assessment to be provided.

Care must be taken when interpreting these figures because they are dependent on the world price projections developed within the IFPRI model. Some suggest these are at the higher end of expected prices, given the implicit relatively low assumptions for the rate of technological growth underpinning the projections. The assumption of no change in hectares per crop is also a simplistic one, and as shown below, is not likely to hold. **Figures are therefore to be considered indicative only and the relative changes are more important than the absolute values.**

Table 8. Agricultural production projections to 2050 in value terms (£ billion)

Crop	Current output (£bn)	2050 – under perfect climate change mitigation (£bn)	2050 - with climate change (£bn)	Implied impact on output (£bn)*
Wheat	1.7	2.50	2.4 – 2.8	-0.11 to +0.32
Sugar beet	0.2	0.3	0.3 – 0.3	0 to 0.02
Potatoes	0.8	0.9	1.0 – 1.4	0.1 to 0.5

Source: ECR team *Note that impact on output is estimated as relative to a case of perfect climate change mitigation. Relative changes are more important than absolute figures.

As this shows, the production values are projected to increase for both sugar beet and potatoes but they are uncertain for wheat. These effects are driven by the fact that despite lower yield projections, the lower overall supply of those commodities in the world market pushes up prices. This rise in price outweighs the effect of falling volumes.

It should be noted that in practice, production would be expected to shift across the country in response to climate change. For example, production of cereals is projected to slightly decline in the South, particularly the South East, and increase

in the rest of the country. Temporary grasslands are projected to increase in the West and decrease in the East. Permanent grasslands are predicted to decline in most parts of England with a small increase in the hilly areas in Scotland and in the North of England (Fezzi *et al.*, 2011).

3.4.9 Devolved Administration issues

It has not been possible to develop projections specific to the Devolved Administrations. However, by understanding the current nature of the agriculture of the sector in each of those nations, inferences can be made as to which climate effects are likely to have greater impact in those areas. The current situations in each of Scotland, Wales and Northern Ireland are described briefly below. Information is taken from the CCRA report (HR Wallingford *et al.*, 2012) for each DA.

Scotland

In 2010, total agricultural area in Scotland was 6.2 million ha (82% grass or rough grazing). There are 52,500 holdings in Scotland, of which some 65% operate on land classified as severely disadvantaged. Only around a third of farms operate on land that is not classified as disadvantaged or less favoured (i.e. not in mountainous areas or those hill farming areas: Defra, 2011a). This creates its own challenges for the sector.

Projections of climate change in Scotland indicate that climatic constraints on crop growth will be lessened in some contexts (a later end and earlier start to the growing season, higher temperatures and reduced occurrence of frosts (Matthews, 2008) but these may also increase exposure to competition from weeds.

Crop yields

Wheat, potatoes and grassland crops are restricted in both their potential and actual extent in Scotland. Combined, they cover around 25% land area of Scotland with the remainder made up of woodland and semi-natural vegetation (rough grazing in an agricultural context) and built-up land. Wheat is a very small proportion of Scotland's agricultural land (1.8% of total area) (Reay *et al.*, 2011). Yields are among the best in the UK due to longer day length and the relative absence of drought risk compensating for the relatively low temperatures. Sugar beet is rarely grown in Scotland.

Seed potato production is highly significant and forms an important export crop, and about 75% of UK seed comes from Scotland. It is the main cash crop in Scotland.

Grass underpins the livestock systems in Scotland, accounting for approximately 1.4 million ha (22% of total area) in 2010. There is a high diversity of grassland types, with a wide range of management and production factors. In 2010, the

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total area of grass and rough grazing was 5.2 million ha, of which 73.3% was rough grazing, 8.2% grass was under 5 years old, and 18.5% was over 5 years old (Scottish Government, 2011). Sward composition will vary considerably in the natural and semi-natural systems, with high competition from non-grass species, whilst intensively managed areas can be with or without clover. Uses will be for silage conservation (possibly with aftermath grazing), where a combination of quantity and quality are sought, or livestock grazing. The number of silage cuts varies per year and location, but 1 to 2 is most common. Grassland is the mainstay of the agricultural industry in Scotland, dominating the dairying land in the south-west, and is extensive in livestock areas in the eastern parts where climatic constraints limit arable production.

Grassland may be reduced in area as a result of expansion of woodland (Scotland has a policy to expand woodland cover to 25% from 18% today by the 2050s) and areas where woodland would be successful tend to be in areas that are currently grassland.

Livestock

Scotland is heavily dependent on ruminant livestock production. Livestock stocking rates vary greatly on a geographical basis. Dairy farms are concentrated in the wetter south-west, but others exist across Scotland. Access can be limited when soils are at or close to field capacity. Nutrient loss rate can be large in the areas of high precipitation, limiting growth unless higher rates of fertiliser applications are used. Natural and semi-natural grazing areas are on soils with poor nutrient status and/or poor drainage. Dry conditions may occur in the summer, limiting growth.

The effects of pests and diseases are less likely to cause problems as the severity of frosts in Scotland is likely to continue to limit pest and disease occurrence.

Northern Ireland

The risks and opportunities presented by climate change for agriculture are very similar to those of Scotland. The CCRA found that the sector is not projected to have severe negative consequences by 2080s, apart from potentially flood risk.

In 2011, there were 24,000 active farms using one million ha of land. Approximately one-third of the farm sector economic output (or more than one half of farm sector gross margin) comes from the dairy sector, even though it makes up approximately 11% of farms (DARD, 2011).

Crop yields

The CCRA (Knox *et al.*, 2012) projected that potato yields may decrease in the future due to a decrease in summer rainfall. Other factors may mitigate this effect to some extent, such as increased CO₂.

The CCRA for Northern Ireland (HR Wallingford *et al.*, 2012b) indicated yields may benefit from climate change.

Grassland productivity increases may present an opportunity for farming in Northern Ireland, given the reliance on grassland-based livestock farming. The proportion of agricultural land that is grassland or enclosed rough grazing is over 90% in Northern Ireland (777,000 ha plus 140,000 ha of rough grazing). The available evidence, although subject to uncertainty, suggests that grass yields are likely to increase over the next 70 years. The CCRA measured projected herbage dry matter yields to increase by 19% by the 2020s, 32% by the 2050s (both at medium emission scenarios) and 45% by the 2080s (high emissions scenario). Another study (Fitzgerald *et al.*, 2008) (using a different approach to the CCRA and including temperature, precipitation and soil moisture as well as CO₂ fertilisation) projected a maximum average increase in yield of 34% by the 2080s. While grass yield can be expected to increase, the ability of livestock to effectively utilise grass through conventional grazing systems is unclear. Higher autumn rainfall may make ground conditions unsuitable for cattle in particular and shorten the grazing period.

Livestock

Livestock forms a significant component of agricultural activity in Northern Ireland – around 81% – with livestock and livestock products accounting for some £1.2 billion in 2010 of the £1.5 billion gross output of the sector (DARD, 2011). In 2010, there were about 1.6 million cattle, 1.85 million sheep, 424,600 pigs and 11.9 million broilers (DARD, 2011).

Given the importance of livestock farming in Northern Ireland, pests and diseases currently unknown in Northern Ireland, but which pose a risk as a result of climate change, are a particular concern. As part of an island located on the western periphery of Europe, geographic factors give some protection from these threats. The Northern Ireland Executive is conscious of the risks and is addressing them via animal health and movement regulations and by co-operation with the Government in the Republic of Ireland in a policy known as Fortress Ireland, which is aimed at establishing conditions that will reduce the risk of incursion from new diseases and pests to the island.

At the time of writing, Northern Ireland has a Bluetongue free status. However, if the pest spreads and an outbreak occurs, it has been estimated that the production losses and disruption to trade would cost the agri-food industry £25 million in Northern Ireland (Northern Ireland Executive, 2010). With the spread of vector-borne diseases, such as Bluetongue, predicted under climate change, the risks to Northern Ireland are considerable.

The scale of the challenge

Wales

Welsh agriculture is dominated by livestock production. Of the 17,100 km² of agricultural land in Wales, 12,700 km² (75%) is permanent grass and 800 km² (10%) is rough grazing. Land with potential to grow arable crops is 2,100 km² (12%), about half of this is short term grassland with the remainder of predominantly woodland (HR Wallingford *et al*, 2012a)

Many of the risks and opportunities to agriculture in Wales are similar to those experienced in other regions of the UK. For example, opportunities include increases in crop yield, new cropping opportunities and carbon storage. The main potential adverse impacts include declining water availability and the potential for new pests and diseases.

Crop yields

The CCRA (Knox *et al*, 2012) projects that based on higher temperatures and CO₂ concentrations, crop yields would be maintained or improved in the future. The impact of climate change on grass is particularly important in Wales, given the significance of livestock. The CCRA predicts grassland yields to increase in Wales by 6 to 20% by the 2020s and 14 to 35% by 2080s (projections based on a single site in Wales and for a medium scenario p50). This benefit could be offset by lower summer rainfall in combination with higher temperatures.

Wheat is not grown on a large scale in Wales but may increase by about 40% by the 2020s and 70% by the 2050s (projections for medium emission scenario p50 and relative to 1961-90 baseline) providing water, nutrients and pests/diseases do not become constraints. However, PSMD is projected to double by the 2080s and supplementary irrigation may be required for high value horticultural crops.

Livestock

Many local economies are dominated by agriculture, with a high proportion of livestock farming or forest areas. The production of red meat contributes over 40% of the annual total value of Welsh agricultural output and is valued at over £360 million. Distributed throughout Wales, beef and sheep holdings employ over 65,000 people and play a pivotal role in supporting the rural economy (Farmers' Union of Wales, 2012).

Given the dominance of livestock farming in Wales, pests and diseases are a particular concern, as are the effects of increases in precipitation and waterlogging on pasture – putting pressure on grazing land and increasing soil erosion. A northwards spread of the Bluetongue virus has been documented, believed to be related in part to climate change. Another problem highlighted in the CCRA is the effect of increases in precipitation and waterlogging on pasture. Not only would this put pressure on grazing land, but could also lead to an increase in soil erosion, diffuse pollution and breakdown of soil structures.

This section has explored the scale of the challenge or opportunity facing agriculture as a result of climate change. The next Section explores the context in which adaptation actions would be considered.

4 Context for adaptation

Key messages

- Adaptive capacity is the ability of a sector, and the actors within it, to take action to adapt to climate change.
- Adaptive capacity of the agricultural sector overall is considered to be relatively high. Many decisions made in farms can be made over a short time period; these are related to operations, production decisions and the continual replacement of assets. Adaptive capacity could be relatively low when actions have a longer lead-time, involving multiple organisations (both within and outside the sector) such as access to water, response to coastal erosion, or breeding traits in plants.

4.1 Introduction

This section focuses on the context for adaptation including an assessment of the adaptive capacity of relevant (non-government) actors and the policy framework in which they operate.

Whether adaptation is likely to be taken to address climate threats effectively requires two key factors to be considered:

- **Adaptive capacity (see below):** Adaptive capacity is a necessary condition for the design and implementation of effective adaptation strategies, so as to reduce the likelihood and magnitude of harmful outcomes resulting from climate change (Brooks and Adger, 2005).
- **Adaptation actions (Section 5):** There are many adaptation actions that individuals and organisations are already taking in parts of the sector, and which would be expected in the future. These may be in response to an event or consequence of climate change (reactive) or as a result of government policy (planned).

Government policy is briefly outlined before exploring adaptive capacity in this Section. The adaptation actions currently being taken, and those likely in the near-term, are then discussed in Section 5.

4.2 The policy environment

The UK agriculture sector is heavily influenced by the policy landscape at national, EU and international levels. At the UK and EU level, most policies (often in the form of regulations) relate to environmental protection and

sustainability, while others – notably the Common Agricultural Policy (CAP) – relate to the operation and performance of the sector.

The implications of policies on adaptation vary:

- Some are **directly targeted** at adaptation; and,
- Some are **part of a broad policy framework that impacts on behaviour and incentives to take adaptive action.**

Understanding the UK's policy landscape is important because this affects the nature of activity in the sector and therefore its ability to adapt¹⁷.

In general, there are several policies that are likely to facilitate or require adaptation actions including the Soil Protection Review, animal welfare legislation and Catchment Sensitive Farming.

Water is an essential input to the majority of agricultural activity, and this is the area which is likely to be substantially affected by climate change. Meeting the requirements of the European Water Framework Directive (WFD)¹⁸ could become increasingly challenging for farmers. The lack of water available for abstraction could limit some farmers' ability to exploit opportunities from climate change.

Some of the environmental protection regulation (e.g. Pesticides Directive and GM legislation) could serve to limit the measures farmers can use to respond to challenges created by climate change.

There are uncertainties created for farmers over future revenue streams because of the CAP reform review. This could have a potential impact on the financial viability of some farms. This may encourage adaptation if farmers are proactive in ensuring their future profitability should CAP funds fall, but may also deter adaptation actions in the future if the farms' survival is dependent on the CAP's revenue streams (especially in response to variable weather).

¹⁷ Detailed assessments of the impacts of international policies (beyond the EU) are outside the scope of this report.

¹⁸ This came into force in the 2003 and became part of UK law in December 2003.

4.3 Adaptive capacity

For the purposes of the ECR, adaptive capacity, or the ability to adapt, is analysed using a simplified framework informed by the Performance Acceleration through Capacity Building (PACT)¹⁹ model (Ballard *et al.*, 2011) and the “weakest link” hypothesis²⁰ (Yohe and Tol, 2002; Tol and Yohe, 2006). Both PACT and the weakest link models introduce the idea of discrete levels of an attribute and allow identification of where an actor is now and where they would like to be, while illustrating the areas that need most development to get to the desired end point (Lonsdale *et al.*, 2010).

This project defined adaptive capacity using the CCRA definition:

Adaptive capacity

“The ability of a system/organisation to design or implement effective adaptation strategies to:

- adjust to information about potential climate change (including climate variability and extremes),
- moderate potential damages,
- take advantage of opportunities, or cope with the consequences”

Source: Ballard *et al.*, 2011 (CCRA – modified IPCC definition to support project focus on management of future risks)

Adaptive capacity refers to both the structural capacity within the overall sector, and also the capacity of different actors in the sector. The assessment of these factors allows exploration of the ability of actors to implement effective climate change adaptation measures.

In assessing the ability of the agricultural sector to adapt to projected impacts of climate change, this project considers two factors: the **structure** of the sector in general terms (i.e. the role and size of different organisations involved), and the **organisations** in the sector - the function of key players who make critical

¹⁹ This model was chosen as it was used in the CCRA, from which this project follows on, and because in a UKCIP review of adaptation tools it was ranked as the most robust (Lonsdale *et al.*, 2010). The PACT model identifies six clear stages of development when organisations take on the challenge of climate change. These are called response levels (RLs) rather than stages, as each level is consolidated before moving to the next. RLs 2 and 3 are characteristic of ‘within regime’ change, RL4 is characteristic of ‘niche experimentation’ (or ‘breakthrough projects’) and RL5 is conceptualised as regime transformation. RL6 would be conceptualised at the landscape level. In this report, the RLs were used very simplistically as a comprehensive assessment of the adaptive capacity of the sector using PACT could not be undertaken. It is recommended that this be undertaken in further work.

²⁰ The weakest link hypothesis enables assessment of the potential contribution of various adaptation options to improving systems’ coping capacities by focusing on the underlying determinants of adaptive capacity. In this report, the determinants were used to assess capacity of an actor rather than an adaptation option. This was used as it provides socio-economic indicators by which an actor’s adaptive capacity may be categorised. It enables the weakest part of an actor’s capacity to be shown providing an area to focus adaptation responses.

decisions and their performance (i.e. gross margins, outputs and benefits delivered). An analysis of these two factors will describe the ability of the sector to adapt to climate change and the extent to which the opportunities and risks described in Section 3 are likely to be addressed. It should be noted that adaptive capacity is not only needed to optimise decisions based on climate change adaptation, but for other decisions with long term implications (Ballard *et al.*, 2011).

4.3.1 Structural adaptive capacity

The analysis of structural adaptive capacity has been derived from evidence from published studies and qualitative evidence from interviews with a wide range of experts within the sector and the outputs of the one-day Adaptation Forum held with stakeholders by the ECR team. The information below is a summary of the assessment of adaptive capacity.

This project examines productivity (yields) and production so the focus is at the farmer level and the influence of other actors on farmers' decision-making, although the value chain is also discussed.

This description of structural adaptive capacity can be used to **identify specific types of decisions where further assessment of climate change implications will be important**. These include:

- Development of new varieties specific to the UK (where there is a long consequence time);
- Decisions such as water storage and irrigation where capital costs are relatively high and many different parties can work together;
- Approaches to incorporate value of ecosystem services into decision making; and,
- Supply chain management, including relationships between retailers and producers.

Sector complexity

The agricultural sector is complex. This means that decisions may be more difficult to make as there are more people or organisations to consult and their agendas differ (Ballard *et al.*, 2011). This also means that there will be greater variability in the context of risk tolerance.

Actors in the value chain who will exert different levels of influence include: farmers; researchers and breeders; industry associations or trade bodies and levy boards; government; retailers; food processors, and wholesalers.

At the farmer level, the complexity grows, as farms may be split by:

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- **Product:** Sub-sectors based on product, e.g. arable, horticulture, livestock, pigs, poultry, etc., each of which have different agendas. Just under half of all holdings are pigs, poultry, livestock or dairy, with around 25% accounted for by cereals and crops. This differs in the DAs: in Wales 44% holdings are pigs, poultry, livestock or dairy and in Northern Ireland this is 90%. In Scotland 30% holdings are cereals and cropping (Defra, 2011a).
- **Farm size:** Within each sub-sector, there are also significant differences in terms of size of farm and business model.
- **Farmer type:** The sector is also segmented in relation to the types of farmer, as can be illustrated by Defra's segmentation approach (Wilson *et al.*, 2010)²¹.

Although agriculture is a complex sector, complexity is reduced by **the recent trend for consolidation** resulting in a few large and powerful actors including retailers, agrochemical companies and agribusinesses (Renwick *et al.*, 2012). The largest farms hold the most significant proportion of land. For example, in 2010, the largest 20% of farms (more than 100 ha) held 73 % of UK agricultural land; the smallest farms (less than 20 ha) account for 47% of holdings but together hold just 4% of agricultural land (Defra, 2011a).

These small farms are more vulnerable to climate change and tend to have less capacity to plan for longer-term or access to finance to respond to risks. A significant barrier for smaller farms (usually livestock farms) is a lack of scale so that substantial investments are disproportionately more costly.

Agriculture in the UK has many functions, including food production, protection of natural resources, providing a physical landscape and supporting rural livelihoods. It is required to deliver an increasingly diverse range of private and public goods driven by policies as well as market forces.

The sector has many **interdependencies** with other sectors (particularly land use and planning, and natural environment and energy), which lead to trade-offs between food production and environmental protection (Angus *et al.*, 2009), weakening the adaptive capacity.

²¹ This approach segments farmers into: custodians, lifestyle choice, pragmatists, modern family business and challenged enterprise, each of which has different drivers and characteristics. For example, of the sample in the Farm Business Survey:

53% were 'pragmatists': av. 140 ha, Farm Business Income (FBI) £48,000;
 21% were 'modern family businesses': av. 182 ha, FBI £88,000;
 14% were 'custodians': av. 119 ha farm, FBI £32,000;
 7% were 'lifestyle choice': av. 106 ha, FBI £14,400;
 4% were 'challenged enterprises': av. 76 ha, FBI £30,200

The sector's **reliance and interaction with international markets** (commodity prices and energy or oil price for equipment and fertilisers) and the instability of global food and energy prices limit the sector's focus on medium and long-term climate change pressures.

According to industry experts, future productivity will involve closer relationships across water, soil, varieties and inputs requiring many different parties to work together. There is also an increasing requirement for local co-operation for shared infrastructure/equipment, securing inputs and managing waste (e.g. straw, silage, slurry).

Dependencies

Agriculture covers a range of interconnected sectors and stakeholders. Interdependencies with other sectors include power (e.g. for machinery or other equipment), transport (e.g. to move products and livestock or to access farm land) and water provision among others. The adaptive capacity of farmers is critically dependent on the adaptive capacity of other actors. In particular, the behaviour of farmers upstream can affect water quality and quantity, and access to water can be dependent on licensing and the requirements of other water users nearby. This can lead to trade-offs between actors and can weaken adaptive capacity. The dependencies highlight the need for co-ordination and for farmers to work with other land and water users in designing resilience.

Decision lifetime

Where the outcomes of decisions are long-lasting, (e.g. a water storage reservoir, which may be used for several decades), decisions need to take into account a longer term future that is inherently uncertain, but may have more severe impacts (Ballard *et al.*, 2011).

Farmers tend to have a **lead-time of less than one year for operational decisions** (e.g. planting times, varieties, choice of inputs, etc.). Exceptions to this include longer-term structural decisions where large investment (infrastructure and machinery), significant business decisions (e.g. changing products grown), permits and stakeholder engagement (e.g. reservoirs require planning permission and EA approvals, construction of processing facilities) are required.

Consequence time is short for many farm-based decisions, but long within the wider sector, e.g. in the development of new varieties (it can take 10-15 years from synthesis to market).

Activity levels

Adaptive capacity is strong where activity levels are high, i.e. when assets are replaced or new assets are created relatively often. Where decisions are made frequently, there is the potential to build learning and bring in emerging climate knowledge, but this only happens where there is recognition of the issues and the

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processes to bring this into decision-making. The short-term nature of most farming decisions means that **activity is relatively high**. For example, farmers replace equipment regularly, and plant arable and horticultural crops most years, so there are regular opportunities to make adaptation decisions, such as introducing different varieties/crops and different management techniques.

In other areas of the value chain, supermarkets make produce-buying decisions frequently, so can move from suppliers in different locations almost immediately (according to an industry expert). However, activity levels are lower in other parts of the sector, such as crop breeding, where new varieties take a long time to develop and are not quickly replaced.

Maladaptation

Action or investment that enhances vulnerability to climate change impacts rather than reducing them is termed maladaptation (UKCIP, 2012). In some cases adaptive capacity can be lowered as scarce resources need to be diverted to undoing maladapted decisions (Ballard *et al.*, 2011).

A particular potential area of maladaptation is **potential conflict between mitigation and adaptation**. Agriculture as a sector offers opportunities to mitigate the portion of global greenhouse gas (GHG) emissions that are directly dependent upon land-use, land-use change, and land-management techniques (Rosenzweig and Tubiello, 2007). Although it is not the purpose of this project to consider mitigation measures, it is extremely important to consider **the links between adaptation and mitigation to avoid conflicts and to find synergies where possible**, for example, reducing use of fossil fuels and fertilisers, and/or increasing carbon sequestration in soil and vegetation (Glendining *et al.*, 2009).

In agriculture, retailers and food processors tend to specify the products they want (often reflecting consumer demands) and this can result in maladaptive actions by farmers. For example, farmers may grow horticultural crops that require significant water use but meet supermarket quality requirements, or farmers may meet supermarket requirements to grow crops without compost or without using sewage sludge, despite such measures not aiding soil protection.

Maladaptation may also arise due to the sector's dependency on natural resources and a lack of co-operation between different enterprises with the potential to over-exploit these resources (e.g. water abstraction in a catchment). **The interdependency with other sectors can lead to maladaptation when decisions are made from the perspective of one sector only**. For example, in order to prevent maladaptation, land-use planning decisions should ideally be made taking into consideration all those affected, (e.g. built environment, natural environment, agriculture etc.). Another case of maladaptation could arise where ploughing of grassland in the north and west for arable crops would release carbon and exacerbate climate change.

4.3.2 Organisational adaptive capacity

Table 9 sets out a summary of the adaptive capacity of actors in the agriculture sector. The actors are key entities in the agricultural value chain (including those beyond the farm-gate). For farmers, while the segmentation is based on sub-sector only, a discussion of other factors to consider is included.

Unless otherwise specified, the data in **Table 9** has been compiled from interviews with stakeholders, experts and findings from the ECR Agricultural Adaptation Forum.

Table 9. Organisational and adaptive capacity

Actor	Resources	Processes	Organisation	Summary
Farmers (generic)	<ul style="list-style-type: none"> - Family-run farms with limited access to finance and ability to diversify. - Landowners are able to use collateral to increase leverage. - Information available but not readily processed into form usable by farmers. - Lack of knowledge (e.g. only 4% farmers seeking advice about impact of climate change on their business: FPS, 2011). 	<ul style="list-style-type: none"> - Prominence of short-term decision-making based on weather. - Decisions driven by productivity and market forces. - Behaviour changes with clear signal of climate change (e.g. 3 years out of 5, ADAS, 2008). - Uncertainty of legislation (e.g. CAP) makes it difficult for farmers to adapt. - Regulatory requirements in relation to farming practices, availability and use of inputs (fertilisers) and outputs (waste), income payments, produce quality and animal welfare reduce capacity. 	<ul style="list-style-type: none"> - Limited farm-to-farm collaboration except industry-level organisation, contractors and specific shared issues (e.g. water storage). - Typically older farmers with less access to technologies and some resistance to change, however this is changing as younger generations come in with new approaches. 	<p>Significant variation in adaptive capacity across farmers of different products and different sizes.</p> <p>This is a combination of farmers responding to stimuli from others and efficient management based on current business models.</p>
Variation by: Arable	<ul style="list-style-type: none"> - Significant capital requirements for equipment and infrastructure (e.g. driers). - Medium gross margins: wheat at £915/ha.²² - Increasing use of technology (e.g. precision agriculture). 	<ul style="list-style-type: none"> - Examples of processes to manage susceptibility to global fluctuations - Increasing role in marketing product and ensuring quality. 	<ul style="list-style-type: none"> - Use of agronomists, land managers to support decision making. 	<p>MEDIUM/HIGH</p> <p>As above and in particular farmers tend to focus on best practical option within current business models; there are some examples of 'breakthrough' initiatives for larger agribusinesses.</p>

²² Using a wheat price of £117/tonne (average 2010) and an average yield of 8 t/ha

Actor	Resources	Processes	Organisation	Summary
	<ul style="list-style-type: none"> - Young generation of farmers often knowledgeable on emerging technology and science. - Natural capital - significant effort in maintaining soil resources. 			
Horticulture (including potatoes)	<ul style="list-style-type: none"> - Natural capital: importance of securing reliable sources of water (and in some locations, irrigation). This includes security of abstraction licenses. - Very high gross margins as costs are so high: £4,478/ha.²³ 	<ul style="list-style-type: none"> - Managing quality and meeting retailers requirements are critical. 	<ul style="list-style-type: none"> - Relationship with retailers or processors key; involvement in growers groups can be an important network. 	<p>MEDIUM</p> <p>While farmers focus on responding to purchaser signals, short-term efficient management measures are in place. There are also examples of breakthrough projects.</p>
Dairy and livestock (including grass)	<ul style="list-style-type: none"> - Dairy has high capital investment and low margins; trend towards larger herds and production-led models. - Livestock: slower rate of new technology adoption. - Focus on direct determinants of production (vs. soil function etc.). 	<ul style="list-style-type: none"> - Managing quality and meeting retailers requirements are critical. - Decision-making occurs over longer time period (animal life time). 	<ul style="list-style-type: none"> - Retailers play key role in sector; limited examples of diversification. - Important role of vets and feed formulators. 	<p>LOW</p> <p>Action tends to be driven in terms of current business priorities and responding to signals from others.</p>
Pigs	<ul style="list-style-type: none"> - Limited access to finance to adapt infrastructure requirements. 	<ul style="list-style-type: none"> - Managing quality and meeting retailers requirements are critical. - Decision-making occurs over longer time period (animal life time). 	<ul style="list-style-type: none"> - Industry is closely networked with high levels of information sharing. - Retailers play key role in sector. 	<p>LOW</p> <p>Action tends to be driven in terms of current business priorities and responding to signals from others.</p>

²³ Potato price of £143/t with an average yield of 44 t/ha

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Actor	Resources	Processes	Organisation	Summary
Suppliers - (fertilisers, pesticides, energy, equipment, seeds - includes breeders)	<ul style="list-style-type: none"> - Able to invest in longer term; often supported by investments in markets outside the UK. - Strong capability on role of specific input/technology; in some cases this does not capture long term aspects. 	<ul style="list-style-type: none"> - Often use supplier relationship with limited use of risk sharing. - Strong innovation/ R&D processes in some companies. 	<ul style="list-style-type: none"> - International corporations with institutional frameworks for decision-making. - Strong competition with few examples of individual companies able to play leading role. 	<p>MEDIUM</p> <p>Systems, and processes are often well-developed; there are some examples of proactive and coordinating activities in major agri-chemical businesses.</p>
Food wholesalers	<ul style="list-style-type: none"> - While capital is available, business model based on high volumes and low margins. - Strong knowledge-base to ensure security of supply. - Strong technology and innovation processes. 	<ul style="list-style-type: none"> - Play a powerful role in specification and setting price. - Supply chain management able to secure suppliers internationally. - Able to manage price volatility through trading function. 	<ul style="list-style-type: none"> - Able to shift suppliers over a short period of time. - Some cases of forming close relationships with supplier. 	<p>MEDIUM</p> <p>Systems and processes are often well developed with some examples of breakthrough projects.</p>
Retailers - e.g. large supermarkets	<ul style="list-style-type: none"> - While capital is available, business model based on high volumes and low margins. - Strong knowledge base to ensure security of supply. - Strong technology and innovation processes. 	<ul style="list-style-type: none"> - Play a powerful role in specification and setting price. - Supply chain management able to secure suppliers internationally. - Able to manage price volatility through trading function. 	<ul style="list-style-type: none"> - Able to shift suppliers over a short period of time. - Some cases of forming close relationships with supplier. 	<p>MEDIUM</p> <p>Systems and processes are often well-developed with some examples of breakthrough projects.</p>
Food processors - e.g. millers, manufacturers	<ul style="list-style-type: none"> - Larger companies have international networks to introduce technology. - Smaller processors can be dominated by shorter-term requirements of retailers. 			<p>MEDIUM/HIGH</p> <p>Systems and processes are often well-developed with some examples of breakthrough projects.</p>

Context for adaptation

4.3.3 Key messages on adaptive capacity

Adaptive capacity of the sector overall is considered to be relatively high, however, it varies significantly within and across sub-sectors. The adaptive capacity of the sector is weakened by its complexity including high variety of farming types, size, and business models.

There are a number of key sensitivities:

- While the incomes for some sub-sectors are low (e.g. pig farming), in many cases, farmers with a strong business model often have access to capital. The majority of farms have a low level of liabilities but a minority are heavily indebted (Defra, 2012a).
- A number of sub-sectors (e.g. arable) have undergone or are undergoing a shift with younger generations bringing in new technology and management approaches. In other sub-sectors, development of understanding of climate change and its impacts is less mature.
- Many decisions made in farms can be made over a short time period; these are related to operations, production decisions and the continual replacement of assets. Adaptive capacity could be relatively low where actions involve a longer lead-time, or where they involve multiple organisations (both within and outside the sector), such as access to water, response to coastal erosion, and breeding traits in plants.
- Separation of land ownership from farmers who take actions is important. For tenants, the decision-making process is affected by length of time of lease agreement, the flexibility to invest or change business model, and the ability to secure finance/loans using land as collateral is substantially reduced.
- Small businesses (family farms) with limited financial and managerial capacity to adapt are likely to be most vulnerable. Larger agri-business can invest in 'no regrets' investments such as high flow storage reservoirs and are able to secure longer term, closer relationships to suppliers, customers etc.
- Certain actors play a more critical role than others in driving/restricting adaptation. These include the actors in the wider supply chain, i.e. buyers and retailers, and trusted advisors (e.g. for dairy, this includes vets, feed advisors; for arable, agronomists).

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4.3.4 Building adaptive capacity

There are a number of actions that are required to build adaptive capacity in order to respond to the needs identified in this section. Some actions are generic, e.g. education or training, while others are specific to the particular climate impact e.g. access to drought-resistant varieties. This report considers both types of actions in the following section.

5 Adaptation actions

Key messages

There are many adaptation actions that are currently being taken by many across the sector, or are likely to be taken in the near-term. However there are some key barriers to effective adaptation, namely:

- **Intra-value chain dependencies** which can lead to a lack of incentive to develop climate change-resilient breeds and varieties of crops; long-lead times may hinder timely progress; and, a lack of translation of research into products;
- **Cross-sector dependencies:** the reliance on the natural environment by farmers means they are susceptible to the natural changes in, for example, water availability and the prevalence of pests and diseases. Adaptive actions by others in these areas can impact on farmers' adaptive capacity;
- **Information failures** accessible and practical information for farmers in relation to the climate change risks and the appropriate responses under particular conditions is often limited. Managing uncertainty over the impacts of climate change is a particular issue;
- **Co-ordination** across a range of parties can be a barrier to effective adaptation in a particular locality where farmers could jointly benefit from an action; and,
- **Behavioural failures** in terms of short-term views and resistance to change can hinder the implementation of effective adaptation.

5.1 Introduction

This section provides an overview of some of the categories of actions different actors in the sector are already taking, and would be expected to take in order to maximise opportunities or minimise climate change risks. The categories include actions to build adaptive capacity as well actions that reduce the particular risks of climate change. The actions range from practical, well-tested methods to more innovative adaptations, and from low cost to expensive capital investment schemes.

These categories of actions were informed by literature-review and discussions with sector experts. They were refined and verified in the stakeholder interviews

(Annex 1) to ensure that the ECR considered the key sorts of actions to address the particular risks considered. The actions described below are categorisations of a number of individual actions, which in future could be disaggregated. The interviews were conducted under Chatham House Rules, and so in this report the stakeholders are not referred to individually or by name.

Much of the literature on adaptation to climate change has been at a conceptual or generic level (Adger *et al.*, 2007; Howden *et al.*, 2007; Iglesias *et al.*, 2007). This has shaped the understanding of what adaptation is, and the importance of the processes and responsibilities regarding adaptation. However, less research exists to quantify the predicted effects of adaptation actions in reducing climate impacts on agricultural yield (Barnes *et al.*, 2010).

For the purposes of the ECR, the adaptation actions considered are those that are already being taken or are expected to be taken. The actions include:

- **Planned adaptation:** this tends to be (but is not exclusively) anticipatory adaptation, undertaken or directly influenced by governments or collectives as a public policy initiative. These actions tend to represent conscious responses to concerns about climate change (Parry *et al.*, 2007).
- **Reactive adaptation:** taken as a reactive response to climatic stimuli as a matter of course (without direct intervention of a public agency) (Parry *et al.*, 2007). Since farmers are continually adapting to changing conditions, whether in response to political, market, economic or social factors, a changing climate may simply be another pressure to which they must adapt.

In some cases, actions could be considered both planned and reactive (for example, a reactive response to a current risk could lead to planned adaptations to limit future exposure). Both planned and reactive adaptations have the potential to be ‘wrong’ or lead to maladaptation in the long term or for wider society. Consequences may need to be countered with further action, such as building adaptive capacity and by taking specific actions.

Many of these **adaptation actions relate to building the adaptive capacity** of the farming sector, such as raising awareness. For the purposes of this report, building adaptive capacity is not described as a separate action in itself, but is an integral part of each adaptation option, as the greater the capacity of the individual, the more likely it is for an action to be taken.

The list of actions set out here is not exhaustive, but is intended to illustrate the key types of responses to climate change that actors in the agriculture sector are taking/will take without government intervention. The actions focus on the farmer and site-specific actions.

The categories of actions are described in detail in Annex 6. They are briefly set out below with a description of the action, and a summary of the barriers and

Adaptation actions

enablers, and potential outcomes²⁴. Policy or legislative requirements that act to facilitate or hinder actions are also noted. Categories considered are:

- New breeds and varieties;
- Storage infrastructure and buildings;
- General farming practices for crops and livestock;
- Responses to pests and diseases;
- Water management;
- Soil management;
- Ecosystem services and agri-environment management;
- Knowledge transfer; and,
- Financial risk management

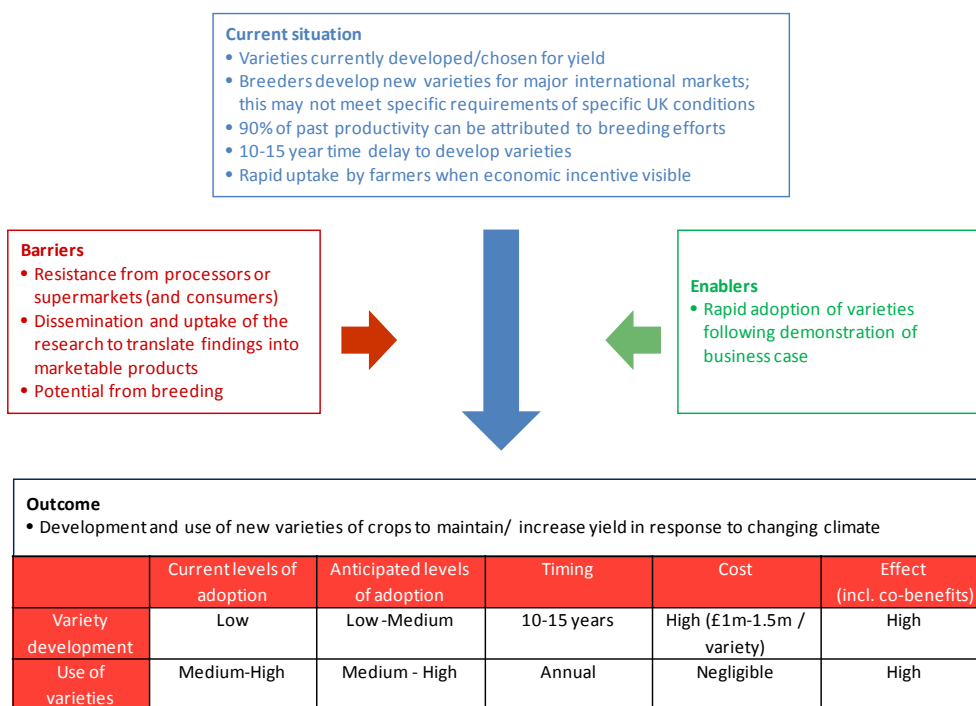
5.2 Key categories of actions

5.2.1 New breeds and varieties

A changing climate brings a need for crops to be better adapted to their new conditions. This may include developing new crop cultivars (e.g. drought resistant varieties); using new varieties of crop or new crops (e.g. grapes, soft fruits); and using new varieties of forage. **Figure 6** provides a summary.

²⁴ The potential outcomes include extent of current and future adoption, timing, cost and effectiveness. Costs are relative to the sector. For example, high cost is major infrastructure investment or change in approach or strategy (e.g. hundreds of thousands or millions); low cost is the individual cost of a change to processes or operations, information provisions, or minor investment in equipment (e.g. thousands or tens of thousands).

Figure 6: Summary of new breeds and varieties adaptation actions



Source: Based on published information where cited and stakeholder interviews

Extent of adoption of adaptation actions

At present, yield is the main driver for new varieties (e.g. the HGCA Recommended Lists of new varieties are primarily based on yield) and there is little evidence that UK breeders are developing new traits for climate resilience, as they are not saleable. More research is happening internationally where the markets are larger, however, these do not translate exactly to specific conditions on UK farms. Once new varieties or breeds have been commercially developed and a clear business case has been demonstrated, farmers tend to adopt them rapidly, although take-up of new varieties by farmers varies between sub-sectors.

Key barriers

Research for new varieties requires significant funding (e.g. annual cost of £1 - £1.5 million for commercial wheat breeding), yet the annual income of UK breeders is only £40 million. Breeders only have the incentive to invest where the returns from doing so are likely to justify the costs. Where the return does not reflect wider society benefits – such as being able to adapt to climate change (e.g. by being more drought-tolerant) – then **there is no incentive for breeders to invest in the relevant research** (DTZ, 2010). Returns from such breeding would also be uncertain, which is a further barrier. This suggests a **market**

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failure in that the returns for breeders do not reflect the external benefits of climate resilient breeds. The **long lead-times for breeding** (new varieties take 10-15 years to develop) can also be a barrier to having the right information and products available for farmers when they need them to adapt to climate change.

Processors or supermarkets (and consumers) have specific requirements in terms of taste and appearance of their products that can create an incentive to grow maladapted or vulnerable varieties. The high level of global competition facing UK farmers suggests that consumers and retailers have substitutes available to meet their needs, so there is a market incentive for breeders to produce what the market demands in the short-term, rather than investing where returns may be uncertain.

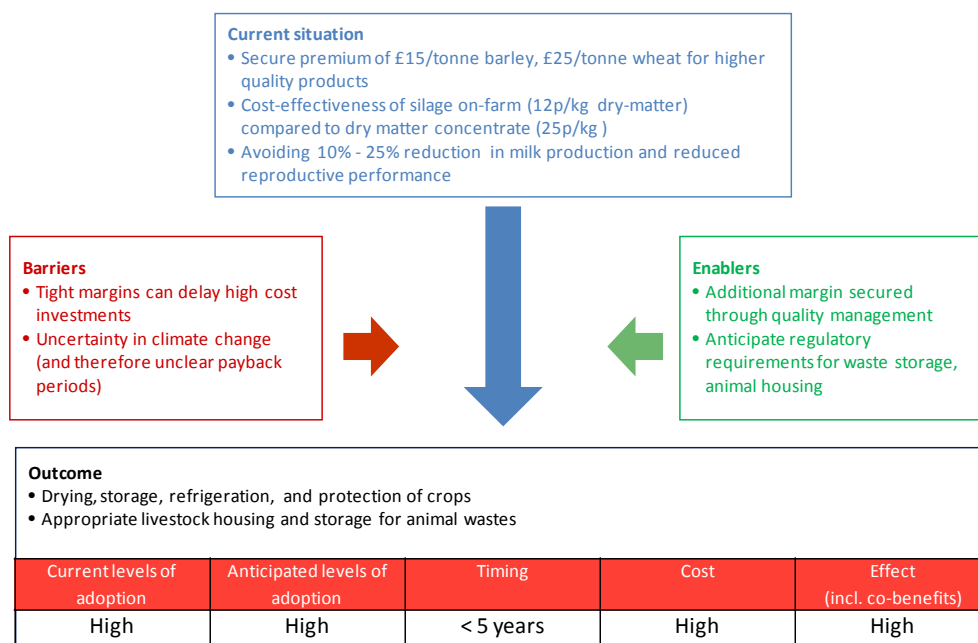
Effect of response

Almost 90% of the increase in national average cereal yields since 1982 is attributed to innovation in plant breeding, with an estimated gross value of £373 million to £445 million per annum in 2010 prices (DTZ, 2010). The gross return on industry investment is estimated at an extremely high 40 to 1 (DTZ, 2010). A survey of 600 farmers at the Oxford Farming Conference 2012 singled out plant breeding as the most important scientific development for future agricultural production.

5.2.2 Storage infrastructure (buildings)

Increased temperatures, heavier rainfall and increased extreme weather events will demand more or improved seed, crop and silage storage and protection. In addition, facilities to dry crops; use of in-store cooling, ventilation and insulation for better refrigeration to cool crops; appropriate housing for livestock, pigs and poultry; and secure and covered storage for animal wastes, are also likely to be required. **Figure 7** provides a summary.

Figure 7: Summary of storage infrastructure adaptation actions



Source: Based on published information where cited and stakeholder interviews

Extent of adoption of adaptation actions

Adoption of these measures is expected to be very high (e.g. ADAS, 2008; Defra, 2011b). The investment will occur on all farms as a market decision: without protection, production will suffer.

Key barriers

These actions require capital expenditure, so, if they became essential for adaptation to climate change, a lack of finance may make an enterprise commercially unviable. **Investments will depend on farm profit margins, which vary considerably** - tenant-type capital²⁵ can vary from under £164,000 to £600,000 (Wilson *et al.*, 2010). Postponement of investment may occur where **there are unclear payback periods, i.e. an information failure** due to uncertainty in climate change and its associated indirect impacts.

²⁵ Tenant type capital includes closing valuations for: machinery, livestock, glasshouses, permanent crops, crops, forage, cultivations, stores, liquid assets, and Single Payment Scheme entitlements

Adaptation actions

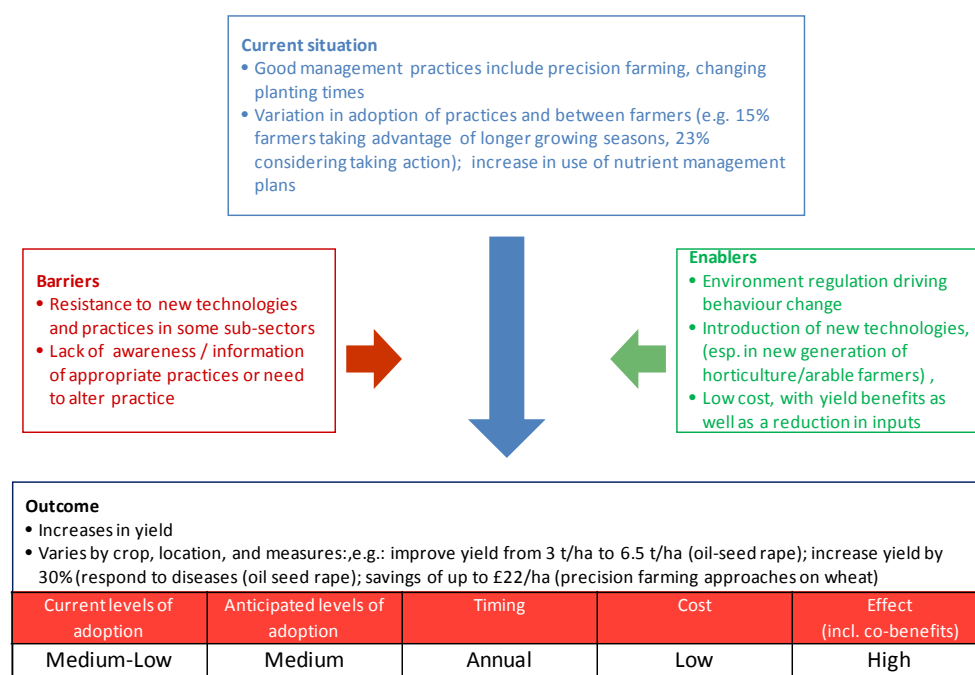
Effect of response

If the capital investment is not made, it could lead to an inability to secure a premium on crops due to inadequate crop drying and storage. Silage stores are cost-effective, despite the high capital cost. The capital investments required for livestock housing should prevent loss in productivity due to over-heating and the costs of non-compliance with animal welfare regulations.

5.2.3 Farming practices - crops

There are many farming management practices in limited use today that will strengthen farmers' resilience, for example, practices that deliver soil conservation; input (fertiliser, pesticides) efficiency and reduction (such as precision agriculture); general operational good practice (such as changing planting dates, rotational cropping etc.). **Figure 8** provides a summary.

Figure 8: Summary of (arable) farming practices adaptation actions



Source: Based on published information where cited and stakeholder interviews

Extent of adoption of adaptation actions

There is significant variation in adoption of these measures, but the FPS (2011) and Farming Futures (2011) surveys indicate that, despite being able to improve productivity today at reasonably low cost, the practices are not widely followed (FPS, 2011).

Adaptation actions

Key barriers

The main reason for lack of up-take appears to be **behavioural and information-related**. Farmers do not appear to see an immediate economic benefit **at present to changing practices**. This could be a **behaviour failure** or due to a **lack of information** over the benefits of changing behaviour. Others think the measures are too impractical, or not relevant (ADAS, 2008), and precision applied agriculture is expensive and only cost-effective on larger farms (some farms lack adequate **economies of scale**). Differences in adaptive capacity mean that larger farms consistently take more action than smaller farms (FPS, 2011).

Effect of response

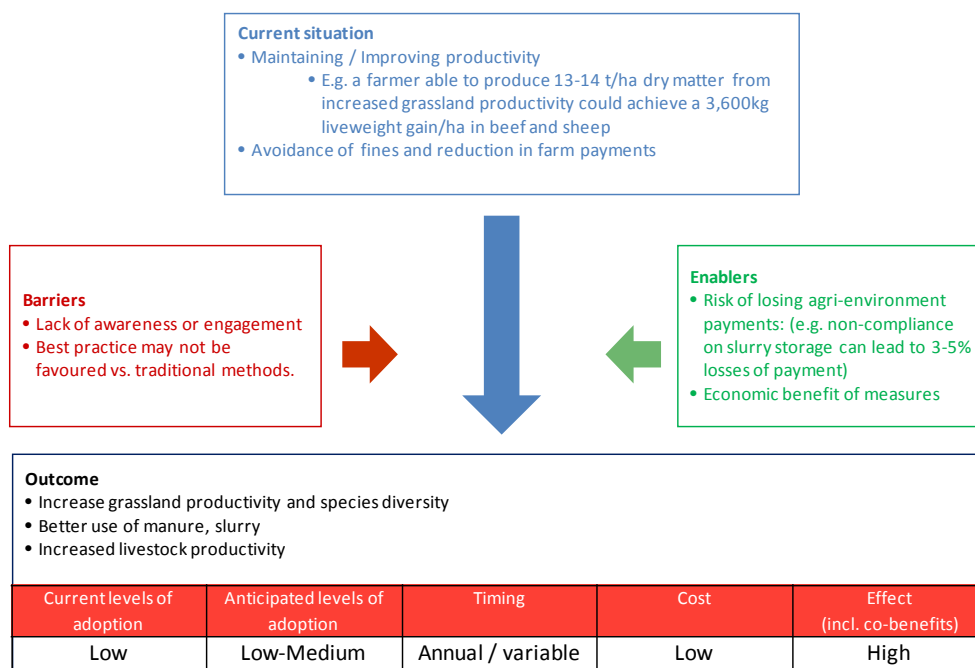
Changing farming practices can lead to increased yields by an achievable combination of present knowledge, practice and directed production-specific information. The practices listed above are straightforward, low cost, 'low-adaptation' strategies that will be **important short-term 'no-regrets' options**. There are **many co-benefits** beyond the economic benefit of an increase in yield, such as a reduction in inputs, and environmental benefit from better land-management, soil quality and targeting of chemicals.

5.2.4 Farming practices – livestock

There are various measures that livestock and dairy farmers can take to improve livestock productivity and manage risks associated with management of waste. These include: increasing grassland production, growing pasture with diverse plant species, more effective recycling of farm waste (manure, slurry), and general good operational practice, such as provision of shade or keeping livestock off water courses. **Figure 9** provides a summary.

Adaptation actions

Figure 9: Summary of (livestock) farming practices adaptation actions



Source: Based on published information where cited and stakeholder interviews

Extent of adoption of adaptation actions

Established farming practices, such as the increased use of rotation and short-term leys, better use of permanent pasture, use of mix forage including catch crops, all improve grassland productivity (ADAS, 2008). These practices are particularly important in Scotland, Wales and Northern Ireland where grassland is an important land-use. However, many of these practices are not widespread among farmers and adoption is low.

Key barriers

Lack of awareness of best practice is a particular difficulty with adoption of these sorts of measures and some farmers can be resistant to change, i.e. **behaviour** is a constraint.

Effect of response

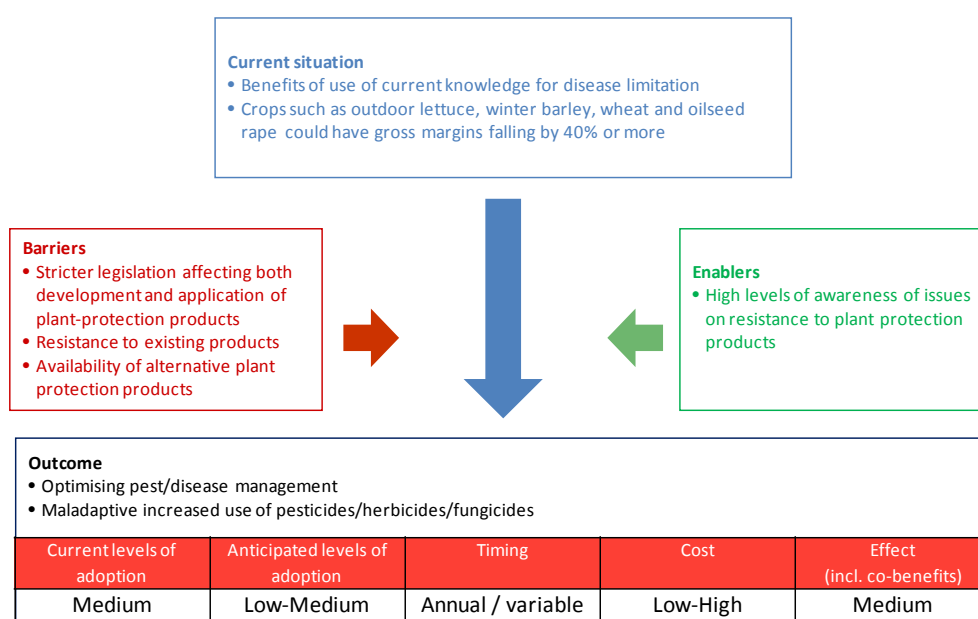
The benefits of climate change on grassland may not be fully realized on the basis that grassland productivity is under-developed. Increasing grassland productivity could improve margins and increase livestock productivity (EBLEX, 2010). Good operational management has many **co-benefits**, such as reducing fertilizer

cost, reducing environmental pollution, better soil management, so increasing best practice farm management is an **important ‘no-regrets’ measures**.

5.2.5 Pests and diseases management

There are a number of measures used today to respond to changes in pests and diseases as a result of climate change: increasing use of pesticides/herbicides/fungicides; and optimising pest management, such as monitoring, early warning systems, and integrated pest management (IPM). **Figure 10** provides a summary.

Figure 10: Summary of pest and disease management adaptation actions



Source: Based on published information where cited and stakeholder interviews

Extent of adoption of adaptation actions

Measures to respond to pests and diseases are being taken: according to the FPS, (2011), 29% of respondents are already taking action. Increased use of pesticides/herbicides/fungicides to deal with risks is the immediate adaptation response of most farmers, but better management for pests is increasing (e.g. integrated pest management²⁶, monitoring and information networks).

²⁶ The Endure Information Centre website disseminates information on pest management. It offers a European quality selection (European Best Practices) of practices with validated Integrated Pest Management (IPM) measures including prevention, chemical pest and disease control as well as non-chemical alternatives such as biological control measures.

Adaptation actions

Stakeholders indicated that farmers are very aware of issues around resistance to plant protection products, particularly given regulatory restrictions and the reduction in available, cost-effective options.

Key barriers

Barriers include the **uncertainty of how diseases and pests will evolve and spread** and the **time-lag in developing disease-resistant varieties** (discussed above). IPM is not particularly new but it is not mainstream and needs further understanding, as is being developed by the PURE project²⁷. Increasing restrictions in plant protection legislation will constrain the products available, but incentivise better management. There are also **tensions between policy objectives, which mean that farmer actions may be constrained in their ability to apply plant protection products in order to protect the natural environment**, but this would assume that policy makers have determined this to be the best overall outcome for society on the basis of relative costs and benefits.

Effect of response

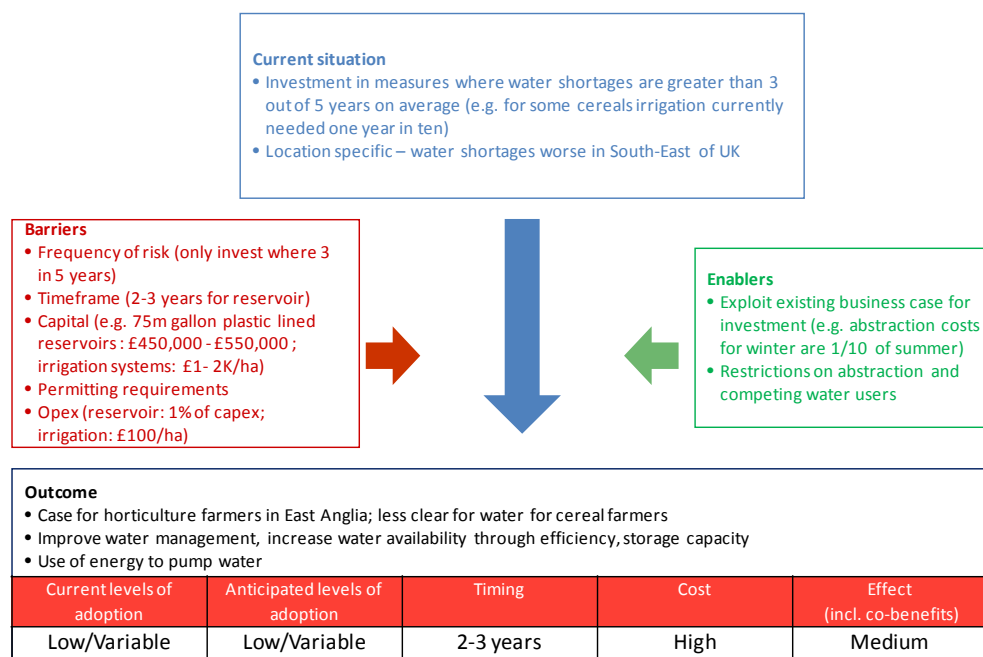
Increasing use of chemicals may be effective in the short-term, but this is not a desired adaptation response as there may also be adverse impacts associated with chemical use, e.g. greenhouse gas emissions, and environmental pollution. **Optimising pest management strategies will therefore be extremely important.** These can be extremely effective and have immediate benefits (Spink *et al.*, 2009), provided adaptive capacity increases so that knowledge in identification and monitoring of diseases is widespread. Disease control can aid mitigation, reducing emissions by increasing yields per tonne (Fitt *et al.*, 2011; Smith *et al.*, 2007).

5.2.6 Water management

Water management includes managing water availability (scarcity and flooding) and use. The immediate reactive adaptation option where water is scarce is to abstract more water, where licences allow. Other planned measures considered include improving irrigation efficiency, water storage capacity, and using sustainable drainage systems. **Figure 11** provides a summary.

²⁷ <http://www.pure-ipm.eu/taxonomy/term/5>

Figure 11: Summary of water management adaptation actions



Source: Based on published information where cited and stakeholder interviews

Extent of adoption of adaptation actions

Farmers in drought-prone locations are already pursuing opportunities for irrigation/water storage where it is feasible. In the face of restrictions on abstraction, competing water users, and increased flooding, farmers are taking more significant measures to manage water, (e.g. switching to new irrigation technologies, water storage reservoirs, or sustainable drainage systems). Co-operation between landowners and farmers in catchment areas can mean that capital costs are shared²⁸, and farmers are increasingly working together forming abstraction groups (Rudge and Gowing, n.d.).

Key barriers

Access to abstraction licences, and tightening conditions on the licences, could be a barrier where they are relied upon for investments. **Uncertainty** over the frequency of events (droughts or floods) means that payback times are unclear. Building reservoirs can be expensive, with many associated costs (e.g. surveys,

²⁸ An example of this form of collaboration is the United Utilities and RSPB led Sustainable Catchment Management Programme (SCaMP) that worked to improve water catchment management by for example, providing fencing for livestock, and new waste facilities to reduce run-off etc. See: <http://www.unitedutilities.com/AboutSCaMP.aspx>

Adaptation actions

permissions, professional fees, etc.). Other barriers are the lack of ability to secure **access to water resources** (e.g. current challenges of winter abstraction) and requirement for significant infrastructure and expenditure, as well as technical feasibility, permitting requirements, and indirect barriers, such as pumping water from a reservoir, which requires energy. **A lack of widespread co-operation across landowners** (where feasible) is a barrier for small-scale farms that would otherwise benefit from co-ordinated action given the potential to share capital costs.

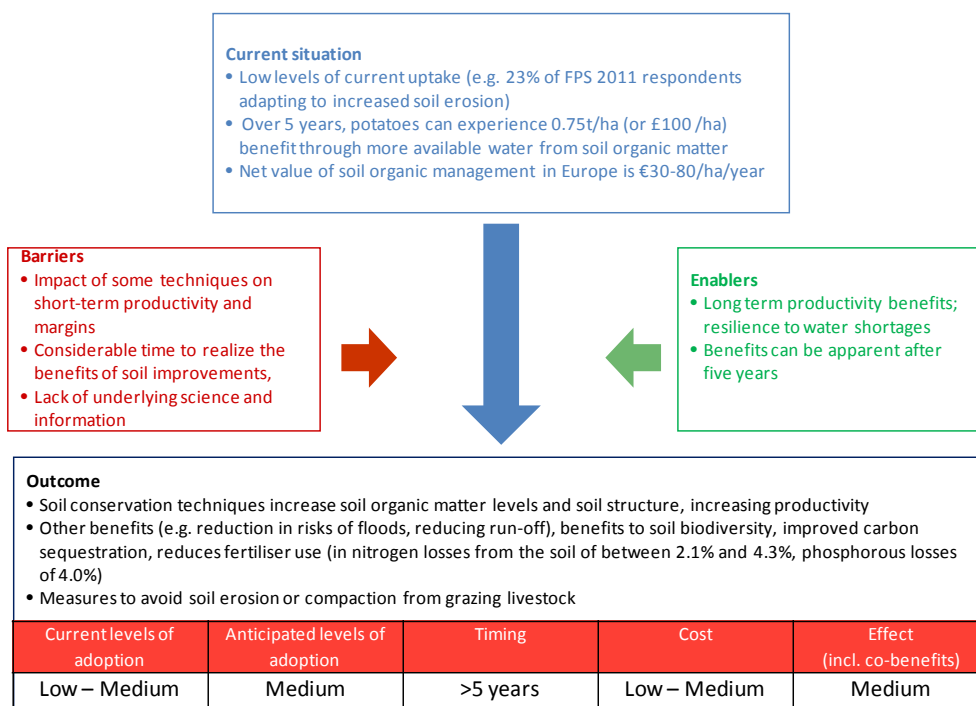
Effect of response

An immediate reactive response to dealing with increased temperatures and soil aridity is to **increase water abstraction**. This is arguably maladaptive as increased demand occurs in the same areas and at the same time. This means that other adaptation measures need to occur, such as winter abstraction and storing water, or drip irrigation. These are very effective, but expensive. In addition, in the long-term they may be maladaptive as farmers may need to move areas leaving most of the infrastructure behind. Three themes have been identified as part of a successful irrigation strategy: working together, making best use of available water and developing a knowledge base (Knox *et al.*, 2009).

5.2.7 Soil management

Soil management includes a range of measures to maintain and enhance soil organic matter and soil function. These include: using soil conservation techniques (e.g. no-till farming, cover crops, contour ploughing); using mulches to conserve water; using measures to avoid soil erosion and compaction. **Figure 12** provides a summary.

Figure 12: Summary of soil management adaptation actions



Source: Based on published information where cited and stakeholder interviews

Extent of adoption of adaptation actions

Awareness of the importance of soil structure in agriculture is growing, but there is still a low level of uptake of management measures (FPS, 2011).

Key barriers

Barriers include the **impact of some techniques on short-term productivity and margins** (implying a behavioural issue focusing on short-term outcomes at the expense of longer term outcomes), and the **time-frame** before improvements are seen in soil structure (minimum 5 years). In addition, stakeholders feel there is still a **lack of underlying science and information** on benefits realized from good soil management, which is attributed less importance than water and air.

Effect of response

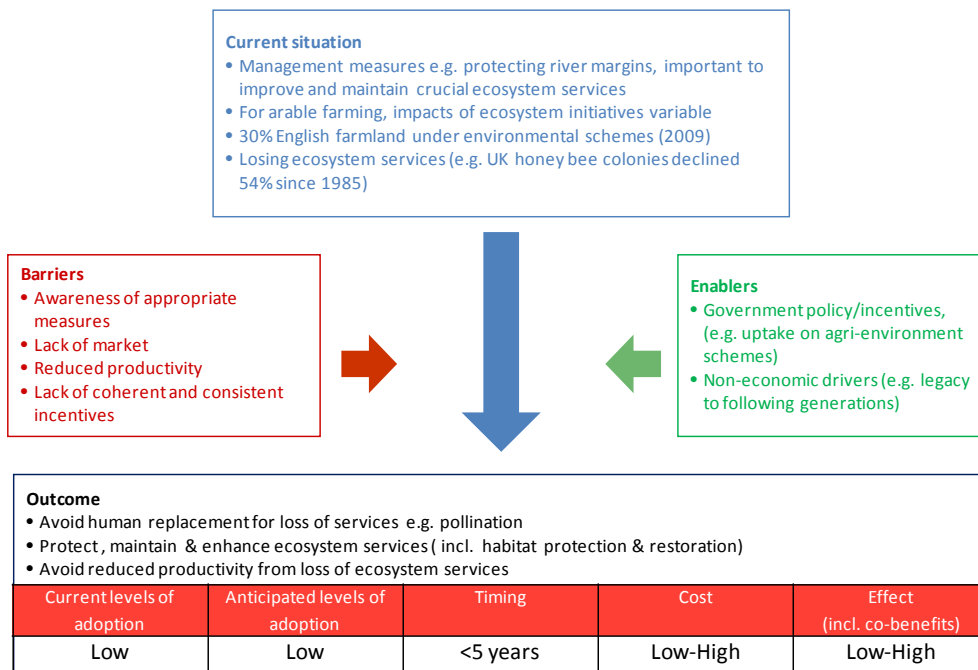
There are a number of examples illustrating the considerable benefit of improvements of soil function to productivity. There are also **many co-benefits** associated with improving soil quality, for example, reduced fertiliser use, reduced flood risks, reduced run-off (better water infiltration and retention), benefits to biodiversity, and higher quality soil has a better soil carbon content.

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5.2.8 Protecting ecosystem services

Given the close interface between agricultural productivity and the natural environment, many of the adaptation actions discussed under other categories (e.g. pest management and soil management) will have positive or negative implications for the natural environment. Other measures to protect and maintain ecosystem services include: actions to compensate for reduced ecosystem services (e.g. replacement for bee pollination); protecting and restoring habitats (e.g. restoring natural river profiles); and improving ecosystems services on farms (e.g. planting trees as wind breaks and buffer strips to protect surface water bodies and encourage biodiversity). **Figure 13** provides a summary.

Figure 13: Summary of protecting ecosystem services adaptation actions



Source: Based on published information where cited and stakeholder interviews

Extent of adoption of adaptation actions

Action taken to preserve or enhance ecosystem services is likely to have a higher take up in farms in agri-environment schemes than those without them. There is evidence that farmers have responded well to the incentives offered by Entry Level Schemes. According to a number of stakeholders, the future adoption will be strongly influenced by the coherence and consistency of incentives.

Key barriers

A key market failure relates to the **lack of market for ecosystems services**. The value of ecosystem services is not priced within the market-place so there is no market incentive for farmers to take action to preserve or enhance them (there would be no return to them from doing so, and they face little cost from not protecting them). About £400 million each year is paid to England's land managers through Agri-Environment Scheme options designed to protect soils and water, with the majority of funding provided through two strands of Environmental Stewardship: Entry-Level Stewardship and Higher-Level Stewardship, but without these or similar schemes, the market incentive would not exist.

Effect of response

Agriculture and the natural environment are intrinsically linked (UK NEA, 2011). Where Environment Stewardship schemes exist, they ensure farmers minimise their impacts (Boatman *et al.*, 2008), however only one-third of agricultural land is covered by these. Addressing reduced ecosystem services is a longer-term risk, but it could be very costly should it become necessary to find alternatives or use human replacement of these services (e.g. a replacement cost scenario was used to estimate the value of insect pollination to the UK apple market, suggesting a value of £82 million (90% of the total market value of the crop) (Marris *et al.*, 2009).

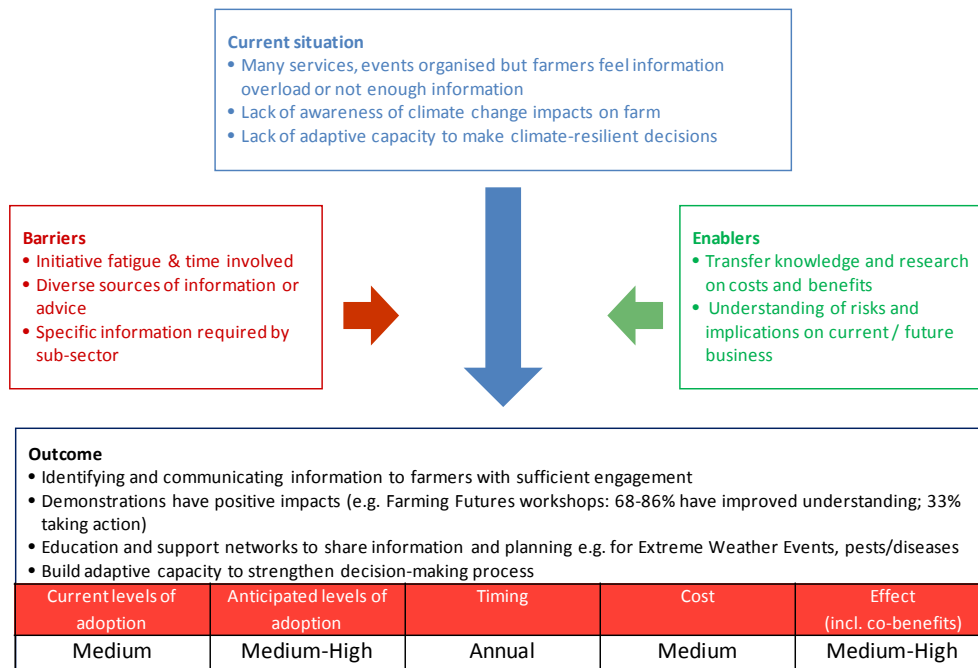
Generally, protecting ecosystem services has **many co-benefits** in other sectors. It can encourage tourism, maintain rural livelihoods and landscapes, provide amenity value, protect water quality, provide flood defence and encourage biodiversity.

5.2.9 Knowledge Transfer

This category includes identifying and communicating information to farmers, including the extent to which knowledge is taken up by farmers and then implemented, and the extent to which information supports decision-making. **These adaptation actions are designed to build adaptive capacity** and include translational research of academic findings into commercially usable findings, education and support networks to share information and experiences, and planning for extreme weather events. **Figure 14** provides a summary.

Adaptation actions

Figure 14: Summary of knowledge transfer adaptation actions



Source: Based on interviews and information from a range of published studies

Extent of adoption of adaptation actions

Although a wealth of information exists for farmers in terms of tools and guidance, awareness of climate change is still relatively low at the farm level (Farming Futures, 2011). Numerous technological and non-technological issues are known, and may be applied, but require governance and education to put them in place (Pereira, 2011).

Key barriers

There appears to be a **lack of consistency** in messages received by farmers (AEA, 2010), a **lack of mainstreaming of climate change** so it is still a separate side issue (IGER, 2002), and farmers are unclear what the effects will be and many do not know what to do to adapt (Farming Futures, 2011). There is a **lack of awareness of new technologies or new practices**. This is more pronounced in some sectors, such as livestock, which stakeholders suggest is generally more resistant to change. Other barriers to effective knowledge transfer include the **highly fragmented nature** of the knowledge and social networks of farmers leading to an absence of common values, a need for hands on experience (Buttel, 2001). This **lack of adaptive capacity** is a barrier to the successful adoption of all other adaptation responses.

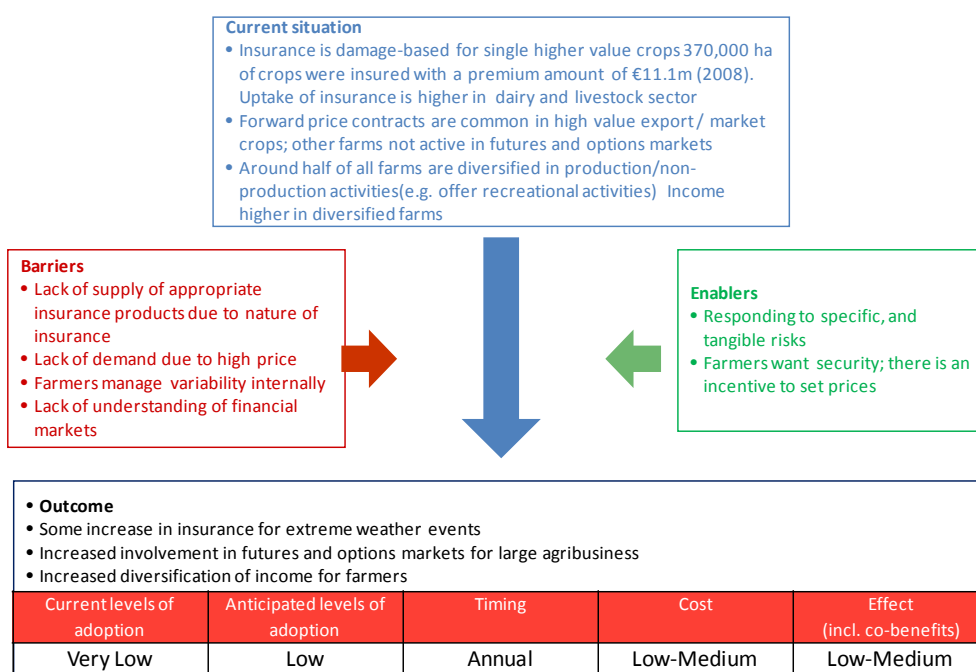
Effect of response

Knowledge transfer affects every adaptation measure and is a cross-cutting issue. It can be extremely effective. All the adaptation responses discussed in this report will benefit from applied research to effectively transmit knowledge to change farming practices (Gladders *et al.*, 2006). Building farmers' adaptive capacity in this way will improve the ability of all farmers to make climate-resilient decisions, increasing the adoption and effect of all adaptation responses. Evidence from past initiatives suggests that knowledge transfer alone does not necessarily address barriers, as there may still be a lack of access to finance.

5.2.10 Financial risk management

Farmers will face a number of production risks from climate change that can increase the volatility of their incomes. This is compounded by the need to respond to market risks, which can be strongly influenced by international drivers. Measures include: developing and purchasing crop and farm insurance; becoming involved in futures and options markets and diversifying income sources. There are a number of other measures, which have been used or considered in the past such as price stabilisation mechanisms; these are not considered here. **Figure 15** provides a summary.

Figure 15: Summary of financial risk management adaptation actions



Adaptation actions

Source: Based on published information where cited and stakeholder interviews

Extent of adoption of adaptation actions

Financial risk management is an area where **major agri-business is able to respond but smaller farms are less able** to exploit mechanisms. There is currently very **little availability of insurance** in the UK to cover crops against weather risks. Where they exist, insurance products are primarily damage-based, focusing on the single higher value crops (Northern Ireland Assembly, 2008; Hazell, 2011). While very few farmers are actively involved in the futures and options markets, forward price contracts are common. Given the volatile commodity markets, farmers want security and there is an incentive to set prices. **Approximately half of all farms are diversified** in terms of production and non-production activities (Defra, 2011a).

Key barriers

The adoption of insurance across the sector is driven in part by **lack of demand due to high costs** (Morgan, 2007) and **lack of supply** of appropriate insurance products. However, insurance against storm and flood damage is increasing. Qualitative evidence suggests that there is **limited knowledge among farmers** on the price of volatility and alternative responses, so smaller farms will avoid investing in futures markets. The same is true for diversification: lack of knowledge of the benefits prevent farmers from taking action.

Effect of response

In general, **insurance is extremely effective** in dealing with damage caused by specific events, such as from hail-storms. However, it can act as a disincentive for farmers to manage their practices to reduce risk (Kimura *et al.*, 2010) – this is the common effect economists refer to as “moral hazard”. Forward pricing arrangements are effective in hedging against downside risks rather than reducing the variability of a price. **Income tends to be higher in diversified farms**; this higher level of income is important in assessing the capacity of those farms to adapt to projected climate change.

5.3 Uncertainties and limitations

There are a number of uncertainties and limitations of the analysis of adaptation actions including:

- **Interaction between measures:** The measures discussed in this section do not occur in isolation of each other. For instance, the implementation of measures to address soil function influences the approach to managing water.

Adaptation actions

- **Timeline:** Farmers and others in the sector are continually adapting to changing conditions. While projections of productivity look to the 2050s, the analysis of adaptation actions in this report are primarily based on activities occurring in the present or near future and on the experience of experts and stakeholders today.
- **Subjective assessments:** Assessing the extent of adaptation measures and their likelihood of increasing in extent in the future is in part subjective and based on the views and opinions of stakeholders and experts. The work is inevitably biased by the views and opinions of the stakeholders that responded to requests for interviews and those that attended the ECR Agriculture Adaptation Forum.
- **Comprehensiveness:** The work is not comprehensive in scope and is limited by the expertise of the particular experts and stakeholders that responded to the work. Given the diversity of the sector, some generalisations are inevitable.
- **Nature of the evidence:** Although there is some evidence on isolated costs of specific options, there is little readily available evidence as to the economic impacts of different options compared with others and the cost implications of taking one option rather than another particularly when put in the context of many other options. There are few data generally available on the quantified impacts of adaptation decisions and whether or not, and to what extent, decisions will mitigate climate risks.

5.3.1 Cross-sectoral links

In many of the adaptation actions discussed above, the impacts of the action are cross-sectoral, and responses therefore need to be cross-sectoral. For example, the responses of a farmer to flooding on land need to be integrated with the responses of local decision-makers to flood risk to protect nearby residential areas. The responses of farmers to risks around flooding and water scarcity generally should be considered with responses of planners to impacts on ecosystem services and forestry (please see the ECR Reports on Forestry and on Natural Flood Management).

5.3.2 Devolved Administrations

Given the dominance of livestock in all the DAs compared with wheat, sugar beet or potatoes, those adaptation measures around livestock or building adaptive capacity more generally will be of most relevance. These include: new forage varieties; storage infrastructure – for livestock housing and silage/waste storage facilities; soil management – particularly with increased heavy winter rainfall

Adaptation actions

causing waterlogging and erosion; knowledge transfer; and financial risk management.

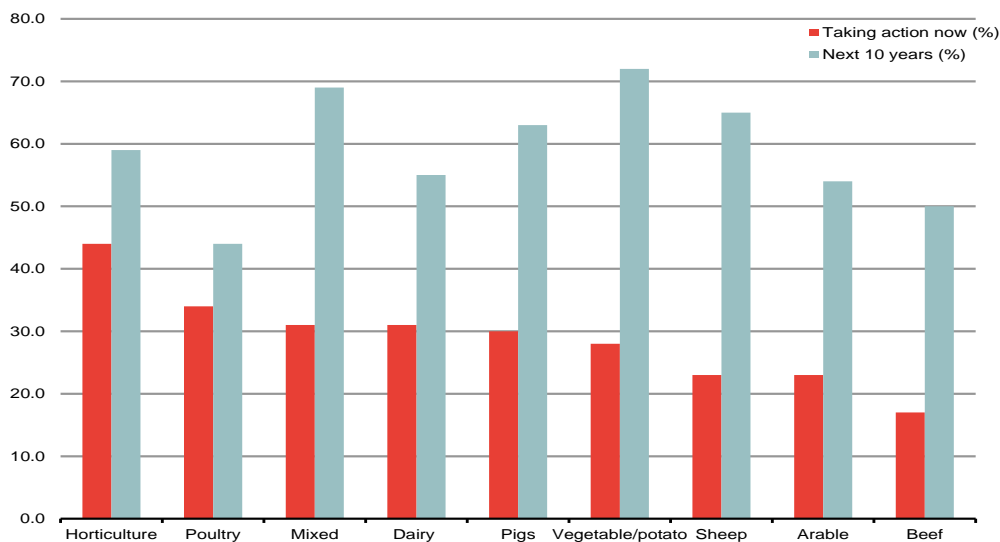
5.4 Summary of current and anticipated adaptation

It is important to gain a general view of the current and expected degree of effective adaptation so that key barriers can be identified and addressed through intervention by government or other bodies.

At present **farmers tend to be making short-term adjustments to optimise income without major system changes**. Approximately 10% of farmers are considering opportunities from climate change; 10-30% are already considering how to respond to risks of flooding, drought, soil erosion, pests and diseases among other threats to income (Defra, 2011e). Details of supporting evidence are provided in Annex 6.

There is also variation in the **extent to which farmers are taking action to respond to climate change now, and the extent to which farmers believe their farms will be affected by climate change in the next 10 years**, as **Figure 16** illustrates.

Figure 16. Extent to which farmers are taking action to respond to climate change now, and the extent to which farmers think they will be affected by climate change in the next 10 years (sample size 395)



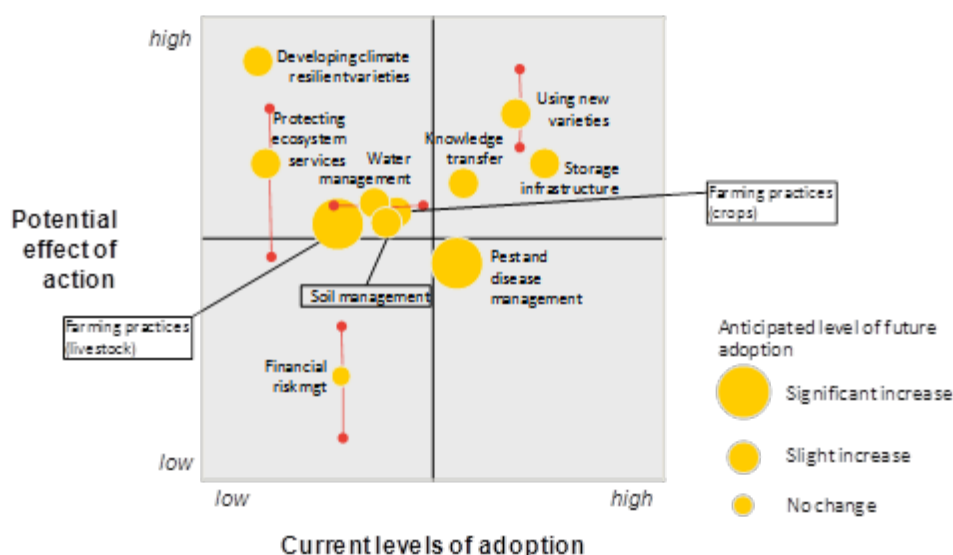
Source: Farming Futures, (2011)

On the basis of adaptive capacity and adaptation actions discussed in this Section, an assessment has been made of the extent to which adaptation actions

are currently being taken, and whether they would be likely in the near-term (to 2020).

Figure 17 provides a simplified summary of the extent of current adoption of adaptation actions and expected future adoption under current policy and drivers of behaviour, and an initial view of their effectiveness. Further consideration of their effectiveness would require a detailed assessment of the costs and benefits of the action. The approach provides a framework for summarising a substantial amount of information. The summary uses the classifications “high, medium and low” used within **Figure 6** to **Figure 15**. Those classifications were determined based on the evidence from published literature, stakeholder input and academic expertise, set out within this report and Annex 6. It is intended to provide a basis for further discussion as part of future stakeholder engagement.

Figure 17: Summary of current and anticipated effects of different adaptation actions



Source: ECR analysis

Note: Scales are qualitative and relative to the sectors included. The **current levels of adoption** include decisions that are infrequent (e.g. purchase of storage infrastructure) as well as common practice (such as framing practices). **Effectiveness** varies from limited scope due to impact on yield productivity, time frames or effort involved (e.g. capacity building among individual suppliers) to major changes in risk management. Increases in future adaptation are shown only for adaptation actions without further incentives, essentially over the next 10 years or so.

The position of each measure is based on the classification used within this chapter, but could vary considerably depending on sector and company.

The yellow dots positioning the adaptation actions in **Figure 17** are scaled according to the extent to which an increase in uptake in the future is expected (without further intervention). The red lines illustrate variation in the levels of

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adoption and effectiveness of actions across different farmers. Further detail on the relative effectiveness of actions is in Annex 6.

The top right corner of **Figure 17** shows those actions where adaptation is generally working well, such as using new varieties. Overall, and in the short-term, these actions are broadly effective and widespread. Those actions in the top left corner are assessed as relatively effective but not widespread, suggesting that significant barriers to action exist. It should be noted that it may not be justified to increase adoption of these actions, however – that will need to be assessed on the basis of the costs and the benefits. The actions in the bottom right are widespread and not effective, either because they are driven by factors other than climate change, or they may be simple to implement. Actions in the bottom left corner are neither particularly effective nor are widespread.

It is important to note that adaptation actions taken are not necessarily always appropriate to address particular climate change threats – they can lead to maladaptation if action is taken without full consideration of the longer term risks. In these cases, intervention may be required to correct the maladaptation.

Key findings of **Figure 17** are:

- Actions in the top half of the chart indicate that where they are taken, they are expected to be effective. The most effective measures include climate resilient variety development and use; measures to protect ecosystem services; water management; soil management and knowledge transfer.
- The most effective measures, (e.g. the development of new varieties by breeders), have low adoption rates at present and are not expected to increase in use without further intervention. This suggests the potential prevalence of significant barriers to adoption.
- Many of the measures being adopted at present are expected to increase slightly in the future, suggesting a degree of further adaptation without further intervention. This is likely to be because farmers are used to responding to climate risks generally.
- Many measures show low-medium adoption and medium effectiveness. This suggests that there are barriers associated with adaptive capacity that could increase adoption and enhance the effectiveness of actions if addressed.
- Financial risk management, and particularly insurance, is not greatly effective as it does not reduce a climate risk. It has use in limited circumstances, helping farmers bear the burden of loss due to a particular risk.

In summary, although there are measures that will be taken in future with moderate effectiveness, to ensure the future adoption of the more effective measures, further intervention will be required.

Over a longer time period, it is not clear whether anticipated levels of adoption of measures will be sufficient to respond to increasing weather variability, with increased frequency of extreme events, and long term impacts on productivity. Adaptation could result in more substantive **structural changes in relation to production** (transformational adaptation). These could include: land use changes to stabilise production as yields fluctuate; and changing from crops with high inter-annual yield variability (wheat) to crops with lower productivity but more stable yields (pasture) (Olesen and Bindi, 2004).

5.5 Barriers to effective adaptation

The assessment of adaptive capacity and of adaptation actions above suggests that there are particular barriers that either prevent measures being taken, or from being effective, or both. This could be due to a range of factors, which are discussed below.

As noted above, although barriers may exist, actions located in the top left of **Figure 17** may not all be worthwhile increasing – that would need to be subject to an appropriate cost-benefit analysis for the given context in which they are considered.

As described earlier in this report, barriers have been categorised in terms of market failures, policy failures, behavioural constraints and governance constraints. These are explored below.

5.5.1 Market failures

Dependencies are an important factor because they imply the presence of external costs or benefits imposed on another party, without those costs or benefits being accounted for in decision-making. In the case of agriculture, these arise as a result of:

- **Value-chain dependencies:** the actions by some in the value chain can affect the resilience of others to climate change threats. For example, farmers cannot grow climate resilient varieties unless the research to develop those varieties has occurred, and that research has been translated into commercial products. Research requires considerable investment, which is only made where the returns from doing so justifies the costs, and where these returns do not reflect wider public benefit (e.g. using less water), there is little incentive to invest. A further aspect to value chain dependency relates to the interaction between consumer demand and the varieties of crops that farmers produce. Farmers will only grow crops for which they are able to

Adaptation actions

identify a market; where climate resilient crops do not meet consumer preferences (for example in shape or taste) they will not purchase them. There is therefore limited incentive to farmers to grow them; and,

- **Cross-sector dependencies:** agricultural activities are inherently linked with the natural environment. Therefore, the resilience of the agricultural system and its adaptation actions can impact on the natural environment, and *vice versa*. This could either be positive or negative, but a lack of transparency over such effects is likely to lead to lower adaptive capacity. Water availability and soil moisture deficit are likely to be particular issues for farmers as many rely heavily on the availability of these natural resources, which are likely to become increasingly important under a range of climate change scenarios. The interdependencies with the natural environment are also considered as part of the ECR report “Natural Environment Theme: Natural Flood Risk Management”.

Information failure is a common issue from several perspectives:

- **Uncertainty in the degree of climate change impacts:** This is discussed further in Annex 2. Of particular issue for farmers is the variability in the weather across and within seasons and from year to year, and the extent to which they may be subject to low probability-high impact events. For example, pests and diseases could have substantial implications for crop yields, but their likelihood is uncertain.
- **Lack of tailored, practical information relating to risks and appropriate actions to manage them, targeted at those who need it most:** although steps are being taken to share information with farmers (through extension services, for example), stakeholders have suggested that information is in some cases overwhelming for farmers so they are often unsure how it relates to them and how best to use it. Information relating to best practice actions (including their costs and benefits and the conditions under which they are effective, based on real experience of others) is often limited in availability.

Missing markets for ecosystems services: this is a well-researched area and arises as a result of externalities – there are wider costs and benefits that are not accounted for in decision-making processes. This is already being addressed, at least in part, through government funding programmes, such as agri-environment schemes. The absence of a market for ecosystem services reduces the incentive for farmers to take appropriate action to protect it.

5.5.2 Policy failure

There are several examples where the policy framework is specifically likely to hinder effective adaptation action. Barriers include (i) the time taken to gain

planning permission approvals for large investments (such as reservoirs) can cause unnecessary costs and extended delays; and, (ii) particular regulations can hinder the flexibility to develop and implement plant protection sprays. The latter largely stems from competing policy objectives.

5.5.3 Behavioural constraints

There are several forms of behavioural barrier to effective adaptation. Stakeholders highlighted that there is sometimes a resistance to change farming practices and to embrace new technologies. There is also resistance to changing practices or taking actions that are deemed irrelevant. Lack of awareness of best practice is a particular difficulty in some cases, e.g. small beef/dairy farmers can become isolated.

Small farms often lack adaptive capacity: their tight profit margins mean that they are not as able to invest time and resources into adaptation as other, larger organisations. This can lead them to focus on the short-term, which risks missing opportunities to change behaviour now to facilitate longer-term gain (for example, where some actions may have long lead-times, such as with new infrastructure). ‘Short-sightedness’ can also result from the fact that actions such as soil management can take a long time to take effect. A desire for near-term results can lead to a reliance on alternatives like fertilisers rather than taking action that would yield better results in the longer-term.

5.5.4 Governance

The range of small farms in the sector implies a high degree of diversity. Notwithstanding this, it is likely that at the local level there could in some cases be a case for large-scale investment, drawing on the resources of several people. A lack of co-ordination of parties in a particular area where there may be common benefit from an intervention, such as a reservoir, could lead to missed opportunities to enhance resilience.

This Section has explored the key categories of adaptation actions along with the barriers to effective adaptation. The next Section investigates the case for intervention.

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Key messages

- There is a clear lack of certainty over the future timing and impacts of climate change on the UK, especially at the local level. Decisions affecting the resilience of agriculture to potential events or changes in weather patterns must therefore be robust.
- Iterative adaptation roadmaps outline a pragmatic way forward to prepare the UK for climate change. They combine actions but require iterative steps with constant review and modification to allow a flexible approach that facilitates learning over time.
- Roadmaps have been shown in this Section in response to threats posed by drought and soil moisture deficit; increases in pests and diseases and variability in production. They should be considered illustrative only. They suggest immediate focus on ‘no regrets’ actions, such as building adaptive capacity through enhancing knowledge, understanding and targeted areas; then over time, low cost actions such as enhancing farming practices and co-ordination of activities across farms and catchments; and strategic actions which have long lead times such as plant breeding.
- Some actions will need to be innovative or breakthrough initiatives, as opposed to merely incremental change to current practices or processes. There will also be the need for transformational adaptation over time: actions that are adopted at a much larger scale, that are truly new to a particular region or resource system, and that transform places and shift locations.
- Effective implementation of roadmaps will require supporting conditions to be in place such as a flexible and supportive policy framework, and consolidation of a support network.

6.1 Adaptive management

This Section focuses on the case for intervention by drawing on the findings from previous Sections of this report. It describes an approach through which decisions can be made in the context of uncertainty – adaptive management – and illustrates this through adaptation roadmaps. Illustrative ‘what if?’ scenarios are also shown to indicate the relative effectiveness of adaptation actions if

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particular barriers are overcome. The Section concludes with recommended interventions to address barriers and facilitate effective adaptation.

6.1.1 Developing an effective adaptation strategy: adaptive management

The analysis in previous sections has discussed the scale of the potential impact and costs of flooding and temperature-related risks to health and well-being. It has also explored the adaptive capacity of individuals and organisations, the adaptation actions that could be taken and their potential effectiveness, and the key barriers that may constrain adaptation actions being taken.

This section builds on the analysis by introducing the concept of ‘adaptive management’ in order to offer a suggested roadmap for some adaptation actions over time.

The projected nature and impacts of climate change in the UK over future decades, particularly when considering to the 2050s and beyond, are subject to a degree of uncertainty (Annex 2 presents more detail). Decisions affecting the resilience of agriculture to potential events or changes in weather patterns must therefore be robust.

Uncertainties are particularly problematic for planning large, high cost adaptation options with long lifetimes, as such investments are costly to reverse and their design is dependent on what assumptions are made today about climate over its lifetime. If decisions are made without considering this uncertainty, there is a risk of over- or under-adaptation, wasted investments or unnecessary retrofit costs (Reeder and Ranger, 2011). Adaptation decisions must therefore be robust in the face of a fast changing and uncertain climate (Hall, 2007).

In this project, adaptive management is suggested through an illustrative roadmap as a pragmatic and effective way to allow appropriate actions to be taken (where there is a case for doing so) in the presence of uncertainty. It involves constant monitoring and reviewing actions taken, and further small iterative steps to be taken, consistent with a strategic direction. Adaptive management therefore allows parties to learn over time and for new information to be reflected in decision-making processes. The intention is to maintain as much flexibility as possible for future options. The essence of the approach is to be clear on the direction of travel, or the vision for the desired outcomes or the management/goals, and the uncertainties about how to achieve these outcomes (Murray & Marmorek, 2004).

In the long term, the direction of travel may need to change, and incremental changes may no longer be appropriate as the vulnerabilities and risks may be so sizeable that they overwhelm even robust human use systems. Transformational adaptations will then be required: those that are adopted at a much larger scale, that are truly new to a particular region or resource system, and that transform places and shift locations (Kates *et al.*, 2012). Anticipatory transformational

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adaptation is extremely difficult to implement because of uncertainties about climate change risks and adaptation benefits, high costs, and institutional and individual mind-set that prefers to maintain existing resource systems and policies than create massive change. This approach allows flexibility to be incorporated into adaptation measures from the start where possible. For example, using measures that are suitable over a broad range of possible future climates or by designing the adaptation measure so it can be adjusted over time (Fankhauser *et al.*, 1999). Flexibility is also incorporated into the overall adaptation strategy, by putting the adaptation in a sequence, and leaving options open to deal with a range of possible future scenarios.

6.1.2 Illustrative roadmaps for agriculture

The illustrative risk-based roadmaps developed in this Section are intended to show “packages” of adaptation actions that can be implemented over time to respond to particular climate risks. This report has not set out detailed adaptation pathways (such as Thames Estuary 2100 Project) because it has not assessed the “known thresholds” for climate change (Reeder and Ranger, 2011) or limits to adaptation actions. Future work should analyse the thresholds of individual climate risks and what the limits of specific actions may be in reducing a particular risk.

The majority of the actions described in this report are operational, and so are less dependent on thresholds for a particular climate change risk than a decision about physical investment might be. No one action will be sufficient, but the actions must be taken as a package.

The roadmaps consider a number of different risks and adaptation actions that fall within the categories discussed in Section 5; these are set out in a time-frame to illustrate how the issues could be managed adaptively. Building adaptive capacity is included within the actions, as illustrated. Some of the actions within the roadmap will continue to occur without further support, while others will require intervention by government or other stakeholders.

For agriculture, the roadmaps are focused on reducing climate threats using shorter term reactive and anticipatory adaptation measures, such as emergency planning, maintaining existing infrastructure, reducing pollution, better warning systems for disease, etc.. Prioritising adaptation options in the face of uncertainty leads to focus on those actions that are:

- **No-regrets:** those actions which are worthwhile (i.e. they deliver net socio-economic benefits) whatever the extent of future climate change. These types of actions include those justified under current climate conditions (UKCIP, 2007). This may include building adaptive capacity or enhancing climate knowledge, improving farm management practices.

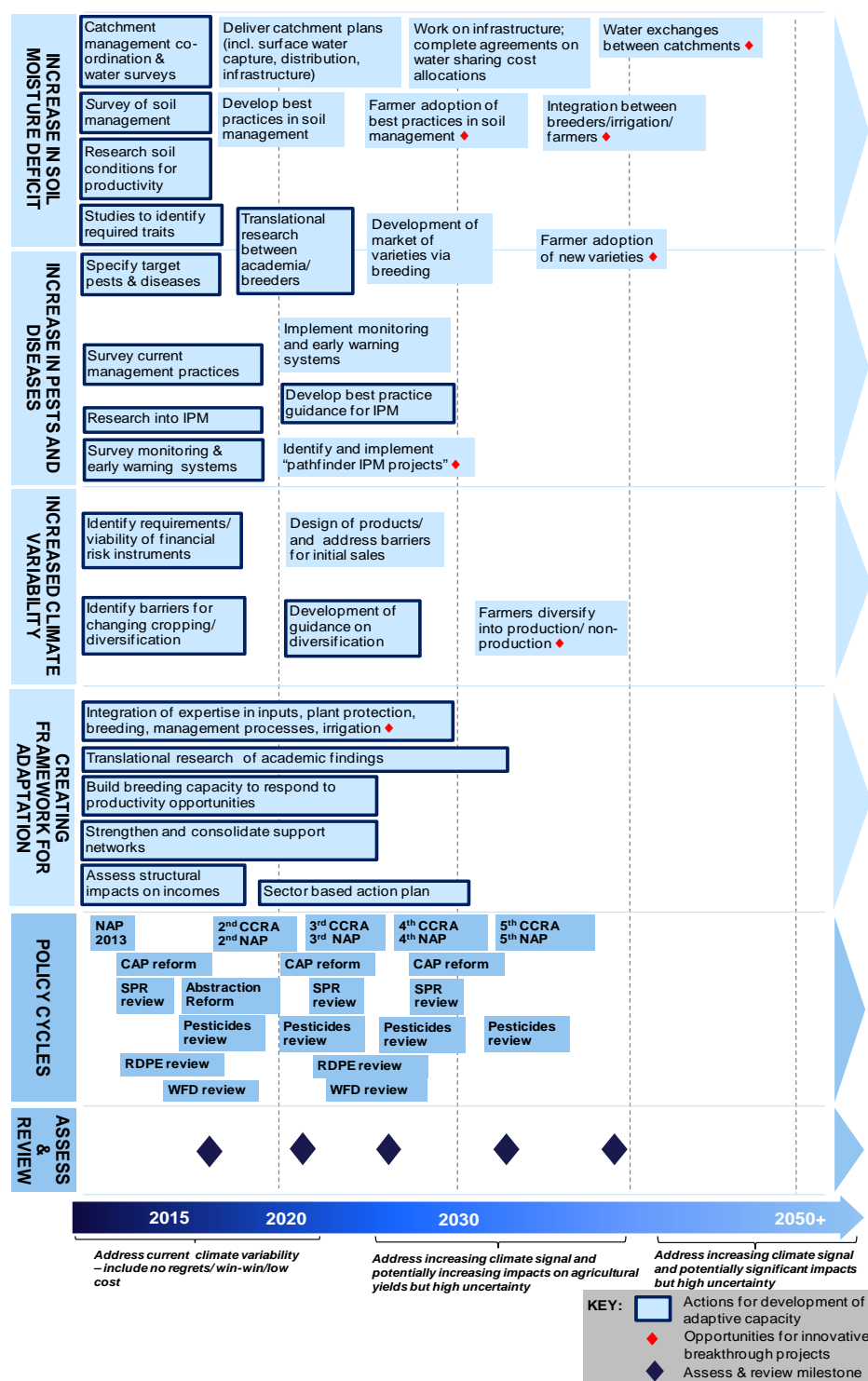
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- **Win wins:** actions that minimise climate risks or exploit opportunities, but also have other social, environmental or economic benefits (UKCIP, 2007). For example, actions to protect ecosystem services have a variety of co-benefits, as do more effective farming practices.
- **Low regrets/low cost:** actions with relatively low associated costs, and relatively large associated benefits, although the benefits will primarily be realised under projected future climate change (UKCIP, 2007). These include such actions as altering farming practices, and improving storage infrastructure.
- **Strategic options with long lead times:** these can include longer term decisions related to investments in developing climate resilient breeds and varieties.

The roadmap involves putting in place incremental adaptation options, rather than undertaking large-scale adaptation in one go. Actions are designed to allow for incremental change, including changing direction, as knowledge, experience and technology evolve. Delaying a specific action can be part of this, where that decision is accompanied by a commitment to continue to build adaptive capacity and monitoring and evaluating the evolving risks (UKCIP, 2007).

Adaptive management aims to ensure that actions taken will not be maladaptive if climate change progresses at a rate different from expected today, and to review any and all unintended consequences. Any action chosen should be taken with the engagement of stakeholders and drawing on available data to allow progress and emerging outcomes to be monitored and reviewed.

Figure 18: Illustrative roadmaps



Source: ECR analysis

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Within **Figure 18**, most of the actions in the short term relate to building capacity to ensure that the future ability of those in the sector to adapt is enhanced. This creates a framework for adaptation, although other adaptation actions, such as farm practices, will be happening at the same time.

Short-term actions focus on evidence-building due to the uncertainty of the climate threats and opportunities. Such evidence-building is designed to provide primary information to inform subsequent decisions. These measures keep later options open and may be repeated over time as the roadmaps are refined and iterated. These include:

- Surveys of soil management practices and pest management practices;
- Strengthening and consolidating support networks; and,
- Studies to identify required breeding traits.

Actions in the medium term are those which may not require early action (for example, the decisions of farmers whether to diversify), or need further information before they are taken. Following research activities, development of best practice actions and implementation of research findings will occur, based on the research outcomes. These processes are iterative, allowing flexibility in decision-making. Actions include:

- Translational research on pests and breeding traits between academics and commercial breeders;
- Development of best practice in soil and water management;
- Development of guidance on issues, such as diversification; and,
- Development of a sector based action plan.

Figure 18 also shows that some actions are likely to be innovative or breakthrough initiatives. This refers to those that are significant changes to existing practice, rather than just incremental changes to current processes or decisions. These could include:

- Identifying and implementing innovative integrated pest management (IPM) projects to manage pests and diseases;
- Diversification into other forms of production or non-production activities; and,
- Water exchanges between catchments.

Where incremental adaptation is no longer appropriate, and significant changes are required, transformational adaptation may be necessary. In initiating transformational adaptation, supportive social contexts and resources will be key enabling factors (Kates *et al.*, 2012). Innovative transformational adaptation actions should be considered in detail in future iterations of the ECR as

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information and understanding develops. Early steps that should be developed include:

- Incorporating transformation adaptation into risk management, and
- Initiating research to expand the menu of innovative transformational adaptations.

Underpinning these roadmaps is the need to consider the conditions under which adaptation actions as a whole are likely to be effective. Effective adaptation requires a range of conditions to be in place, such as a supportive and stable policy framework and other supporting mechanisms.

Coordination

There are important interdependencies between the actions in the roadmaps. For example, many of the actions (such as development of resilient varieties, or best practice IPM) rely on capacity building (such as studies into required traits or research into IPM). The base must be established before other costlier actions are taken later on.

Although, as noted above, many of the adaptation actions focus on operational measures, there are many other actions to consider; for example, land-use planning and flood defence measures. These are cross-sectoral actions that could benefit agriculture and other sectors, but will require coordination of responses between actors and sectors. For example, implementation of early warning systems applies to forestry (see the ECR Forestry Report) and even to the health sector (see the ECR Health and Wellbeing Report). The resilience of agricultural productivity will depend to a certain extent on the resilience of related actors, e.g. infrastructure (for example, see the ECR Buildings and Infrastructure Theme: Power Generation and Transmission report), planning decisions relating to use of water upstream and downstream, and decisions affecting the natural environment and ecosystem services (see the ECR Natural Environment Theme: Natural Flood Risk Management report).

Review points

The review points are where policy and practice can be assessed and evaluated and then refined in light of recent developments, new information and better understanding of climate risks and research outputs. The review points are designed to coincide with policy cycles (e.g. of the NAP and CCRA, CAP) and points where adaptation actions should be maturing. These frequent review points will enable adaptation actions to be developed iteratively, with consideration of inter-dependencies and linkages between actions.

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Earlier review points allow for analysis of short-term measures under current variability, with win-win/no regret characteristics, and particularly those that build adaptive capacity. The review points allow for consideration of different actions in the context of developing evidence on climate risks. Some actions may be more or less appropriate in future time periods, depending on the level of projected change and on socio-economic developments. At each review point, options must be considered as portfolios of short, medium and long-term responses, thereby allowing enough time for decisions with long lead-in times. There may be additional review points where major review and consultation is required, such as where there are repeated extreme weather events or if the upper end of projections and uncertainty ranges are approached.

These frequent review points are important to ensure adaptive management develops iteratively and considers inter-dependencies and linkages across actions.

6.2 Exploring the potential effectiveness of actions

The roadmaps illustrated in **Figure 18** show packages of actions that could address particular climate threats, in the presence of uncertainty (climate change uncertainty is described in Annex 2). However, they do not provide an indication of the extent to which actions would be effective. To illustrate this, a series of **illustrative** ‘what if?’ scenarios have been examined.

These show what the impacts of adaptation might be under particular assumptions. It is important to note that more detailed analysis would be required to develop accurate estimates of the scale of the effects.

‘What if?’ scenarios are, by definition, driven by their underlying assumptions. Results described should be interpreted as indicative of the broad scale of impacts only, and not taken with face-value precision. There will be wide margins of uncertainty around all results. Their value here is to indicate the potential direction of effect and relative scale of impact.

Consistent with the roadmaps in **Figure 18**, the ‘what if?’ scenarios explored relate to:

- The impacts of managing increases in soil moisture deficit and drought through research to develop climate-resilient breeds or irrigation for wheat and sugar beet;
- Enhanced management of pests and diseases for wheat; and,
- Wide-scale knowledge transfer and dissemination to facilitate implementation of best farm practices for wheat.

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6.2.1 Illustrative 'what-if?' scenarios explored

The five quantified scenarios presented below are based on the projections discussed in Section 3, together with their findings in relation to the effectiveness of adaptation actions (Section 5). All of the analyses in this section draws on the IFPRI projections (Nelson *et al.*, 2010) used in the rest of this report. Other projections are available (some suggesting higher baseline yields than are used here) and this uncertainty should be noted.

The purpose of these scenarios is to illustrate the scale of the relative effects where they are implemented. It has not been possible within the scope of this report to say how many farms would be expected to adopt them, but this analysis does allow us to show indicative effects where they are implemented.

Owing to a lack of evidence, it has not been possible to explore scenarios relating to the extent to which farmers or organisations in the sector as a whole would implement adaptation measures (i.e. the impact of breeding climate resilient breeds, investment in irrigation systems, etc.). Therefore, these scenarios illustrate the potential impacts in the cases in which they are implemented. They show: yields with no additional adaptation (i.e. beyond that which is market-led in the short-term in response to market prices) and yields with further adaptation actions, and therefore the opportunities that are available if barriers discussed in the report are addressed. In some cases, the adaptation actions on their own do not address the full scale of the challenge, implying that other actions may need to be combined with them as a package.

This is **not an exhaustive set of 'what-if' scenarios**. To illustrate the impacts of, for example, better accounting for the potential positive contribution of agriculture to ecosystem services would need far more detailed analysis than is possible here. Nor has it been possible to explore the long-term structural changes that may occur in agricultural activity, such as a shift in the location of some crops in response to climate change or the ability of farms to manage increased variability in yields.

6.2.2 Managing increases in soil moisture deficit and drought

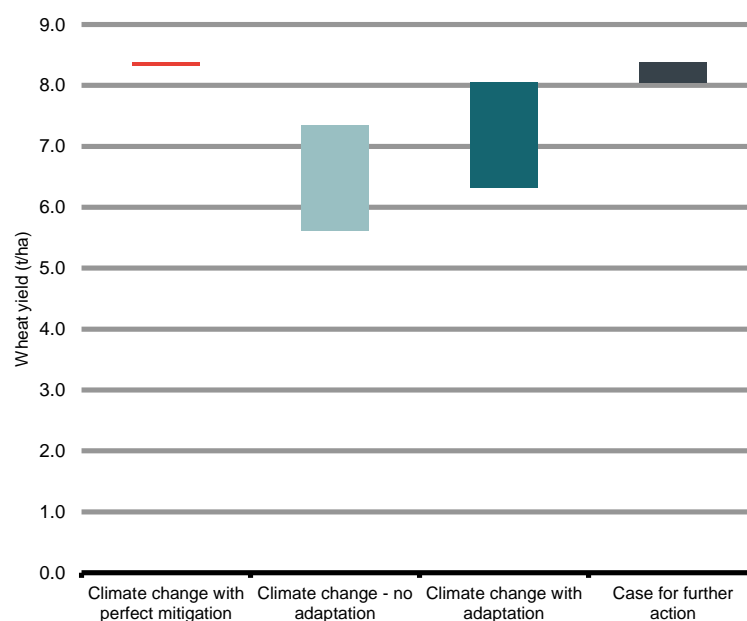
Illustrative 'what if' scenario 1: What if drought impacts were managed through research and use of climate-resilient breeds of wheat?

Drought is an extreme weather event (therefore would not be reflected in long-term yield projections). It is estimated that 30% of current UK wheat acreage is planted on drought-prone land, such that annual losses average 1-2 t/ha (Dodd *et al.*, 2011). As climate change is projected to increase the occurrence of droughts, breeding wheat varieties which have deeper root systems can reduce the adverse impacts on wheat yields. This needs to be considered together with adoption of best farming practices, such as those related to soil management (Scenario 5).

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Figure 19 (as with all ‘what-if’ charts below) shows the potential impacts of drought resistant-breeds in the first bar if climate change was perfectly mitigated. The subsequent bars from left to right illustrate the impacts of climate change plus drought on yields (light blue bar), how these might be improved by breeding (dark green bar) and the ‘gap’ remaining (dark grey bar). The length of the bars reflects the upper and lower bounds of uncertainty (based on the evidence) where implemented.

Figure 19. Illustrative what if scenario 1: what if impacts of drought on wheat in 2050 were managed through wheat breeding?



Source: Based on Nelson *et al.*, (2010) and Foulkes *et al.*, (2002)

Figure 19 shows that if climate change were perfectly mitigated in 2050, average wheat yields in 2050 could vary between 8.3 t/ha and 8.4 t/ha across different socio-economic scenarios²⁹. Climate change (excluding any future change in CO₂ concentrations) could reduce average yields to a range of 7.6 and 8.4 t/ha but drought could, in some places of the UK, reduce this further by 1-2 t/ha

²⁹ These wheat yields are for SRES A1B emission scenario, all wheat cultivars are varieties of winter wheat and assumed to be heat tolerant and yields were not affected by heat stress around anthesis (flowering)

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implying yields of 5.6 t/ha to 7.4 t/ha³⁰ (i.e. 12-30% lower than without the impacts of climate change). Breeding crops more resistant to drought (e.g. with deeper root systems) could avoid losses of up to 0.7 t/ha (Foulkes *et al.*, 2002)³¹, so yields could increase to about 6.3 to 8 t/ha.³² Even with this adaptation response, wheat yields remain below the case in which climate change is perfectly mitigated. **This suggests breeding could mitigate some 35% of the impacts of drought conditions.**

Other baseline projections would suggest different impacts of breeding. For example, field experiments by Rothamsted Research suggest yields in 2050 with climate change could be in the range of around 9.5-11 t/ha (excluding drought effects) (i.e. some 15% higher than without climate change (Semenov and Shewry, 2011)). Mitigating the impacts of drought using the assumptions above relating to drought and breeding impacts suggest yields only a little (perhaps 3%) below where they are projected to be without drought. These uncertainties and variations should be noted.

This highlights the need for drought assessment to be undertaken at the local level for particular cost-effective actions to be identified.

Illustrative ‘what if’ scenario 2: What if drought impacts on wheat were addressed through irrigation (where this was viable)?

Beginning with the same impacts of drought as in Scenario 1, here the adaptation action explored is irrigation. Evidence suggests that averaged across varieties, yields could increase by between 29% and 68% relative to rain-fed crops (Dodd *et al.*, 2011). Importantly, the yield response depends on a range of factors, such as when the deficit for rain-fed crops occurs and at what stage of the crop development cycle (Dodd *et al.*, 2011). Illustratively, this suggests that what could have been a decrease in yields of some 1-2 t/ha (as above) from drought on top of the long term climate change effects to the 2050s, could instead lead to an increase in yields to perhaps 7.2 to 12.3 t/ha. **Figure 20** illustrates the effects.

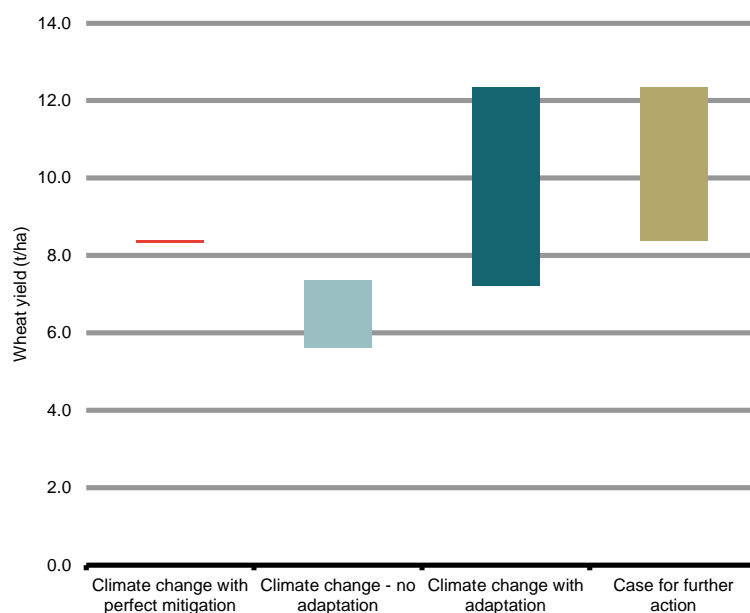
³⁰ Using results from Foulkes *et al.*, (2002) which state that wheat varieties of Rialto and Mercia lost 2.8 t/ha while Riband and Haven which lost 3.5 t/ha due to drought conditions; based on an average of experiments in three dry years, 1993-94, 1994-95 and 1995-96

³¹ This is taken to be the difference found between those varieties that are drought tolerant and those that are not.

³² The IFPRI projections of climate change with no adaptation include adaptation to the extent of farmer response to price changes.

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Figure 20. Illustrative what if scenario 2: What if impacts of drought on wheat in 2050 were managed through irrigation (where viable)?



Source: ECR analysis based on Nelson *et al.*, (2010), Dodd *et al.*, (2011)

This suggests that irrigation, where viable, could mitigate the impacts of water deficit and increase yields beyond the initial drought impact (as indicated by the gold bar).

It is important to note that although irrigation can produce impressive increases in wheat yield over a range of genotypes, sites, and soil types, wheat is rarely irrigated in the UK (approximately 1% of the acreage in 2000). Few growers are likely to do so because of the investment costs relative to the return for low value crops. When water is available and conditions are dry, it is likely that irrigation would be applied to higher value vegetable crops such as potatoes (Dodd *et al.*, 2011).

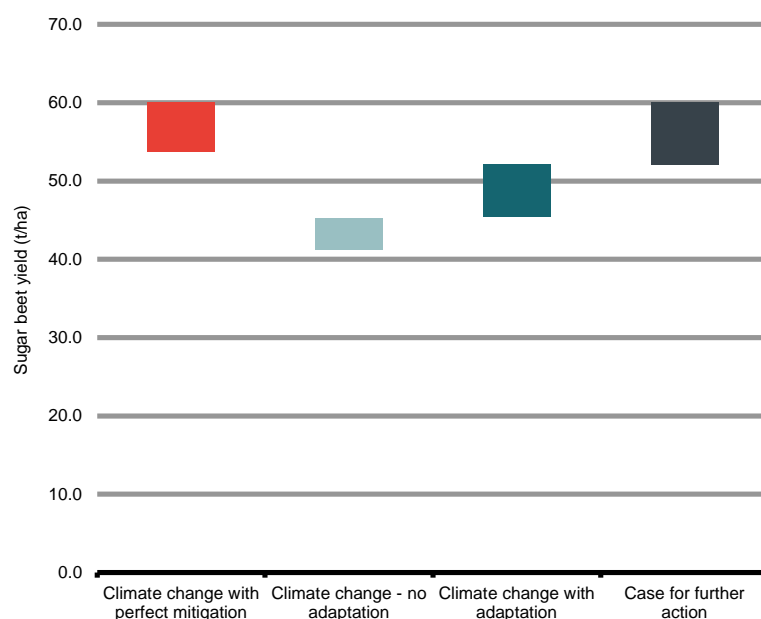
Again, sensitivity tests based on field research results suggest that if climate change increased yields in 2050 above the case without a climate change effect (Semenov and Shewry, 2011), projected average yields for crops on irrigated land could be higher still.

Illustrative ‘what if’ scenario 3: What if droughts impacts on sugar beet yields were addressed through breeding resilient varieties?

Climate change could reduce yields of sugar beet by potentially over 20% based on the IFPRI analysis in Section 3 (to around 54 to 60 t/ha), as shown in **Figure 21**.

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Figure 21. Illustrative what if scenario 3: what if impacts of drought on sugar beet in 2050 were addressed through breeding?



Sources: Nelson *et al.*, (2010), Qi and Jaggard (2008), expert advice.

The IFPRI projections of sugar beet yield do not account for extreme events like drought. Incorporating the impact of drought could lead to a further decline in yields by 24% in 2050 under a high emissions scenario (Qi and Jaggard, 2008)³³.

Expert evidence suggests that breeding drought resistant varieties could reduce these losses by 10-15%. If such breeds were used in places of drought, yields would therefore be higher than otherwise³⁴. Despite this contribution of resilient breeds, further action would still be required given the magnitude of impact of long-term climate change, which together with the residual impact of drought suggests yields could be perhaps 20% lower than without climate change.

Using different projections would provide different results and the impacts of drought will vary by location and when in the cycle of crop development they take place.

³³ Median case sugar beet yield reduction due to drought in sandy loam soils

³⁴ The IFPRI projections of climate change with no adaptation include adaptation to the extent of farmer response to price changes.

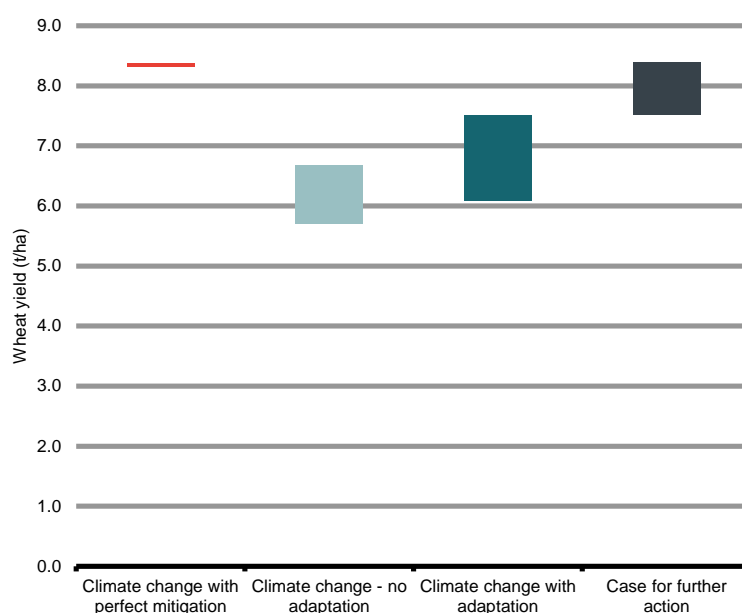
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6.2.3 Managing pests and diseases

Illustrative ‘what if’ scenario 4: What if better management of pests and diseases of wheat was implemented?

Expert advice suggests that for wheat in 2050, the scale of impact of pests and diseases could lead to a 40% reduction in wheat yield initially, but this may stabilise at 20-25% over time. Using the stabilised value for illustration, this suggests yields with climate change plus the impact of pests and diseases with no adaptation could vary between 5.7 t/ha to 6.7 t/ha in 2050³⁵, as shown in **Figure 22**. This is lower than the baseline level of yield without climate change (around 8.3-8.4 t/ha).

Figure 22. Illustrative what if scenario 4: impact of better management of pests and diseases on wheat yields in 2050



Source: Based on Nelson *et al.*, (2010), Dodd *et al.*, (2011) and Farmers Weekly (2011)

Better management could increase average yields by around 5 – 10% (Farmers Weekly, 2011). Despite this action, further adaptation could be needed, as indicated by the dark grey bar on the right of the chart. Yields could still be just under 1 t/ha lower in 2050 than without climate change.

³⁵ The IFPRI projections of climate change with no adaptation include adaptation to the extent of farmer response to price changes.

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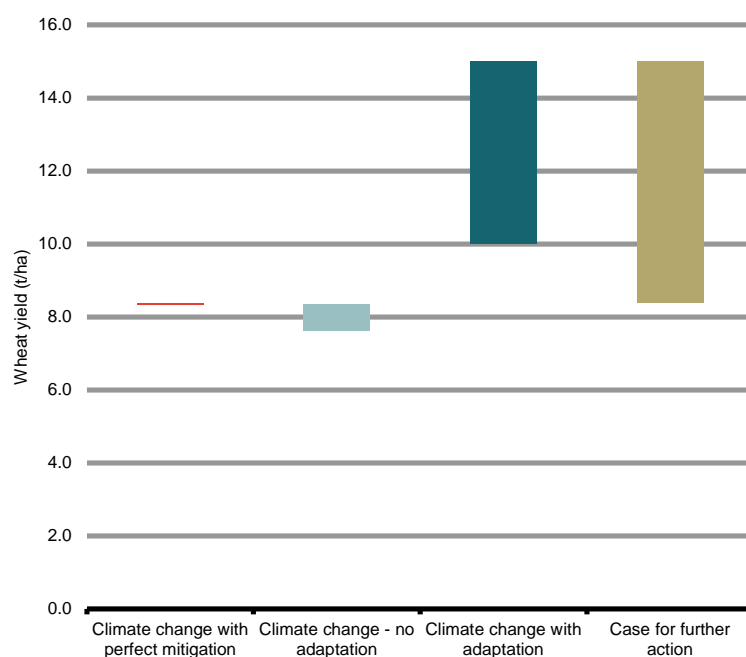
6.2.4 Wide-scale knowledge transfer and dissemination of farming best practices

Illustrative ‘what if’ scenario 5: What if there is an increase in knowledge transfer and extension services to educate farmers on adaptation measure for wheat?

Implementation of best practices would be intended to increase the average wheat yields overall by providing the know-how to bring the poorest yields up to the average and further increasing the higher yield achievers. We therefore show the effects of increasing average wheat yields to a range of 10-15 t/ha by 2050 (as advised by experts), noting that projected yields in 2050 given climate change are projected (based on IFPRI) to be around 8.3 t/ha.

As shown in **Figure 23** the benefit of taking this action could be substantial (and is here shown to be relatively greater than other projections may suggest because of the IFPRI projected impact of climate change being negative).

Figure 23. Illustrative what if scenario 5: What if best practice was implemented wide-scale to achieve annual average wheat yields of 10-15 t/ha by 2050?



Source: Based on Nelson *et al.*, (2010), Foulkes *et al.*, (2002), expert advice

This shows that if this achievement was delivered, the impact of climate change would be surpassed by up to 6.6 t/ha (over 75% higher than without further adaptation to achieve this). This is shown by the gold bar in **Figure 23**, which

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sits higher than the yield with perfect climate change mitigation i.e. the extent to which yields may exceed those expected without further climate change.

6.2.5 Key messages

These ‘what-if?’ scenarios suggest that there are potential ways in which individual actions are able to mitigate, at least in part, the potential threats from climate change.

What this analysis has not been able to show is the impacts of packages of actions because of a current lack of evidence. Such packages could, if appropriately designed, deliver effective adaptation.

This **indicative** analysis suggests:

- **Managing soil moisture deficit and drought** through breeding drought-tolerant wheat varieties could suggest yields about 10% higher than without such adaptation. Combining this with irrigation could boost yields substantially, offering yields about 29-68% higher than rain-fed crops (Dodd *et al.*, 2011). Drought **tolerant** sugar beet varieties could mitigate around 10-15% of the adverse impacts (based on expert advice) of drought (which could otherwise reduce yields by about 24% (Qi and Jaggard, 2008);
- **Better management of pests and diseases** for wheat (which could otherwise reduce yields by about 20-25%, according to expert advice) could lead to yields being on average 5-10% higher (Farmers Weekly, 2011); and,
- **Wide-scale implementation of well-targeted knowledge transfer and implementation of pest practice which incorporates the above** could increase average yields substantially. We have indicated a rise here to emulate the current record yield rate of 15 t/ha, though it is noted that some suggest higher average yields could be possible (Casey, 2011).

The barriers to action noted throughout this report, however, suggest that wide-scale implementation of these actions is unlikely, though it may occur in some cases.

6.3 Recommendations

The case for further intervention by government or other bodies flows from the evidence presented throughout this report.

The case for intervention by government or other bodies is likely to exist where:

- **Organisations or individuals lack the adaptive capacity** to be able to adequately prepare for climate change. It is critical to **target vulnerable**

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groups or organisations, who are often lacking in adaptive capacity and must rely on others' adaptive actions.

- There are **significant barriers or constraints** to implementing effective adaptation action. This may be because markets lack the required information to allow appropriate signals to be sent to parties to take appropriate action.
- The **UK may otherwise become 'locked in'** to a path that could lead to maladaptation or removes the flexibility required to effectively manage uncertainty.

Importantly, **whether adaptation actions are implemented should be guided by appropriate and proportionate assessment of the costs and benefits of action** (including those that can be monetised and those that cannot) relative to the alternatives (including no further action). This must include the consideration of expected benefits and costs of buying time and flexibility to adapt in the future.

It is important to prioritise actions on the basis of the extent to which they are 'no-regrets' (deliver benefits irrespective of climate change), 'win-wins' (deliver co-benefits aside from adaptation), low cost, or they are able to avoid 'lock in' to actions which may otherwise lead to maladaptation. Building adaptive capacity is a top priority in the short-term.

In summary, the analysis has shown a case for intervention in relation to:

- **Managing dependencies across the value chain and across sectors, in the context of uncertainty.**
- **Managing increases in soil moisture deficit and drought:** conventional breeding may keep pace with long-term climate change to some extent. However, stability of variety performance across a range of climatic conditions, particularly when there is increased variability in weather, may become increasingly important. Market incentives are often driven by the need to meet current market demands which are not likely to reflect climate resilience so there is little market incentive for climate resilient traits to be prevalent in research.

The long lead-times for breeding (10-15 years) suggest that market incentives for breeding activities may not be adequate to keep pace, particularly if climate change occurs faster than projected. Co-ordination failures across the value chain also lead to an absence of translation of research to market products. Furthermore, high costs of water storage infrastructure or

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irrigation are barriers for some, and opportunities to share the costs of large infrastructure across catchments may be missed.

- **Managing pests and diseases:** barriers exist in relation to the use and development of plant protection products and availability of alternative products (recognising the policy objective to protect the environment). Better management is likely to be required, such as the development of guidance around integrated best practice management of pests and diseases. In some cases, incremental change to current processes may not be adequate so innovative pathfinder integrated pest management products may be needed.
- **Managing increased variability in production** is likely to be an increasing problem for farmers and may in the longer term be a driver for structural change at the sector level (in terms of the location of some activity) and at the farm level as farmers may need to manage greater variance in yields from year to year. This could, for example, point towards diversification in some farms and a reliance on breeding to enhance the stability of yields given climate variation.

It is important to recognise that farmers sit within a wider system and a broad range of conditions need to be in place for the effective implementation of adaptive management and the suggested roadmaps.

6.3.1 Recommended interventions

The analysis suggests the following recommendations:

- **Develop adaptation roadmaps at the appropriate scale to identify effective adaptation strategies to manage climate change risks. Undertake research to develop a better understanding of the dependencies across agriculture and the natural environment and other sectors, and ensure the roadmaps account for these.** Roadmaps should incorporate packages of actions; review points to allow learning and modifications to take place over time; incremental changes to existing processes (sharing information, etc.) and the potential for transformational actions (e.g. developing integrated pest management).
- **Build adaptive capacity in relation to:**
 - **Breeding activities by ensuring climate change adaptation is embedded within research programmes.** This is likely to require expertise to be integrated across the value chain.
 - **Undertaking case study research involving cost-benefit analysis of a range of adaptation actions** implemented across a range of contexts to understand the conditions under which they are likely to be effective.

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- **Identify appropriate bodies to be accountable for overseeing and advising on the translation of academic research into UK products, services and actions.** This would allow a greater level of understanding at the farm-level to help overcome behavioural barriers to adapting to climate change and breeding to develop climate-resilient traits specific to the UK. A national extension service, if appropriately designed to communicate practical, timely and easily accessible information, could offer significant benefits through disseminating and translating applicable research for farmers.
- **Identify appropriate local champions to co-ordinate actions to facilitate the delivery of cost-sharing practices across catchments.** This could be appropriate where smaller farms are currently constrained by low incomes, particularly in relation to large infrastructures, such as those for water or storage.
- **Identify appropriate existing communication channels and farmer support networks to deliver practical knowledge and best practice in relation to the management of pests and diseases and water constraints, in particular.** Behavioural barriers in relation to the uptake of new technologies or perceptions of longer term uncertainties could therefore be addressed.

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