Met Office

Climate impacts and adaptations in the UK food system

A synthesis report of Met Office reports to Defra Food, Farming and Natural Environment Climate Service (FFNE): 2015–2025

Executive Summary

Climate change represents a systemic risk to the UK's food system. Observed climate impacts are already disrupting production, raising costs, and increasing volatility, and the evidence shows that these risks will intensify over the next few decades.

The UK is likely to experience hotter, drier summers; warmer, wetter winters; and more frequent extreme weather events (Met Office, 2026). Extreme heat in summer 2022 reduced chicken meat production by 9% (Davie et al. 2023), while prolonged wet conditions in 2024 resulted in 20% lower agricultural production compared with 2023 (Defra, 2024). Agriculture is already incurring losses of around £1 billion per year from extreme weather alone, excluding wider economic, environmental and social costs (Defra, 2024).

Since 2015, the Defra-funded Met Office Food, Farming and Natural Environment (FFNE) climate service has provided scientific evidence to inform UK policy on agriculture and food security [highlighted in green]. This report synthesises a decade of that evidence and shows that the present food system is currently exposed to unprecedented risks from future changes in climate.

UK Agriculture

UK agriculture is very vulnerable to climate risks including heat, drought, flooding, and changing seasonality, which can cause large, frequent and compounding production losses. Under FFNE, in collaboration with ADAS, research has begun on the feasibility of uptake of a variety of adaptation strategies to build resilience to climate change (Foulkes, Oliver & Clarke., 2023, 2024).

Arable and Horticulture

Direct climate impacts (e.g., high temperatures, droughts, flooding) reduce yields and increase variability, particularly for climate sensitive crops such as wheat. Indirect impacts on soil health, pests, pathogens, pollinators and fertiliser effectiveness further compound risks.

Climate change is also constraining when farming can happen. Wet soils reduce trafficability and workability, delaying planting, spraying and harvesting. Projections show (Oliver et al. 2025):

- More wet soil days in the winter, increasing risks of delayed operations and soil damage.
- Later soil drying in autumn (by ~2-3 weeks by mid-century).
- Substantially high summer soil moisture deficits across all emission scenarios.

Livestock Systems

Livestock are increasingly exposed to climate-related risks such as flooding and heat stress, with measurable impacts on growth, fertility, mortality and welfare. For instance, heat stress projections show (Davie, Garry & Pope, 2021):

- Beef cattle in south-west England could experience 5-20 heat-stress days per year by mid-century, up from ~1 historically.
- Pigs in eastern England could experience 20-30 heat stress days per year by mid-century, up from ~2.5 historically.

These impacts imply rising costs, lower production, and increased welfare risks unless widespread adaptation and resilience measures are adopted.

Food Security and International Risks

The UK imports over half of its food, including around 45% of its vegetables and 83% of its fruit, making it highly exposed to climate impacts overseas (Defra, 2023, in Cottrell, Crocker, Falloon, 2024b). Between 2021 and 2024, overlapping shocks (including extreme weather, COVID-19 recovery, post-EU exit adjustments and Russia's invasion of Ukraine) demonstrated how quickly global disruptions translate in UK food price inflation, which peaked at 19.2% in March 2023, one of the highest rates in the G7 (Defra, 2024). Climate change is expected to drive 30-50% food price inflation by 2035, disproportionately affecting low-income households (Kotz et al. 2024).

Climate risks extend beyond production to processing, storage, transport and retail, where disruptions can cascade through supply chains (Falloon et al., 2022). High-Impact Low-Likelihood (HILL) events (Bacon et al. 2025), such as extreme weather, climate tipping points (e.g., AMOC collapse), or more sever climate trajectories, could cause severe, long-lasting disruption to UK food availability and affordability.

The Future

Climate change poses increasing risks to the UK food system. However, with the right mix of policy, innovation and coordinated action, adaption can strengthen resilience while also benefitting farmers, consumers, productivity, animal welfare and Net Zero goals.

Actions to strengthen farm resilience include:

- Embedding climate adaptation into everyday policy and farming practice.
- Providing targeted support that reflects different risks across arable, horticulture and livestock sectors.
- Reducing barriers to action by simplifying administration, improving access to finance, and expanding education and advisory services.

Further research should:

- Expand beyond arable crops to include non-cereal crops, livestock, fisheries and ecosystem interactions.
- Improve understanding of large-scale climate drivers (e.g., ENSO), HILL events, and adaptation effectiveness.
- Strengthen near-term evidence (2030s), indicators, and knowledge of regional variations across the UK.
- Take a whole-system view of the food chain, including global trade, supply disruptions, compound and cascading impacts, and the balance between self-sufficiency and international reliance.

Hotter, drier summers and extreme heat

Projected climate change in the UK (by 2070)*

Summers are up to 60% drier depending on the region. Hot summer days are between 4 and 7°C warmer.

Key Impacts on Agriculture and Food Systems

Arable and horticulture: crop failure, reduce yields/quality, increased pests, irrigation strain.

Livestock: heat stress, reduced fertility, reduced production, higher mortality, reduced forage, reduced water availability.

Examples: Beef cattle heat stress days in SW England rise ~1 to 5-20 days my mid-century. Pigs heat stress days in E. England rise 2.5 to 20-30 days.

Food security: supply shortages and price spikes from global shocks.

Priority adaptation and resilience actions

Crop and soil: heat/drought tolerant varieties, earlier maturing crops, diversify cultivars, mulching, no/reduced tillage, organic matter to retain moisture.

Water: night irrigation, improved irrigation scheduling, water storage, efficient water use.

Livestock: shade, ventilation, night grazing, heat-stress monitoring, cooling systems, drought-tolerant forage mixes.

Policy & System: Farming Investment Fund supports water management; improving farm resilience through affordable low-cost actions.

Example: day-to-day decisions can improve climate resilience, for instance nocturnal catching and/or thinning for poultry.

Wetter winters and flooding

Projected climate change in the UK (by 2070)*

Winters are 30% wetter

Key Impacts on Agriculture and Food Systems

Arable and horticulture: crop submersion, soil compaction, delayed operations, increased mould/mycotoxins.

Livestock: drowning, hypothermia, lameness, mastitis, contaminated water, reduced access to grazing.

Examples: In 2024, winter rainfall was +29%, and spring rainfall was +32% (vs 1991-2020), causing 25-30% crops to fail to establish and impacts to livestock (delayed turnout, poaching, lamb hypothermia).

Priority adaptation and resilience actions

Soil & drainage: add organic matter, cover crops, reduce compaction, improve drainage and runoff containment, manage nutrient leaching after floods.

Crop choice: waterlogging-tolerant varieties, adjust planting/ harvest windows.

Livestock: raised access, extra bedding, hygiene, emergency planning, reduced turnout on saturated fields.

System resilience: flood contingency plans, resilient infrastructure, storage improvements, and diversified sourcing to reduce dependence on single regions.

Example: new infrastructure to store, distribute and drain water can improve resilience to drought, waterlogging and flood risks.

Changing seasonality and warmer winters

Projected climate change in the UK (by 2070)*

Winters are between 1 and 4.5°C warmer.

Key Impacts on Agriculture and Food Systems

Arable and horticulture: earlier growth, reduced vernalisation, frost risk, shifting pests and disease timing.

Livestock: altered grazing seasons, increased insect burdens, changes in forage quality and timing.

Food security: Increased supply variability and uncertainty. International import risk increases due to seasonal shifts, affecting UK fruit/veg supply.

Priority adaptation and resilience actions

Crop and timing: adjust crop calendars, diversify varieties, use early-maturing types, spread planting risk via cultivar diversity.

Pest management: enhanced advisory support, monitoring, integrated pest management, crop covers.

Livestock: flexible grazing rotations, diverse forage mixes, adjust housing/ventilation timing, monitoring for parasites.

System resilience: improve supply chain flexibility through diversified/domestic sourcing, and support from Catchment Sensitive Farming and advisory services.

Example: indoor agriculture could allow a greater variety of crops to be grown in the UK.

*Climate Risks, Impacts and Adaptations in the UK Food System * based on the high emissions scenario (RCP8.5), where the world continues to create high levels of emissions using the 2018 UK Climate Projections (UKCP).*

Recognition of Met Office Research

"The impact of climate change and weather patterns on the agri-food sector are vital to understand, and the Met Office are pivotal in this area. The Met Office has a long history of data collation, and their forecasting is a useful tool for our agri-supply industry members."

John Kelley – Chief Operating Officer, Agricultural Industries Confederation

"The Society of Agriculture recognises the vital role of the Met Office research and insights in strengthening understanding of climate risks and resilience across food and farming. The evidence shared at the IAgrM National Farm Management Conference really highlighted how climate science is supporting informed decision making and long-term adaptation across the UK agrifood sector"

Mark Suthern – Trustee, Society of Agriculture

"The Met Office modelling work on heat stress and water has been really interesting in thinking about future resilience within our supply base, both globally and within the UK"

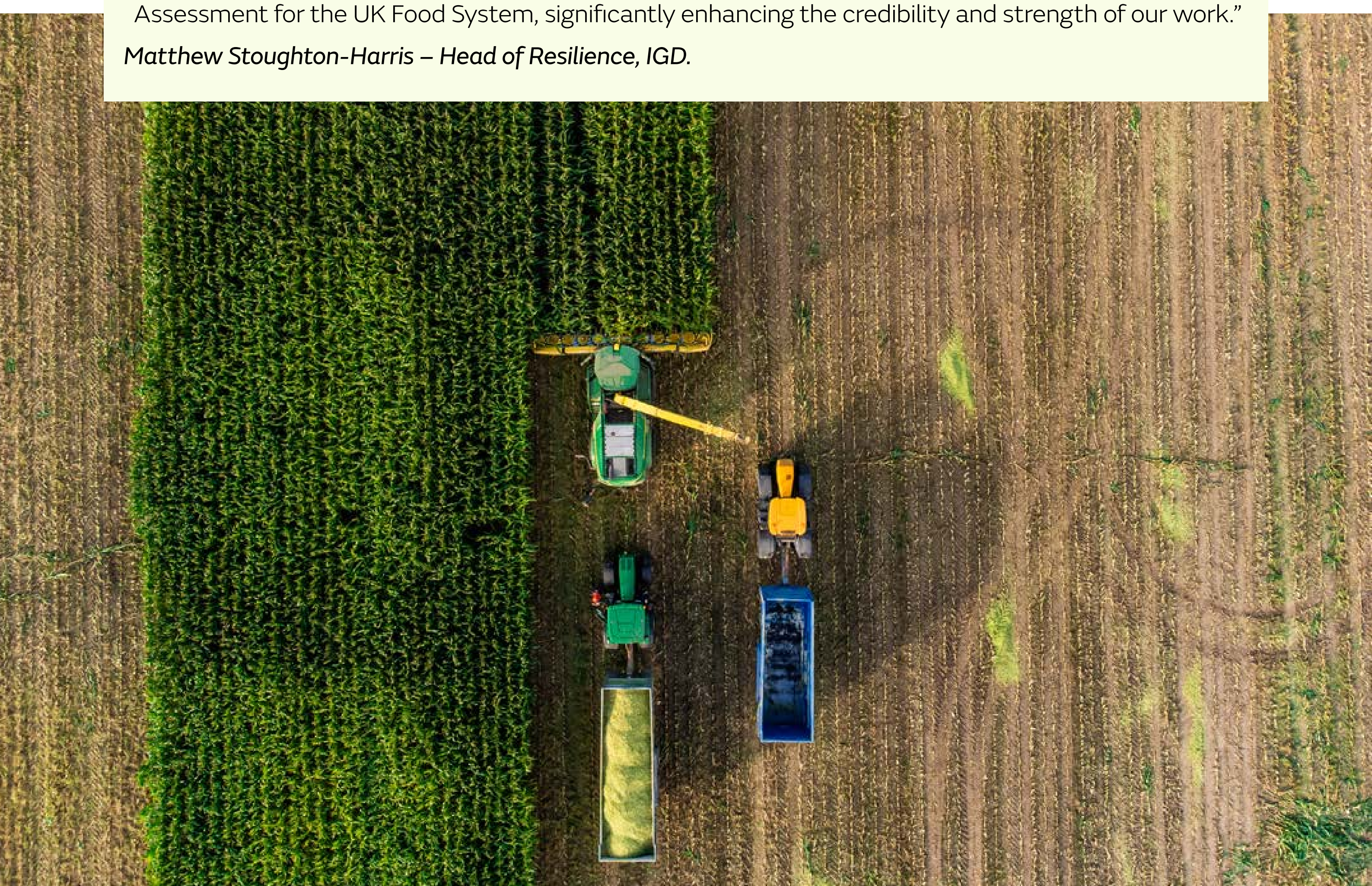
Guy Stuart – Director of Technical, Sainsbury's Supermarkets Ltd.

"Recent years have continued to highlight the vulnerabilities in our food supply chain resulting from extreme weather - drought depriving dairy units of sufficient water, fields disappearing under a deluge of rainfall and key transport routes becoming impassable thanks to flooding. The Met Office's work helps provide a clear outline of future risk and likely locality, appropriate agrifood adaptation methods and benefits of further action. They've been particularly good at condensing complex insights into easily accessible formats which is profoundly important when you're trying to disseminate understanding about climate change through a diverse business."

Harriet Bell – Regenerative Farming Lead, Riverford Organic Farmers

"The Met Office's expertise has been invaluable as a trusted stakeholder in IGD's Climate Risk Assessment for the UK Food System, significantly enhancing the credibility and strength of our work."

Matthew Stoughton-Harris – Head of Resilience, IGD.



1. Introduction

Climate projections show that the United Kingdom (UK) is likely to experience hotter, drier summers, and warmer, wetter winters, alongside an increase in extreme weather events such as heavy rainfall, droughts, and heatwaves (Met Office, 2026). These changing conditions are already affecting the UK's food and farming systems. For instance, the record-breaking high temperatures of summer 2022 reduced chicken meat production by 9%, while wet conditions in 2024 resulted in 20% lower production compared to 2023 (Davie et al., 2023; Defra, 2024).

Met Office climate science is helping UK farmers and the wider food security to prepare for a changing climate. This work includes a range of climate services funded by Defra (the Department for Environment, Food and Rural Affairs). The Defra-funded Met Office climate service on Food, Farming and Natural Environment (FFNE) has been running since 2015. It focuses on understanding the impacts of climate change on UK agriculture, UK food security, and international risks, aiming to inform policymakers about adaptation needed in the UK agri-food sector. This work involves close collaboration with Defra and supports key national policy processes including the UK Food Security Report, the Climate Change Risk Assessment, the National Adaptation Programme, and the UK's Global Food Security Programme.

Over the past decade, the Met Office has delivered a sustained programme of climate science advice to Defra through the FFNE service. This report aims to provide a 'best of' synthesis, bridging together and showcasing the most significant research, findings and insights produced during this period. This will highlight how climate science can support adaptation, resilience and long-term planning in UK food and farming.

This report is presented in two parts:

- **UK agriculture**. Examines the risks, adaptation options and resilience across domestic food production, including arable and horticultural systems, livestock systems and agricultural policies.
- **UK food security and international risks**. Explores risks to UK food production beyond domestic production, including climate impacts on post-primary production, international risks to food supply, and High-Impact Low-Likelihood (HILL) events, including extreme weather, tipping points, and severe climate scenarios.

2. UK Agriculture

UK agriculture is very vulnerable to climate risks including heat, drought, flooding, and changing seasonality, which can cause large, frequent and compounding production losses (Falloon et al., 2022). New agricultural policies and initiatives have been announced, for instance the Environmental Land Management schemes (ELMs) (see 2.4 Agricultural Policies) (Ffoulkes & Oliver, 2023). There is also funding for climate-resilient crop and livestock breeds, with DEFRA's Genetic Improvement Networks promoting research to develop crops with better yield, resilience and disease resistance (Box 2) (Cottrell et al., 2023, 2024a,b). There is a lack of awareness of resilience building activities, with many farmers unaware of the full range of adaptation options and their relative cost-effectiveness (Wheeler & Lobley, 2021). As a result, recent work has assessed quick wins (measures that are effective, low cost and easy to implement) in farming (**Table 2 and 4**; Ffoulkes, Oliver & Clark., 2023, 2024).

2.1 Arable and Horticulture Systems

2.1.1 Risks and Opportunities

Climate change poses both direct and indirect risks to agriculture (Cottrell et al., 2021). Direct risks arise from changes in both the average and variability of key meteorological variables, particularly temperature and rainfall, which can significantly affect the productive capacity of crops such as wheat (Box 1). These changes also increase the likelihood of heat stress, drought, waterlogging, and flooding, potentially leading to substantial yield reductions. In addition, climate change exposes agriculture to a range of indirect risks. For instance, agricultural productivity depends on the abundance and composition of pollinators, pests, and pathogens, as well as on soil health and fertility, all of which are influenced by climatic conditions. Similarly, rainfall patterns can affect the accessibility of land (due to waterlogging) and have an impact on fertiliser effectiveness, while high temperatures can lead to heat stress for farmers.



Risk Category	Drought, Water Scarcity, Extreme Heat and Heatwaves	Changing Seasonality	Flooding and Wet Conditions
Crop growth, development, yield and quality	▪ Crop failure, damage, and yield reduction. Delayed emergence, early maturity, reduced growth and vigour. ▪ Sun damage, fruit set failure (e.g., watercore), physiological disorders. ▪ Reduced nutritional value, reduced quality (size, shape, blemishes), reduced shelf life.	▪ Earlier and faster crop development ▪ Reduced or failed vernalisation. ▪ Yield increases (e.g., sugar beet, leafy veg, some fruits) or yield decreases in autumn-sown cereals and oilseeds. ▪ Increased vulnerability to late frosts.	▪ Crop loss and yield reduction from submersion. ▪ Stunted growth and root development; lodging (e.g., cereals). ▪ Reduced quality and shelf life.
Pests, diseases, weeds and pollination	▪ Changes in pest, disease and weed pressure. ▪ Increased incidence of some pests, reduced levels of some diseases. ▪ Decreased efficacy of pesticides, herbicides and biocontrol. ▪ Impacts on pollination from altered pollinator populations.	▪ Reduced winter kill and increased pest/disease carryover. ▪ Emergence of new pathogens, increased dispersal, genetic variation and virulence, changing pest and disease patterns. ▪ Reduced herbicide efficacy from increased weed growth. ▪ Altering timing and availability of pollinators.	▪ Increased spread of disease via floodwaters. ▪ Increased susceptibility of damaged crops. ▪ Increased moulds and mycotoxins. ▪ Higher slug populations. ▪ Increased persistence of pathogens and vectors.
Soil health, water and nutrients	▪ Increased soil moisture deficit, increased evapotranspiration. ▪ Hardened soils and cracking, increased soil erosion from bare ground. ▪ Nitrogen losses via volatilisation.	▪ Increased evapotranspiration and water demand, changes in water availability. ▪ Altered irrigation requirements and timing, insufficient water supply in some regions.	▪ Waterlogged soils, soil erosion, compaction and poaching. ▪ Nutrient losses and leaching, damage to soil biology, potential long-term soil degradation.
Farm operations, infrastructure and logistics	▪ Disruption to crop schedules and continuity of supply. ▪ Increased requirement for storage temperature control. ▪ Farm systems stressed by extreme weather.	▪ Changes to crop calendars and operation timings, altered winter manure spreading windows. ▪ Increased cooling needs for storage, reduced drying requirements for some crops.	▪ Disruption to planting, drilling, harvesting, spraying and manure spreading. ▪ Damage to farm infrastructure; transport delays affecting inputs and outputs, overstocking risks.
General farming and fire risks	▪ Workforce health impacts from heat stress and sun exposure. ▪ Increased wildfire risk, combine harvesters overheating leading to crop fires, conditions favourable for wildfire spread.	▪ Increased exposure to abrupt temperature changes, increased incidence of hard frosts, fewer snow events reducing crop protection.	▪ Increased water-borne diseases from damaged waste systems. ▪ Environmental pollution and water quality deterioration.
Economic impacts, opportunities and land-use change	▪ Price impacts form lower crop quality, reduced profitability, ▪ Opportunities from reduced pest incidence ▪ Quality improvements for some crops (e.g., viticulture), increased suitability of higher-altitude land.	▪ New or alternative crops becoming suitable (if water is not limiting). ▪ Regional benefits from drier winters; yield gains linked to fewer frost events (e.g., blackcurrants).	▪ Financial losses from crop damage, yield loss and infrastructure damage. ▪ Increased costs for remediation and storage.

Table 1 *outlines the key risks to arable and horticultural systems associated with a changing climate (drought, water scarcity, extreme heat and heatwaves, changing seasonality, flooding and wet conditions). It summarises the findings from Foulkes, Oliver & Clarke (2023, 2024); two reports produced through a partnership between ADAS and the Met Office, which identified key climate impacts and adaptation measures to support resilience in agricultural systems.*

Box 1: UK wheat yield depends on key meteorological variables.

UK wheat yields are strongly dependent on key meteorological variables, particularly temperature and rainfall, as well as solar radiation and soil conditions. Understanding how these factors interact, and how they might change under future climate scenarios, is essential for assessing climate risks to UK agriculture.

Influence of large-scale climate patterns on UK wheat yields

Cottrel & Pope (2021) examined how large-scale atmospheric and oceanic climate patterns affect UK weather and, in turn, wheat yields. These can simultaneously affect multiple meteorological variables over an extended period during the UK wheat growing season (October-September).

- **North Atlantic Oscillation (NAO)**. The NAO is the atmospheric pressure gradient between low pressure over Iceland and high pressure over the Azores. Changes in its strength and location influence the North Atlantic jet stream and, consequently, UK weather.
    - A positive (stronger) NAO is typically associated with milder and wetter UK conditions.
    - A higher NAO index in the November after planting is linked to greater rainfall in the following spring and summer (pre-harvest), which tends to result in lower wheat yields.
- **Other climate patterns investigated**:
    - Summer North Atlantic Oscillation (SNAO): Higher SNAO values tend to lead to reduced winter and spring rainfall in the UK.
    - El Niño-Southern Oscillation (ENSO): Changes in ENSO tend to lead to increased winter and spring rainfall in the UK.

Both of which tend to lead to greater anomalies in UK wheat yield.

Further research is needed to understand how these large-scale drivers may evolve under climate change and what this means for UK agriculture.

Month-to-month climate effects on wheat yield

Bacon, Pope & Cottrell (2021) expanded on this work by analysing how monthly variations in temperature and rainfall influence UK wheat yields.

- **They found that lower yields were associated with**:
    - Above-average temperatures in November, December, February, March, April, May, June and July
    - Above-average rainfall in October, November, March, April, May, June and July.
- **In contrast, higher yields were associated with**:
    - Above-average temperatures in October, January, August and September.
    - Above-average rainfall in January and February.

These relationships are likely to shift as the UK climate continues to warm, seasonal patterns change, and new wheat varieties are introduced. The mean summer temperature across the UK wheat growing region is 15.6°C (1981-2010), which is within the optimum temperature range for UK wheat yields (14.2 -16.1°C). Under a high emissions scenario (RCP8.5), future mean summer temperature is projected be 19.0°C (2041-2070), exceeding the current range of optimal temperatures for UK wheat yields. As a result, whilst wheat production would still be possible, yields may significantly reduce, due to the increased occurrence of heat stress and reduced water availability. However, the impacts would be less severe under more moderate warming scenarios.

Importance for future agricultural planning

Understanding how UK wheat yields depend on meteorological variables is critical for:

- Yield forecasting
- Projecting climate change impacts on agriculture
- Informing crop breeding and adaptation strategies

For example, Pope & Roper (2020) used a Bayesian modelling framework to test stimulated wheat cultivars under a range of climate conditions; this information helps to understand the blend of cultivars that would maximise average UK wheat yield and minimise yield variability in the present-day and under future climate scenarios.

2.1.2 Adaptation and Resilience Measures

Adaptation is required to mitigate the risks that the changing climate brings to the UK agri-food system. Some adaptation occurs autonomously (through decisions of individual farmers), but there also needs to be large-scale adaptation to deliver the full extent of adaption in a timely manner. Different categories of adaptation for UK arable systems have been evaluated (Cottrell & Crocker, 2023a,b,c), including:

- **Regional diversification**. Climate risks could be mitigated by changing the location within the UK of different types of arable production. UK regions have significantly different climates from each other in the context of interannual variability. For instance, average summer temperatures in the Eastern region are 2.9°C warmer than those in Scotland. The regions with the warmest summer temperatures are also the driest, with the average summer rainfall in the eastern regions more than 30 mm lower (per month) than in the wettest regions (Wales, North-West and Scotland. As a result, warmer and drier conditions could encourage westward expansion of arable farming. Any resilience benefit is strongest if, in the same period, crop yields respond differently in different regions; a crop yield shock in one region may be offset by increased yields in another.
- **Alternative crops**. Alternative crops which have climate-resilient characteristics may provide improved resilience, such as improved drought resilience from plants with deeper rooting systems. However, there would need to be careful consideration, for instance:
  - What would be the effects on soil and how would crop rotation be managed?
  - What does this mean for nutrition and food availability?
  - Do alternative crops provide the same number of calories and other nutrients?
- **New varieties of crops**. New varieties of crops can have characteristics that provide improved resilience (Box 2). Another avenue to explore would be to consider whether mixing varieties or companion planting of different species could improve resilience.
- **Water management**. New infrastructure to store, distribute and drain water can improve resilience to drought, waterlogging and flood risks.
- **Agroforestry**. Agroforestry (planting trees as part of farming systems) can improve resilience to multiple climate hazards, as well as improving biodiversity and carbon storage.
- **Controlled-environment agriculture**. Indoor agriculture (including greenhouses, vertical farming) allows the environment to be controlled and protected against climate hazards. It could allow a greater variety of crops to be grown in the UK, providing resilience to the food system from climate hazards affecting imports.
- **Day-to-day decisions**. Operational decisions can improve climate resilience, for instance adopting best practice techniques for soil conservation, such as contour ploughing.

Adaptation category	Drought, Water Scarcity, Extreme Heat and Heatwaves	Changing Seasonality	Flooding and Wet Conditions
Crop selection and diversity.	▪ Grow heat-tolerant and drought resistant varieties. ▪ Choose slow-maturing varieties, grow earlier maturing varieties where appropriate. ▪ Increase diversity of cultivars (maturity, resistance), grow a range of varieties with different flowing rates to spread risk.	▪ Adjust crop and variety choice to suit altered seasons; diversify varieties to manage uncertain crop calendars.	▪ Select crops and varieties more tolerant of waterlogging and wet harvest conditions.
Soil management and protection.	▪ Adopt no-till or reduced tillage systems. ▪ Increase use of compost, green manures and mulches to retain moisture and protect soils.	▪ Addition of organic matter to improve resilience, protect soil surface using compost, green manures and mulches.	▪ Addition of organic matter to improve water absorption, protect soil surface to reduce erosion and compaction ▪ Test soil nutrient levels following flooding.
Water management and irrigation practices	▪ Irrigate/water crops at night to reduce losses, increase irrigation where necessary (e.g., pre-harvest irrigation for root and bulb crops, including potatoes).	▪ Plan irrigation and water use to reflect longer growing seasons ▪ Capability to cool crops to storable temperatures (e.g., ventilation fans).	▪ Improve runoff containment and drainage ▪ Adjust water management to avoid saturated conditions.
Crop establishment, timing and operations	▪ Establish crops early ▪ Avoid harvesting during the hottest part of the day to reduce fire risk and produce temperature. ▪ Target production to specific periods of the year (horticulture).	▪ Alter timing of fertiliser, manure and slurry applications to reflect changing seasonal conditions ▪ Adapt crop calendars and operational timings.	▪ Alter timing of fertiliser, manure and slurry applications to avoid wet conditions ▪ Adjust planting and harvesting windows to reduce damage.
Pest, weed and crop protection management.	▪ Increase cultural and mechanical weed control, grow pest- and disease- resistant varieties. ▪ Increase use of crop covers (e.g., netting, frost hessian).	▪ Increase advisory input to manage changing pest, disease and weed pressures under new seasonal patterns.	▪ Reduce pest and disease pressure through improved soil and water management ▪ Buffer strips and good practice to limit pathogen spread.
Farm systems, infrastructure and supply chains.	▪ Avoid high-risk operations during extreme heat ▪ Improve farm system resilience to extreme weather impacts.	▪ Use farm advisory services to support decision making under changing seasonality. ▪ Engaging with and adapt supply chains to increased variability	▪ Develop flood contingency plans, review resilience of power supply. ▪ Improve drainage and buffer strips ▪ Engage supply chains to manage disruption.

Table 2 *outlines the 'Quick Win' adaptation options for arable and horticultural systems that are low cost, easy to implement and effective. It is a summary of the findings from Foulkes, Oliver & Clarke (2023, 2024); two reports produced in a partnership between ADAS and the Met Office. Note - some of these need further research.*

Box 2: Crop breeding programmes

Overview: Genetic Improvement Networks (GINs)

- Genetic Improvement Networks (GINs) are a long-standing, Defra-funded pre-breeding programs. Their purpose is to identify genetic traits that support: productivity, sustainability, climate resilience, and nutritional quality.
- The Met Office Hadley Centre (MOHC) is working with 4 GINs including, Wheat (WGIN), Oilseed Rape (OREGIN), Vegetable (VeGIN), and Pulse Crop (PCGIN). The aim is to use crop breeding to improve the ability to address emerging climate pressures (Cottrell et al., 2023, 2024a,b).

Climate Risks and Wheat Breeding

- Wheat is particularly vulnerable to heat stress during anthesis (typically late May to early June), and persistent heat stress can significantly reduce yields.
- Cottrell et al. (2024b) demonstrated the likelihood of a year experiencing a heat stress event for 3 consecutive days. For a June anthesis, they projected that such heat stress events will increase from 1 to 2-3 days out of 10 by mid-centry across most of the arable region (Fig. 1).
- Such analysis enables breeders to consider the balance between ensuring resilience to such heat stress events or developing varieties with earlier anthesis.

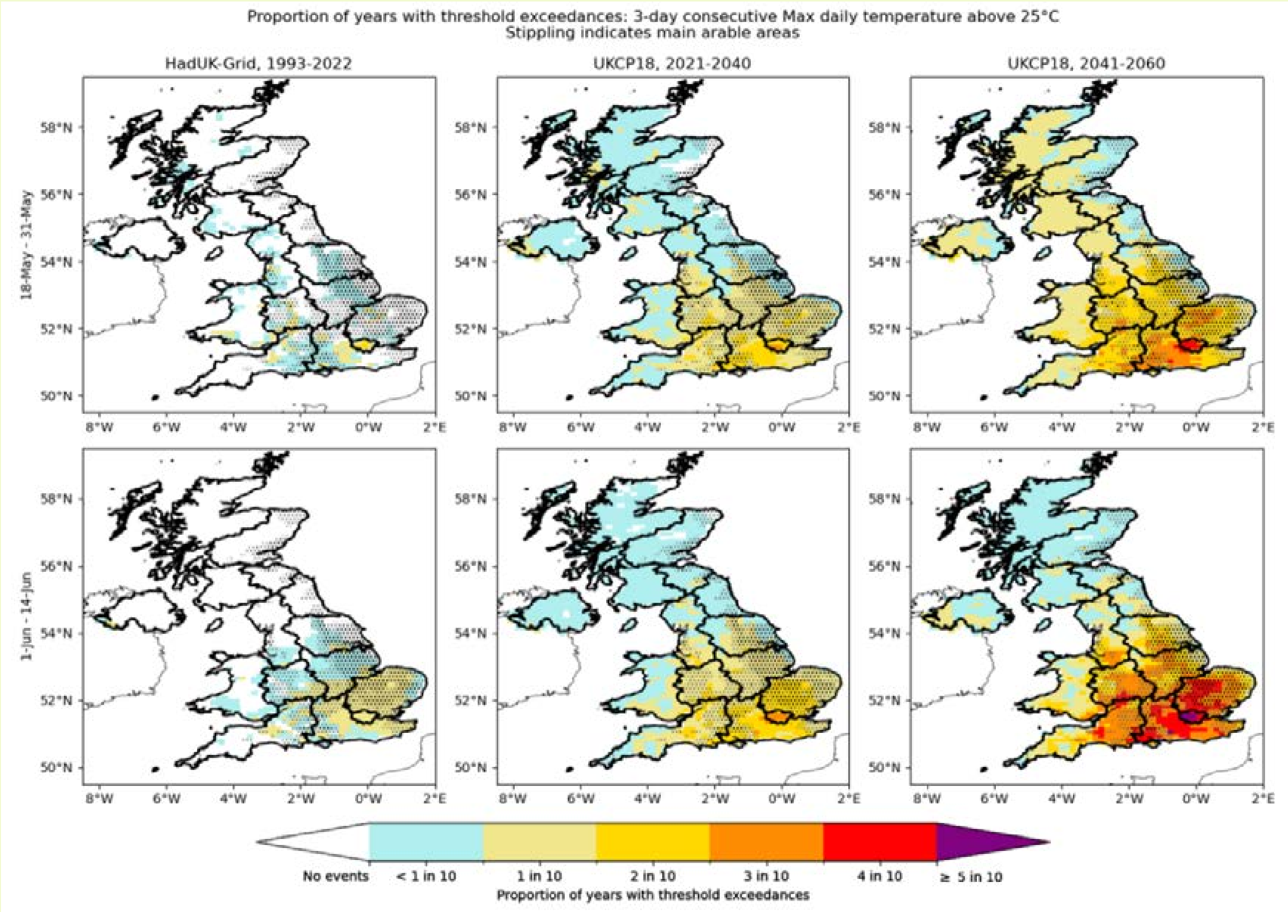


***Figure 1**: Likelihood of a year experiencing a heat stress event for two consecutive anthesis periods (18th-31st May, 1st-14th June) for 3 time periods (left = historical 1993-2022, centre = near future 2021-2040, right = mid-century 2041-2060).*

Climate Risks to Horticultural Crop

- Many horticultural crops (such as salad and leafy green crops) are particularly vulnerable to severe climatic events. For instance, lettuce has a threshold of 26°C above which wilting occurs (Dufault et al. 2009 in Cottrell et al., 2023).
- Cottrell et al. (2023) predicted the probability of passing this threshold for 3 consecutive days for two different locations in the UK (West Maling and Southport). For example, in West Malling the likelihood of this occurring is projected to increase by 10% in the 2020-2049 period for large parts of July and August.
- Warmer winters also pose challenges. Fewer cold days can disrupt vernalisation, which some crops need to flower. Cottrell et al. (2024a) predict that, across the East of England and East Midlands, fewer than 6 out of 10 years will experience 25 days with a daily maximum temperature below 8°C by mid-century. This is compared with at least 9 out of 10 years historically (1994-2022).
- Warmer temperatures are also expected to reduce frost days. This may reduce the priority to develop frost resilience for some crops, or alternatively, allow changes to planting and harvesting dates, and additional priorities for genetic development.

Implications and Further Research

- It is challenging to determine the ideal phenotype required to thrive in the projected environmental conditions. However, the impacts of extreme climate events can be correlated with phenotypic responses, and so there is scope to breed varieties with resilience to specific stresses.
- Further research that could add value to the GIN programmes include:
  - Assessing risks associated with a broader range of weather and climate variables (e.g., rainfall), and at different stages of the crop cycle (e.g., drilling). This should also consider evolving risk profiles driven by compound events, as well as indirect impacts on crops such as shifts in pest and disease pressures.
  - Evaluating second-order benefits, such as enabling breeders and researchers to better quantify the scale and relative importance of future climate risks, helping to demonstrate the value of developing climate-resilient varieties to commercial seed companies.

2.2 Livestock Systems

2.2.1 Risks and Opportunities

A changing climate can impact livestock in terms of both productivities, as well as health, survival and welfare. These impacts can be both direct (such as from thermal stress) or indirect (such as through the availability and quantity of feed and forage).

Davie, Garry & Pope (2021) provide a summary of the impacts of heat stress on livestock:

- **Overview**. Heat stress can impact livestock through physiological stress, reduced growth, reduced quantity/quality of milk produced (cattle, sheep, pigs), reduced quantity and size of eggs (poultry), increased mortality and illness, decreased fertility and reproduction, and increased welfare concerns. Different livestock types have different levels above which they experience heat stress (THI thresholds).

Temperature Humidity Index (THI) combines information about daily mean temperatures and relative humidity to quantify livestock heat stress.

- **Cattle**. Many cattle are located in South-West England, Shropshire and North-West England. The number of days exceeding the heat stress threshold, for both dairy cattle (THI 70) and beef cattle (THI 72), is likely to increase from the baseline (1998-2017) to future period (2051-2070). For instance, the average number of days which the threshold for beef cattle is exceeded is projected to increase in South-West England from ~1 in the baseline period to ~5-20 in the future period.
- **Pigs**. Pigs are mainly located in Yorkshire and the Humber, and East of England. The average number of days expected to exceed their heat stress threshold (THI 72) is projected to increase from ~0-2 in the baseline period to ~10-20 in the future period for Yorkshire and the Humber, and from ~2.5 to ~20-30 for the East of England.
- **Poultry**. Poultry in England are mainly located in Shropshire/Herefordshire, East of England, and Lincolnshire. In the East of England, the average days per year in which the threshold of poultry broilers (THI 78) is exceeded is projected to increase from ~0-0.05 in the baseline period to ~1-4 in the future period.
- **Implications and future research**. These results improve understanding of climate risks to UK livestock and can help inform requirements for potential adaptation measures. Further research could involve livestock heat stress early warning systems, investigating projections of cold stress, and research into alternative heat stress metrics and/or thresholds.

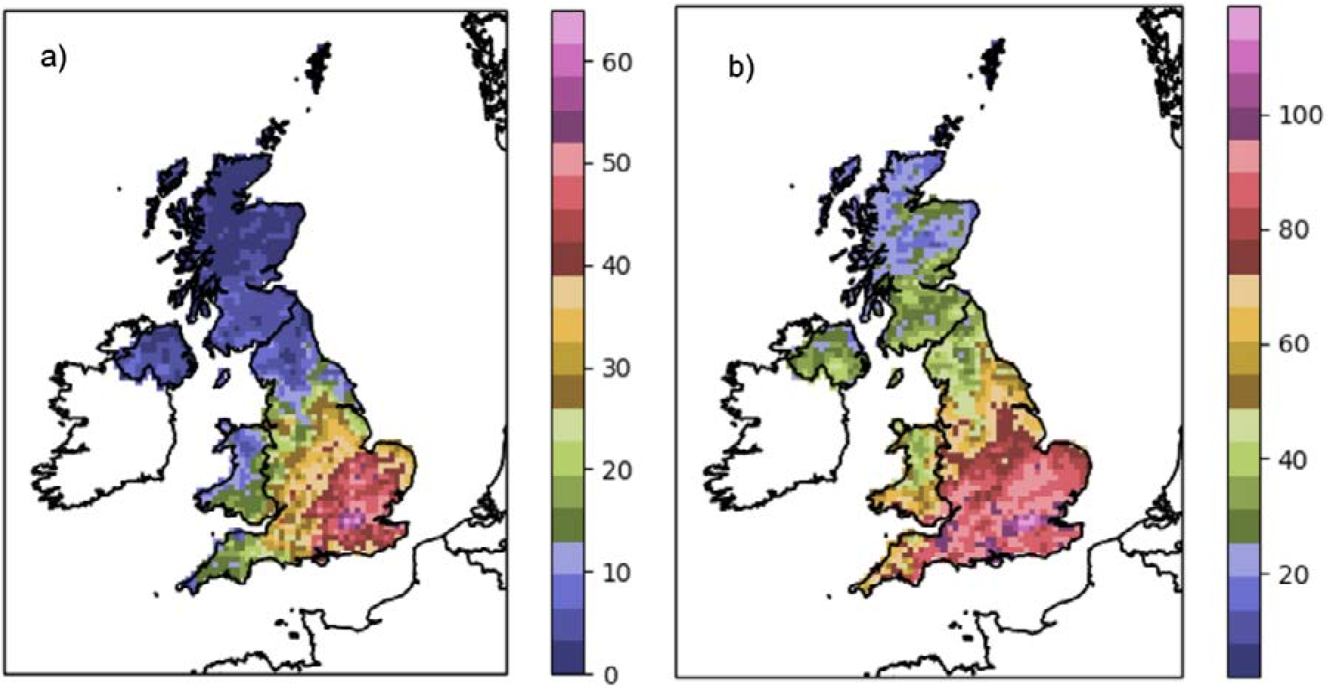


***Figure 2**: the maximum number of days when dairy cattle and laying poultry are expected to experience heat stress (THI exceeds 70), in any of the stimulated years during a) baseline (1998-2017) and b) future (2051-2070).*

Impact Category	Drought, Water Scarcity, Extreme Heat and Heatwaves.	Changing Seasonality	Flooding and Wet Conditions
Animal health, welfare and productivity	▪ Heat stress in livestock (during transport, outdoor exposure and housed systems), fertility issues. ▪ Reduced productivity due to lower feed intake, reduced milk yield on hot days ▪ Increased pneumonia linked to heat stress, outdoor pig photosensitisation (sunburn), reduced cleanliness in pigs.	▪ Changing seasonal patterns in livestock mortality (e.g., warmer springs increasing ruminant deaths). ▪ Increased insect burdens (flies, red mites) causing stress and reduced productivity ▪ Animals benefits from increased vitamin E and B12 from more sunshine, but risks from excessive sunshine (sunburn).	▪ Loss, injury or death from drowning, hypothermia following prolonged exposure to cold floodwater. ▪ Reduced milk and egg production due to stress. ▪ Metabolic diseases (e.g., grass tetany, milk fever, ketosis), increased respiratory disease (e.g., pneumonia) from damp housing and poor air quality ▪ Increased mastitis, lameness, foot rot and liver fluke.
Feed, forage and pasture production	▪ Increased risk of forage failure, damage and yield reduction ▪ Reduced grass growth, quality and ground cover, reduced grazing availability and fewer cuts for winter forage, reduced nutrient content in grasslands. ▪ Silage spoilage.	▪ Changes in forage quality affecting dry matter intake and productivity. ▪ Longer grass growing season (earlier and later) ▪ Warmer upland conditions enabling improved pasture productivity.	▪ Poor pasture utilisation due to contamination by floodwater ▪ Loss of hay and silage harvests, limited access to pasture during wet winters. ▪ Potential pasture yield increased under sustained wet conditions.
Water availability and quality	▪ Reduced availability of natural water sources (ponds and streams). ▪ Increased soil moisture deficit affecting forage. ▪ Restricted water availability for cooling (particularly pigs).	▪ Indirect changes in water demand linked to longer growing seasons and productivity shifts.	▪ Contamination of livestock drinking water sources, reduced water quality increasing health risks.
Pests, parasites, diseases and biosecurity	▪ Reduced efficacy of herbicides, pesticides and biocontrol for forage crops ▪ Increased vulnerability of stressed animals to disease.	▪ Increased insects and ectoparasites ▪ Changing incidence of toxic weeds posing risks to livestock. ▪ Drying of muddy areas benefiting parasite and worm control.	▪ Increased disease risk from contaminated feed and water, increased pathogen exposure during flooding; higher infection risk due to stress and poor hygiene.
Farm operations, infrastructure and systems	▪ Farm systems stressed by extreme weather ▪ Increased risk of wildfires affecting grazing land ▪ Workforce health impacts form heat stress and sun exposure.	▪ Warmer conditions altering grazing calendars and management practices.	▪ Difficulties accessing livestock during flood events, transport stress from emergency relocation and mixing of stock ▪ Increased time indoors requiring more bedding, waterlogging limiting feeding and bedding activities. ▪ Additional slurry and manure management.
Economic impacts, risks and opportunities	▪ Reduced livestock productivity and output, higher costs from supplementary feeding ▪ Water provision and forage losses ▪ Wildfire-related losses.	▪ Productivity gains in some regions (e.g., warmer upland farms) ▪ Potential efficiency gains from longer grazing seasons.	▪ Financial losses from livestock deaths, reduced production, feed spoilage. ▪ Infrastructure damage and increased veterinary and management of costs.

Table 3 *outlines the climate impacts to livestock systems (from drought, water scarcity, extreme heat and heatwaves, changing seasonality, flooding and wet conditions). It is a summary of the findings from Foulkes, Oliver & Clarke (2023, 2024); two reports produced in a partnership between ADAS and the Met Office.*

2.2.2 Adaptation and Resilience Measures

Adaptation measures are required to protect the welfare of livestock and limit potential reductions in productivity in response to a changing climate. For instance, the projected increases in heat stress conditions (section 2.2.1 Risks and Opportunities) suggest that substantial adaptations might be required in the future. Cottrell & Crocker (2023a,b,c) evaluated different categories of adaptation for UK livestock systems including:

- **Changing location within the UK**. Climate risks could be mitigated by changing the location of different types of agricultural production. For instance, summer drying in the East and South-East could make such regions more suitable for grassland/ livestock production, and arable/ horticulture production could be moved to the North-West. However, this may increase exposure to other climate hazards; wetter winters in the North-West could limit machinery accessibility for planting and drilling.
- **New breeds of livestock**. New varieties of livestock can have characteristics that provide improved resilience to climate hazards.
- **Livestock housing**. Improved insulation, ventilation and cooling systems can improve resilience to heat stress.
- **Agroforestry**. Planting trees as part of livestock farming systems can improve resilience to multiple climate hazards, as well as improving biodiversity and carbon storage.
- **Operational decisions**. Day-to-day decisions can improve climate resilience, for instance nocturnal catching and/or thinning for poultry.
- **Future challenges**. These include managing efficiency whilst ensuring that welfare standards are maintained, and ensuring greenhouse gas emissions are taken into consideration.

Adaptation Category	Drought, Water Scarcity, Extreme Heat and Heatwaves.	Changing Seasonality	Flooding and Wet Conditions
Forage selection and diversity	▪ Use deeper rooting/persistent forage (e.g., vetch), and/or row heat-tolerant/drought resistant forage. ▪ Use a mix of forages including catch crops.	▪ Grow earlier maturing forage varieties, grow a range of varieties with different flowering dates to spread risk.	▪ Select forage varieties more tolerant of waterlogging and wet harvest conditions.
Land and pasture management	▪ Increase use of old permanent pasture (common grazing). ▪ Implement fire breaks between fields, hedgerows, and woodland, remove excess dead foliage and leaf litter.	▪ Adjust grazing rotations to align with shifted forage growth cycles.	▪ Implement land management strategies to improve drainage and prevent standing water in grazing areas.
Resource and Infrastructure	▪ Switch to lighter-coloured plastic for silage to prevent spoiling. ▪ Provide mud wallows for pigs, use diurnal (daytime) or summer housing, provide shelter for pigs to avoid sunburn.	▪ Review and adjust housing ventilation for shifted temperature peaks.	▪ Provide extra clean, dry and deep bedding, use alternative bedding (woodchips, dry slurry) if straw supply is low. ▪ Check for and prevent draughts at animal level.
Husbandry and operational timings	▪ Adopt nocturnal grazing for cattle/sheep, transport animals at night. ▪ Avoid harvesting forage at peak heat of day. ▪ Thin poultry flocks prior to heat, leave poultry outdoors at night.	▪ Coincide 60-day dry period with mid-summer and calve in September (cattle).	▪ Take frequent checks on animals, split animals into smaller groups if sheds are overstocked. ▪ Increase frequency of scraping out housed stocks.
Pest, disease and health management.	▪ Grow forage less susceptible to pest and disease pressures. ▪ Monitor heat-related stress and respiratory issues.	▪ Increase advisory input to manage changing pest and disease pressures under new seasonal patterns.	▪ Maintain rigorous hygiene (scraping/bedding) to prevent food rot or pathogens common in wet conditions.
Farm Systems, Advisory and Risk	▪ Engage with farm advisory services. ▪ Use seasonal climate forecasts. ▪ Spread supplier base to reduce risk of supply issues.	▪ Use advisory services to guide adaptation choices based on changing seasonal patterns.	▪ Develop flood contingency plans. ▪ Review resilience of infrastructure to prolonged wet periods.

***Table 4** outlines the 'Quick Win' adaptation options for livestock systems that are low cost, easy to implement and effective. It is a summary of the findings from Foulkes, Oliver & Clarke (2023, 2024); two reports produced in a partnership between ADAS and the Met Office. Note - some of these need further research.*

Box 3: Case study of the 2022 heatwave on poultry and potential adaptations.

Davie et al. (2023a,b) examined the impacts of the 2022 heatwave on poultry production and identified potential adaptation strategies to improve resilience to future extreme heat events.

During the summer of 2022, record breaking high temperatures were experienced across the UK, with wide ranging impacts on the food system. These included increased energy demand and costs for cold storage, failures of refrigeration systems in some retail facilities, and severe heat stress in livestock. Future climate projections indicate an increased likelihood and duration of such extreme high temperatures, highlighting the importance of learning from the 2022 event to strengthen future resilience.

UK chicken meat production was significantly affected. Production was 9% lower in July 2022 compared with July 2021, alongside rising energy costs associated with production and refrigeration. During August 2022, chicken meat production was 5.2% lower than the June of the same year, equivalent to the loss of approximately 4.8 million chickens. Stakeholder interviews indicted that extreme heat was a primary driver of premature mortality, with some farmers reporting losses of up to 80% of their stock (Davie et al., 2023a).

Several adaptation measures were identified to reduce heat-related risks in the poultry sector. These include the use of more heat-tolerant chicken breeds, reducing stocking densities, installing dehumidification cooling and misting systems, improving ventilation, and enhancing the resilience and efficiency of retail refrigeration. Nutritional adaptations, such as vitamin supplementation, were highlighted as relatively simple and low-cost options to help mitigate heat stress. Lessons from poultry production systems in warmer countries may also offer valuable insights for adaption in the UK.

However, financial constraints were identified as a major barrier to implementation. Unlike some other livestock sectors, poultry farming currently has limited access to targeted subsidies or grants for heat-mitigation infrastructure. Improved domestic funding mechanisms could play a key role in enabling poultry producers to invest in adaptations necessary to cope with increasing heatwave risk.

2.3 UK Agricultural System as a Whole

Oliver et al. (2025) further developed the work by Ffoulkes, Oliver & Clarke (2023, 2024) by identifying priority hazards and adaptation measures, as well as key challenges and drivers, across the UK agricultural system. These are summarised in Table 5.

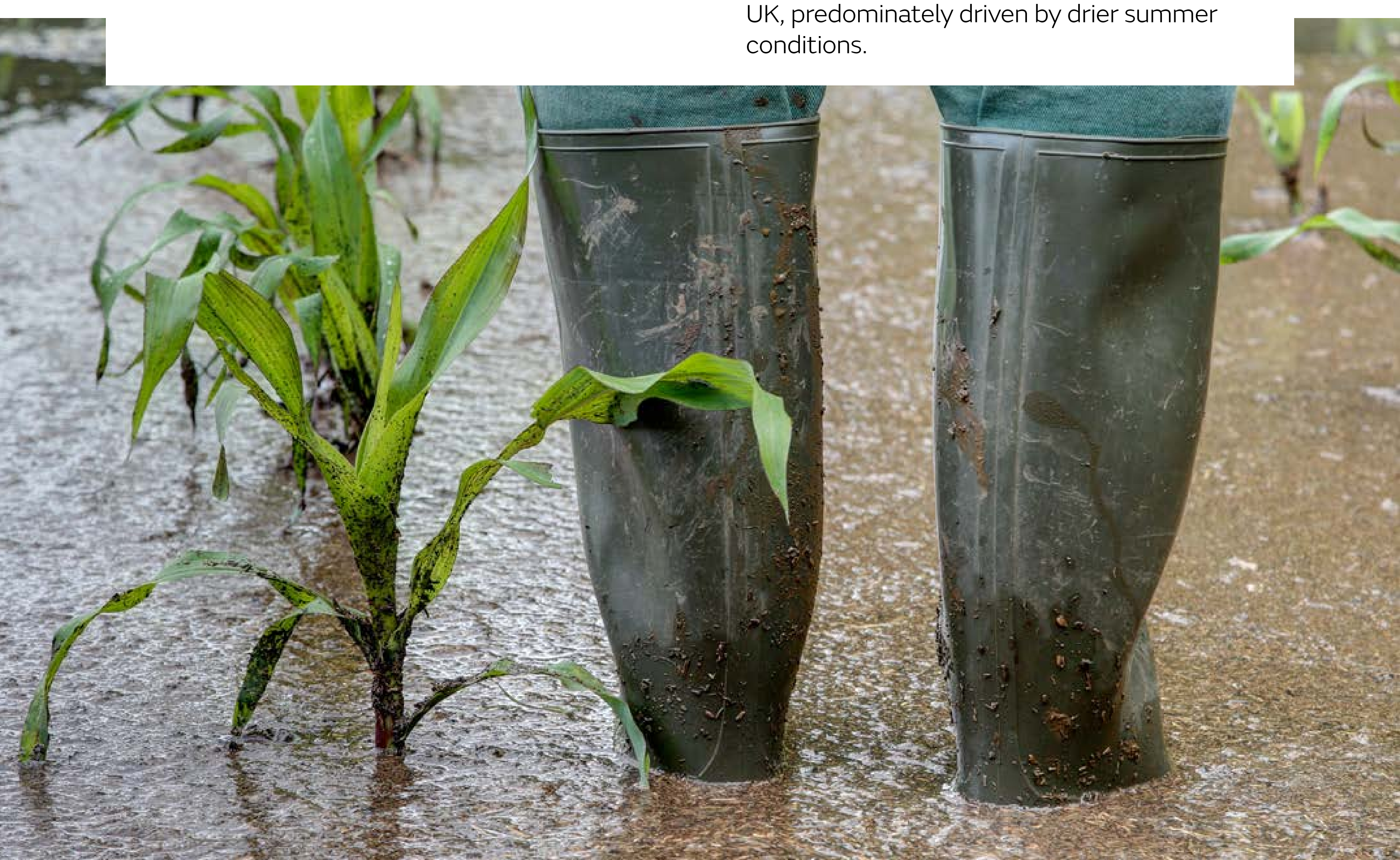
They also explored how field operation days might change under a changing climate. Field operation days are days where the land is dry enough to allow farming activities (e.g., crop protection, cultivation, drilling and grazing) to happen without damaging the land. The quantity of moisture in the soil is a key driver of field operation days. In particular wet soils can constrain trafficability (accessing fields with heavy machinery) and workability.

The wet winter and spring of 2024 illustrates how climate can impact on-farm activities across both arable and livestock systems:

- The winter of 2024 was milder and wetter than average, with rainfall across December, January and February 29% above the 1991-2020 average. This prevented an estimated 25-30% of UK winter crops from being established. The wet winter was followed by a wet spring, with rainfall 32% above the 1991-2020 average. For instance, this resulted in some farms being eight weeks behind their planting schedule for spring barley.
- The prolonged wet weather also had implications for livestock, with a delayed spring turnout due to waterlogged ground. Some farmers experienced significant problems with poaching (damage done to soil structure by heavy loads such as cattle), where turnout was unavoidable, such as spring calving dairy herds. Farmers also reported the impact of heavy rainfall on lambs, as they are highly vulnerable to hypothermia.

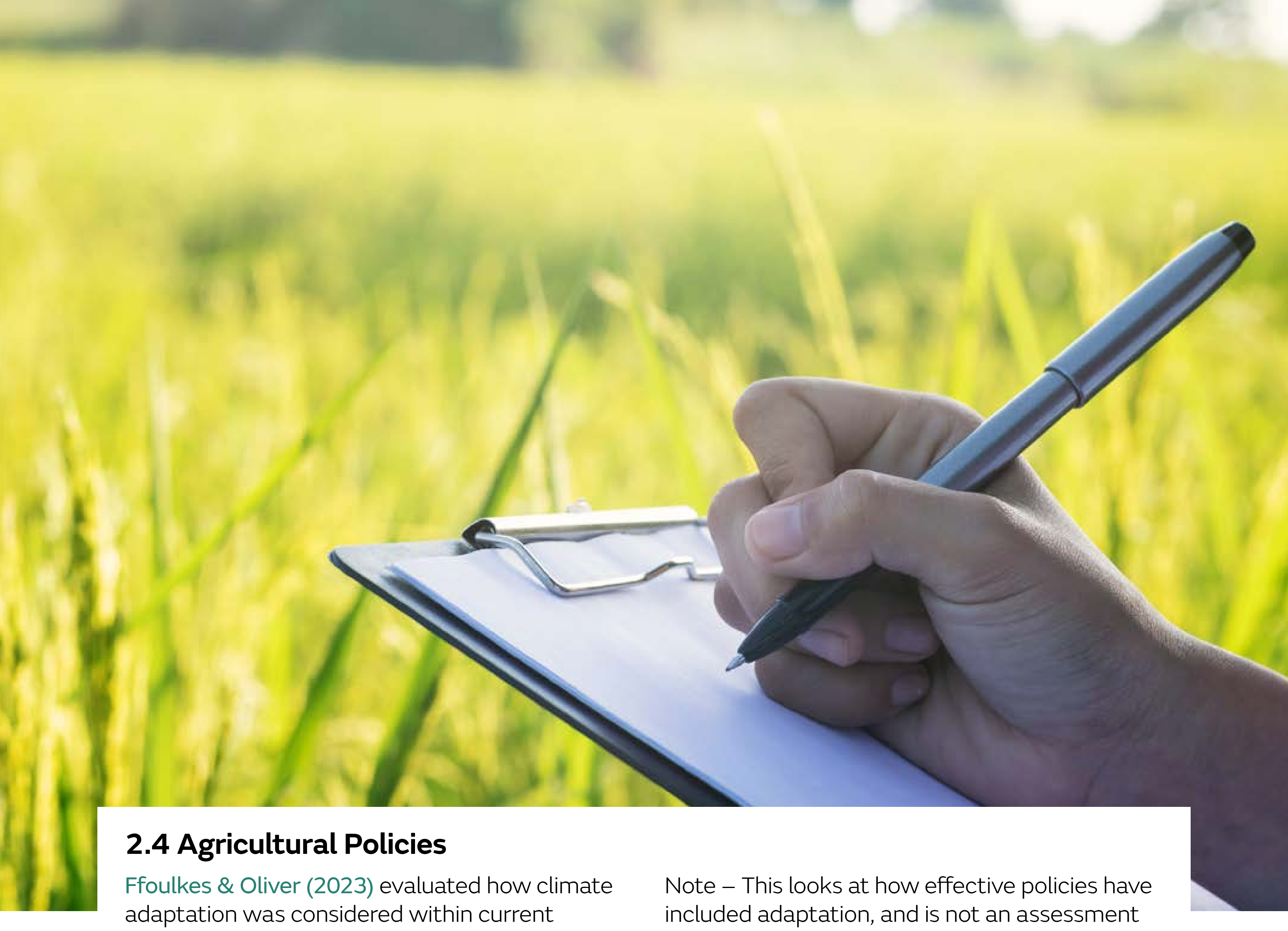
The number of wet soil days (days a year with soil moisture at or above field capacity) was used to project how future climate change will impact field operation days (Arnell & Freeman, 2021 in Oliver et al. (2025); Cottrell, Crocker & Falloon, 2025):

- It is projected that there will be a broad reduction in wet soil days in the autumn (varies with soil type), with soils expected to reach an equivalent soil moisture level around 2-3 weeks later by the future period (2041-206), compared with the baseline period (2001-2020). This could lead to increased trafficable days per month in autumn, but this change is typically significantly smaller than interannual variability.
- In contrast, in the winter it is projected that there will be a slight increase in the number of wet soils days across all soil types.
- In general, for low, medium and high emission scenarios (RCP2.6, 6.0, 8.5), soil dryness (Potential Soil Moisture Deficit) is projected to increase substantially over time in the UK, predominately driven by drier summer conditions.



Priority adaptation actions	Arable (priority hazard = high rainfall)	Horticulture (priority hazard = low rainfall)	Livestock (priority hazards = low rainfall, high rainfall, extreme temperatures)
Easy to implement and high impact 'quick wins'.	▪ **Choose crop varieties with lodging resistance/ pod shatter resistance (combinable).** ▪ **Choose more resistant crop varieties better suited to extreme rainfall exposure (potatoes).** ▪ **Practices to reduce soil erosion e.g. overwinter cover crops (combinable).*** ▪ **Improved targeting of organic matter additions to improve water absorption – compost (potatoes), locally sourced manures (combinable)*.** ▪ **Plant deep rooting overwinter cover crops to improve soil structure, compaction and infiltration (combinable)*** ▪ **Improved targeting of organic matter application - imported organic material (sugar beet).**	▪ **Increase pre-harvest irrigation to aid harvesting of root/bulb crops in dry ground (field veg).** ▪ *Practices to increase soil organic matter content and improve water retention (field veg).** ▪ *Mulch the soil surface around base of trees once every 3 years to improve soil water holding capacity (perennials & top fruit).* ▪ **Adopt accurate irrigation scheduling (e.g. automated, sensor-based system) (fully protected).** ▪ *Implement water management practices to improve water use efficiency (partially protected).*	▪ *Grow drought resistant forage (e.g. mixed herbal leys; leguminous forage and hay crop) (grass).** ▪ *Develop and implement a flood contingency plan with vet to mitigate against health and welfare risks (pigs – indoor/outdoor).* ▪ **Take appropriate action in the event of a flood to maintain animal health (poultry – housed).** ▪ *Agroforestry to provide shade for livestock (i.e. silvo-pasture) (cattle -graxed, sheep)** ▪ **Reduce housed cattle numbers*** ▪ *Improve farrowing arcs to make them more heat resistant e.g. insulation and reflective paint (pigs - outdoor).*
Moderate to implement and moderate impact	▪ **Companion plant with a cereal (e.g. barley) to provide protection to sugar beet in early growth stages (sugar beet).** ▪ *Switch cropping on areas of fields that are regularly flooded to perennial crops (e.g. grass, willow) (combinable, sugar beet)*.* ▪ **Adopt soil conservation practices e.g. cover crops to improve soil structure (potatoes)*** ▪ *Installation, restoration and regular maintenance of land drainage system (potatoes).*	▪ Install trickle irrigation system using precise application to crop stage of development (perennials & top fruit). ▪ Install rainwater harvesting and storage systems to enable reuse of water to reduce abstraction (partially protected).	▪ *Access alternative water supply (e.g. use of 'grey' water) for livestock drinking water (cattle – grazed/ housed, sheep)* ▪ *Ensure building integrity - repair roofs, ensure guttering is clear and block draughts (pigs – indoor, poultry housed/ free range).* ▪ *Ensure integrity of farrowing arcs and polytunnels (pigs – outdoor).* ▪ *Install more/better drainage pipes and free draining material around housing (poultry – free range).* ▪ *Housing redesign (improved permanent ventilation e.g. integrated or free-standing fans) (poultry – free range/ housed).*
Difficult to implement or low impact		▪ **Increase on-farm water storage capacity (e.g. reservoirs, dams) (fully protected).**	▪ **Housing redesign (ventilation with evaporative cooling) .**

***Table 5**: Priority adaptation actions across UK farming sectors. High rainfall includes extreme rainfall, flooding, prolonged wet conditions and waterlogging, while low rainfall refers to drought and water scarcity. Extreme temperatures refer to both extreme heat and extreme cold events. Adaptation options are grouped by implementation difficulty and impact. Green = easy to implement/high impact 'quick wins', orange = moderate to implement/moderate impact, and red = difficult to implement/low impact. Cost categories are indicated by formatting: bold = low cost, italics = moderate cost, and normal font = high cost. Actions marked with * contribute positively to net-zero goals. Adapted from Oliver et al. (2025).*



2.4 Agricultural Policies

Ffoulkes & Oliver (2023) evaluated how climate adaptation was considered within current agricultural policies (summarised in Table 6), classifying each policy for how effectively it included adaptation:

- **Effective** – the policy includes adaption and the measures are expected to be suited to significantly improve on-farm climate adaptation.
- **Moderately effective** – the policy includes adaptation and the measures are expected to be suited to improve on-farm climate adaptation, although the range of measures are limited or exclude key adaptations.
- **Limited effectiveness** – the policy includes adaptation to some extent, likely indirectly, but the measures are expected to be largely insufficient or unsuited to improve on-farm climate adaptation.
- **Ineffective** – the policy does not include measures to address on-farm climate adaptation.

Note – This looks at how effective policies have included adaptation, and is not an assessment of the effectiveness of the policy, just its adaptation merits.

There is opportunity to further incorporate adaptation and/or resilience measures into policy to improve on-farm awareness of the importance and benefits of adapting and highlight the actions that are already available. Falloon et al., (2023) conducted a workshop to understand potential adaptation and policy responses to the impacts of weather and climate extremes. Common policy themes identified were changes to trade agreements, support for resilient practices, innovation and cross food chain waste reduction, cross-government risk and/or opportunity mapping, and increased education and communication.

Policy Vehicle		Policy Aim	How effectively is adaptation included?
Agriculture Act 2020		Legislative framework designed to replace the agricultural support schemes in the Common Agricultural Policy following the UK's exit from the EU	Effective - adaptation and mitigation are considered, and adaptation appears central to the Act's aims.
Environment Act 2020		Designed for setting of long-term targets relating to the natural environment or people's enjoyment of the natural environment	Ineffective – the act does not detail specific adaptation measures; recognition of climate adaptation could improve resilience of long-term targets
25 Year Environment Plan		Sets out broad government actions to help 'the natural world regain and retain good health'	Effective – provides a clear picture of how agricultural adaptation is planned to contribute to a healthy natural environment
Environmental Land Management Schemes	Sustainable Farming Incentive	Rewards farmers for farming practices that help produce food sustainably and protect and improve the environment.	Moderately effective – some of its actions are expected to contribute to improved farm climate resilience, but the list of actions are not exhaustive and exclude key areas of adaptation
	Countryside Stewardship	Provides financial incentives for farmers, foresters and land managers to look after and improve the environment	Moderately effective – some its actions do support adaptation, although it could support additional adaptations, such as allocated land for flooding
	Landscape Recovery	Offers farmers and land managers to bespoke an agreement to produce environmental and climate goods across landscape scale projects >500ha	Moderately effective – individual projects will address adaptation (and mitigation) in different ways, and are designed for large-scale adaption, there could be greater emphasis on adaption within the project criteria
Catchment Sensitive Farming		Partnership between Natural England, Defra and the Environment Agency providing one-to-one advice to farmers to help them reduce water and air pollution and protect soils	Moderately effective – its advice is highly relevant to adaptation, but it does not explicitly name adaptation or resilience, framing itself within these may increase awareness of importance of on-farm adaption
Government Food Strategy		Sets out key priorities for action within the UK food system, to deliver government's ambition for a prosperous agri-food sector, so all can achieve a healthy/sustainable diet	Moderately effective – recognises the importance of supporting farms to adapt to the changing climate but adaption needs to be better represented holistically within the strategy
Farming Investment Fund		Provides grants to improve productivity and animal health and welfare	Effective – contains multiple items that support farm level adaption
Farming Transformation Fund (within the Farming Investment fund)	Slurry Infrastructure Water Management	Grants to improve or expand slurry storage capacity and to cover slurry stores. Capital items to improve efficiency of use of water for irrigation	Effective – both grants clearly fund on-farm adaptation actions
	Calf Housing for Health and Welfare	Grant to build new, upgrade or replace existing calf housing buildings to deliver health and welfare benefits for calves	Limited effectiveness – potential opportunity to support climate proofing for key climate hazards e.g., insulation, free draining material
	Improving Farm Productivity Added Value	Capital items to improve productivity through use of robotic equipment and/or slurry acidification equipment. Farm buildings, machinery or equipment that will add value to crops or livestock	Ineffective – neither grant considers adaptation, the Improving Farm Productivity could include productivity benefits of adaptation, such as new technologies for pest and disease surveillance

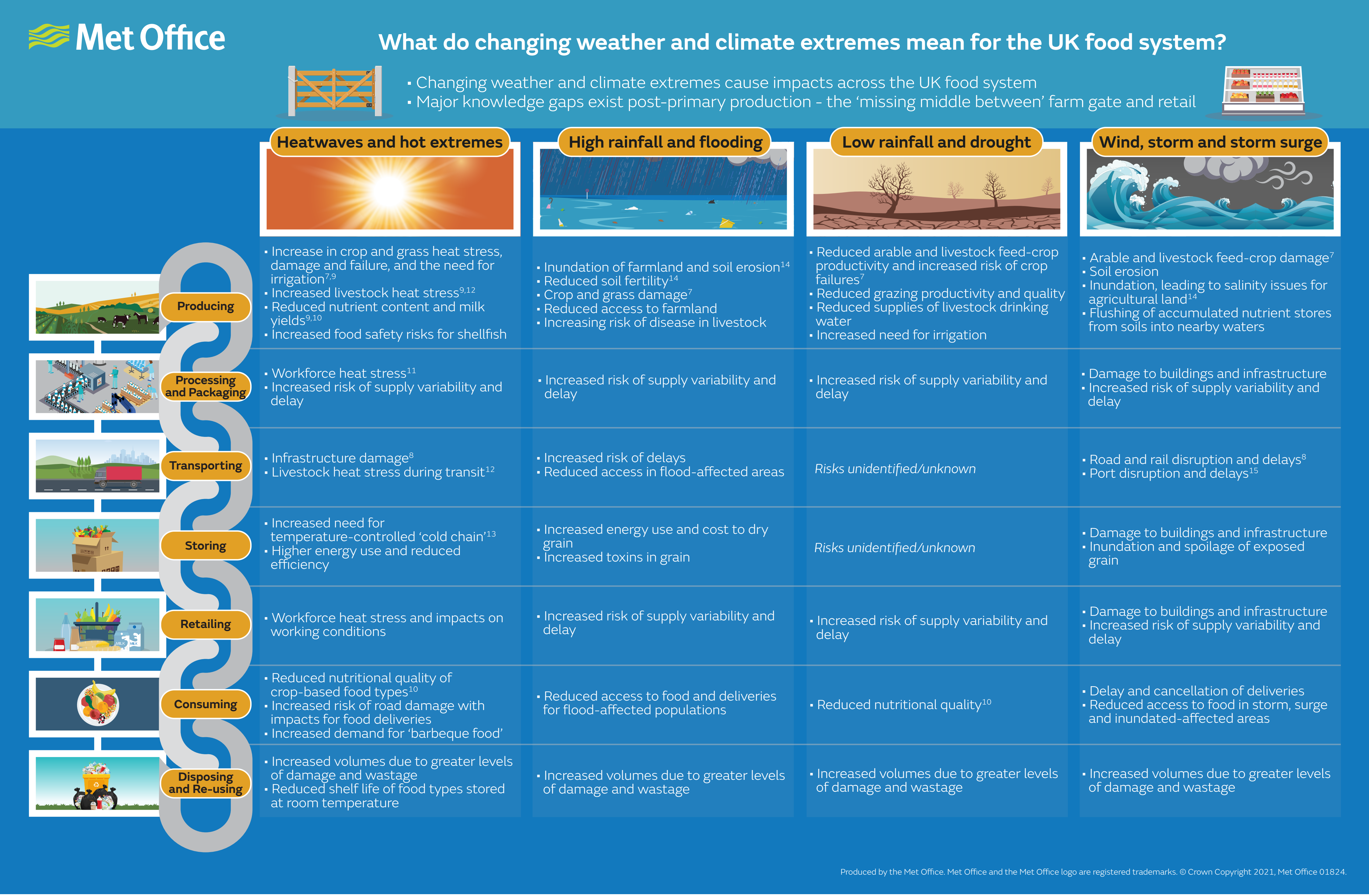
Table 6*: Review of how climate adaption is considered within current agricultural policies. Looks at how effective policies have included adaptation, so it is not an assessment of the effectiveness of the policy, just its adaptation merits. Green = effective, orange = moderately effective, red = ineffective. Adapted from Ffloulkes & Oliver (2023) (collaboration between Met Office and ADAS).*

3. UK Food Security and International Risks

Risks to food security, defined as “when all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life” (FAO, 1996), are focused on the impacts of climate change across the whole food system. This includes food production (both domestic and imported), food manufacturing, and considers population groups that are most likely to be affected.

UK food security has a strong international dimension. The UK imports over half of its food and is strongly dependent on internationally sourced ingredients, inputs, and packaging materials (Defra, 2024). Changes in climate and extreme events will change the suitability of sourcing regions for producing different foods, and disruptions in climate-vulnerable countries can rapidly destabilise UK food production (Cottrell, Crocker, Falloon. 2024b; Davie., 2025). Climate-induced disruptions are also likely to intersect with geopolitical, economic and energy shocks, amplifying systemic risks. Recent climate shocks have been linked to food price rises in the UK and are predicted to cause a 30-50% food price inflation by 2035 (Kotz et al. 2024). High-Impact Low-Likelihood events (HILL) including potential tipping points, such as AMOC collapse, extreme weather events or levels of climate change beyond projected could fundamentally alter how the UK food system currently operates (Bacon et al., 2025).

Along with the significant risks to food production, there are risks to other supply chain activities and these risks can cascade throughout the food system into much bigger and disruptive responses (Falloon et al., 2022). Therefore, both preventative and reactive strategies are required to ensure resilience to climate change and avoidance of food insecurity. This includes both adaption and re-orientation so that the UK food system continues to support UK citizens to eat an affordable and nutritious diet.



What do changing weather and climate extremes mean for the UK food system?

- Changing weather and climate extremes cause impacts across the UK food system
- Major knowledge gaps exist post-primary production - the 'missing middle between' farm gate and retail

	Heatwaves and hot extremes	High rainfall and flooding	Low rainfall and drought	Wind, storm and storm surge
Producing	▪ Increase in crop and grass heat stress, damage and failure, and the need for irrigation[7,9] ▪ Increased livestock heat stress[9,12] ▪ Reduced nutrient content and milk yields[9,10] ▪ Increased food safety risks for shellfish	▪ Inundation of farmland and soil erosion[14] ▪ Reduced soil fertility[14] ▪ Crop and grass damage[7] ▪ Reduced access to farmland ▪ Increasing risk of disease in livestock	▪ Reduced arable and livestock feed-crop productivity and increased risk of crop failures[7] ▪ Reduced grazing productivity and quality ▪ Reduced supplies of livestock drinking water ▪ Increased need for irrigation	▪ Arable and livestock feed-crop damage[7] ▪ Soil erosion ▪ Inundation, leading to salinity issues for agricultural land[14] ▪ Flushing of accumulated nutrient stores from soils into nearby waters
Processing and Packaging	▪ Workforce heat stress[11] ▪ Increased risk of supply variability and delay	▪ Increased risk of supply variability and delay	▪ Increased risk of supply variability and delay	▪ Damage to buildings and infrastructure ▪ Increased risk of supply variability and delay
Transporting	▪ Infrastructure damage[8] ▪ Livestock heat stress during transit[12]	▪ Increased risk of delays ▪ Reduced access in flood-affected areas	*Risks unidentified/unknown*	▪ Road and rail disruption and delays[8] ▪ Port disruption and delays[15]
Storing	▪ Increased need for temperature-controlled 'cold chain'[13] ▪ Higher energy use and reduced efficiency	▪ Increased energy use and cost to dry grain ▪ Increased toxins in grain	*Risks unidentified/unknown*	▪ Damage to buildings and infrastructure ▪ Inundation and spoilage of exposed grain
Retailing	▪ Workforce heat stress and impacts on working conditions	▪ Increased risk of supply variability and delay	▪ Increased risk of supply variability and delay	▪ Damage to buildings and infrastructure ▪ Increased risk of supply variability and delay
Consuming	▪ Reduced nutritional quality of crop-based food types[10] ▪ Increased risk of road damage with impacts for food deliveries ▪ Increased demand for 'barbeque food'	▪ Reduced access to food and deliveries for flood-affected populations	▪ Reduced nutritional quality[10]	▪ Delay and cancellation of deliveries ▪ Reduced access to food in storm, surge and inundated-affected areas
Disposing and Re-using	▪ Increased volumes due to greater levels of damage and wastage ▪ Reduced shelf life of food types stored at room temperature	▪ Increased volumes due to greater levels of damage and wastage	▪ Increased volumes due to greater levels of damage and wastage	▪ Increased volumes due to greater levels of damage and wastage

***Figure 3**: Key risks to UK food system activities from climate change and weather extremes. Source: Falloon et al. (2022).*

3.1 Risks to UK Food Security

3.1.1 Climate impacts on post-primary production (Falloon et al., 2022).

Future changes in weather and climate extremes could have wide-ranging consequences on the UK food system (Fig. 3). Whilst strong evidence exits about the impacts of long-term climate trends and extremes on primary food production, there is a lack of research concerning post-primary production. These include the processing, storage, transportation and consumption of food, and constitute major economic and social dimensions.

Falloon et al. (2022) identified key risks to post-primary production food system activities:

1. **Increased variability in supply quantity and quality**. This can affect processing where it depends on a reliable input supply and quality standards that determine end use.
2. **Heat and cold effects on workforces across the food chain**.
3. **High temperature and humidity impacts on storage and transport**. Increases in ambient temperature will strongly affect food dependent on the cold chain, as it can increase food spoilage and food poisoning risks. This will increase energy use leading to positive feedback whereby changing climate increases energy consumption and hence greenhouse gas emissions, leading to further climate change.
4. **Changes in consumer demand**. For example, during high temperatures, the demand for barbecue food, salads and fresh fruit increases but supply may also be impacted through heat stress
5. **Impacts of extreme weather on food safety, transport and infrastructure**. Concerns lie in the increased risks from algal pools, pathogens/fungi, increased food contamination and waterborne diseases via heavy rainfall and flooding, and indirect impacts from infrastructure damage. For instance, storm surges and flooding can disrupt port facilities and other transport infrastructure, causing delays and depreciation of goofs and additional costs.

Even when considering only one type of meteorological extreme, impacts could potentially propagate through the food chain with complex cumulative effects, yet this remains a significant knowledge gap.

3.2 International Risks

Given the dependence of the UK food system on imports, it is exposed to adverse climate impacts affecting international agricultural production, international distribution networks and transport networks. However, there are key challenges in improving the risk of the international food supply chain, for instance, increasing food system resilience can have an adverse impact on system efficiency. Changes to transport routes and/or distribution networks can also affect greenhouse gas emissions with implications for Net Zero.

Therefore, there is a need to understand how climate-related disruptions will impact food supply chains and supporting supply chains (e.g., agricultural inputs such as fertiliser or agrochemicals, seeds, packaging etc.). In addition, there needs to be consideration of the interaction of climate hazards with non-climate global events (Cottrell & Crocker 2023a,b).

3.2.1 Case studies of international risks (Cottrell, Crocker, Falloon. 2024b; Davie., 2025):

The UK is highly reliant on imports for its fruit and vegetable supply (Fig. 4), with domestic production accounting for around 55% of vegetables and just 17% of fruit (Defra, 2023, in Cottrell, Crocker, Falloon, 2024b). To better understand the implications for UK food security, the Met Office conducted two case studies examining horticultural imports from Spain and Italy, offering insight into international agricultural production risks:

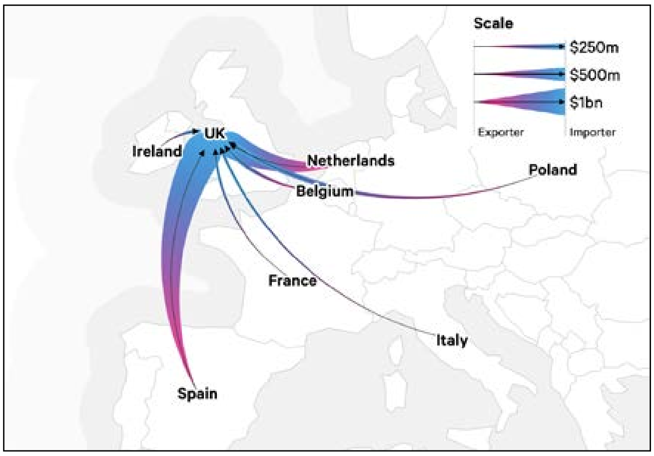


Figure 4: *Major vegetable imports to the UK from Europe in 2022. Arrow is proportional to the scale of imports by value. Source: Chatham House (2022). Available at:* https://resourcetrade.earth/?year=2022&exporter=eur&importer=826&category=72&units=value&autozoom=1

Spain case study:

- **Water stress**. Droughts and water stress are already causing challenges for agriculture in Spain, and are projected to increase in the future. For instance, dry events (when total precipitation minus potential evapotranspiration is more than 200 mm below the historic average) have typically occurred infrequently; less than 20% of years for most regions. However, by the 2050s, model projections show an increased likelihood of such dry events, occurring up to 40% of years.
- **Heat stress**. climate projections indicate increases in average temperatures across Spain in all seasons. There is a strong seasonality of imports from Spain to UK, with a marked reduction in summer and early autumn, reflecting both the increase in domestic UK production in these months and the months when temperatures in Spain are too hot for greenhouse production. By the 2050s heat stress events where it is too hot to grow crops such as sweet peppers and tomatoes in greenhouses, are projected to also occur in May and October, indicating a potential risk to imports to the UK in these months.
- **Vernalisation**. Many fruit trees require a period of cold temperatures in order to emerge from dormancy and produce fruit. Projected warming temperatures put this vernalisation requirement at risk, for instance, by the 2050s, such warmer winter events are projected across areas of substantial fruit tree production.

Italy case study:

- **Tomatoes**. Over half of prepared or preserved tomato imports to the UK are from Italy, with the major regions being Emilia-Romagna (~38%) and Puglia (~25%). Tomatoes are at risk from increasing temperatures, for instance parts of Emilia-Romagna are projected to experience daily maximum temperatures above 45°C by the 2050s, at which tomato plants are damaged.
- **Apples and Pears**. Italy was the third highest exporter of fresh apples to the UK from 2021-2024. It is unclear what the changes are to vernalisation risk, with winter mean temperatures projected to increase in the 2050s, but remain below 10°C in northern apple and pear growing regions. Extreme heat and moisture stress can impact quality and quantity of apples, associated with sunburn, cracking and browning.

Climate variables are only one factor affecting the risks to agricultural production. Adaptations could reduce these risks, e.g., more efficient water usage, desalination, alternative crop varieties, change in crop production locations. From the perspective of the UK, climate risks to production in one international location might be mitigated by production from elsewhere. This includes alternative international locations or, for some crops, increased domestic production.

3.2.2 High-Impact, Low-Likelihood (HILL) events on UK food security (Bacon et al., 2025).

Bacon et al. (2025) provide a summary of the potential impacts of High-Impact Low-Likelihood (HILL) events on UK Food Security if they do take place. If HILL events do occur, they are anticipated to result in large impacts on the environment and socio-economic systems important to regional and global food supply. Three categories of HILL events are explored:

1. Plausible extreme (high impact) weather events with lower likelihoods of occurrence than those experienced more routinely.
2. Large-scale tipping points in the climate system (Fig. 5), where elements of the climate system shift relatively rapidly and irreversibly into a different state.
3. Levels or rates of climate change beyond the likely ranges assed by the Intergovernmental Panel on Climate Change (IPCC).

1. Extreme weather events:

- **Large-scale harvest failures**. Persistent weather patterns (e.g., extended heat, drought, or rain systems) can affect large regions at once. This raises the risk of simultaneous crop failures in multiple global food-producing regions. Even if the UK is not directly affected, global impacts can disrupt supply chains and push up food prices. The likelihood of these events increases as global warming rises.
- **Compound events**. When extreme events happen together or back-to-back (e.g., drought followed by flooding), impacts are worse than single events. For instance, East Africa (2020-2023) experienced successive droughts and heavy rainfall, driving severe food insecurity. These compound risks are expected to become more frequent, but are still often underestimated in risk assessments.
- **Record-breaking extremes**. Climate events that exceed historical records are becoming more common. Food systems are not designed for such extremes, increasing vulnerability. Impacts depend on timing and sector, for instance during the UK's 2022 heatwaves wheat yields remained high due to the timing of the hottest spells, but poultry farming suffered heavy losses due to heat stress, cooling failures, and higher energy costs (Box 3).

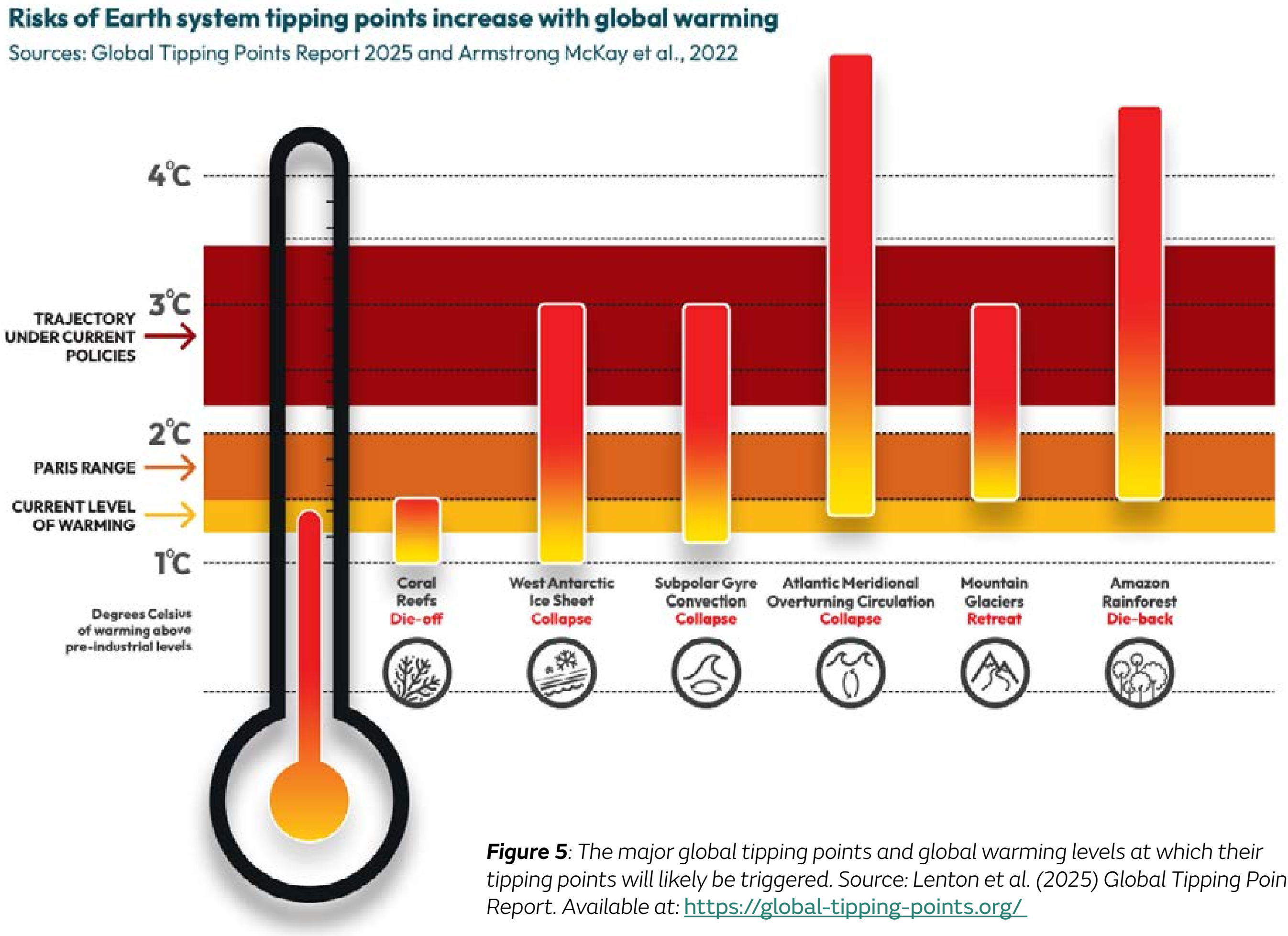
2. Climate tipping points (large, potentially irreversible changes, Fig. 5):

- **Greenland and West Antarctic icesheets**. Evidence suggests that these icesheets may be nearing thresholds at which their decline and eventual loss is inevitable, though uncertainty remains. The IPCC has evaluated a HILL scenario in which the triggering of these tipping points could contribute an additional 20 cm to global sea level rise by 2050, and up to a metre by 2100. Risks to the UK include flooding of key infrastructure (e.g., Port of Dover) and low-lying farmland (e.g., Greater Lincolnshire). Globally, risks include disrupted trade, displaced populations, salinised soils, and pressure on land and water, all affecting food markets and supply chains.
- **Atlantic Meridional Overturning Circulation (AMOC)**. This major ocean current regulates climate by transporting heat and nutrients across the Atlantic Ocean. It is likely to weaken due to freshwater from melting ice; abrupt collapse before 2100 considered unlikely, but the magnitude of slowdown is uncertain. A strong slowdown or collapse could cause cooling in the Northern Hemisphere, altered rainfall patterns, disrupted marine ecosystems. These changes would affect agriculture, especially in Europe and parts of Asia and destabilise global food prices (Richie et al. 2020). For Britain, the land area for arable production is predicted to fall from 32% to 7% under AMOC collapse (Richie et al. 2020).
- **Labrador Sea subpolar gyre (SPG)**. Part of the AMOC system and could collapse at lower warming levels than full AMOC collapse. Likely impacts include cooler temperatures and changes in rainfall in North-West Europe. Could disrupt crop yields, growing seasons, and food trade.
- **Amazon rainforest savannisation**. The Amazon could shift from rainforest to drier savannah-like system due to climate change and deforestation. Full transition could take 50-200 years; it is unclear if it will occur this century. The impacts include regional drying and reduced rainfall for agriculture, global carbon release, accelerated warming, increased risk of simultaneous crop failures across global breadbaskets (key food-producing regions).

- **Irreversible melt of non-polar mountain glaciers**. This is currently expected to be triggered around 2°C warming (likely by mid-century). In the short term, this would cause more meltwater and flooding risk, and in the long-term loss of reliable freshwater. Major food and water security risks in regions such as Andes, Himalayas, central Asia and the upper Indus Basin.
- **Changes to monsoon systems**. There is some evidence of a tipping point in the West African monsoon, toward a greener, wetter Sahel. This could improve farming, but also increase heat stress and land pressure. There is low confidence this shift will happen before 2100. The Indian monsoon could also be affected indirectly by other tipping points (e.g., AMOC).
- **Die-off of low-latitude coral reefs**. At 1.5°C warming, most low-latitude coral reefs are expected to die off. Coral reefs support major fisheries and livelihoods, and so their loss would disrupt global seafood supply chains, including industries like Indian Ocean tuna fishing. Already at 1.4°C of global warming, coral reefs are crossing their tipping point and experiencing unprecedented dieback (Lenton et al., 2025).
- **Abrupt permafrost thaw**. Sudden thaw can release large amounts of methane and CO_2, accelerating warming. It is estimated to add ~0.04°C of warming per degree of global warming. This would have indirect food impacts via faster warming, plus direct damage to infrastructure and transport networks in permafrost regions.

3. Cascading risks and high-than-expected warming:

- **Greenland ice melt poses the highest risk of triggering a global tipping point cascade**. Meltwater could weaken the AMOC, potentially contributing to West Antarctic ice sheet collapse and possible effects on the Amazon. While full cascades may unfold beyond 2100, they remain highly relevant for policy decisions today.
- **If warming exceeds IPCC projections due to higher climate sensitivity or unexpected emissions growth, it will have severe implications for food security**. This would include lower crop yields and nutritional quality, water scarcity, pest and diseases and greater disruption of global food and supply chains. Higher warming also increases the chance of crossing multiple tipping points, worsening inequality and long-term food insecurity.



Risks of Earth system tipping points increase with global warming

Sources: Global Tipping Points Report 2025 and Armstrong McKay et al., 2022

***Figure 5**: The major global tipping points and global warming levels at which their tipping points will likely be triggered. Source: Lenton et al. (2025) Global Tipping Points Report. Available at: https://global-tipping-points.org/*

4. The Future

4.1 Ways Forward

This report highlights that climate change presents real and growing risks to the UK food system, but it also shows that there are clear, practical pathways to reduce those risks while delivering wider benefits for farmers, consumers and the environment. With the right mix of policy, innovation and coordinated action, adaptation and resilience can become engines of positive change.

UK agriculture already has a strong foundation to build on. Many adaptation options are well understood, technically feasible and, in several cases, deliver immediate co-benefits for productivity, animal welfare and Net Zero goals. Priorities emerging from Met Office research include:

- **Mainstreaming adaptation into policy and practice**, so farmers clearly see the benefits of acting early and are supported to adopt measures that are already available.
- **Targeted support for sector-specific risks**, recognising that priority hazards differ across arable, horticulture and livestock systems.
- **Reducing barriers to action**, by lower administrative burdens, improving access to finance for expensive measures, and expanding education and advisory services.

These measures not only reduce climate risk, but also improve long-term farm viability, environmental outcomes, and resilience to shocks in the food system.

4.2 Further Research

Climate change impacts, adaptation responses and resilience within the food system are complex and continually evolving, and there are several opportunities for future research, including:

- **Broaden the focus beyond arable crops**. The majority of research focuses on arable crops; there is a need to greater understand the effect on non-cereal crops, livestock and fisheries production. There is also a need to consider the intertwined impacts of species and ecosystems.
- **Understand large-scale climate drivers**. Further research is needed to understand how large-scale drivers e.g., ENSO, may evolve under climate change and what this may mean for UK agriculture and food security. There is also a need to better understand HILL events and the effectiveness of differing adaptation options.
- **Improve evidence of near-term climate change and regional variations**. There is limited evidence for the short-term impacts of climate change (e.g., 2030s) with most projections focusing on the 2050s and 2080s. There is also limited evidence on climate impacts specific to different regions within the UK.
- **Adopt holistic, system-wide approaches**. Research needs to account for the entire food chain and the complex interplay between domestic production and global trade. There is a need to understand how climate-related disruptions will impact trade and supply, and how these climate hazards will interact with non-climate global events. There is also a significant knowledge gap for the impacts of compound and cascading events across the food chain.
- **Domestic production vs overseas production**. There is also knowledge gap as to whether the UK should lean towards self-sufficiency or global trade, and/or which direction climate change will drive countries to.

4.3 Further Information

Food farming and natural environment climate service (FFNE) webpage and publicly available reports:

Analysis of Heat Stress for UK Livestock using UKCP18 Climate Data – this report quantifies the occurrence of heat stress days in the present (1998-2017) and explores how heat stress conditions may change in the future (2051-2070) across the UK for a range of livestock types: dairy cattle, beef cattle, pigs, broiler chickens and laying chickens.

Sub-national International Climate Projections – the report explores how analysis of climate projection data can add insight to international agricultural production risks of relevance to food security, using Spain as an example.

Sub-National Climate Projections - Italy – Extends the analysis of the previous report to key horticulture products that the UK imports from Italy: tomatoes, apples and pears.

Research to assess resilience measures that support UK agriculture in adapting to drought, extreme heat, and wildfires – this project revisited the adaptation options of a previous project conducted by ADAS (2008) to produce a set of figures for aggregated farm sectors that set out adaptation options for specific climate variables (drought, extreme heat, and wildfires), considering the cost, impact, and ease of implementation for each option.

Research to assess resilience measures that support UK agriculture in adapting to changing seasonality and extreme rainfall – this project revisited the adaptation options of a previous project conducted by ADAS (2008) to produce a set of figures for aggregated farm sectors that set out adaptation options for specific climate variables flooding, wet conditions and changing seasonality and to consider the cost, impact and ease of implementation of each adaptation measure.

High-Impact Low-Likelihood outcomes for UK food security: A literature review – this research provides a summary to Defra of the potential impacts of High-Impact Low-Likelihood (HILL) events on UK food security if they do take place. The research outlines the likelihood of each event occurring; it is intended to be an indicative study, the uncertainties and caveats outlined in the text should be considered.

Related Links:

Climate Change in the UK – Met Office

What will climate change look like near me? BBC

Agriculture Horticulture Development Board (AHDB)

Catchment Sensitive Farming: advice for farmers and land managers.

References

Bacon, J. et al. (2025). "High-Impact Low-Likelihood outcomes for UK food security: A literature review." Met Office report for Defra. Available at; https://sciencesearch.defra.gov.uk/ProjectDetails?ProjectId=21834.

Bacon, J. Pope, E. Cottrell, A. (2021). "Modelling UK wheat yields." Met Office report for Defra.

Chatham House (2022). Major vegetable imports to the UK from Europe in 2022. Available at: https://resourcetrade.earth/?year=2022&exporter=eur&importer=826&category=72&units=value&autozoom=1

Cottrell, A. & Pope, E. (2021). "Predictability of UK wheat yields". Met Office report for Defra.

Cottrell & Crocker, T. (2023c). "Resilient UK crops: Insights from regional climate data". Met Office report for Defra.

Cottrell, A. & Crocker. T (2023a). "Assessment of resilience measures for UK agri-food system." Met Office Report for Defra.

Cottrell, A. & Crocker. T (2023b). "UK agri-food system adaptation workshop". Met Office report for Defra.

Cottrell, A. Barker, G. Chappel, L. Crocker, L. (2023). "Building resilience in horticulture: Integrating crop breeding programs with climate information. Adaptation partnership: VeGIN and MOHC case study". Met Office report for Defra.

Cottrell, A. Crocker, T. Falloon P. (2024a). "Integrating crop breeding programs with climate information. Adaptation partnership: VeGIN and MOHC". Met Office report for Defra.

Cottrell, A. Crocker, T. Falloon, P. (2024b). "Sub-national international projections". Met Office report for Defra. Available at: https://sciencesearch.defra.gov.uk/ProjectDetails?ProjectId=21717.

Cottrell, A. Crocker, T. Falloon, P. (2025). "On-farm climate adaptations: soil moisture projections". Met Office report for Defra.

Cottrell, A. et al. (2021). "UK agri-food system climate risk evidence review". Met Office report for Defra.

Cottrell, A. Griffiths, S. Crocker, T. Falloon (2024b). "Integrating crop breeding programs with climate information. Adaptation partnership: WGIN and MOHC". Met Office report for Defra.

Davie, J. (2025). "Sub-national international climate projections – Italy". Met Office report for Defra. https://sciencesearch.defra.gov.uk/ProjectDetails?ProjectId=21953

Davie, J. et al. (2023a). "Building resilience to the impacts of climate extremes on the UK food chain – a poultry meat case study for the 2022 heatwave." Report created in partnership with University of Exeter, Met Office and ASDA.

Davie, J. Garry, F. Pope. E. (2021). "Analysis of heat stress for UK livestock using UKCP18 climate data". Met Office report for Defra. Available at: https://sciencesearch.defra.gov.uk/ProjectDetails?ProjectId=21665.

Davie, J.C et al. (2023b). 2022 UK heatwave impacts on agrifood: implications for a climate-resilient food system. *Frontiers in Environmental Science*, 11:1282284. https://doi.org/10.3389/fenvs.2023.1282284.

Defra (2024). *United Kingdom Food Security Report* 2024. GOV.UK. https://www.gov.uk/government/statistics/united-kingdom-food-security-report-2024.

Falloon, P. (2023). "Impacts of weather and climate extremes on the UK food chain – scoping adaptation and policy responses and their consequences: workshop report." Met Office Report for Defra.

Falloon, P. et al. (2022). What do changing weather and climate shocks and stresses mean for the UK food system? *Environmental Research Letters*. 17: 051001. https://doi.org/10.1088/1748-9326/ac68f9

FAO (1996). *Report of the World Food Summit*. Rome Italy.

Ffoulkes, C., Oliver., H and Clarke, J. (2024). Research to assess resilience measures that support UK agriculture in adapting to changing seasonality and extreme rainfall. ADAS report for the Met Office and Defra. Available at: https://sciencesearch.defra.gov.uk/ProjectDetails?ProjectId=21797.

Ffoulkes, C., Oliver., H and Clarke., J. (2023). Assessing resilience and adaptation measures for UK agriculture. ADAS report for the Met Office and Defra. https://sciencesearch.defra.gov.uk/ProjectDetails?ProjectId=21796.

Kotz, M et al. (2024). Global warming and heat extremes to enhance inflationary pressures. *Communications Earth & Environment*, 5, 116. https://doi.org/10.1038/s43247-023-01173-x.

Lenton, T. et al. (2025). 2025 *Global Tipping Points Report*. University of Exeter. Available at: https://global-tipping-points.org/.

Met Office (2026). *Climate change in the UK* [Accessed 02/02/26]. Available at: https://weather.metoffice.gov.uk/climate-change/climate-change-in-the-uk.

Oliver, H. et al. (2025). "Developing the evidence-base to support adaptation and resilience measures in UK agriculture". Reported conducted by ADAS and the Met Office for Defra.

Pope, E. & Roper, W. (2020). "Exploring a Bayesian statistical approach for modelling UK wheat trials." Met Office Report for Defra.

Richie, P. et al. (2020). Shifts in national land use and food production in Great Britian after a climate tipping point. *Nature Food*. 1, 76-83. https://doi.org/10.1038/s43016-019-0011-3.

Wheeler, R. & Lobley, M. (2021). Managing extreme weather and climate change in UK agriculture: Impacts, attitudes and action among farmers and stakeholders. *Climate Risk Management*. 32, 100313. https://doi.org/10.1016/j.crm.2021.100313.

Appendix

List of Met Office reports for Defra FFNE Service.

Report	Summary
UK climate service for agriculture: agroclimatic indices for UK winter wheat. Jennings, S. 2015.	This study highlights lodging and excessively wet conditions are particularly threatening to wheat production in the current climate.
UK climate service for farming and food system resilience: Assessing the relationship between climate variability and global wheat production. Kent, C. et al. 2016.	A systems approach is used to conceptualise and understand the climate risk to the United Kingdom wheat production and food security.
UK climate service for farming and food system resilience: A UK winter wheat feasibility study. Bradshaw, C et al. 2016.	This study assesses the feasibility of developing a climate service for the UK food and farming sector, with as specific focus on winter wheat.
Advances in understanding climate-related wheat production variability. Pope, E. & Kent, C. 2017. a) Supplementary material to main report: assessment of meteorological influences on inter-annual variations in global wheat yield for the present day under climate change. Pope, E. & Falloon, P. 2017. b) Supplementary material to main report: wheat global shocks – technical background. Kent, C. 2017.	Explores the characteristics of inter-annual yield variability, and the likelihood of production shocks across multiple regions. a) Investigated key aspects of the present-day and future climate risk to wheat production, including how year-to-year variations are likely to change due to climate change, and the climate factors associated with wheat production shocks. b) Provides the technical information behind the methodology and results detailed in Pope and Kent (2017).
UK Food Security: quantifying climate-related crop production variability. Kent, C. Davie, J. Bradshaw, C. 2018. a) UK Food Security: quantifying climate-related crop production variability. Supplementary material. 2018.	Highlights the magnitude of the climate influence on wheat and soybean yield variability and its role in adverse growing conditions across multiple regions. a) Observed climate impacts on imports of wheat and soyabean.
UK Food Security in a Changing Climate – Annual Report. Pope, E. et al. 2019. a) Supplementary material for "UK Food Security in a Changing Climate". Pope et al. 2019.	Describes four new studies exploring large-scale meteorological influences on stable crop production that could affect the UK's food system. The analysis focuses on winter wheat in the UK, France and Germany, spring wheat in Canada, and soybean production in the Americas. a) Covers the four different work strands completed: a characterising water availability in the present day, changes in water availability using the latest UKCP18 climate projections, wheat quality, and links between large-scale modes of natural climate variability and crop productivity.
Exploring a Bayesian statistical approach for modelling UK wheat trials. Pope, E. & Roper, W. 2020.	Describes the application of a data-driven, Bayesian modelling approach to explore the non-linear dependence on UK wheat yield each year using monthly mean temperature and precipitation.
Using climate model ensembles to investigate changes in UK rainfall erosivity. Bacon, J et al. 2020.	Quantifies present-day and future estimates of annual mean rainfall erosivity, a combined measure of rainfall total and intensity.
Modelling UK wheat yields. Bacon, J., Pope, E., Cottrell, A. 2021.	Demonstrate a new approach for interpreting how UK wheat yield responds to natural variations in temperature and rainfall, and discuss implications for mid-century wheat yield forecasts.

Predictability of UK wheat yields. Cottrell, A. & Pope, E. 2021.	Analyses relationships between large-scale patterns of climate variability and UK temperature and rainfall, and their usefulness as predictors of UK wheat yield variations.
UK agri-food system climate risk evidence review. Cottrell, A. Davie. J. & Bacon, J. 2021.	Brings together existing knowledge, evidence, and tools, to strengthen the evidence base for decision making, and identifies priority research areas.
UK agri-food system climate risk evidence review: Supplementary Report. Cottrell, A. Davie. J. & Bacon, J. 2021.	Additional detail from the documents reviewed, organised in the the same structure as the same report.
Analysis of heat stress for UK livestock using UKCP18 climate data. Davie, J. Garry, F. Pope, E. 2021.	Quantifies the occurrence of heat stress days in the present (1998-2017) and explores how heat stress conditions may change in the future (2051-2070) across the UK for a range of livestock types.
Assessment of resilience measures for the UK agri-food system. Cottrell, A. & Crocker, T. 2023.	Identifies and evaluates key adaptation measures that improve the resilience of the UK agri-food system.
Assessing resilience and adaptation measures for UK agriculture. Ffloulkes, C. Oliver, H. Clarke, J. (ADAS). 2023.	Produced a set of figures for aggregated farm sectors that set out adaptation options for specific climate variables (drought, heat, and wildfires).
Resilient UK crops: Insights from regional crop yields and regional climate data. Cottrell, A. & Crocker, T. 2023.	Explored the possible resilience benefits from regional diversification of UK crop production.
Resilient UK crops: Insights from regional crop yields and regional climate data: Supplementary Material. Cottrell, A. & Crocker, T. 2023	Provides supplementary material for UK regions, including correlations between UK crop yields and variables and Gaussian Yield Response Function model
UK agri-food system adaptation workshop: developing collaborative research opportunities to improve climate resilience of the UK agri-food system. Cottrell, A et al. 2023.	Workshop designed to improve mutual understanding of the adaptation and resilience options of the UK agri-food system, identify research gaps and potential synergies and potential for future collaboration.
Building resilience in horticulture: Integrating crop breeding programs with climate information Adaptation partnership: VeGIN and MOHC case study. Cottrell, A. et al. 2023.	During 2022/23 MOHC and VeGIN worked together with a view to improving the ability to address emerging climate pressures through crop breeding.
Building resilience to the impacts of climate extremes on the UK food chain – a poultry meat case study for the 2022 heatwave. Davie, J. et al. 2023.	Provides a case study of the 2022 summer heatwave across the poultry industry supply chain. Engages with stakeholders from the Met Office, ASDA, Defra and poultry farms.
Research to assess resilience measures that support UK agriculture in adapting to changing seasonality and extreme rainfall. Ffoulkes, C. Oliver, H. & Clarke, J. 2023.	Produced a set of figures for aggregated farm sectors that set out adaptation options for specific climate variables (flooding, wet conditions and changing seasonality).
Rapid review of key policy vehicles. Ffoulkes, C & Oliver, H. 2023.	Evaluates if and how climate adaptation is considered within current agricultural policies.
Impacts of weather and climate extremes on the UK food chain – scoping adaptation and policy responses and their consequences: workshop report. Falloon, P. et al. 2023.	Explores potential adaptation/policy responses to the direct impacts of weather and climate extremes on the food chain, and the resulting consequences.
Integrating crop breeding programs with climate information. Adaptation partnership: WGIN and MOHC. Cottrell, A et al. 2024.	Uses climate information to provide advice on wheat breeding targets, including changes to heat stress risks, changes to mean monthly temperatures and changes to Growing Degree days.
Sub-national international climate projections. Cottrell, A, Crocker, T, Falloon, P. 2024.	Explores how analysis of climate projection data can add insight to international agricultural production risks of relevance to food security, using Spain as an example.

Sub-national international climate projections – Italy. Davie, J. 2025.	Analyses key horticultural products that the UK imports from Italy: tomatoes, apples and pears.
UK national climate-crop modelling capability (UKNCCC) for food security monitoring and impact assessment: workshop report. Falloon, P. Barker, E. Crocker, T. 2025.	Brings together key expertise and capability in crop-climate modelling, facilitating coordinated participation in relevant existing international modelling intercomparison projects (MIPs) and the establishment of new, UK-focused crop model intercomparisons.
On-farm climate adaptation: Soil moisture projections. Cottrell, A. Crocker, T. Falloon, P. 2025.	Focuses on the risk of excessive soil moisture in limiting the ability to access land with heavy machinery without causing damage to the soil, and how this risk might change in the changing climate.
Supporting on-farm adaptation in UK agriculture: workshop synthesis. Ffloulkes, C et al. 2025.	Expands evidence-base for climate impacts, adaptation measures, and policy levers that could enhance resilience of agricultural systems in the UK.
Developing the evidence-base to support adaptation and resilience measures in UK agriculture. Oliver, H et al. 2025.	Expands the evidence-base for climate impacts, adaptation measures, and policy levers that could enhance the resilience of agricultural systems in the UK, including a detailed assessment of how field operations and machinery workdays will change.
High-Impact Low-Likelihood outcomes for UK food security: A literature review. Bacon, J. et al. 2025.	Provides a summary to Defra of the potential impacts of High-Impact Low-Likelihood (HILL) events on UK Food Security if they do take place.

This report was prepared by Jess Bocking on behalf of the Met Office/Climate Security team and Defra (FFNE).