School of Sustainable Food and Farming

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Water security and UK fresh produce production

Policy & literature review

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Executive summary

UK outdoor fresh produce production, including legumes, brassicas and root vegetables, is important for both the farming economy, public health and national food security. However, many of these crops depend on irrigation to achieve consistently high yields and marketable quality. At the same time, the UK Government's *A New Vision for Water* highlights growing concerns over water availability, recognising that long-term resilience will require significant changes in water management, allocation and efficiency.

This desk review draws on UK Government policy and regulatory guidance, UKCP18 and eFLaG climate and hydrological projections, Defra/ADAS crop water requirement data, and a structured review of the available literature on crop responses to water stress to assess the risks that water insecurity poses to UK fresh produce production. The review focuses on water availability rather than water quality, while recognising the close links between the two.

Water security is becoming a strategic challenge for UK agriculture. Irrigation abstraction is increasingly constrained by environmental flow requirements, drought restrictions and greater regulatory powers to amend or revoke abstraction licences. This means that existing licences cannot guarantee water supply during critical growing periods. Uncertainty reduces confidence in long-term investment in irrigation infrastructure and compounds wider financial pressures on the sector.

These regulatory challenges coincide with a changing climate. Projections indicate drier summers, wetter winters and more frequent, prolonged droughts, particularly across southern and eastern England where much of the UK's fresh produce is grown. Declining river flows, reduced groundwater recharge and tightening abstraction constraints are expected to increase water scarcity, with eastern and south-eastern catchments facing the greatest risks. Scotland, Wales and the South West are projected to experience lower, though increasing, levels of risk.

Water stress is most damaging during key crop development stages, such as curd initiation, tuber bulking and fruit set, rather than being determined by seasonal water demand alone. Crops grown on light sandy soils are particularly vulnerable because they require more frequent irrigation. Existing UK guidance on crop water requirements is largely based on historic climatic conditions and may need updating to reflect increasing weather variability and changing abstraction constraints.

Published evidence on crop responses to water stress is limited for many UK fresh produce crops. Most studies focus on peas, beans, lettuce, broccoli, strawberries, chicory and a small number of other crops, while little evidence exists for crops such as leek, beetroot, baby leaf and pumpkin. Consequently, this review also draws on European field studies and controlled-environment experiments.

Across the evidence base, salinity consistently has negative effects on crop performance, while drought generally reduces yield, growth and biomass, although effects on crop quality are more variable and sometimes positive. Nutritional composition can increase under moderate water stress through higher concentrations of beneficial compounds, but responses differ considerably between crops and cultivars. Very little evidence was identified on the impacts of waterlogging, and the limited UK evidence base means findings should be interpreted with caution.

However, it is clear from the evidence that the consequences of water stress for growers are substantial. Drought can reduce yields by 50–80% in peas and beans and by up to 65% in cabbage, while also lowering marketable yield through defects such as forking, cracking, splitting and undersized produce. Economic pressures are intensified by increasing abstraction restrictions, with reductions in licensed water availability directly affecting farm income. Although on-farm reservoirs and collaborative water management initiatives can improve resilience, they require significant investment and may not fully offset increasing water scarcity, particularly during consecutive dry years.

Overall, the evidence indicates that climate change and increasing pressure on water resources are likely to increase production risk, yield variability and the costs of irrigation-dependent fresh produce production. Without improvements in water management, regulatory approaches and on-farm resilience, the long-term viability of some UK fresh produce systems is likely to come under increasing pressure.

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1 Introduction

Fresh produce underpins rural livelihoods and UK diets. Field vegetables such as brassicas, root vegetables and legumes were valued at £1.6 billion in 2024. Brassica production alone was worth £372 million and carrots worth £219 million (Defra, 2025). Fresh produce also plays a central role in public health, forming the basis of dietary guidance to eat at least five portions of fruit and vegetables a day. Maintaining a reliable, quality domestic supply of these crops therefore matters both economically, for national food security and for public health.

UK production of fresh produce crops is geographically concentrated in regions already experiencing high levels of summer water stress, particularly eastern and south-eastern England (Knox et al., 2010; Weatherhead and Knox, 2000). Irrigation is a critical production input for many fresh produce systems as crop quality and marketability are sensitive to water availability during key developmental stages. Water stress can reduce crop size, increase physiological disorders and lead to cosmetic defects that prevent crops meeting retailer specifications, even if total yields are only moderately affected (AHDB, 2019b). Fresh produce systems are therefore dependent on timely and reliable irrigation to maintain both commercial quality standards and contractual supply obligations (Hess and Knox, 2013).

The overlap between production geography and water scarcity makes water security a fundamental issue for the sector. Much of this production sits within areas that the Environment Agency has formally classified as seriously water stressed, including the Anglian Water region (Environment Agency and Defra, 2021). More than 50,000 hectares of UK horticultural land were irrigated in 2019, using around 75 million m^3 of water, much of it drawn from catchments already defined as having no water available for further abstraction or classified as over-licensed (AHDB, 2019b). The Environment Agency's National Framework for Water Resources projects a shortfall of up to 5 billion litres a day in public water supply alone by 2055 without further action, with a further 1 billion litres a day likely to be needed by other sectors, including agriculture (Environment Agency, 2025). This threat is illustrated by recent droughts, demonstrating the vulnerability of the sector. For example, UKCEH's assessment of the 2022 drought recorded widespread impacts on crop and grass yields across England (Barker et al., 2024). Ensuring a secure and reliable water supply for fresh produce growers is therefore essential to sustain both the economic value and the quality standards on which the sector depends.

This report synthesises academic and policy thinking on water security for fresh produce crops and is part of a wider programme of work. The report sets out the policy context within which fresh produce growers must operate, followed by a summary of climate and hydrological projections that are likely to influence future water security. Details of crop water requirements are outlined, including likely risks to crops under water stress. This is augmented by a review of crop specific studies to illustrate crop responses to water stress based on scientific research. Finally, the report outlines the on-farm impacts on water availability, including yield, quality and growth impacts, abstraction licensing issues, infrastructure needs and catchment based approaches.

2 Methods

Each section of the report briefly summarises the methods used. The full methodology is available in Appendix 1.

3 Policy and regulatory context for water security

Snapshot

- Water policy increasingly prioritises sustainable abstraction and environmental protection, resulting in tighter regulation of irrigation water access.
- Abstraction licences do not guarantee water availability during critical growing periods, increasing uncertainty and financial risk for fresh produce growers.
- Although investment in reservoirs and efficient irrigation is encouraged, high capital costs and complex planning and regulatory requirements constrain adoption.
- Growing policy tension exists between protecting freshwater ecosystems and maintaining domestic fresh produce production, highlighting the need for more integrated approaches to water and food security.

3.1 Scope and approach

A desk-based review of existing UK policy and regulation was carried out to provide context. This section is not intended to be exhaustive, but sets the scene for the regulatory environment in which farmers operate in relation to water availability.

3.2 Strategic policy context

Water security has become a strategic challenge for UK agriculture as climate change, population growth, environmental degradation and increasing competition between sectors place growing pressure on finite water resources. Although water policy is devolved, all four UK nations increasingly prioritise sustainable abstraction, environmental protection and climate resilience. In England, the Environment Agency's *National Framework for Water Resources* (2025) emphasises balancing water availability across public supply, agriculture, industry and the environment while improving the resilience of water systems under future pressures. Similarly, the UK's Fourth Climate Change Risk Assessment (CCRA4) identifies increasing risks from drought, water scarcity and pressure on freshwater ecosystems under future climate change, highlighting the need for adaptation across sectors, including food production (Environment Agency, 2025; Met Office, 2026).

These challenges are particularly notable for fresh produce production. The UK remains a net importer of fruit and vegetables. Domestic production supplies 16% of fruit and 53% of vegetables consumed nationally (Defra, 2024). Consequently, maintaining resilient irrigation supplies has implications for individual farm businesses and for wider food security and the resilience of domestic production.

Government policy has increasingly sought to balance agricultural water demand with environmental protection. The Environment Agency's national framework prioritises restoring sustainable abstraction, improving ecological resilience and protecting rivers, wetlands and

groundwater systems (Environment Agency, 2025). As a result, abstraction regulation has become progressively more restrictive in many catchments to address environmentally unsustainable abstraction, restore ecological flows and improve the resilience of freshwater ecosystems (Environment Agency, 2025, 2026; Knox et al., 2010).

The UK Government's White Paper *A New Vision for Water* (Defra, 2026a) places greater emphasis on water quality than water availability. Proposed reforms include consolidated national pollution standards and increased farm inspection frequency, while measures addressing water availability are comparatively limited to continued support for on-farm water storage, improved resource planning and the proposed transfer of abstraction and impoundment regulation into the Environmental Permitting Regulations. Although these measures acknowledge the importance of water resilience, improving irrigation water availability is not a central focus of the policy agenda.

3.3 Abstraction regulation and irrigation security

For fresh produce growers, abstraction licensing is a fundamental determinant of water security. In England, abstraction exceeding 20 cubic metres per day generally requires an Environment Agency licence, with many licences now incorporating conditions such as hands-off flow restrictions that prohibit abstraction when river flows fall below environmentally defined thresholds (AHDB, 2019a). These conditions are intended to protect aquatic ecosystems during low-flow periods but can restrict irrigation when crop water demand is greatest.

The policy direction outlined in the Government's White Paper and reinforced by the CCRA4 suggests that regulatory pressure on abstraction is likely to increase, particularly within environmentally sensitive catchments (Defra, 2026a; Met Office, 2026). Consequently, growers may face reduced flexibility for summer abstraction alongside greater reliance on winter water storage, irrigation efficiency improvements and collaborative water management approaches. For growers producing perishable crops under fixed planting schedules and retailer contracts, such restrictions can create operational and financial risks (Hess & Knox, 2013; Knox et al., 2010).

Holding an abstraction licence does not guarantee access to water during critical irrigation periods. During drought conditions, abstraction may be curtailed when crops are most vulnerable to water stress. The Environment Agency retains emergency powers under Section 57 of the Water Resources Act 1991 to temporarily restrict spray irrigation abstraction during severe drought where necessary to protect public water supplies and the environment (Environment Agency, 2026). The Environment Agency has been examining ways to minimise the environmental impact of water abstraction at the driest times of year (Sutcliffe et al., 2023). They are moving towards more flexible licensing by managing catchments dynamically and monitoring abstraction, discharges and water availability in close to real time. New technology such as precision irrigation and smart farming tools is expected to cut unnecessary water use and make consumption more efficient. A smart metering trial is currently under way on one farm catchment in East Anglia to support this data-led approach (Environment Agency, 2026).

The water resources licensing digital service (WRLS) has also been upgraded to send licence holders e-alerts when hands-off-flow conditions change. Future upgrades to WRLS are planned to bring in real-time river and groundwater level data checked against licence conditions, eventually allowing predictive forecasting (Environment Agency, 2026).

Concerns regarding longer term licence security have increased among growers(Sutcliffe et al., 2023). While some abstraction licences were historically granted for extended or effectively permanent periods, most are now time limited and subject to periodic review. Regulatory reforms have strengthened powers to amend or revoke licences where abstraction threatens environmentally sensitive habitats or prevents achievement of ecological objectives under the Water Framework Directive and Environment Act 2021. This has increased uncertainty surrounding future water access and may discourage investment in irrigation dependent fresh produce production (Hess & Knox, 2013).

3.4 Barriers to adaptation

Increasing water insecurity coincides with wider structural challenges facing UK agriculture. The Government's *Farming Profitability Review* identifies rising input costs, labour shortages, climate volatility and limited investment capacity as constraints on farm business resilience (Batters, 2025). These pressures reduce growers' ability to invest in adaptation measures, despite increasing recognition that resilient water management will be essential under future climatic conditions.

Investment in irrigation infrastructure, such as reservoirs, pumping systems, filtration and precision irrigation technologies, requires substantial upfront capital expenditure and is often associated with long payback periods. Although policy and industry guidance increasingly encourage on-farm water storage and more efficient irrigation, uncertainty surrounding future abstraction rights may reduce grower confidence in making investments (Hess & Knox, 2013).

Industry guidance increasingly promotes resilience based approaches to agricultural water management. AHDB identifies winter water storage, collaborative abstraction, diversified water sources and improved irrigation efficiency as key strategies for improving resilience (AHDB, 2019b). Similarly, the UK Irrigation Association (UKIA) advocates improved irrigation scheduling, water stewardship and investment in storage infrastructure to strengthen resilience under increasing climate variability. However, adoption remains uneven, particularly among smaller growers, owing to financial constraints alongside planning and regulatory barriers (Hess & Knox, 2013).

Planning requirements can present a significant obstacle to developing on-farm water storage. Construction of irrigation reservoirs typically requires engagement with local planning authorities and, for larger schemes, full planning permission where developments may affect landscape character, ecology, flood risk, drainage or public rights of way. Even where agricultural permitted development rights apply, prior approval procedures and environmental assessments are frequently required (Farmers Weekly, 2025; UK Government, 2026). Consequently, growers may face lengthy and complex approval processes involving planning authorities, the Environment Agency and other regulators before projects can proceed (NFU, 2025). These requirements increase costs, extend development timescales and add further uncertainty to investments that could improve both agricultural water security and environmental resilience through increased winter water storage (House of Lords, 2026).

3.5 Balancing environmental protection and food security

Current policy reflects an increasingly complex balance between protecting freshwater ecosystems and maintaining resilient domestic food production. Water policy in England has progressively prioritised ecological restoration and sustainable abstraction, while agricultural policy seeks to strengthen food security, climate resilience and domestic production capacity. These objectives can create tensions where irrigation dependent agriculture operates within

environmentally stressed catchments (Environment Agency, 2025; Knox et al., 2010). This tension is particularly evident in fresh produce production, as many of the regions best suited to field vegetable cultivation are also those experiencing the greatest pressure on water resources. Without sufficient adaptation, increasing restrictions on summer abstraction could constrain domestic fresh produce production and increase reliance on imported produce (AHDB, 2019b; Environment Agency, 2025; NFU, 2021).

Supporting both environmental recovery and agricultural resilience will therefore require more integrated approaches to water governance. This may include greater recognition of irrigation as a strategic component of national food resilience, alongside improved support for winter water storage infrastructure and policies that better integrate environmental protection with long term food production objectives (AHDB, 2019b; Environment Agency, 2025; NFU, 2021).

4 Climate and hydrological projections

Snapshot

- UK summers are projected to get drier while winters get wetter by 2050.
- River flows and groundwater levels are set to decline steadily across England and Wales.
- Droughts are expected to become both longer lasting and more severe.
- East Anglia and the South East face the greatest water stress and irrigation risk.
- Wetter winters are unlikely to offset the loss of summer water availability.

4.1 Purpose and scope

Understanding how water availability is expected to change is fundamental for UK growers. This section examines climate and hydrological modelling data to illustrate changes in rainfall patterns, drought frequency, seasonal water availability and catchment-level pressures.

4.1.1 Evidence base and approach

Data for climate and hydrological modelling was obtained from two principal sources:

- UK Climate Projections (UKCP18) is the standard UK climate scenario framework (Met Office, 2018)
- Enhanced Future Flows and Groundwater (eFLaG) is the key source for hydrological projections and data is based on UKCP18 (UKCEH, 2023)

Both portals enable manipulation of scenarios to illustrate climate projections geographically. Extracted graphics were mostly based on RCP8.5 emissions scenario for consistency with most hydrological modelling which uses high emissions scenarios. Where necessary, multiple charts are presented to ensure the period between 2026 and 2050 is covered. Note that baseline time periods differ between the two sources. The 10th, 50th and 90th percentiles show the range of climate conditions that may occur according to the models. The 50th percentile represents a typical year, with half of the years having higher values and half having lower values. The 10th and 90th percentiles represent relatively low and relatively high conditions that occur in around one year out of ten.

4.2 Rainfall seasonality

The UKCP18 precipitation projections for the 2020-2058 period indicate a clear seasonal redistribution of rainfall across the UK, characterised by drier summers and wetter winters relative to a 1981-2000 baseline.

Figures 1a-c show that under the central estimate (50th percentile), summer rainfall changes are relatively modest overall but tend toward drying in parts of southern England. In the 10th percentile, widespread precipitation reductions are shown while the upper end (90th percentile) scenario indicates the potential for wetter summer conditions. This reflects uncertainty in summer precipitation projections. In contrast, winter projections (Figure 2a-c) show a more consistent trend toward increasing precipitation. The largest increases are likely to occur in western and northern regions of the UK. Taken together, the projections suggest increasing seasonality in UK water availability with a tendency toward reduced summer rainfall and greater winter precipitation, especially in regions already vulnerable to drought and abstraction pressure.

4.3 Hydrological response

4.3.1 Transient low flows / levels

Transient low flows and water levels are critical for UK fresh crop production due to high dependency on reliable seasonal water resources. Overall, the projections indicate a substantial increase in drought risk and declining reliability of summer water availability.

Figures 3a–d show projected low river flows and groundwater levels under Q30, Q50, Q70 and Q90 conditions (eg. the flow in cubic metres per second or the level in metres above ordnance datum (AOD) which was equalled or exceeded for 30%/50%/70%/90% of the record). As conditions become drier, the reductions in river flows and groundwater levels become more widespread and severe across England and Wales. Even under Q30 conditions, many catchments in southern and eastern England show declines compared with the baseline period. Under Q50, Q70 and especially Q90 conditions, these declines extend across more catchments, with many showing reductions of 20–40% and some experiencing even larger decreases.

The most consistently affected regions correspond closely with the UK's principal irrigated horticultural zones, including East Anglia, the South East, Lincolnshire, the East Midlands and parts of Yorkshire. In contrast, western and northern upland catchments, particularly in Scotland, generally show smaller reductions and occasional increases, reflecting greater water availability.

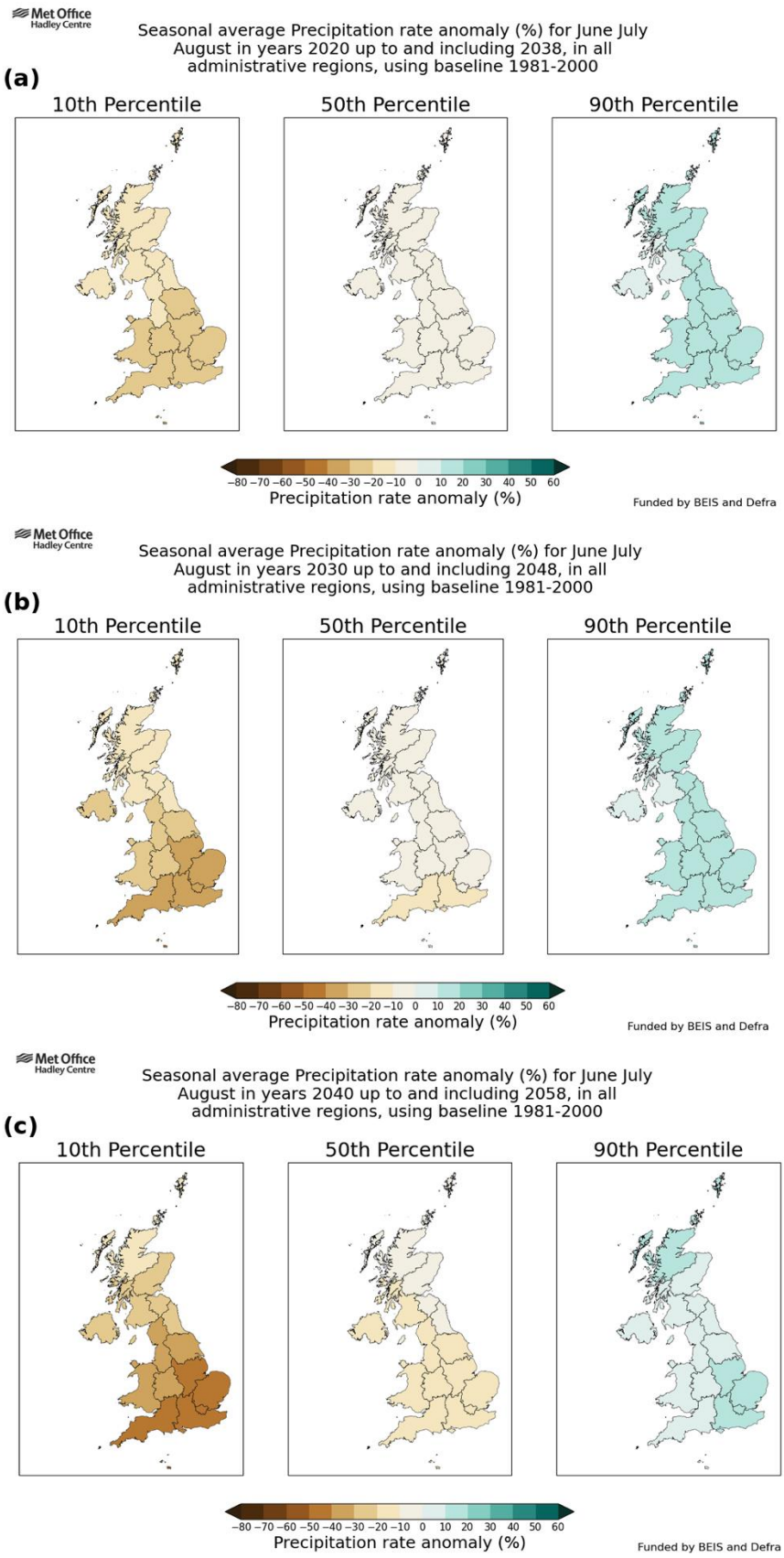


Fig 1. Summer precipitation change % using baseline 1981-2000 for years (a) 2020-2038; (b) 2030-2048; (c) 2040-2058 with 10th, 50th and 90th percentiles. Data is based on RCP8.5 emissions scenario for consistency with other high-emissions pathways used in hydrological modelling.

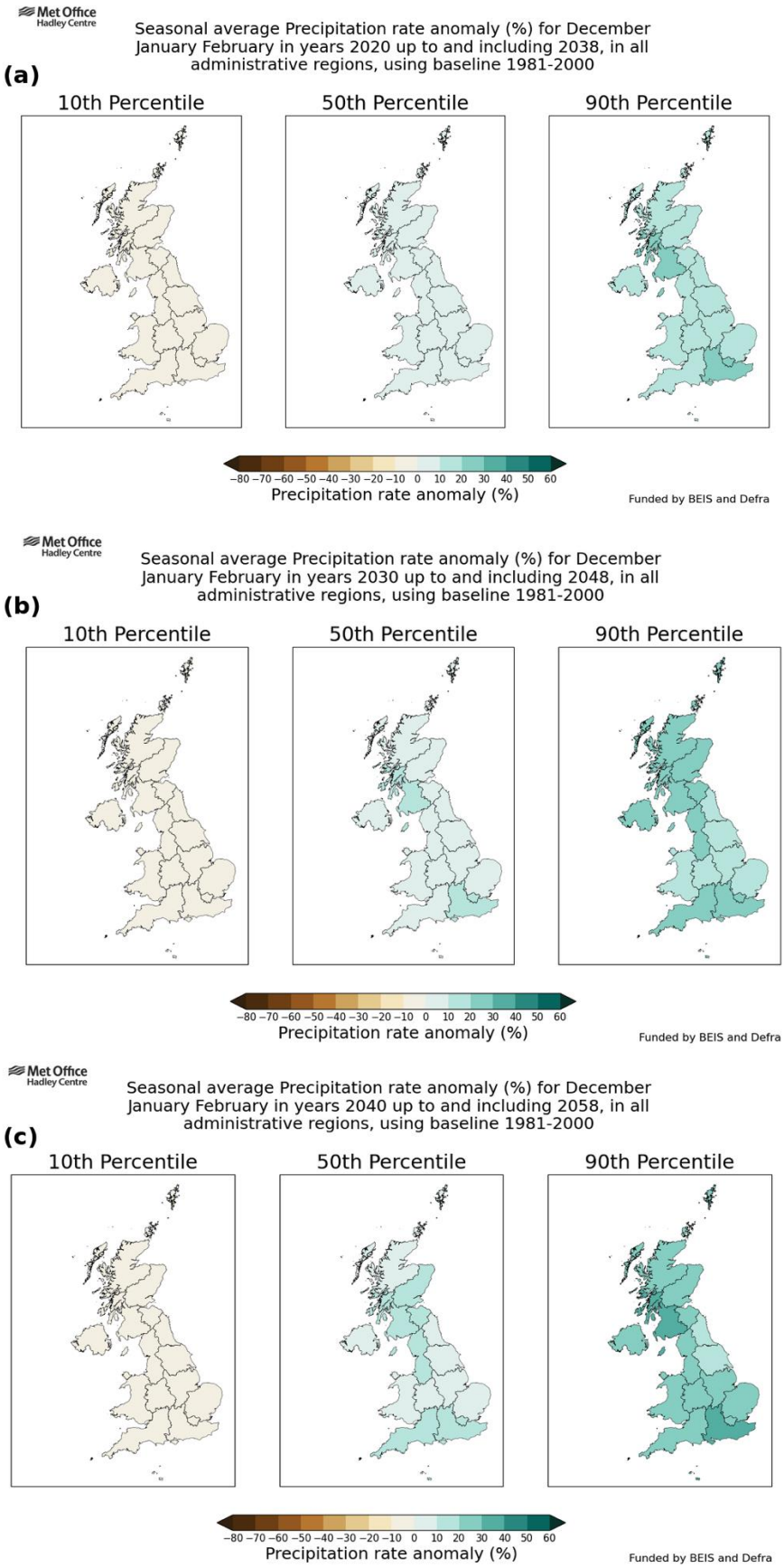


Fig 2. Winter precipitation change % using baseline 1981-2000 for years (a) 2020-2038; (b) 2030-2048; (c) 2040-2058 with 10th, 50th and 90th percentiles. Data is based on RCP8.5 emissions scenario for consistency with other high-emissions pathways used in hydrological modelling.

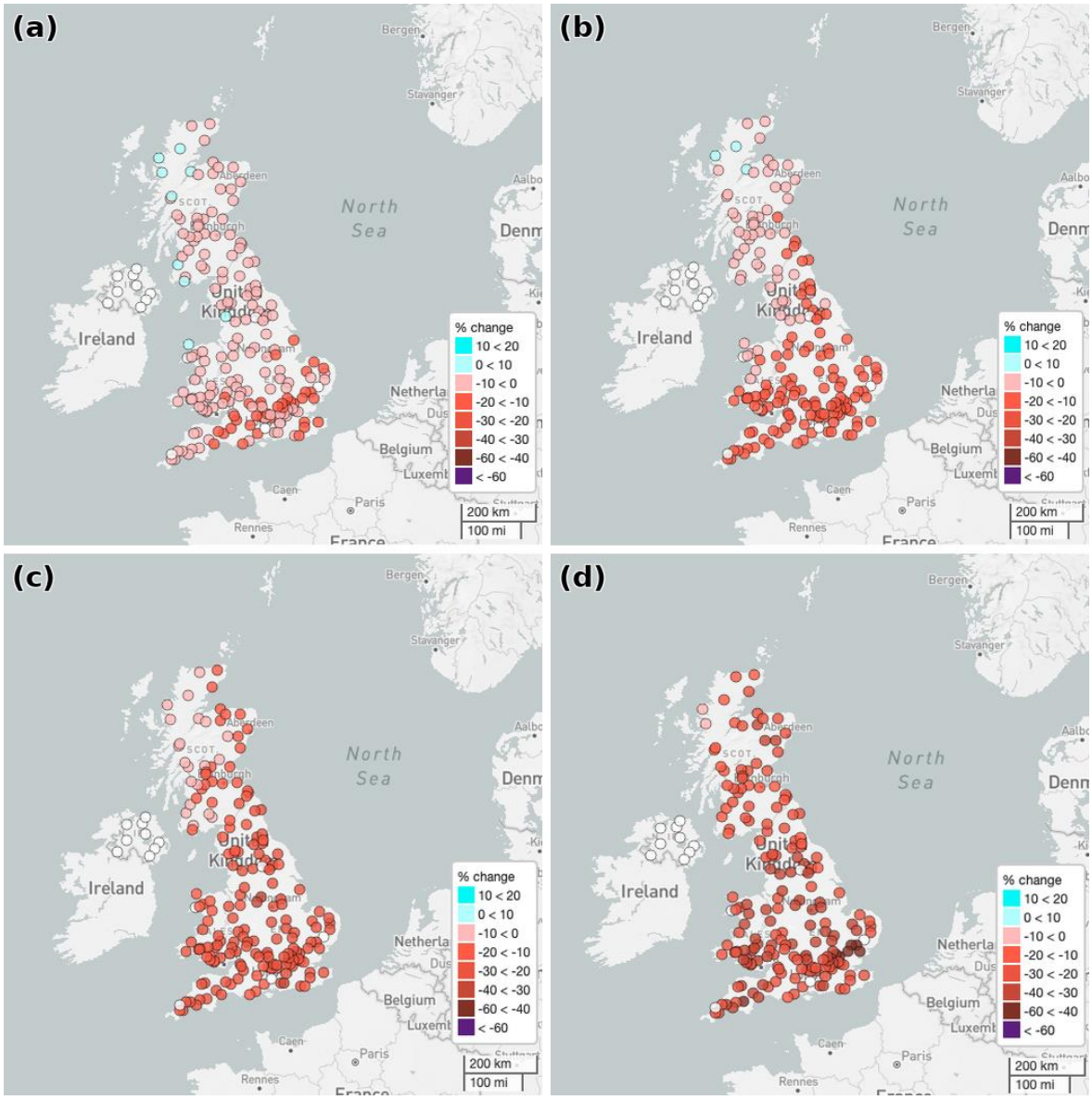


Fig 3. Projected changes in low river flows and groundwater levels across the UK under future climate conditions at (a) Q30 / L30 percentiles (eg. The flow in cubic metres per second or the level in m AOD which was equalled or exceeded for 30% of the record); (b) Q50 /L50; (c) Q70 / L70; (d) Q90 / L90, using the eFLaG hydrological projections. % change from Baseline (BL): 1989–2018 and Near Future (NF): 2020–2049.

4.3.2 Groundwater recharge

Many irrigation systems depend on groundwater supplies to maintain crop growth and quality during dry periods and transient low-flow conditions (Environment Agency, 2026). Compared with the historical baseline, projected groundwater recharge for 2020–2049 shows a shift in both the timing and distribution of recharge across the UK (Figures 4a–d). The largest reductions are projected in summer and autumn, while spring changes are generally small and mixed. Winter recharge increases in some western and northern upland catchments, reflecting wetter winters, but these gains are unlikely to offset the substantial summer and autumn declines across much of England and Wales.

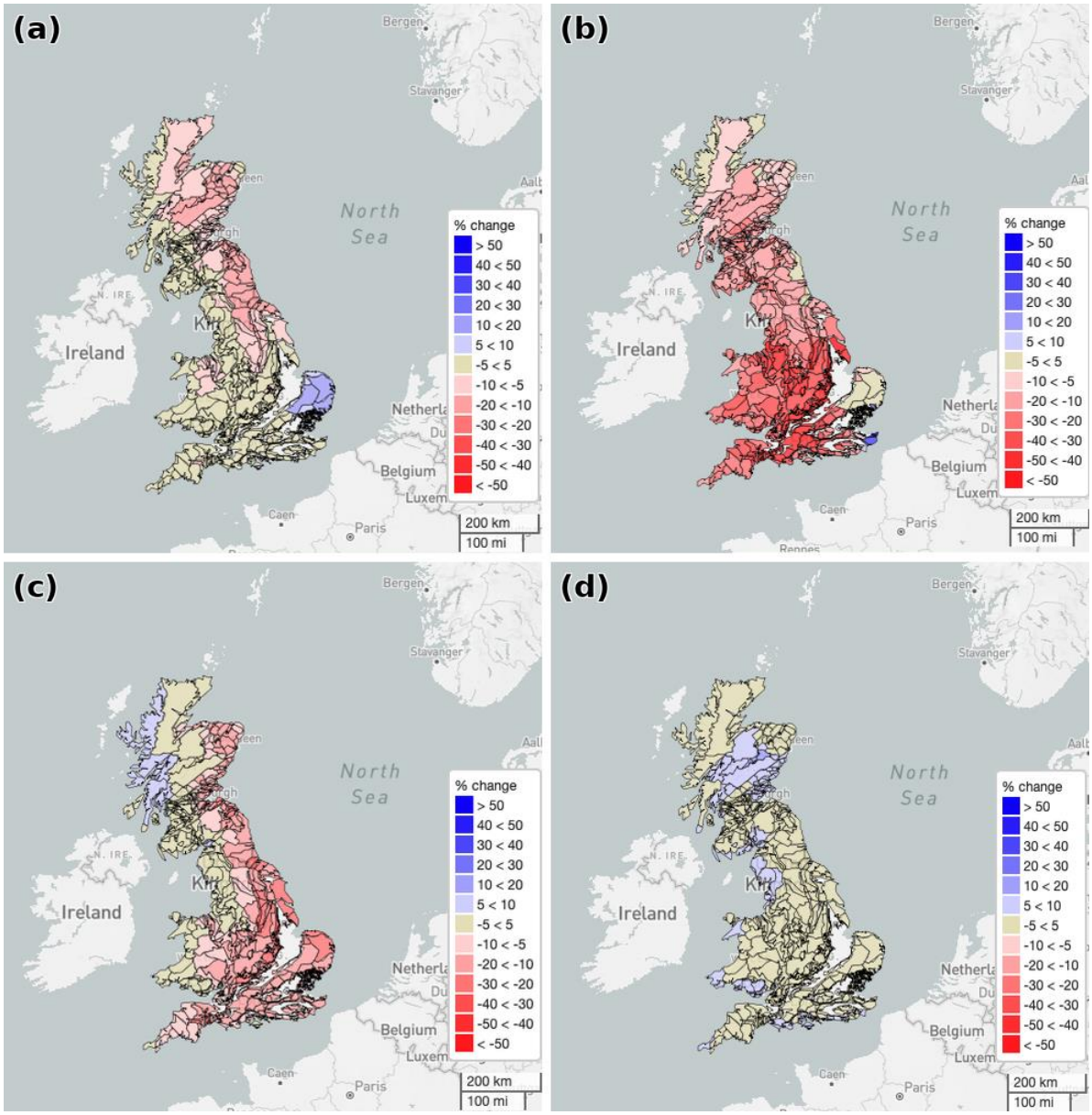


Fig 4. Projections of changes in groundwater recharge expressed in percentage changes for the 558 groundwater bodies in England, Scotland and Wales. Statistics are summarised as seasonal averages: (a) spring; (b) summer; (c) autumn; (d) winter, using the eFLaG hydrological projections (https://hydroprojections.ceh.ac.uk/eflag/groundwater-recharge). % change from Baseline (BL): 1989–2018 and Near Future (NF): 2020–2049.

Summer recharge declines are widespread across southern, eastern and central England, with many areas showing reductions of 20–50%, particularly in East Anglia, Lincolnshire, the South East and parts of the Midlands. Similar patterns continue into autumn, suggesting slower aquifer recovery after increasingly dry summers. Overall, the projections indicate a growing seasonal imbalance, with less recharge during the growing season and greater reliance on winter recharge. This is likely to increase groundwater drought risk and reduce the reliability of groundwater resources for agriculture, particularly in already water-stressed catchments. No data was available for Northern Ireland.

4.4 Water resource implications

Drought can reduce crop yields and quality, affecting farm incomes and, where food shortages occur, increasing food prices (Environment Agency, 2026; see also Section 7). The eFLaG hydrological projections indicate that drought risk is likely to increase across much of England and Wales during 2020–2049 compared with the baseline period. This is reflected in longer droughts, larger water deficits and greater overall water stress, although the extent of change varies across the country.

Projected drought duration (Figure 5a) increases most across southern and eastern England, particularly in East Anglia, the South East, the Midlands, Yorkshire and Lincolnshire. Maximum water deficits (Figure 5b) show a similar pattern, indicating that droughts are lasting longer and becoming more severe. Changes in cumulative water stress (Figure 5c) are more concentrated, with the largest increases in eastern and south-eastern England. In contrast, many northern and western upland catchments, particularly in Scotland, show smaller changes or even reductions, reflecting greater water availability and resilience.

Overall, the projections suggest that southern and eastern England will face the greatest increase in drought risk by mid-century. Longer, more severe droughts are likely to reduce summer water availability, place greater pressure on rivers and groundwater, and increase the risk of water shortages for irrigation in the UK's main fresh produce growing areas.

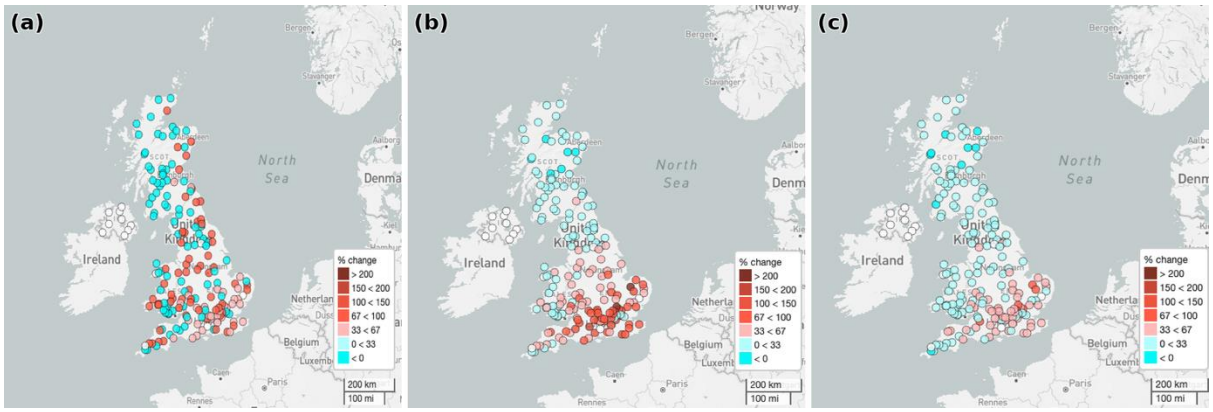


Fig 5. Drought event characteristics as % change from Baseline (BL): 1989–2018 and Near Future (NF): 2020–2049 for (a) duration; (b) maximum deficit; (c) total deficit. Data is based on the G2G model (Grid to Grid), developed by UKCEH which is useful for broad spatial interpretation.

4.5 Summary

Climate and hydrological projections consistently indicate increasing seasonal water stress across much of southern and eastern England by mid-century, characterised by drier summers, declining low flows, reduced warm-season groundwater recharge and more persistent hydrological droughts. Table 1 summarises the key projections and outlook for the main fresh produce growing regions in the UK based on the data above, combined with National Framework for Water Resources (Environment Agency, 2025) and the UK Climate Change Risk Assessment evidence (CCRA4, 2026). These changes are expected to reduce the reliability of summer water availability for irrigated horticulture, particularly in catchments already experiencing abstraction pressure and environmental flow constraints. The likely most extreme changes will be seen in the South East and East Anglia, corresponding to Environment Agency classifications of ‘serious water stress’.

Table 1. Summary of key projections and outlook for main fresh produce growing regions of the UK

Region	Key fresh produce profile	UKCP18 rainfall projection to 2050	Drought stress projection	Seasonal water availability outlook	Catchment-level pressure outlook	Overall agricultural risk implication
East Anglia	Leafy salads, brassicas, carrots, onions, potatoes, outdoor vegetables	Strongest projected summer drying in UK; modest winter wetting	Very high; substantial increases in drought duration, low flows and groundwater deficits	Markedly reduced summer water reliability; greater dependence on winter storage	Extremely high abstraction and environmental flow pressure	Very high risk. Irrigation reliability likely to become a major production constraint without expanded storage and water-sharing infrastructure
Kent / South East	Top fruit, salads, brassicas, soft fruit, protected crops	Strong summer drying signal; limited winter recharge gains	Very high; severe increases in drought duration and deficits	Significant decline in dependable summer water availability	Extremely high catchment and abstraction pressure	Very high risk. Existing water stress likely to intensify substantially, increasing vulnerability of irrigated horticulture
Lincolnshire	Brassicas, root vegetables, salads, potatoes, field vegetables	Significant summer drying; some winter recharge increase	High to very high; persistent low-flow and groundwater stress	Increasing seasonal imbalance with summer deficits intensifying	High pressure in fenland and chalk-fed catchments	High risk. Seasonal water shortages and abstraction constraints likely to increasingly affect production reliability
Yorkshire & the Humber	Brassicas, salads, carrots, root crops, outdoor vegetables	Moderate-to-strong summer drying in eastern areas; wetter winters possible	Moderate to high, especially eastern catchments	Declining summer low flows and recharge in eastern catchments	Increasing pressure in eastern lowland catchments	Moderate-high risk. Eastern horticultural areas likely to face increasing irrigation and abstraction pressure
West Midlands	Brassicas, field vegetables, protected horticulture, salads	Moderate summer drying; mixed winter increases	Moderate; drought persistence increases but less severe than east/south-east	Reduced summer availability but less acute than eastern England	Moderate catchment pressure with some local stress hotspots	Moderate risk. Water stress likely to become more operationally significant during prolonged dry summers
Cornwall / South West	Brassicas, cauliflowers, salads, potatoes, horticultural field crops	Moderate summer drying; wetter winters	Moderate	Increasing summer deficits but buffered by maritime climate	Catchment pressures variable but generally lower than east/south-east	Moderate risk. Water stress likely to increase episodically, particularly during prolonged drought years
Lancashire	Protected horticulture, salads, brassicas, potatoes	Smaller summer drying signal; wetter winters more pronounced	Low to moderate	Generally more resilient water availability profile	Lower abstraction pressure overall	Lower relative risk. Water availability pressures likely manageable compared with eastern England, though drought frequency may still increase
Pembrokeshire	Potatoes, brassicas, field vegetables	Limited summer drying; stronger winter wetting	Low to moderate	Comparatively resilient seasonal water balance	Relatively low catchment stress	Lower risk. Climate impacts likely less severe than eastern and south-eastern England
Scotland (Tay & Dee Valleys)	Soft fruit, brassicas, potatoes, field vegetables	Smaller summer drying signal; stronger winter wetting	Low to moderate, with some local increases	Generally more favourable water availability outlook	Lower abstraction pressure and greater hydrological resilience	Relatively lower risk. Water availability likely to remain more reliable than major English horticultural regions, though local drought sensitivity may still increase

Source: Based on data from UKCP18, eFLaG (Hannaford et al., 2023), National Framework for Water Resources (Environment Agency, 2025), UK Climate Change Risk Assessment (CCRA4, 2026)

5 Water requirements for fresh produce crops

Snapshot

- UK fresh produce crops exhibit large differences in water dependency, with salads, celery and brassicas presenting the greatest sensitivity to restricted water supply.
- Critical growth stages, rather than full season demand, represent the greatest production risk under limited water availability.

5.1 Purpose and scope

This section provides a synthesis of crop water requirements for key UK fresh produce crops, focusing on relative demand, critical response periods and sensitivity to water availability. The intention is not to prescribe irrigation practice, but to establish a crop-level reference point for understanding water dependency across the fresh produce sector.

5.1.1 Evidence base and approach

The primary evidence source for this task is Defra/ADAS *Irrigation Best Practice: Water Management for Field Vegetable Crops*, most recently updated in February 2012 (ADAS, 2012). This remains the most detailed UK-specific source of crop level irrigation response data.

While published guidance on irrigation scheduling and legislation has moved on since 2012, the underlying crop physiological relationships and soil water principles have not changed (ADAS, n.d.). As such, the guide provides a robust foundation for relative crop comparisons.

5.2 Indicative crop water requirements and sensitivity

Across UK field-grown fresh produce crops, water demand is highly variable and strongly influenced by crop type and canopy structure, rooting depth, soil water holding capacity and timing of water stress relative to key growth stages (AHDB, 2026).

Table 2 summarises water requirements for priority crop groups, drawing from ADAS irrigation response data and cross-referenced with recent publications (ADAS, 2012; AHDB, 2026; UKIA, 2020). Values should be interpreted as indicative requirements under UK field conditions, rather than precise prescriptions.

5.3 Soil type and water availability sensitivity

Soil water holding capacity strongly moderates crop water requirements (AHDB, 2026). Light, sandy soils hold limited available water and require more frequent, precise irrigation to maintain crop performance. Heavier soils provide greater buffering capacity but still exhibit yield and quality penalties when critical soil moisture deficits are exceeded during response periods. For most crops, critical soil moisture deficits occur when 35–55% of available water within the rooting zone is depleted. Avoiding depletion beyond this point during response periods is central to maintaining yield and quality.

Table 2. Approximate water requirements and sensitivity of key UK fresh produce crops

Crop group	Approximate seasonal irrigation requirement	Key crop response period(s)	Sensitivity to water stress	Primary risk if water limited
Celery and related crops (including celeriac and fennel)	~180–200 mm	Throughout crop life	Very high	Severe loss of quality, reduced succulence and marketability
Leafy salads (including lettuce, rocket, cress, spinach, spring greens, mixed leaves and outdoor herbs)	~120–150 mm (higher under intensive, multiple cut systems)	Entire growing period, particularly establishment and rapid leaf expansion	High	Yield loss, poor leaf quality, disease risk from uneven wetting
Potatoes (tuber crops)	~150–200 mm*	Tuber initiation and bulking	High	Significant yield reduction, quality loss
Soft fruit (including strawberry and raspberry)	~150–200 mm*	Flowering and fruit development	High	Reduced fruit size, quality and yield
Brassicas (including cabbage, broccoli, cauliflower, kale, sprouts, swede and turnip)	~120–150 mm	Curd or button initiation and development	Moderate–high	Reduced head size, uneven development, yield variability
Carrots (representative of deeper rooting root crops)	~120–150 mm	Establishment and mid-season root expansion	Moderate	Increased splitting, scab risk, quality downgrades
Alliums (including onions and leeks)	~100–130 mm	Bulb initiation to swelling	Moderate	Poor bulb sizing, delayed maturity
Cucurbits (including courgette, marrow, pumpkin and squash)	~120–150 mm	Flowering and fruit set	Moderate	Reduced fruit set, misshapen produce
Sweetcorn (maize crops)	~120–150 mm	Tasselling and cob fill	Moderate	Poor cob development
Legumes (beans and peas)	~100–140 mm*	Flowering and pod fill	Moderate	Reduced pod set and yield
Beetroot, parsnips and radish (moderate demand root crops)	~100–140 mm	Early growth and root swelling	Low–moderate	Reduced size, surface defects
Perennial vegetables (including asparagus, rhubarb and artichoke)	~80–120 mm*	Early growth and shoot/bud development	Low–moderate	Reduced seasonal yield

Source: Adapted from Defra/ADAS Irrigation Best Practice Guide (2012) with additional crop group expansion.

5.4 Limitations of legacy guidance and interpretation

While the ADAS irrigation guide remains an essential reference, it is important to note that it reflects historic climate and water availability conditions and does not explicitly account for recent increases in weather volatility or abstraction constraints, which are addressed elsewhere in this report. The figures presented here should be interpreted as baseline crop water needs.

6 Evidence for the effects of water stress on fresh produce crops

Snapshot

- Published UK field study evidence is extremely limited, necessitating review of European studies.
- Evidence is concentrated in a small number of crops, e.g. peas, beans, chicory, lettuce and some herbs. Limited or no evidence for other crops including beetroot, leek and most cucurbits.
- Water stress is predominantly negative for crops, especially salinity stress. Limited evidence was found for the effects of waterlogging.
- Nutritional content can sometimes be positively affected by water stress, but this may be at the expense of yields.
- Some crops are almost entirely negatively affected by water stress (e.g. celery, artichoke and asparagus) whereas others show a more mixed picture and are potentially lower risk (e.g. strawberry, chicory and carrot).

6.1 Purpose and scope

A targeted review of selected fresh produce crops was undertaken to determine how water availability affects specific crops. The intention was to establish whether certain crops or production systems may become increasingly difficult to sustain in particular regions under future conditions.

6.1.1 Evidence base and approach

A hierarchical approach to evidence gathering was used to identify crop specific studies and on farm impacts of water stress (see Section 7):

- First, existing meta-analyses and systematic reviews were identified and reviewed manually.
- Second, primary studies identified through search and screening were fed into AI software to extract key information including study design, crop, type of water stress, outcome assessed and direction of effect. Studies were given a quality ranking based on a simplified study design appraisal.
- Third, a random sample of 20% of studies were manually reviewed to validate the use of AI data extraction.

This structured, staged approach reduced risk of bias and enabled determination of broad patterns and evidence gaps in the project timeframe. Field experiments were prioritised, however, given the lack of data for some crops, a sample of controlled environment studies were also synthesised. Grey literature in the UK was searched for additional primary data but yielded no results.

This is not a systematic evidence review and results are only intended to provide a picture of broad patterns, rather than reflect all available evidence. Evidence was gathered from Europe

only and excludes studies on potential mitigations against water stress. Full methods are detailed in Appendix 1.

6.2 Geographical distribution of evidence

Published UK field study evidence is extremely limited. The review therefore draws on European field studies and a limited sample of controlled environment experiments. This resulted in 65 studies drawn from 53 articles, providing 342 data points. Studies from Italy provide 43% of data points, studies from Spain 20% and Germany 9%. There is less data from other European countries, and only 10 data points from the UK (Figure 6). The evidence is weighted towards mediterranean climates and therefore not directly comparable to the UK. However, according to hydrological projections, conditions within the UK may increasingly resemble warmer environments. The review of this evidence is therefore valid as it enables learnings, despite the different climatic zones.

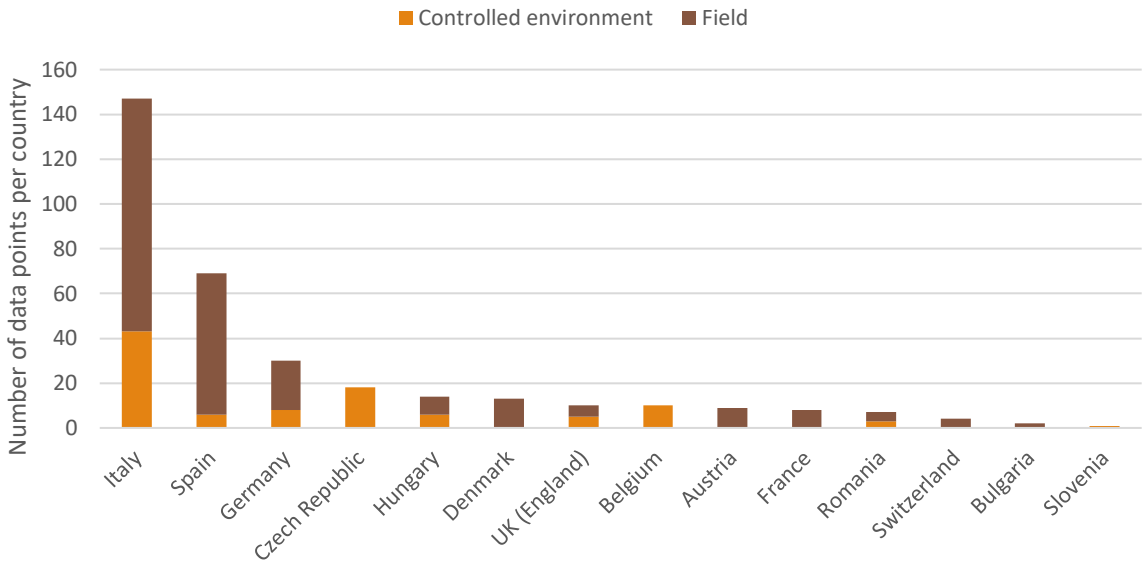


Fig. 6. Number of data points per country from a review of European field studies and a sample of controlled environment experiments.

6.3 Evidence for fresh produce crops

The highest number of data points is for legumes, with an equal split between beans and peas. This is followed by culinary herbs, leafy vegetables, brassicas and root vegetables. Less evidence is available for berry crops and perennial vegetables with very limited evidence for cucurbits (Figure 7). Most crop groups are dominated with data for two or three crops. For example, sage and rosemary are by far the most investigated culinary herbs, chicory and lettuce account for the majority of data points for leafy vegetables and brassicas are dominated by broccoli, cauliflower and cabbage. A high volume of field-based evidence for some crops exists, including pea, strawberry, carrot, celery and cabbage and no evidence for others, including leek, pumpkin, beetroot and baby leaf (Table A5). Most studies on, for example, lettuce are carried out under controlled conditions due to complexities of creating experimental drought conditions in the field. Studies on potato and onion are numerous. For this reason, data for these two crops is derived from existing meta-analyses.

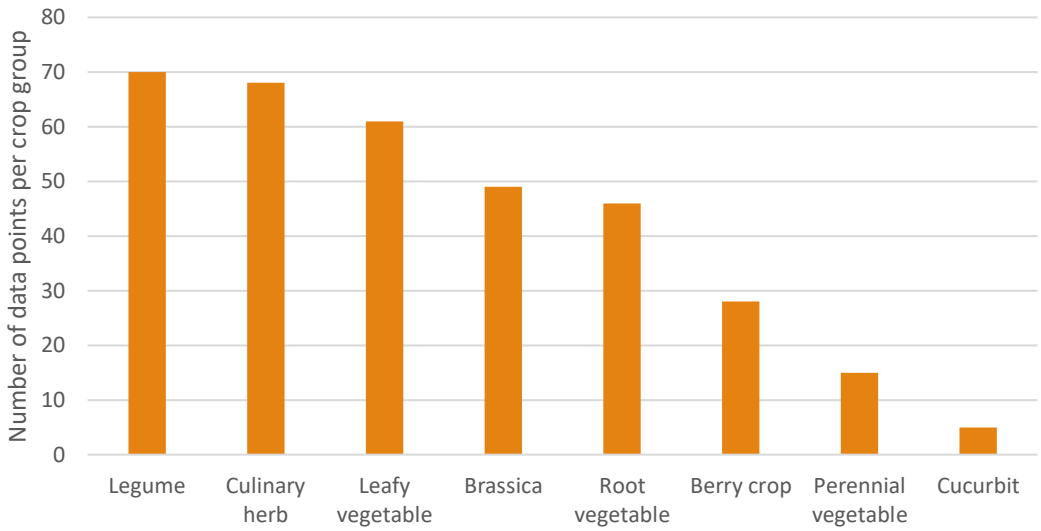


Fig. 7. Number of data points per crop group from a review of European field studies and a sample of controlled environment experiments (excludes potato and onion).

6.4 Quality appraisal of evidence base

A simple quality appraisal rating was applied to each study (see Appendix 1: Methods). All data from root vegetables and brassica crops were from high quality studies, as were most studies on leafy vegetables, excluding chicory. Within other crop groups, there was some variation, with most of this seen in culinary herbs. Studies on sage and rosemary included the only low quality studies based on study design criteria, however overall, the quality of studies was high (Table A5). Potato and onion data was retrieved from meta-analyses and not subject to quality appraisal. Details of the number of studies/data points relating to these crops are highlighted in the text where relevant.

6.5 Types of water stress investigated in scientific research

Drought was the most frequently investigated type of water stress (71% of data points), followed by salinity (25% of data points). Waterlogging, high temperature and combined drought with high temperature have very limited data (Figure 8). In addition to these figures, all investigations of onion and potato were carried out under drought conditions.

6.6 Range of outcomes investigated in scientific studies

Physiological responses are the most investigated outcome, although many of these do not have an agronomic effect. Removing studies where the effect is unlikely to affect the crop yield, quality, etc. shows that nutritional content is the most investigated (64 data points). Quality and yield are both frequently researched (53 and 51 data points respectively). Disease incidence and establishment are the subject of few studies. Yield and water productivity were investigated in meta-analyses on both potato and onion.

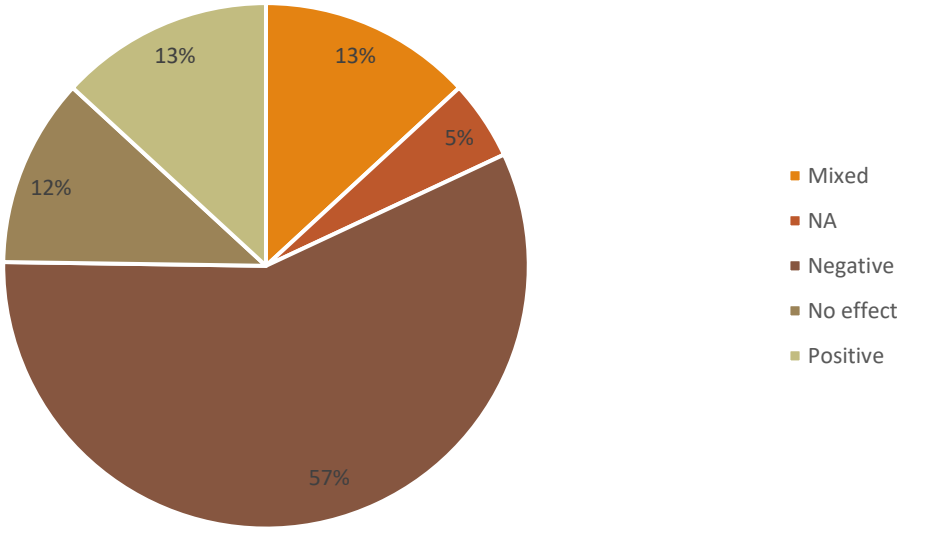


Fig. 8. Percentage of data points by type of water stress investigated in studies (excluding potato and onion)

6.7 Overview of agronomic effects of water stress

The findings below are only intended to provide an indication of broad patterns, as studies have only been subject to a simple quality appraisal. Additionally, the evidence base contains a sample of controlled environment experiments but not all available evidence is represented.

Salinity stress produces the most consistently negative results: 70% of outcomes are negative, with very few positive responses (11%). Drought is harmful but slightly more variable (57% negative, 13% mixed, 12% no effect, 13% positive). Waterlogging has very little evidence (n=5), with results split between negative and mixed.

Excluding potato and onion, 57% of data points show a negative effect of water stress, with a relatively even split of positive (13%), mixed (14%) and no effect (11%). The remaining 5% of studies analysed relationships and therefore no direction of effect was recorded. This pattern in data is largely consistent when restricted to field studies. Further details of agronomic effects are provided in Section 7.

6.8 Crop group and crop level patterns of water stress responses

Some crops are almost exclusively negatively affected by water stress, e.g. celery, rocket, artichoke, whereas other crops have more mixed results, e.g. strawberry, carrot, chicory. Figure 9 shows the percentage of data points associated with a direction of effect by crop group, and the below evidence provides examples of how some crops are affected by water stress.

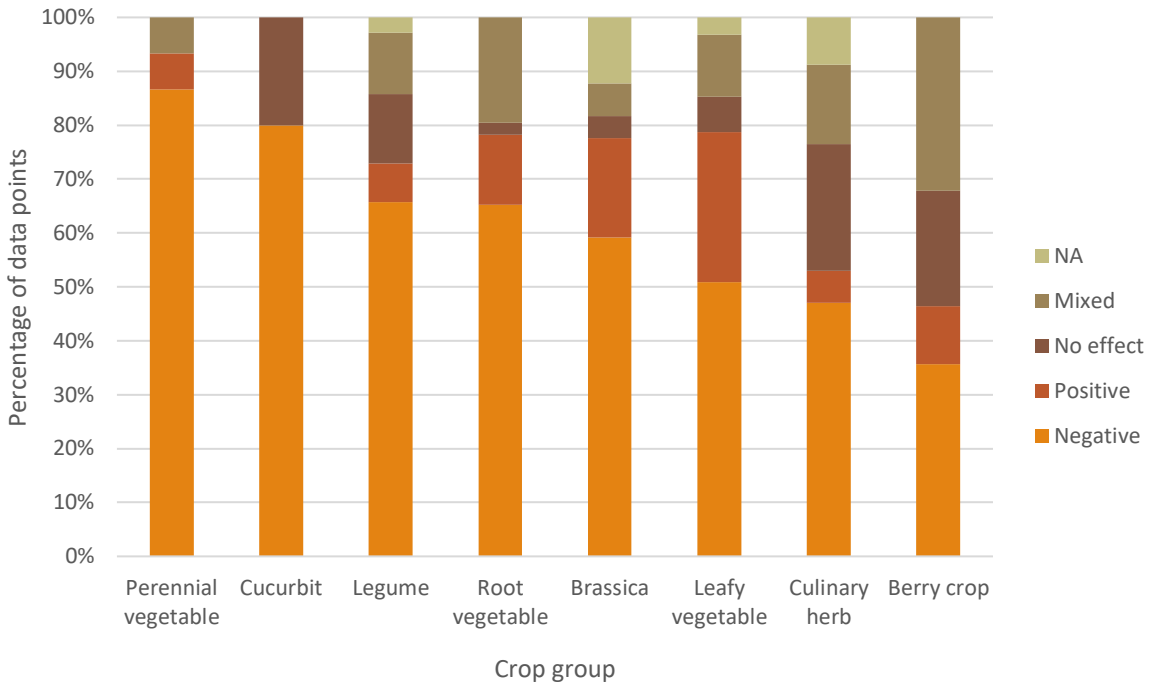


Fig. 9. Percentage of data points associated with a direction of effect by crop group (excludes potato and onion). Note that direction of effect is for all agronomic outcomes including yield, biomass, quality, crop growth, nutritional content, physiological response, disease incidence and establishment. Perennial vegetables and cucurbits are based on relatively low numbers of studies and therefore confidence is lower. Results should be interpreted with caution.

6.8.1 Legumes

The evidence suggests that legumes (bean and pea) were often negatively affected by drought, though the timing of drought within the season mattered. A field study in France found pea seed yield fell by approximately 38% in the driest year (3.89 vs 6.26 t/ha), with cold-test seedling vigour almost halving (32% vs 63% normal seedlings). Irrigating only during seed filling, not during flowering, largely restored seed weight which suggests that late season water availability is disproportionately important for seed quality. No effect on seed germination was found in any year of the study (Fougereux et al., 1997). A controlled environment study revealed that drought significantly reduced total plant dry mass in bean across both cultivars tested (Boutraa & Sanders, 2001) and deficit irrigation reduced bean canopy development by around 50% (Alomari-Mheidat et al., 2023). A field study across 46 common bean landraces in Italy found drought reduced average grain yield by 33% and seed number by 22%, though six drought-tolerant landraces showed negligible yield loss. This underlines the scope for genotype selection to manage risk (Preiti et al., 2026). Drought reduced pea stand density, particularly on sandy soils with poor moisture retention during germination (Tataw et al., 2014) and increasing salinity progressively reduced bean plant survival, falling to 0% at the two highest salinity levels tested (Mori, 2011).

6.8.2 Culinary herbs

Culinary herbs (mint, oregano, rosemary, sage and thyme) were the most drought-tolerant family, with only around half of agronomically relevant outcomes negative. Field studies carried out in Spain on culinary herbs including thyme, mint and sage showed no effect on dry weight under drought conditions, but variable effects on fresh weight. Mint suffered a 27% reduction in fresh weight, sage showed no significant effect under different drought scenarios and thyme

was affected by cultivar, with a 31% reduction in fresh weight for one and no effect for another (García-Caparrós et al., 2019). Similarly, in another study, herbage yield of oregano reduced by 17–30% depending on year (Azizi et al., 2009). However, essential oil traits sometimes improved under stress: drought increased essential oil yield by 30% in one rosemary cultivar at one site, alongside shifts in aromatic compound composition (Formica et al., 2024). A study on mature rosemary shrubs in Spain recorded a steep decline in physiological response as net CO2 assimilation fell by around 75% during summer drought before recovering fully after autumn rainfall. This suggests that established, drought-tolerant culinary herbs can also be affected under sustained water deficit (Munné-Bosch et al., 1999).

6.8.3 Leafy vegetables

Leafy vegetables (lettuce, rocket, chard, chicory and spinach) showed the widest crop-to-crop variation of any family. Rocket and chard were largely negative affected. In one study, salinity reduced rocket marketable yield by 70–79% depending on cultivar (Schiattone et al., 2017). A high quality field trial in Italy found aboveground dry mass of chard fell progressively from as early as 10 days after transplanting, reaching around 46% of the control biomass by 37 days under rainfed conditions (Delfine et al., 2003). In chicory, nutritional content tended to increase, whereas yield, quality, biomass and growth were all negatively affected with one study showing a yield reduction of 30–52% (Delfine et al., 2022; Vandoorne et al., 2012). Limited evidence was available for spinach but results were largely positive. A high quality field study in Germany found that just a 10% reduction in water supply significantly increased ascorbic acid, carotenoid and flavonoid content in spinach, indicating that even small water deficits can raise the nutritional density of some leafy produce (Schlering et al., 2020). Mixed results for lettuce showed that marketable yield decreased linearly with increasing soil salinity in field and controlled environment experiments (Di Mola et al., 2013; De Pascale & Barbieri 1995) whereas drought had a positive effect on phenolic and amino acid content under drought conditions (Ćavar Zeljković et al., 2023). The authors also found that effects on sugar content in lettuce was cultivar dependent in a controlled environment experiment (Ćavar Zeljković et al., 2023).

6.8.4 Brassicas

Data shows that brassicas (broccoli, cauliflower, cabbage and kale) were severely affected by drought in both yield and growth. Yield was reduced by 65% in cabbage (Maggio et al., 2005) (see also Ben Ammar et al., 2023), however data is derived from single studies. Salinity responses were more nuanced: in one study, salinity reduced cauliflower/broccoli marketable yield and head weight by 58–69% (De Pascale et al., 2005). However, a high quality field study on seven broccoli cultivars in Spain found that 80 mM salinity left inflorescence yield unaffected in most cultivars, with significant reductions in only two of seven and yield increases in two others, while leaf and inflorescence glucosinolate content rose in most cultivars regardless of the yield response (Rios et al., 2020). Ben Ammar et al. (2023) found that drought reduced cauliflower plant weight by up to 73% in most accessions tested but slightly increased it in one. While the overall direction of effect on growth is clear, exceptions can still occur at the genotype level, and there may be some trade-offs with nutritional content. For example, drought raised leaf and root glucosinolate content in broccoli, cauliflower and kale, in some cases several-fold, consistent with a stress-induced defensive response (Ben Ammar et al., 2023). However, we caution interpretation of results due to the limited spread of studies.

6.8.5 Root vegetables

Root vegetables (potato, carrot, celery and radish) were most negatively affected. Drought and salinity reduced celery shoot dry weight, with drought causing the larger loss (64% vs up to 38% under the most severe salinity treatment) (De Pascale et al., 2003). In carrots, drought

increased forked or split carrot roots, particularly after late-season drought followed by rain (Sørensen, 1999), while radish showed both quality gains (higher dry matter and ascorbic acid) and losses (lower glucosinolate and phenol content) under drought (Schlering et al., 2019).

In pooled global studies, potatoes largely show negative yields under drought conditions, but improved water use efficiency (Yu et al., 2020; Daryanto et al., 2016). UK potato studies (all high rated) indicate that growth, quality and some physiological responses that affect dry matter are also negatively affected, for example stomatal conductance was significantly lower in a UK field study on potato, albeit with some variations between cultivars (Jefferies & Mackerron, 1997) (see also Hunterburg et al., 2021; Papathanasiou et al., 1999). Yield reductions in tuber crops (potato and beetroot) were affected by the stage in plant growth cycle, with the greatest yield reductions observed during tubernisation and lower reductions during the vegetative phase, according to a global meta-analysis (Yu et al., 2020). Another meta-analysis found that the degree of yield reduction in multiple root crops (including potato) was influenced by soil texture (Daryanto et al., 2016).

6.8.6 Berry crops

Evidence for berry crops was dominated by strawberry as data retrieved for raspberry were unrelated to agronomic outcomes. Total yield reduced by 13–19% depending on cultivar under a 40% water reduction (Marcellini et al., 2022), and marketable fruit yield also declined in most cultivars under deficit irrigation (Ariza et al., 2021). However, quality traits, such as titratable acidity, were more often unaffected or cultivar-dependent and some cultivars tolerated a 20% water reduction without yield loss (Marcellini et al. 2022). This highlights the importance of the duration and depth of drought conditions.

6.8.7 Perennial vegetables

Perennial vegetables (artichoke and asparagus) showed the most consistently negative responses of any family, with around 85% of agronomically relevant outcomes negative. Salinity reduced artichoke marketable head yield by 48% (Cantore, 2004) and depleted potassium, magnesium and calcium in artichoke tissue, weakening ionic balance and directly contributing to head atrophy (Boari et al., 2011). Deficit irrigation significantly reduced asparagus marketable spear yield (Campi et al., 2019) and drought reduced net CO2 assimilation in asparagus, limiting the carbon reserves stored in the root crown that determine the following season's spear yield (Schaller & Paschold, 2009).

6.8.8 Alliums

Singh et al's. (2021) global meta-analysis found onion bulb yield fell at every level of deficit irrigation tested. An 8–26% drop was recorded with up to 50% less water, worsening sharply beyond that. At moderate deficit (50–65% of full irrigation), however, onion produced significantly more yield per litre of water applied (+11%), even as total yield remained approximately 26% lower. This suggests water saving potential in that range before losses become severe. A field study in Denmark found that drought delayed the onset of sprouting in stored onion bulbs, which may be one advantage, although yield was significantly lower (Sorensen & Grevsen, 2001). No data was retrieved for other allium crops.

6.8.9 Cucurbits

Cucurbit evidence in the matrix is limited to a single field study on courgette, and no recent evidence. No other cucurbit crop (marrow, pumpkin or squash) was represented, and drawing overall conclusions for this crop family is not advised. The courgette study found that drought

reduced fruit protein content by around 65% and RNA content by around 72% alongside a 21% fall in fruit osmotic pressure. This indicates that reduced fruit growth was accompanied by impaired solute transport and protein synthesis rather than simple water loss from the fruit (Cocucci et al., 1976).

6.9 Influence of soil texture on crop responses to water stress

Soil texture class is not reported for 41% of observations, limiting analysis. Where data exist, negative outcomes dominate across all soil types. There is no clear pattern suggesting that heavier or lighter soils reliably buffer or worsen the effects of water stress). A meta-analysis on root tuber crops including potato, found that tuber yield in coarse soil (sand, loamy-sand and sandy-loam) experienced significantly greater drought-induced tuber yield loss than medium (e.g. silt-loam, clay-loam) or fine (e.g. clay, sandy-clay) (Daryanto et al., 2016). The data here are generally insufficient to draw conclusions about soil type as a modifier of water stress impact. although industry bodies suggest that lighter soils are more prone to drought stress (AHDB, 2019) and the effect of soil texture on available water capacity is widely recognised, where light or sandy soils generally have lower AWC than heavier soils with a clay content (AHDB, n.d.) (see Appendix 2). Soil health also plays a fundamental role in water retention and water availability however this information was not recorded to the level that would enable analysis.

6.10 Effect of crop growth stage on crop responses to water stress

Crop growth stage at the time of stress exposure was not analysed to assess effect, as growth stage descriptions varied too widely across studies. In most cases, growth stage could not be reliably separated from the overall study period or measurement timing to support meaningful comparison.

6.11 Summary

The literature review showed that evidence for the effects of water stress on fresh produce crops in Europe is concentrated in mediterranean climates. The scope of the evidence means that we are unable to assess how different crops respond to water stress in different parts of the UK. However, the generally high quality evidence from across Europe (and a sample of controlled environment experiments) does indicate that the effect of water stress on fresh produce crops is largely negative. Results vary depending on the crop, outcome investigated and sometimes depending on the accession or cultivar.

7 On-farm impact of water availability

Snapshot

- Water stress affects yield, quality, biomass, growth, nutritional content and disease susceptibility across fresh produce crops.
- Evidence suggests higher production risks, greater yield variability and potential questions on the future viability of some crops.
- Abstraction licensing carries operational risk and shapes farmer behaviour and water use.
- Infrastructure investment reduces risk but is costly with no guaranteed return.

- Catchment collaboration helps individual farms, but broader progress remains slow.
- Water-related input costs are a smaller, growing pressure on margins.

7.1 Purpose and scope

This final section synthesises the operational and economic impacts of water availability on farms. The purpose is to summarise the agronomic effect of water stress on crops and farmer livelihoods, and to consider how operational challenges, such as abstraction licensing and irrigation infrastructure, impact fresh produce growers.

7.1.1 Evidence base and approach

The first part of this section uses evidence drawn from the review of literature on specific fresh produce crops. Secondly, we reviewed scientific literature, industry and government reports to establish operational challenges and how these effect farmers. We specifically looked for information on abstraction licensing and irrigation infrastructure, and the literature is therefore not fully representative of all water-related challenges faced by farmers.

7.2 Effects of water stress on crops

7.2.1 Yield

Yield is captured through marketable and total output including marketable yield, head/heart/spear/bulb weight, tuber yield, seed yield and harvest index (Alomari-Mheidat et al., 2023; Ariza et al., 2021; Campi et al., 2019; Cucci et al., 2014). A fall in yield is an immediate, quantifiable loss of saleable produce, making it the outcome most closely tied to grower income. Yield is the most consistently negative outcome regardless of crop or stress type based on the literature review: 78% of yield observations were negative, with no positive outcomes recorded, and most studies are of high quality (82%).

7.2.2 Quality

Quality directly affects market acceptability and is assessed using indicators such as fruit/head firmness and size, dry matter and sugar/starch content, seed germination and vigour and post-harvest loss (Ariza et al., 2021; Azizi et al., 2009; Cantore, 2004; Cucci et al., 2014; De Pascale & Barbieri, 1995). These traits determine whether produce meets grade specifications, feeding directly into marketable proportion and price, regardless of whether total yield changes. Effects on crop quality shows the most uncertainty, with 35% of outcomes mixed, 33% negative, 17% no effect and 15% positive. Most studies on crop quality are of high quality (91%). The effect of cultivar seems to play an important role in the overall direction of effect on quality traits. These patterns are similar for field studies when controlled experiments are removed.

7.2.3 Biomass

Biomass reflects how much carbon the plant has accumulated overall. A reduction under stress signals impaired carbon capture, which typically constrains organ size and, in turn, yield potential. Metrics used in investigative studies include aboveground biomass, shoot dry weight and root fresh weight (Boutraa & Sanders, 2001; Cantore, 2004; De Pascale et al., 2005; De Pascale et al., 2003). Effects on biomass showed a predominantly negative pattern (78%

negative effects recorded), drawn from high and moderate quality studies. In field studies, slightly less research shows a negative effect on biomass (63%) with more studies showing no effect than when combined with controlled environment experiments (31%).

7.2.4 Crop growth

Growth outcomes are defined by development during the season, including plant height, leaf number and area, canopy cover and diameter and relative growth rate (Alomari-Mheidat et al., 2023; Cocucci et al., 1976; Ben Ammar et al., 2023). Slower or stunted growth can shorten the plant's productive canopy or root system and delay maturity. Growth measures were consistently suppressed by stress (82% negative outcomes based on 95% high quality studies). When considering only field studies, the reported effects are all negative.

7.2.5 Nutritional content

Nutritional content covers vitamins, minerals, antioxidants and other health-related compounds, including ascorbic acid, carotenoids, glucosinolates, flavonoids and mineral ions (Abreu & Munné-Bosch, 2008; De Pascale et al., 2003). These changes do not alter the quantity of saleable produce but do alter its nutritional value. An increase in beneficial compounds under mild stress is generally treated as a positive outcome even though it arises from the stress response. This is why the evidence here shows that outcomes are nearly evenly split between negative (38%) and positive (36%) effects across mostly high quality studies (71% high, 21% moderate, 8% low).

7.2.6 Physiological responses

Physiological responses, for example, stomatal conductance, photosynthesis rate or chlorophyll fluorescence, describe the mechanisms by which stress affects the plant (Abreu & Munné-Bosch 2008; Alomari-Mheidat et al. 2023; Ariza et al. 2021; Ben Ammar et al. 2023). Most physiological responses, such as leaf water potential or antioxidant enzyme activity are diagnostic and do not relate to a direct agronomic outcome. Physiological responses that have an agronomic effect are mixed but weighted towards negative (67%). Study quality is more mixed than other outcomes with 11% low and 24% moderate quality studies so results should be interpreted with more caution.

7.2.7 Disease incidence

Disease and disorder incidence captures physiological defects such as head/atrophic head incidence and root cracking or splitting (Boari et al., 2011; Cantore, 2004; Schmid et al.,2021; Sørensen, 1999). Any increase is detrimental as affected produce is typically downgraded or rejected. Limited data was included in the evidence review but studies showed a negative effect of drought, salinity and waterlogging from high and moderate quality studies.

7.2.8 Crop establishment

Establishment reflects early crop survival and stand density, measured through plant density and plant survival. Poor establishment under stress reduces the final plant population, capping achievable yield irrespective of how the surviving plants subsequently perform. Both studies reporting on this outcome found a negative effect (Mori et al., 2011; Tataw et al., 2014).

7.3 Abstraction licensing

For many growers, the ability to irrigate depends on a licence to abstract water. Irrigated agriculture is heavily concentrated in eastern England, which accounts for around 60% of the total irrigated area and 57% of irrigation water use nationally, much of it in catchments already classified as over-licensed or over-abstracted (Rey et al., 2017; Sutcliffe et al., 2023). In Scotland, water scarcity is a growing issue, also in the east of the country. In 2025, ten river catchments significant scarcity status, with some areas around 40% below average rainfall (SEPA, 2025).

Licensed volumes are calculated using a standardised design dry-year method developed for the Environment Agency in England and Wales (Weatherhead et al., 2002) and still in use today. Demand for irrigation water has grown steadily for decades and climate change is expected to widen the gap between demand and supply further, meaning potential increases in abstraction restrictions (Knox et al., 2010; Weatherhead & Knox, 1999).

Knox et al. (2000) quantified how much a restriction can matter financially, using the Anglian region as a case study. The total potential benefit of irrigation there in a design dry year was £144 million (£2,135 per hectare), whereas a full ban from April to October would have eliminated £139 million of that benefit. As a general guideline, every 10% reduction in abstraction costs farmers around 8% of their potential net income from irrigation (Morris et al., 1997). Salmoral et al. (2019) modelled this risk nationally and found that a drought severe enough to occur roughly one year in ten currently produces estimated on-farm losses of around £29 million (rising above £250 million in extreme years). They project that this figure could reach £226 million by the end of the century as restrictions become more frequent and severe.

In a survey of Anglian region growers, three-quarters had been subject to an abstraction restriction (Rey et al., 2017). In interviews with fruit and vegetable growers, Sutcliffe et al. (2023) found that some farmers managed abstraction licences strategically rather than simply complying with them. For example, growers reported irrigating crops that did not necessarily require water so that their full licensed abstraction appeared necessary during licence reviews. Others described locating new abstraction points where regulators would be less likely to refuse applications. These findings suggest that concerns about future licence restrictions can incentivise strategic water-use behaviours that may increase water use beyond agronomic need. Conversely, growers surveyed in another study described better engagement from the regulator in recent years, sharing information on river and aquifer levels ahead of each season (Rey et al., 2017). Winter abstraction licences, taken when river flows are high, are increasingly promoted and government commitments to speed up licensing for high-flow abstraction and support Water Abstractor Groups (WAGs) are intended to give farmers more confidence to invest (Defra, 2024; Environment Agency 2024).

7.4 Irrigation infrastructure

Where licensed abstraction is unreliable, farmers may turn to on-farm storage. However, this can be expensive and returns are not guaranteed. Reservoir construction alone can cost £1,000–£3,000 per 1,000m^3 before pipework, pumps and an electrical connection, which can add hundreds of thousands of pounds more (James, 2025). Furthermore, stored water is not necessarily cheaper than abstracting directly. Knox et al. (2000) put typical variable costs at £0.40–0.45 per m^3 for direct abstraction against £0.63 per m^3 for reservoir-stored water, on top of fixed irrigation costs of around £300–400 per hectare per year, although these figures may now be outdated.

Following the 2010-2012 drought, Rey et al. (2017) found that two thirds of growers interviewed had invested in winter storage reservoirs. One fifth had decided against investment due to the cost and uncertainty over how often it would be used. Weatherhead et al. (2015) note that many reservoirs built to capture high winter flows sat unfilled after the 2012 drought, suggesting that storage reduces but does not eliminate exposure to consecutive dry years.

Rey et al. (2016) estimated that supplemental irrigation generated approximately £665 million in net financial benefits across the major outdoor irrigated crops in England and Wales during a design dry year, with the largest benefits accruing to soft fruit, potatoes and field vegetables. For individual growers, the gap between planned and actual water use in a dry year can be stark. A Cambridgeshire potato grower reported that during the exceptionally dry 2025 season some potato crops required 70% more irrigation water than budgeted to achieve expected yields (Searle, 2025).

7.5 Input costs

Evidence on the direct cost implications of water scarcity is comparatively limited, but what exists points to substantial additional costs on top of the capital costs discussed above. In a normal year, the fixed costs of running an irrigation system, including equipment, labour and standing charges, run to around £300–400 per hectare before the cost of the water itself (Knox et al., 2000). In dry years, this cost may rise sharply and cannot always be recovered through the price paid for the crop, as growers apply more water more often to hold yields at a normal level (Searle, 2025). Variable irrigation costs include labour, fuel, machinery, repairs and water charges and represent a significant production input that must be offset by gains in crop yield and quality (Rey et al., 2016). For businesses already managing tight margins, this combination of higher water-related costs and uncertain returns adds financial risk in addition to the direct effects of water stress on the crop itself.

7.6 Catchment management and collaboration

Because abstraction pressures are rarely confined to a single farm, growers in water-stressed catchments increasingly manage water collectively through WAGs. Holman and Trawick (2011) found that the proportion of England's irrigated area covered by a WAG grew from 52% in 2001 to 60% by the late 2000s. They argue that this growth reflected farmers' efforts to strengthen collective representation in abstraction licensing and water management, with some WAGs emerging in catchments where proposed abstraction licence reductions were as high as 70%.

The operational case for collaboration is significant. Modelling of the River Lark catchment, where roughly 60% of England's irrigated area is concentrated, found that without water sharing, nine farm businesses faced a combined irrigation deficit of around 1 million m^3 in a design dry year. Sharing water within smaller tributary groups reduced this deficit to 47,000 m^3, and sharing at sub-catchment or catchment scale reduced the risk of a serious annual shortfall to 10% or less (Chengot et al., 2021). Beyond water security, catchment-scale working brings wider benefits, including better relationships with neighbouring landowners and co-benefits for flood risk and biodiversity (Environment Agency, 2025).

The UK Government's 2017 Water Abstraction Plan aimed to increase the proportion of sustainably abstracted surface water bodies from 82% to 90% and groundwater bodies from 72% to 77% by 2021 (Defra, 2017). Survey evidence suggests that only around one in ten Catchment Based Approach partnership coordinators considered the wider approach genuinely effective at addressing unsustainable abstraction specifically (Benson et al., 2022). This is particularly significant for potato production, which represents a major share of irrigation demand and is concentrated in catchments already experiencing water stress, making the

sector especially vulnerable to abstraction restrictions and future water scarcity (Benson et al., 2022).

Industry is also keen to promote catchment based approaches. The WRAP *Roadmap Towards Water Security for Food and Drink Supply* sets out a collaborative strategy for improving water security across. Although aimed primarily at retailers and manufacturers, there is a notable emphasis on catchment-scale water stewardship and climate resilience with implications for farmers. The roadmap highlights that farmers will increasingly be expected to invest in more efficient irrigation, water storage, soil and drainage management and monitoring technologies, while adopting practices that improve water efficiency. These include actions such as reducing pollution, enhancing soil water retention and supporting wider catchment management (WRAP, 2021). Similarly, the NFU's Integrated Water Management Strategy specifically promotes catchment based approaches and calls for greater recognition of the role of farming in being able to mitigate against wider flood and drought risk across communities (NFU, 2021).

7.7 Summary

The on-farm impacts of water stress are multi-faceted. Water stress affects yield, quality, biomass, growth, nutritional content and disease susceptibility across fresh produce crops, with direct implications for grower income and produce marketability. Pressures show that water availability impacts farm businesses beyond this as well. The costs of managing water scarcity are rising even before yield or quality losses are counted. For many growers, particularly in the driest catchments, securing water may now be viewed as critical a part of business planning as it is of agronomy.

8 Central themes

Fresh produce grown outdoors in the UK is vital for farming livelihoods, national food security and public health. However, there is mounting pressure to address water availability for these crops in an increasingly volatile climate. Modelling projections suggest that the UK is likely to experience drier summers, wetter winters and more prolonged and frequent droughts. However, wetter winters are unlikely to bring levels of groundwater recharge required for replenishment. These effects are likely to be felt most acutely in key fresh produce growing regions of the south and east of England. Conflicts and restrictions around abstraction and licensing are also causing uncertainty as to the viability of future production for some irrigation-dependent crops.

The evidence reviewed here suggest that some of the most at risk crops are leafy vegetables including lettuce, chard and chicory; celery; potato and carrot; certain brassicas such as cabbage and broccoli; and peas and beans. The evidence from our review conflicts slightly with existing evidence from Defra/ADAS (2012) in that legumes (beans and peas) are viewed as medium risk, whereas our evidence showed significant effects of water stress on various agronomic attributes when drawing upon studies from Europe. We also found evidence that perennial vegetables such as asparagus are potentially at higher risk than Defra/ADAS (2012) suggest. In short, there are several fresh produce crops that could be seen as at high risk from water stress which are fundamental to UK food production, most notably potatoes. This emphasises the importance of integrated policy that addresses long term risk to UK fresh food production in light of future water scarcity projections. While wetter winters may provide opportunities for winter storage and recharge in some regions, the overall projections suggest

increasing risks of seasonal water scarcity and growing constraints on agricultural production in the UK's key fresh produce regions.

The evidence suggests that the challenge for water policy is ensuring that environmental restoration and food security objectives are complementary. Climate and hydrological modelling between now and 20250 shows that water risk for fresh produce is multi-faceted and cumulative, combining reduced flows, declining groundwater and tightening abstraction. Given the concentration of UK fresh produce production within water stressed regions, policy frameworks that support sustainable abstraction, strategic water storage and irrigation resilience will be critical to maintaining or increasing domestic production capacity while achieving environmental outcomes. As water policy focuses on managing abstraction at catchment scale, effective irrigation management is also becoming a catchment scale challenge, making collaborative approaches a more important component of agricultural water security. Failure to align water, environmental and food policies more effectively may constrain domestic fresh produce production at a time when climate change, population growth and geopolitical uncertainty are increasing the strategic importance of resilient domestic food systems (Environment Agency, 2025; House of Lords, 2026; Met Office, 2026).

8.1 Evidence gaps

There was a dearth of UK studies on water stress in fresh produce crops in our search. It is likely that research occurs, particularly within large suppliers, but perhaps is not published. This restricted the ability to examine the effect of water stress on crop specific outcomes by UK region.

The lack of published field studies carried out in the UK reflects the complexities of creating an artificial water stress environment in the field without introducing confounding factors (e.g. reducing light, ventilation, etc). However, it may also reflect typical weather patterns in the UK, where water stress and salinity may not have historically caused issues with fresh produce. Whereas in areas of the mediterranean familiar with water stress, the topical nature necessitates or encourages more research.

As well as limited UK data, there are substantial evidence gaps for some crops, with no evidence retrieved for crops such as baby leaf, parsnip, leek and most cucurbits. These conclusions suggest that more publicly available research is required for the full range of crops in UK field settings to better understand the risks associated with water stress.

The effect of salinity on fresh produce crops was investigated in the evidence for several crops reflecting a growing concern about the movement of salt water into coastal aquifers and farmland. This is driven by sea level rise and groundwater abstraction. In the UK, salinity is currently rated as low risk but plausible and requiring further research (CCRA4, 2026). We found limited discussion of the threat of salinity in government and industry reports, showing a slight disconnect between the scientific evidence (reporting largely negative effects on crops) and policy action areas. Future policy actions may need to assess salinity risks more closely, particularly in low lying coastal areas such as the Fens, alongside water scarcity.

8.2 Research limitations

We excluded studies investigating methods to reduce water stress in crops, e.g. biostimulants, bacteria and arbuscular mycorrhizal fungi (AMF), due to capacity. This may have reduced the amount of available evidence from the UK and comparable temperate climates. Future work could seek to incorporate such studies to synthesise the latest evidence on dealing with water stress in fresh produce production, which could support management advice.

This research focused on water availability and did not specifically look for evidence on water quality. While these two threats are interlinked and water quality is a critical issue as recognised in the UK Government's paper, A New Vision for Water (Defra, 2026), time constraints of the project necessitated a singular focus. To supplement the evidence here, further research on water quality would be beneficial to better inform policy and management recommendations.

Due to the time restrictions of the project, AI was used to extract standardised data from each study. More than 20% of studies were manually checked and verified for accuracy, however other errors in the data extraction may have persisted. Further details on how AI was applied are available in Appendix 1: Methods.

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Appendices

Appendix 1. Methods

Aims and approach

This policy and literature review on water availability is part of a wider project aiming to strengthen water security in UK fresh produce production by:

- Synthesising academic and policy thinking on agricultural water security
- Developing a practical decision tree for fresh produce farmers
- Agreeing priorities to influence change including delivering a national lobbying campaign culminating in a House of Lords presentation in November 2026

The entire project includes farmer consultation and a national lobbying campaign. The aim of this literature and policy review was to consolidate academic, regulatory and industry thinking on water security in agriculture, which was used to inform some of the farmer consultation. This included identification of key risks, knowledge gaps and emerging themes. The review was carried out in five stages and synthesised into the final report:

1. Review of existing policy and regulation
2. Collation of modelling data on rainfall and water availability
3. Assessment of specific crop water requirements
4. Review of crop specific studies by region
5. Analysis of on-farm impacts of water availability

The methods described here were presented in an *a-priori* protocol and used to direct the research.

1. Review of existing policy and regulation

A desk-based review of existing policy and regulation was carried out to provide the context for the review. This section is not intended to be exhaustive, but enables a better understanding of the regulatory environment in which farmers operate in relation to water availability.
AI was used as a supporting tool to aid in literature discovery, cross-reference regulatory guidance, identify relevant policy documents and extract key policy and regulatory statements. All AI-assisted outputs were manually checked to ensure reliability and accuracy.
Findings were synthesised into a brief policy and regulatory review.

2. Collation of modelling data on rainfall and water availability

Objective

The objective was to gather and synthesise available climate and hydrological modelling relevant to UK agriculture, with a particular focus on the project's priority growing regions. This included analysis of projected changes in rainfall patterns, drought frequency, seasonal water availability and catchment-level pressures. This generates a clear understanding of how water availability is expected to change between now and 2050, and the extent to which this may constrain agricultural production.

Sources of data

Data for climate and hydrological modelling was restricted to two principal sources:

- UK Climate Projections (UKCP18) is the standard UK climate scenario framework
- Enhanced Future Flows and Groundwater (eFLaG) is the key source for hydrological projections and data is based on UKCP18

Both portals enable manipulation of scenarios to illustrate climate projections geographically. Data was largely based on RCP8.5 emissions scenario for consistency with most hydrological modelling which uses high emissions scenarios. Design of the user interfaces on UKCP18 and eFLaG meant including multiple charts to cover the period between 2026 and 2050. In some instances, the timespan extended beyond 2050. Due to different sources, baseline time periods differ but are highlighted in the text.

Data synthesis

The data was used to illustrate broad patterns of projected changes from a baseline, including:

- Summer precipitation
- Winter precipitation
- Low river flows and groundwater levels
- Groundwater recharge
- Drought characteristics (persistence, severity and cumulative water stress)

No reconciliation of multiple models took place and we did not use data to build bespoke models due to time constraints of the project. However, patterns were cross referenced with other key sources (e.g. National Framework for Water Resources, UK Climate Change Risk Assessment evidence base). A matrix delineated by key growing regions summarises changes over time.

3. Assessment of specific crop water requirements

Objective

We reviewed published data on the water requirements of key UK fresh produce crops, including root vegetables, brassicas and leafy salads. This work highlighted how crop-level water demand aligns with broad patterns of projected changes in water availability, identifying where mismatches are likely to occur.

Sources of data

The primary data source was Defra/ADAS Irrigation Best Practice Guide: Water Management for Field Crops (ADAS, 2012). This remains the most detailed UK-specific source of crop-level irrigation response data. The guide draws on multi-year experimental trials and industry experience and remains widely referenced within UK horticulture. While published guidance on irrigation scheduling and legislation has moved on since 2012, the underlying crop physiological relationships and soil water principles have not changed (ADAS, n.d.). As such, the guide provides a robust foundation for relative crop comparisons. Data was cross referenced with other key industry sources including AHDB and UKIA.

Data synthesis

Data on water requirements for fresh produce crops is presented in a table. This includes:

- Indicative seasonal water requirements
- Critical crop response periods
- Sensitivity to soil water holding capacity
- Quality and yield risks associated with water stress

4. Review of crop specific studies

Objective

A targeted review of studies established how water availability affects specific crops. The intention was to determine whether certain crops or production systems may become increasingly difficult to sustain in particular regions under future conditions. The intention was to review crop specific studies by UK region, however this was prohibited by limited publicly available data for the UK on the crops of interest.

Search strategy

To ensure a robust approach to gathering evidence in the timeframe, we used methods used in rapid evidence assessments (REA). We also captured on-farm impacts to address the following section of the report. The search, data extraction and synthesis was guided by the following primary research question:

What is the effect of water availability on fresh produce crops in the UK?

The search strategy was framed using population, exposure, comparator and outcome (PECO) elements:

Population	Any fresh produce crop including root vegetables, brassicas and leafy salads
Exposure	Any naturally occurring water-related stress (e.g. excess rainfall, drought) or water source restrictions (e.g. storage, abstraction)
Comparator	Before/after trials OR no water stress OR long term trends
Outcome	Any operational (e.g. irrigation requirements, abstraction licensing requirements), agronomic (e.g. yield, disease, quality, vigour) or economic (e.g. input costs, profit) impact

We used a hierarchical approach to evidence reviewing, involving three levels:

1. For each crop, we used the CEEDER database and Google Scholar to identify any existing meta-analyses, systematic reviews or scoping/narrative reviews (where adequate methods were used). These were reviewed manually.
2. The remainder of studies identified through search and screening (see process below) were fed into AI software to extract key information including study design, crop, type of water stress, outcome assessed and direction of effect
3. A sample of studies from the database coded by AI (20% of studies) was then manually reviewed and coded at full text to assess accuracy of the coding approach.

This structured, staged approach enabled us to reduce risk of bias, synthesise the most relevant agronomic and economic effects of water stress, and determine broad patterns and evidence gaps efficiently and accurately.

Search string

Initial scoping searches used a range of keywords to identify the most relevant search results. Keywords were tested for specificity and sensitivity using online bibliographic database Web of Science, and the Topic Search function. Details on the initial scoping searches are in Table A4. Based on scoping searches and in agreement with Morrisons, the final search string was (restricted with country filters):

artichoke* OR asparagus OR babyleaf OR bean* OR beetroot OR brassica* OR broccoli OR cabbage* OR carrot* OR cauliflower* OR celeriac OR celery OR chard OR chicory OR courgette* OR *cress OR fennel OR leek* OR lettuce* OR kale OR onion* OR marrow* OR parsnip* OR pea OR peas OR potato* OR pumpkin* OR radish* OR raspberr* OR rhubarb OR rocket OR spinach OR “spring greens” OR sprout* OR squash OR swede OR salad* OR strawberr* OR sweetcorn OR turnip* OR vegetable* OR basil OR coriander OR chive* OR dill OR mint OR parsley OR oregano OR rosemary OR sage OR tarragon OR thyme

AND

flood* OR waterlog* OR drought* OR salinity OR abstract* OR "water scarcity" OR "water security" OR "water stress" OR “water deficiency”

Searches and databases

Searches were undertaken to capture an unbiased sample of published literature from online databases (Table A1) and relevant grey literature from organisational websites. For grey literature, a snowballing approach was used and references of relevant reports checked for other potential sources. Searches were recorded including source, date of search, search terms and number of results.

Table A1. Sources searched for published and grey literature

Published literature	Web of Science CAB Abstracts
Grey literature	ADAS AHDB Defra (incl. A new vision for water: white paper 2026) ClimateXChange Environment Agency James Hutton Institute NIAB SEFARI The Climate Change Committee UK Centre for Ecology & Hydrology UK Irrigation Association UKRI

Screening literature

All retrieved articles were exported into systematic reviewing software, EPPI Reviewer-6, duplicates removed, and remaining articles screened by title and abstract against pre-defined inclusion criteria (see Table A2). Articles were screened at full text where necessary. Articles for second opinion were reviewed by one other researcher against the inclusion criteria and agreement reached.

Priority screening was enabled in EPPI Reviewer which uses machine learning to sort results by relevance. A random sample was screened manually first, allowing the software to ‘learn’ relevant studies. This sample enables the software to then sort results by expected relevance. When results plateaued and lost relevance, the research team agreed an appropriate threshold at which to cease screening.

Eligibility criteria

Inclusion and exclusion criteria reflecting the PECO elements are detailed in Table A2 and determined which items were included in the evidence review.

Table A2. Inclusion and exclusion criteria

	Inclusion criteria	Exclusion criteria
Population	▪ Studies on any of the following crops: Artichoke, asparagus, babyleaf salad, beans, beetroot, broccoli, cabbage, carrot, cauliflower, celeriac, celery, chard, chicory, courgette, watercress, fennel, leek, lettuce, kale, onion, marrow, parsnip, peas, potato, pumpkin, radish, raspberry, rhubarb, rocket, spinach, spring	▪ Studies on non-priority crops ▪ Studies on glasshouse/ greenhouse crops ▪ Crops grown hydroponically ▪ Studies on livestock even if in the rotation ▪ Studies on wild species or hybrid-wild species ▪ Studies investigating development of new drought-tolerant cvs. ▪ Crops grown hydroponically

	greens, brussel sprout, squash, swede, salad, strawberry, sweetcorn, turnip, basil, coriander, chives, dill, mint, parsley, oregano, rosemary, sage, tarragon, thyme ▪ Studies from the UK ▪ Studies from Europe with similar climatic and farming zones ▪ Studies on field crops	
Exposure	▪ Studies on any form of climate-related water stress including drought, high temperatures, extreme rainfall ▪ Studies on any operational form of water stress including limited water storage or abstraction	▪ Studies on water quality or contaminants[1] ▪ Studies on methods for testing drought tolerance ▪ Data on non-water related treatments (e.g effect of inoculant or AMF on plants subjected to different water treatments) ▪ Studies investigating interventions to combat drought effects (e.g. biostimulants, inoculants, seed coatings, biochar) ▪ Studies on deficit irrigation strategies
Comparator	▪ Before/after trials ▪ Irrigated/non-irrigated ▪ Any other form of control ▪ Studies on long term trends	▪ Studies with no direct comparator
Outcome	▪ Studies investigating any agronomic outcome (e.g. yield, disease, quality, vigour) ▪ Any operational (e.g. irrigation requirements, abstraction licensing requirements) ▪ Any economic impact (e.g. input costs, profit)	▪ Studies investigating attitudes towards water security (e.g. social science studies) ▪ Studies on non-consumption related factors (e.g. quality of essential oils in herbs for cosmetics)
General	▪ Field, pot and lab experiments[2] ▪ Peer reviewed journal articles ▪ Grey literature reports / publications ▪ Studies from any date range ▪ Meta-analyses and systematic reviews (coded and analysed separately)	▪ Studies or reports not in the English language ▪ Unpublished sources, blogs and media articles ▪ Studies with no empirical data ▪ Literature reviews ▪ Studies not available at full text ▪ In vitro experiments

[1] Water quality and contaminants are not explicitly included or searched for in the review, but any studies which surface during the search were captured separately and considered in the overall write-up

[2] Field studies were prioritised over pot and lab experiments. Pot and lab experiments were captured separately and a sample included in analysis

Data extraction and coding

Primary studies were catalogued in a searchable database and standardised information for each study was extracted using AI. This includes bibliographic information, study design details and study outcomes. On-farm impacts (relevant to Task 4 of the project) were also captured. A random sample of 20% of articles were then checked manually to ensure quality of data extraction. Full coding details are shown in Table A3. Regions are defined as per the AHDB (2013) Grown in Britain Guide.

Table A3. Coding applied to each study

Category		#	Coding Variable	Coding values
Identifying information		1	Article ID	#
		2	Study number	#
Bibliographic information		3	Author	Text
		4	Article title	Text
		5	Publication year	YYYY
		6	Publication type	Journal | Report | Thesis | Other
Study context		7	Country	Text
		8	Region	South East | South West | West Midlands | East Anglia | East Midlands | Yorkshire | North West | Wales | Scotland (Tay & Dee Valleys) | Other (for Europe studies)
		9	Type of experiment	Field | Pot | Lab
		10	Data collection methods	Primary research | Meta-analysis | Systematic review | Narrtive reviews
		11	Study scale	Plot | Field | Farm | Region
		12	Study design	Experimental | Correlative | Observational
		13	Sample size	#
PECO Elements	Population	14	Crop	See definitive list of crops
		15	Crop growth stage	Germination | Seedling | Vegetative | Fruiting
		16	Soil texture class	Clay | Silty Clay | Silty clay loam | Clay loam | Sandy clay loam | Sandy clay | Silt loam | Sandy silt loam | Sandy loam | Loamy sand | Sand
	Exposure	17	Type of water stress crop exposed to	Drought | Waterlogging | Soil salinity
	Comparator	18	Comparator	Before/after | Long term trend | Control/intervention
	Outcome	19	Outcome category	Irrigation | Abstraction | Yield | Disease | Quality | Vigour | Input costs | Profit | Other
		20	Direction of effect	Postive | Negative | No effect | Not reported
		21	Statistically tested	Y | N
		22	Author's findings	Text
Other		23	Notes	Text

Quality appraisal

Quality appraisal provides a structured assessment of the reliability and robustness of the available evidence. Assessing methodological quality helps to identify potential sources of bias, enables transparent interpretation of findings and allows greater confidence to be placed in conclusions drawn from higher-quality studies.

Each included study was appraised across three domains: study design, randomisation and comparator strength. Study design was scored as observational (0), correlative (1), or experimental (2). Randomisation was scored as absent (0) or present (1). Comparator strength was scored as no comparator (0), control-intervention/before-after/long-term trend (1), or BACI (before-after-control-impact) (2). Scores across the three domains were summed to give a total appraisal score (range 0–5), which was used to assign each study to a quality band: low (0–1), moderate (2–3), or high (4–5). Appraisal was carried out using AI at the level of the individual study and a random sample (same sample as above) were manually checked to ensure consistency.

Data synthesis

Evidence was synthesised to illustrate knowledge clusters and gaps, for example, where there is a lack of evidence on water stress in a specific crop. Synthesis explored where crops might be particularly sensitive to drought, enabling an assessment of high-risk crops and regions.

5. Analysis of on-farm impacts of water availability

Objective

We synthesised evidence relating to the operational and economic impacts of water availability on farms. This included consideration of abstraction licensing constraints, irrigation infrastructure requirements, input costs and the effects of water shortages on yield and crop reliability, where evidence highlights these.

Sources of data

The evidence review described in Task 3 was used to identify on-farm impacts on crops and captured in the evidence database. Secondly, we reviewed scientific literature, industry and government reports to establish operational challenges and how these effect farmers. We

specifically looked for information on abstraction licensing and irrigation infrastructure, and the literature is therefore not fully representative of all water-related challenges faced by farmers.

Data synthesis

Data from the evidence was analysed to identify operational, agronomic and economic impacts, including knowledge clusters and gaps. Visual graphics were used where possible together with a summary of key findings.

Table A4: Search string development (all Web of Science Topic Search 18th May 2026)

#	Rationale	Terms	Results	Notes
1	/	artichoke* OR asparagus OR babyleaf OR bean* OR beetroot OR brassica* OR broccoli OR cabbage* OR carrot* OR cauliflower* OR celeriac OR celery OR chard OR chicory OR courgette* OR *cress OR fennel OR leek* OR lettuce* OR kale OR onion* OR marrow* OR parsnip* OR pea OR peas OR potato* OR pumpkin* OR radish* OR raspberr* OR rhubarb OR rocket OR spinach OR “spring greens” OR sprout* OR squash OR swede OR salad* OR strawberr* OR sweetcorn OR turnip* OR vegetable* OR basil OR coriander OR chive* OR dill OR mint OR parsley OR oregano OR rosemary OR sage OR tarragon OR thyme AND flood* OR waterlog* OR drought* OR salinity OR abstract* OR "water scarcity" OR "water security" OR "water stress" OR “water deficiency”	26,070	Too broad
2	Restrict using country filters to UK	artichoke* OR asparagus OR babyleaf OR bean* OR beetroot OR brassica* OR broccoli OR cabbage* OR carrot* OR cauliflower* OR celeriac OR celery OR chard OR chicory OR courgette* OR *cress OR fennel OR leek* OR lettuce* OR kale OR onion* OR marrow* OR parsnip* OR pea OR peas OR potato* OR pumpkin* OR radish* OR raspberr* OR rhubarb OR rocket OR spinach OR “spring greens” OR sprout* OR squash OR swede OR salad* OR strawberr* OR sweetcorn OR turnip* OR vegetable* OR basil OR coriander OR chive* OR dill OR mint OR parsley OR oregano OR rosemary OR sage OR tarragon OR thyme AND flood* OR waterlog* OR drought* OR salinity OR abstract* OR "water scarcity" OR "water security" OR "water stress" OR “water deficiency”	1,189	Country restrictors not fully effective but manageable
3	Restrict to UK in Topic	artichoke* OR asparagus OR babyleaf OR bean* OR beetroot OR brassica* OR broccoli OR cabbage* OR carrot* OR cauliflower* OR celeriac OR celery OR chard OR chicory OR courgette* OR *cress OR fennel OR leek* OR lettuce* OR kale OR onion* OR marrow* OR parsnip* OR pea OR peas OR potato* OR pumpkin* OR radish* OR raspberr* OR rhubarb OR rocket OR spinach OR “spring greens” OR sprout* OR squash OR swede OR salad* OR strawberr* OR sweetcorn OR turnip* OR vegetable* OR basil OR coriander OR chive* OR dill OR mint OR parsley OR oregano OR rosemary OR sage OR tarragon OR thyme	133	Too restrictive, has removed relevant papers

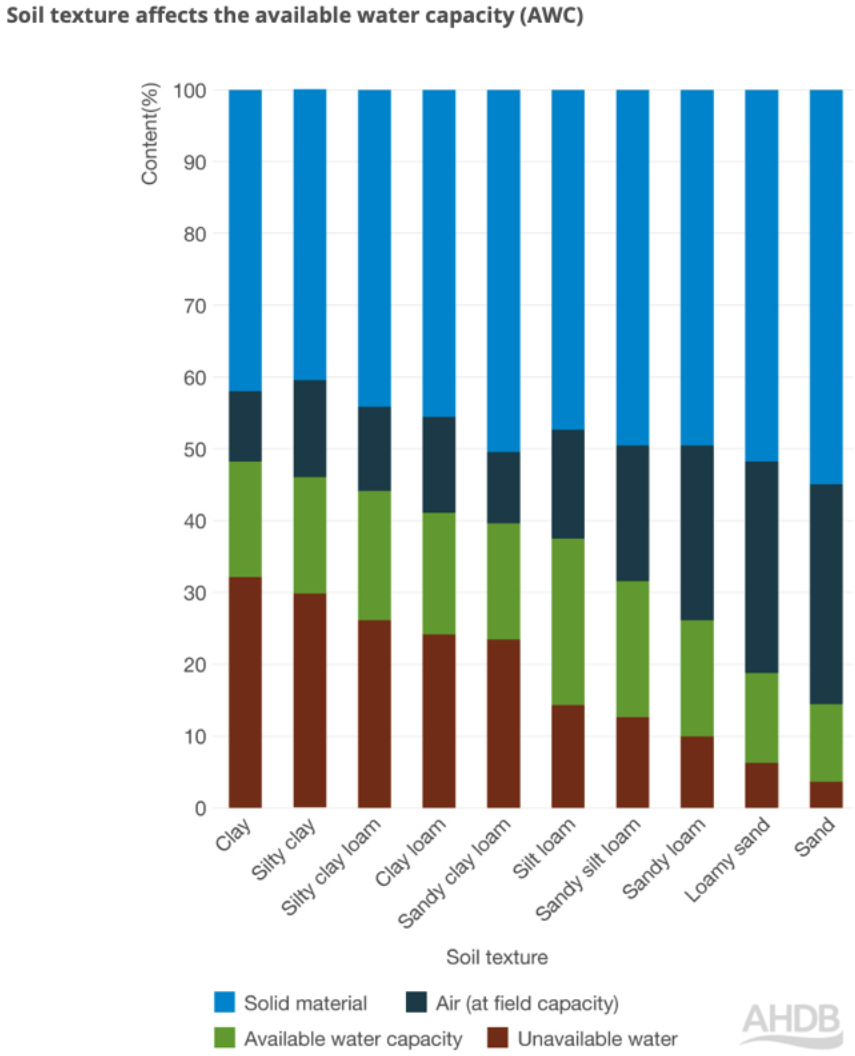
		AND flood* OR waterlog* OR drought* OR salinity OR abstract* OR "water scarcity" OR "water security" OR "water stress" OR “water deficiency” AND UK OR United Kingdom OR Britain OR British OR Engl* OR Scotland OR Scottish OR Wales OR Welsh OR "Northern Ireland" OR "Northern Irish"		
4	Remove UK country restrictors in Topic, add in European countries of relevance using country filter	artichoke* OR asparagus OR babyleaf OR bean* OR beetroot OR brassica* OR broccoli OR cabbage* OR carrot* OR cauliflower* OR celeriac OR celery OR chard OR chicory OR courgette* OR *cress OR fennel OR leek* OR lettuce* OR kale OR onion* OR marrow* OR parsnip* OR pea OR peas OR potato* OR pumpkin* OR radish* OR raspberr* OR rhubarb OR rocket OR spinach OR “spring greens” OR sprout* OR squash OR swede OR salad* OR strawberr* OR sweetcorn OR turnip* OR vegetable* OR basil OR coriander OR chive* OR dill OR mint OR parsley OR oregano OR rosemary OR sage OR tarragon OR thyme AND flood* OR waterlog* OR drought* OR salinity OR abstract* OR "water scarcity" OR "water security" OR "water stress" OR “water deficiency”	7,144	Decent relevance, medical papers towards middle of search results (Austria, Belgium, Croatia, Czech Republic, Demark, England, Estonia, France, Germany, Hungary, Ireland, Italy, Luxembourg, Montenegro, Netherlands, Northern Ireland, Poland, Portugal, Romania, Scotland, Slovakia, Slovenia, Spain, Switzerland, Ukraine, Wales)
5	Restrict by Topic filter	artichoke* OR asparagus OR babyleaf OR bean* OR beetroot OR brassica* OR broccoli OR cabbage* OR carrot* OR cauliflower* OR celeriac OR celery OR chard OR chicory OR courgette* OR *cress OR fennel OR leek* OR lettuce* OR kale OR onion* OR marrow* OR parsnip* OR pea OR peas OR potato* OR pumpkin* OR radish* OR raspberr* OR rhubarb OR rocket OR spinach OR “spring greens” OR sprout* OR squash OR swede OR salad* OR strawberr* OR sweetcorn OR turnip* OR vegetable* OR basil OR coriander OR chive* OR dill OR mint OR parsley OR oregano OR rosemary OR sage OR tarragon OR thyme AND flood* OR waterlog* OR drought* OR salinity OR abstract* OR "water scarcity" OR "water security" OR "water stress" OR “water deficiency”	5,266 CAB Abstracts 855 (when restricted with country filters – good relevance)	Relevance appears good. Removal of health / medical and other topics has improved relevancy NB: over 1000 results are salinity

Table A5. Number of controlled environment and field study data points per crop group and crop, and percentage of data rated as per the quality appraisal. Crops with no data points for either type of experiment are not included.

	Controlled environment	Field studies	Quality appraisal rating
Legume	**39**	**41**	**81% high, 19% moderate**
Bean	27	13	89% high, 11% moderate
Pea	12	28	74% high, 26% moderate
Culinary herb	**10**	**58**	**50% high, 25% moderate, 25% low**
Sage		23	26% high, 26% moderate, 48% low
Rosemary		23	52% high, 22% moderate, 26% low
Thyme	3	6	67% high, 33% moderate
Mint	3	6	67% high, 33% moderate
Oregano	4		100% high
Leafy vegetable	**36**	**25**	**84% high, 16% moderate**
Chicory	10	13	57% high, 43% moderate
Lettuce	18	3	100% high
Rocket	8		100% high
Spinach		6	100% high
Chard		3	100% high
Brassica	**15**	**34**	**100% high**
Broccoli	5	12	100% high
Cauliflower	5	9	100% high
Cabbage		13	100% high
Kale	5	0	100% high
Root vegetable	**6**	**40**	**100% high**
Potato*	NA	NA	NA
Carrot		16	100% high
Celery		14	100% high
Fennel	6	3	100% high
Radish		7	100% high
Allium	**NA**	**NA**	**NA**
Onion*	NA	NA	NA
Berry crop		**28**	**71% high, 29% moderate**
Strawberry		24	83% high, 17% moderate
Raspberry		4	100% moderate
Perennial vegetable	**4**	**11**	**33% high, 67% moderate**
Artichoke		10	100% moderate
Asparagus	4	1	100% high
Cucurbit		**5**	**100% moderate**
Courgette		5	100% moderate

*Potato and onion data retrieved from meta-analyses

Appendix 2. Soil texture affects available water capacity



Source: AHDB (n.d.)