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Mae'r ddogfen yma hefyd ar gael yn y Gymraeg. This document is also available in Welsh.

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Glossary

AAR: Average Annual Rainfall. AAR is a measure of the total amount of rainfall, falling in a calendar year (observation period 1941-1970). This is different to the duration of wetness throughout a calendar year – see FCD.

ALC: Agricultural Land Classification system. This is a robust, scientific system to assess agricultural land quality at a range of mapping scales. The ALC is the only approved system for grading land quality in England and Wales. (See also BMV)

ASR: Average Summer Rainfall (April to September, measured in millimetres). ASR measures rainfall at the critical time of year for crop growth (observation period 1941-1970). This is not used as a standalone criterion but is implicit in some background calculations.

AT0: Median Accumulated Temperature above 0°C (January to June). This measures the warmth of an area during a period critical for germination and plant growth. AT0 is simply a sum of all temperatures above 0°C, summed daily from January to June. This is used in the assessment of overall climate. April to September values of AT0 is used in some background calculations (this is known as ATS, see below).

ATS: Median Accumulated Temperature above 0°C (April to September). ATS is a sum of all temperatures above 0°C, summed daily from April to September.

BMV: Best and Most Versatile land. BMV land is ALC Grade 1, Grade 2 and Sub-grade 3a of the ALC system. BMV land is afforded protection through national planning policy; this policy is different in England and Wales. In Wales, policy states that 'considerable weight should be given to protecting such land from development' whereas in England planning should recognise the 'economic and other benefits' of BMV land and 'where significant development of agricultural land is demonstrated to be necessary, areas of poorer quality land should be preferred to those of a higher quality'.

FCD: Field Capacity Days. FCD is the number of days per year a soil is at Field Capacity. Field Capacity (FC) is maximum water soil content under gravity, i.e. the soil moisture deficit is 0 and the point at which drainage starts. At Field Capacity, soils are considered too wet for cultivation. FCD is a key criterion in ALC assessment of soil wetness and workability.

Interactive limitations. In ALC, these are physical limitations which result from interactions between climate, site and soil. The interactive limitations in ALC are soil wetness, droughtiness and erosion. Interactive limitations allow for similar soils to be assessed differently, in wetter or drier parts of England and Wales. See also Standalone limitations.

LCA: Land Capability Assessment for Scotland. This is the land classification system used in Scotland which is very similar to ALC but differs in several aspects. The LCA uses 7 classes and has greater subdivision of grassland/moorland areas than the ALC.

Liebig's law of the minimum. If a combination of limiting factors exists, *only* the one most limiting determines the overall severity of limitation. This term is used in EC documents and is synonymous with 'most limiting factor' in ALC. (See most limiting factor)

MAFF: MAFF was the Ministry of Agriculture, Fisheries and Food (now Defra).

MAFF 1988 Guidelines/the Blue Book. *The Revised guidelines and criteria for grading the quality of agricultural land (MAFF 1988).* This is the extant and only approved system for grading land quality in England and Wales. The guidelines came into force on 1 January 1989 superseding any previous ALC surveys or guidelines (see MAFF Technical Reports: Tech 11 and 11/1)

MORECS: Met Office Rainfall and Evaporation Calculation System. Provides estimates of evaporation and soil moisture deficit for the UK. It is run each week and produces daily information for a range of crop types and soil properties.

Mineral soils: Mineral soils are soils which are not organic-mineral soil or peaty and have less than 6-10% organic matter. Most lowland arable soils outside Fenland are mineral. See Appendix 2 of the MAFF 1988 Guidelines for definitions.

Most limiting factor (ALC). If a combination of limiting factors exists, the most limiting one only is used to determine severity of limitation and hence ALC Grade. See Liebig's law of the minimum.

Organic-mineral or peaty soils. Organic mineral soils have between 6-25% organic matter, depending on clay content. Peaty soils have 20-100% organic matter, depending on clay content. See Appendix 2 of the MAFF 1988 Guidelines for definitions.

Predictive ALC: The Predictive ALC was introduced in Wales in 2017. It is a web-based model refining ALC grading at an all Wales level. It uses background climate and terrain models, linked to NATMAP soil property data. It then calibrates the data to the ALC system. Predictive ALC Grades (including Subgrade 3a and 3b) can be viewed, along with all Post Revision field surveys. The Predictive ALC has superseded the Provisional ALC maps in Wales and is available on the Welsh Government website. It is the primary source of strategic ALC information in Wales. (See Provisional ALC).

https://gov.wales/agricultural-land-classification-predictive-map

Provisional ALC maps: Maps prepared between 1968 and 1974, classifying all of England and Wales into 5 Grades. The maps were intended as a strategic guide to agricultural land quality. Originally produced at a scale of one inch to the mile (1:63 360) but subsequently generalised to a scale of 1:250 000. The maps series should only be used for a strategic guide to land quality and not relied on for site specific assessments. For a definitive grading, a survey according to the MAFF 1988 guidelines is needed.

The Provisional ALC maps were withdrawn in Wales and replaced by the Predictive ALC in 2017; version 2 (updated in March 2020) is available on the Welsh Government website. (See Predictive ALC).

https://gov.wales/agricultural-land-classification-predictive-map

Soil structure: Soil structure is the aggregation of individual soil particles into discrete units, called peds or structural units. These can be classified into different shapes, sizes etc. Differences between soil structural type and condition can have a large effect on soil water movement. Soil structure is important for soil wetness/workability and droughtiness assessment.

Soil texture: Soil texture is defined according to the relative proportions of sand, silt and clay fractions.

Standalone limitations: In ALC, these are limitations directly affecting grade independent of soil/climate interactions – e.g. flooding, gradient, topsoil stone content and overall climate.

SWC: Soil Wetness Class. SWC is the key descriptor for the severity of soil wetness. SWC measures the amount of the year a soil is wet above certain depths on a scale of I – VI. SWC I is driest, SWC VI is wettest. SWC I to IV are most encountered in ALC. For ALC, SWC is assessed using (a) depth to gleyed horizon and depth to slowly permeable layer – measuring how quickly water can move through a soil profile– and (b) the number of Field Capacity Days (FCD) – measuring the duration of climatic wetness. See Appendix 3 of the MAFF 1988 guidelines for a full definition. (See also Wet).

Wet: In soil wetness class assessment, 'wet' means water films are visible on the surfaces of grains or peds. Excavation below a wet horizon will cause water to flow down the exposed face, though flow may be very slow and confined to major pores and fissures. For a full definition see Soil Survey Field Handbook (Hodgson, 1976).

1 Introduction

- The Agricultural Land Classification in England and Wales (ALC) provides a framework for classifying agricultural land according to the extent to which its physical or chemical characteristics restrict agricultural use. The limitations may affect the range of crops which can be grown, the level and consistency of yield and the associated cost of farming the land. ALC places considerable emphasis on the range of cropping possible as well as the potential of land to support consistently high yields of a narrower range of crops.
- The ALC was originally devised and introduced in the 1960s and it provided a framework for classifying land into five classes (ALC grades 1-5) according to the extent that climatic, soil and site characteristics limited agricultural production. The classification formed the basis for advice given by the Ministry of Agriculture, Fisheries and Food (MAFF) and Welsh Office Agriculture Department (WOAD) on land use planning matters.
- Following a review, the ALC was updated in the 1970s to divide Grade 3 land into sub-Grades 3a, 3b and 3c (MAFF, 1976) because Grade 3 was considered to cover too wide a spectrum of land. Following an extensive review during the 1980s the three-fold sub-division of Grade 3 land was amended and the Grade 3c class was removed. Two subgrades are now recognised: Subgrade 3a and Subgrade 3b, the latter being a combination of the previous Subgrades 3b and 3c (MAFF, 1988[1]). The review also led to the criteria used to assess climatic limitations and climate-soil interactions being updated based on the best and most up to date information available at the time.
- Currently land is still graded in accordance with the guidelines and criteria established in 1988 (MAFF, 1988). Given that the guidelines were published over 30 years ago, it is important that the threshold limits for establishing grading are reviewed and updated to ensure they are valid and appropriate for the future. In addition, major advances in technology (e.g. GIS or remote sensing) since 1988 may provide methods for assessing criteria that were not previously possible.
- The ALC was originally developed as a field-based system, supporting planning policy to protect high quality agricultural land from loss to development. However, more recently, the ALC system has also been used as a modelling platform using national soil, climate and terrain datasets. This has been helpful for assessing future land capability and land suitability for specific crops. Importantly, the requirements for an ALC field assessment tool and for models to assess land capability or suitability can be quite different.

2 Overall objectives

- This project has assessed the factors needed to conduct a full technical review of the ALC system. It will not create a revised ALC but inform what is needed for an updated system. The project consisted of six work packages:
    - Review of existing ALC research and known issues
    - Identification of key technical issues
    - Online technical workshop

[1] The Agricultural Land Classification of England and Wales can be accessed here http://publications.naturalengland.org.uk/publication/6257050620264448 and the accompanying Climatological Data for Agricultural Land Classification here http://publications.naturalengland.org.uk/file/4830386468159488

    - Identification of timescales, costs and risks, expertise and skill sets
    - Testing and trialling options
    - Summary and recommendations
- This report has:
    - Reviewed existing ALC research relating to each of the ALC limitations
    - Reviewed the principles underpinning the ALC methodology
    - Identified the ALC limits that need reviewing and the specific components of the ALC criteria that need updating.
    - Reviewed the options for a new climate dataset.
    - Identified potential methods to update the associated climatic variables (i.e. rainfall, accumulated temperature, moisture deficit and field capacity days).
    - Outlined the methodology that could be used to update the ALC along with testing and trialling options and indicative costings.
    - Summarised and made recommendations for updating the ALC system.

3 The Agricultural Land Classification

- The principal physical factors influencing agricultural production are climate, site (e.g. gradient or microrelief) and soil. These factors, together with interactions between them, form the basis for classifying land into one of six grades from Grade 1: excellent quality to Grade 5: poor quality. Grade 3 is further divided into two sub-grades designated 3a and 3b (MAFF, 1988)[2]. The top three grades (1-3a) are defined by Section 3.58 of Edition 11 of Planning Policy Wales (Welsh Government, 2021) and the National Planning Policy Framework for England (Ministry of Housing, Communities & Local Government, 2021) as the 'best and most versatile' (BMV) agricultural land which is most flexible and productive and suitable for growing a wide range of crops.
- The main limiting physical factors are identified as: climate, soil wetness, soil droughtiness, gradient, flooding, soil texture, soil depth, soil stoniness and soil chemical properties. The final ALC grade given to a location is the lowest grade from any of the criteria (i.e. criteria are combined according to the agronomic law of the minimum, Liebig's law).
- Certain criteria (i.e. soil droughtiness, soil wetness and workability, gradient, topsoil stone content and soil depth) have bespoke, in field, assessment methods to derive an ALC grade. The flooding assessment depends on third party data that is often not easily available. Other criteria (i.e. microrelief, chemical, erosion, frost, aspect, exposure and irrigation)[3] are considered in the ALC Guidelines. However, these are on a case-by-case basis with no specific threshold values to directly arrive at an ALC grade.

[2] http://publications.naturalengland.org.uk/file/5526580165083136
[3] Although irrigation is included in the 1988 ALC guideline the 1997 changes to national planning guidance removed the potential to upgrade land where irrigation was available, and it is no longer used as a factor in grading land.

- In Wales, Grade 1 land is located in small pockets of lowland North East and South Wales (Figure 1[4]) In England, Grade 1 land is located around The Wash, the Vale of York, North Kent and on the North West coast near Ormskirk (Figure 2). Grade 2 land is mainly located in lowland North and South Wales, Anglesey and Pembrokeshire and in Eastern England. Grade 3 land predominates in England whilst in Wales Grade 3 land is more widely distributed and is in low lying coastal and inland areas of Wales, river valleys (e.g. the Wye and Severn) and along the Welsh/English border. Grade 4 and 5 agricultural land is concentrated in the central upland areas of Wales and the north/northeast uplands of England. Only agricultural land of Grade 3b and above will typically be suited to arable crops (MAFF, 1988). However, light Grade 4 land may be cropped in the East and Southeast of England although yields are likely to be limited.

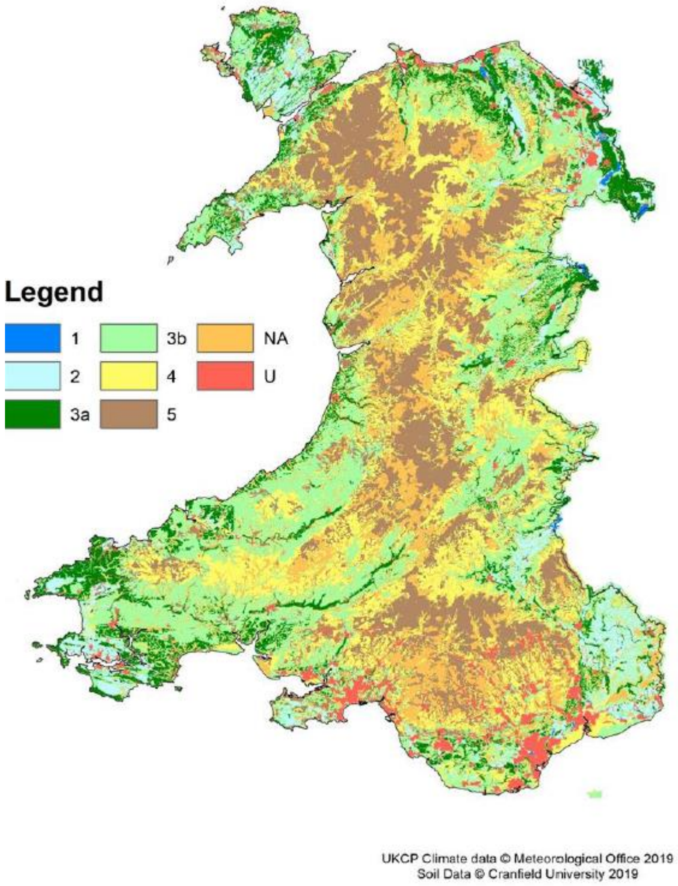

Figure 1. Predictive agricultural land classification (ALC) map for Wales (Source: Keay and Hannam, 2020).

[4] Note that although both Figures 1 and 2 illustrate the location of ALC land by grade in Wales and England, respectively, they are not strictly comparable. Figure 1, the predictive ALC map for Wales was introduced in 2017, it is a web-based model which uses the best available information to predict the ALC grade of land. Figure 2 shows the provisional grades for England based on maps prepared between 1967 and 1974; the maps provide a strategic guide to land quality rather than site specific guidance.

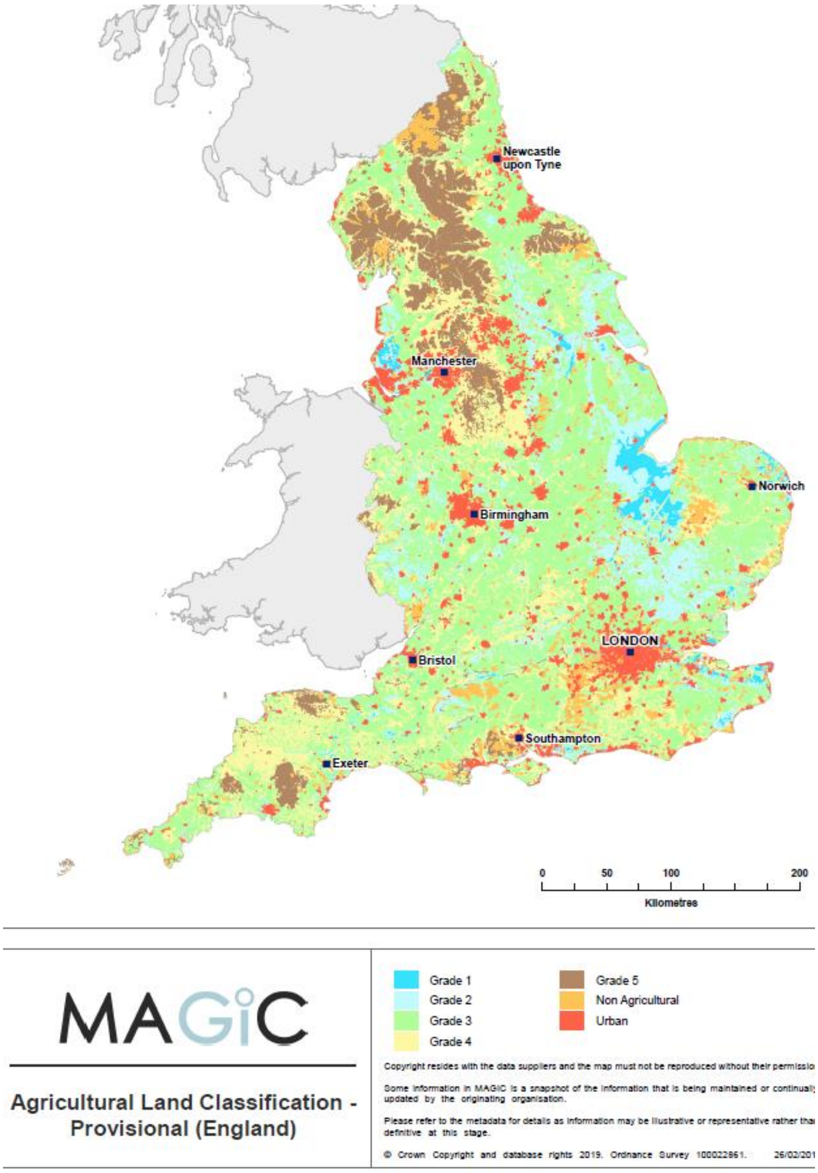

Figure 2. Agricultural land classification (ALC) for England.

4 Principles of ALC

- ALC assesses the limitations to agricultural land in one or more of four principal ways: 1. The range of crops which can be grown, 2. Crop yield potential, 3. Impact on the consistency of yield and 4. Production costs. The ALC system gives considerable weight to the range of crops that can be grown as well as the potential for land to achieve high yields of a narrow range of crops. To ensure a consistent approach when classifying land the following assumptions are made (MAFF, 1988):

    1. Land is graded according to the principal physical factors influencing agricultural production (i.e. climate, site and soil). It is assessed on its capability at a good but not outstanding standard of management.
    2. Where limitations can be reduced or removed by normal management operations or improvements, for example cultivations or the installation of an appropriate underdrainage system, the land is graded according to the severity of the remaining limitations.
    3. Where long-term limitations outside the control of the farmer or grower will be removed or reduced soon through the implementation of a major improvement scheme, such as new arterial drainage, the land is classified as if the improvements have already been carried out.
    4. The grading does not necessarily reflect the current economic value of land, land use, range of crops, suitability for specific crops or crop yield. The grade cut-offs are not specified based on crop yields, although in some cases crop growth may give an indication of the relative severity of a limitation.
    5. The size, structure and location of farms, the standard of fixed equipment and the accessibility of land do not affect grading, although they may influence land use decisions

4.1 Background

- The ALC was introduced in the 1960s when MAFF Technical Report 11 (MAFF, 1966) outlined a national system of agricultural land classification in accordance with the recommendations of a Study Group set up to define the requirements for an up-to-date system. The remit of the group was to:

    i. Consider and define the requirements for an up-to-date agricultural land classification system based on national standards but capable of application to small areas.

    ii. Collect and process relevant data and where practicable, prepare agricultural land classification maps.

- The Group agreed that the system should be:

    i. Capable of clear definition in order that it might be applied with reasonable consistency by different people in different parts of the country

    ii. Suitable for use in national, regional and local surveys

    iii. Readily understandable by planners and other persons not necessarily expert in agricultural matters

    iv. As objective and uncomplicated as possible.

- Following discussion, the Group decided that the best approach was a classification that took account of the permanent physical properties of land influencing crop production, i.e. site, soil and climate. The group also explored the possibility of a supplementary economic classification which would indicate the productivity of the physical grade in financial terms. However, due to problems with the acquisition of objective, up to date, accurate and consistent farm output data this was not progressed.
- In 1976, MAFF reported that the objectives i-iv (outlined above) had largely been achieved although they noted that due to limitations in field survey coverage the system would not give accurate results for areas of land <200 acres (i.e. the maps would not be suitable for making decisions at a local level). It was also noted that Grade 3 land included too wide a spectrum of land; some land that was subject to a moderate degree of limitation had production characteristics of good quality land. As a result, Grade 3 land was subdivided into Grades 3a, 3b and 3c. In 1988 the revised guidelines were published with the aim of updating the system without changing the original concepts.

4.2 The most limiting factor

- The grade or subgrade of land is determined by the most limiting factor present (i.e. Liebig's Law of the Minimum). Liebig's Law is typically illustrated using a wooden barrel with staves of different length; the shortest stave limits how far the barrel can be filled (Figure 3). In effect agricultural production is controlled not by the total amount of resources available but by the scarcest resource (the limiting factor). It is this assumption that underpins the ALC, i.e. the most limiting physical factor determines the final ALC grade. However, this assumption will only be valid if all the factors assessed to determine the final ALC grade (i.e. climate, gradient, microrelief, risk of flooding, soil texture, depth and stoniness, chemical limitations, soil wetness, droughtiness and soil erosion) are equally important determinants of agricultural production.

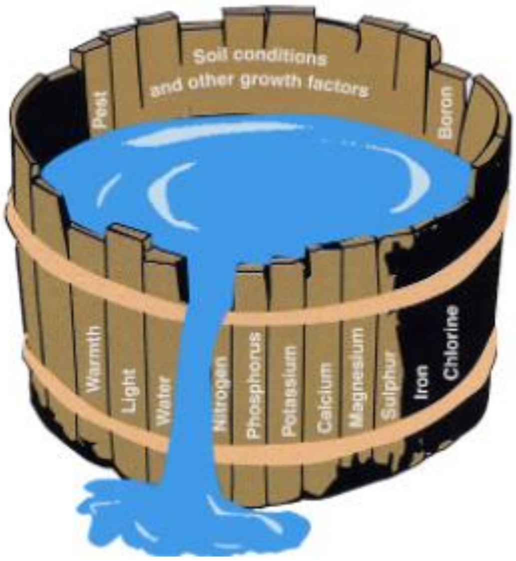

Figure 3. Liebig's Law of the Minimum; the factor in the shortest supply is the most limiting.

- Other land quality assessments use different approaches. For example, the German Muencheberg Soil Quality Rating (MSQR) systems uses eight basic indicators which are given a score of 0, 0.5, 1, 1.5 or 2 (0 is poor, 2 is good) (Mueller *et al.,* 2007); the indicators are then weighted by adding an appropriate multiplier (ranging from 1-3) according to their importance to crop production (Table 1 shows an example where the basic score is 23). The most important factors (which have the highest weighting factor) are soil substrate, rooting depth, profile available water and wetness and ponding. To calculate the final rating a series of thirteen hazard indicators are subsequently assessed and used to modify the final score. Each hazard is given a score ranging from 0 to 2 (as above); a multiplier is then allocated according to the hazard score (from <0 to 3). Finally the lowest multiplier allocated to any of the 13 hazards is applied to the basic score (e.g. 23 (basic score) x 3 (lowest multiplier) = 69 (final score), Table 1. Final scores indicate a soil quality rating of very poor: <20, poor: 20-40; moderate: 40-60; good: 60-80 and very good: >80.

- Future reviews of the ALC should consider whether a weighting system is appropriate for the ALC. Although the ALC recognises that "climate can be overriding in the sense that severe limitations will restrict land to low grades irrespective of favourable soil of site conditions" it is given equal weighting in the final grading.

Table 1. Example of Muencheberg Soil Quality Rating (MSQR) score and weighting factors (Source: Mueller *et al*., 2007).

Basic indicator		**Score**	**Weighting factor**	**Total**
1	Soil substrate	1.5	3	4.5
2	A horizon depth	1.5	1	1.5
3	Topsoil structure	1	1	1
4	Subsoil compaction	1.5	1	1.5
5	Rooting depth	1	3	3
6	Profile available water	2	3	6
7	Wetness and ponding	0.5	3	1.5
8	Slope and relief	2	2	4
Total basic score				***23***
Hazard indicator		**Score**	**Range of multiplier**	**Multiplier**
1	Contamination	2	0.01 to 3	3
2	Salinisation	2	<0.05 to 3	3
3	Sodification	2	<1 to 3	3
4	Acidification	2	<2 to 3	3
5	Low nutrient status	2	1 to 3	3
6	Soil depth above hard rock	2	<0.1 to 3	3
7	Drought	2	<0.1 to 3	3
8	Flooding and extreme waterlogging	2	<0.1 to 3	3
9	Steep slope	2	0 to 3	3
10	Rock at the surface	2	<0.5 to 3	3
11	Coarse soil texture fragments	2	<0.5 to 3	3
12	Unsuitable soil thermal regime	2	<0.5 to 3	3
13	Miscellaneous hazards	2	<0.5 to 3	3
Lowest multiplier				***3***
Final score (23 x 3)				***69***

4.3 The current scope of ALC

- The purpose of the ALC, since inception, is to identify high quality agricultural land so it can be taken account of in development management and land use decisions. In recent years, the ALC system has been used for a wider range of purposes, including the Welsh Predictive ALC and the Welsh Government's Capability, Suitability and Climate programme (CSCP). These have refined the spatial distribution of ALC grades at Welsh level and identified changes in land capability/suitability under different climate scenarios. It is important that any future revisions to ALC retain the ability to identify the agricultural capability of land. This will ensure that the agricultural function is fairly represented in the decision balance for policy development, land use and development management decisions. It is also important that alternative uses for the system are explored. Due to the original brief, the ALC system does not consider the sustainability of production or the wider environmental or amenity value of any land. Environmental and amenity considerations are, however, dealt with separately in the planning system by other specialist assessments.

4.4 Potential future scope of the ALC

- Both the UK and Welsh Governments have set out plans to reward farmers and land managers for sustainable farming practices. In England, the Sustainable Farming Incentive (SFI) will pay farmers to provide public goods such as water quality, biodiversity, animal health and welfare and climate change mitigation, alongside food production. Similarly, in Wales the proposed Sustainable Farming Scheme (due to begin in January 2025) will reward farmers for delivering sustainable land management outcomes (e.g. promoting carbon storage, soil and water quality, flood and drought risk mitigation). The increased emphasis on sustainability could potentially be reflected in the ALC if the remit of the scheme was expanded. However, this is outside the current scope of the ALC which is focused on identifying high quality agricultural land.

- As the policy importance of climate change and, ecosystem services increases, preserving the best agricultural land (i.e. ALC Grades 1, 2 and 3a) for food production alone, may not be the most economic or sustainable land use. Sustainable agricultural production must consider the capability of land to deliver short and long-term food production potential along with other ecosystem services. For example, in Germany, Schiefer *et al.* (2015) investigated soil and land characteristics that could be used to identify arable soils with the most potential for sustainable intensification (increasing yield per unit of input). Organic carbon, clay and silt content, pH, cation exchange capacity, soil depth and slope were identified as the most suitable indicators. Each indicator was allocated a score ranging from 1 (poor) to 4 (excellent); for example, a soil organic carbon content of >4% was rated excellent whereas a SOC content of <1% was rated poor. Scores were then summed to calculate a final score for sustainable intensification (SI) ranging from 6 to 20 and categorised into four groups 1) extensification suggested (score 6-10), 2) not recommended for SI (score >10 with one or more indicators in poor condition), 3) recommended for SI with restrictions (score 11-15) and 4) recommended for SI (score 16-20). A comparison of the SI scores and Muencheberg Soil Quality Rating-MSQR for the same land showed that the most suitable land for SI often had the highest intrinsic yield potential (i.e. it scored highly in the MSQR). However, on some sites which had a high MSQR the SI was low indicating that they were not suitable for sustainable intensification. Similar methodology could theoretically be included in the ALC to identify land that was potentially suitable for sustainable intensification. It is possible that this information could be useful to decision makers in the planning process as an additional marker of high quality agricultural land. However, adopting a system such as that described by Schiefer *et al*. (2015) could create difficulties if used in the context of planning decisions. Potentially, land could change class through relatively short/medium term management history and not long term biophysical differences. This differs from the founding principles of ALC, which classify land according to the extent which its physical or chemical characteristics impose long-term limitations on agricultural use.

4.5 Land capability or suitability

- Agricultural land capability assesses the nature of limitations and degree of limitations imposed on cultivated agriculture by the physical characteristics of a land unit (Bock *et al*., 2018). It is the general assessment of, for example, climatic and soil factors without taking into consideration the current agricultural usage. In comparison, 'land suitability' is an estimate of the fitness of a soil and its landscape for production of a specific agricultural crop (FAO, 1976).
- To some extent the appropriateness of either type of model (capability or suitability) depends on the specific aim of the land assessment. Crop suitability models are designed to be more specific than capability models and may be designed for specific crops, or more usually, broad groups of similar crops (e.g. cereals, oilseeds, maize, root crops etc.). A suitability approach gives a good overview of what crops can be grown in a specific area. In comparison, ALC (an assessment of land capability) is designed to inform land use planning by giving developers a means to compare the quality of agricultural land in England and Wales. A general capability system is good for this purpose.

4.6 Changes in cropping

- Since the inception of the ALC the range of crops grown in England and Wales has changed. However, grassland agriculture (permanent + temporary grass) still predominates in Wales and accounts for around 50% of the area on agricultural holdings in England. In addition, traditional arable crops such as cereals, oilseeds and potatoes continue to dominate arable land in both England (c.80% of cropped land) and Wales (c.60% of cropped land). Consequently, there is limited value in including guidance for new crop types, particularly given that ALC guidance is not intended to indicate the potential for any specific crop type.

4.7 Climate averages

- The ALC system allocates a grade for a particular parameter (e.g. slope or climate) in relation to a series of values that relate to each class. This simple approach works well for parameters that do not show much interannual variability; for example, grade according to gradient is unlikely to change from year to year. However, for climate parameters there may be large year to year variability in rainfall or temperature, consequently the mean or median value may not adequately capture the range of the data.
- Previous changes in climate parameters used to assess land capability has focussed on shifts in long-term multi-year averages that are a feature of established classification systems. However, shorter term climate variability has a very important role in influencing the land capability (Hudson and Birnie 2000). Land where short term (e.g. annual) variation in climate has a significant impact on capability should intuitively have a lower rating than the equivalent land with the same average land capability but a more stable annual class (Brown and Castellazzi, 2014). High variability may effectively constrain some land use options due to the higher risks involved. Currently, established classification systems do not incorporate the impact of climate variability, despite its increasing relevance for adaptive resource management in a changing

climate (Brown and Castellazzi, 2014). This is likely to be because many are used in long-term planning decisions where stability in grading between years is needed. However, short-term variability is undoubtedly important and should be considered in any future reviews of the ALC.

- Van Orshoven *et al.* (2014) identified a series of bio-physical criteria to define natural constraints for agriculture in Europe. To account for between-year variability of temperature accumulation, precipitation amount, evaporative demand and for the soil water balance; those characteristics were classified as either not limiting or severely limiting using a probabilistic approach. An area was classified as constrained if the probability of exceeding the severe annual limit was more than 20% of the number of years in the time series (for example in 7 years out of 30). The two approaches are compared in Table 2 (below) using an example dataset for field capacity days over a 30-year period. The example dataset for FCD in Table 2 shows the average and median FCD along with the probability of exceeding a threshold of ≥230 FCD (the severely limited criteria for 'excess soil moisture' used by Van Orshoven *et al*., 2014). For this example, only the probabilistic method results in the area being classified as severely limited. This reflects the ability of the probabilistic method to capture the range of the dataset rather than either the mean or the median. The ALC uses the median, which is a better measure of central tendency than the mean when the values being analysed have a skewed distribution.
- Climate change predictions suggest that the weather is likely to become more extreme in the future (IPCC, 2020). This suggests that, in the future, it will be more important to consider not just the average climatic conditions when allocating an ALC grade for climate but also the variation around that average.

Table 2. Example FCD dataset

30-Year FCD dataset	Average	Median	Number of times ≥230 FCD
230, 200, 160, 200, **230**, 200, 220, 200, 190, **250**, **230**, 200, 160, 200, **230**, 200, 220, 200, 190, **250**, **230**, 200, 160, 200, **230**, 200,220, 200, 190, **250**	208	200	9 (30%)

5 Review of ALC research

- Any review of the ALC system should consider the findings from relevant research. This will ensure that that any future review of the ALC system is focused on those areas where the need for updating has been identified. To establish the scope of future updates to the ALC this section of the report has reviewed available research of relevance to the ALC. Reviewed publications are listed in Table 3, below, along with a short summary of each report.
- Subsequent sections of the report have reviewed:
    - The ALC climatic dataset
    - Climatic limitations (overall, aspect, frost and wind)
    - Site limitations (gradient, microrelief and flooding)
    - Soil limitations (texture, depth, stoniness and chemical)
    - Interactive limitations (soil wetness, droughtiness, irrigation and erosion).

Table 3. Publications reviewed in this report

Author	Title	Short summary of scope of work
ADAS 1993	Agricultural Land Classification. Assessment of disturbed and contaminated land.	Guidance on the methodology and procedures to be used in assessing disturbed land using the ALC. Additional guidance and specific limitations affecting reinstated, restored or toxic land, land subject to subsidence or contaminated by landfill gas.
ADAS, 1994a	Second revision of the Agricultural Land Classification. Report on the work carried out by ADAS under the 1993/94 Land Use Memorandum of Understanding	First phase of the ADAS work programme to revise the ALC. Selected revision of non-climate parts of the ALC Assessment of the impact of new climatic data on ALC grading
ADAS, 1994b	Revised statistics for the proportion of ALC Grades. Report on the work carried out by ADAS under the 1993/94 Land Use Memorandum of Understanding	New statistics for the proportion of ALC grades using updated climatic dataset.
ADAS, 1995	Second revision of the Agricultural Land Classification. Report on the work carried out by ADAS on the spatial distribution of grade changes. 1994/95 Land Use Memorandum of Understanding. Part 1 of 2. Part 2 of 2	Second phase of the ADAS work programme to revise the ALC. Spatial distribution of grade changes by reference to soil type (77 soil associations)
MAFF and WOAD, 1995	Agricultural Land Classification of England and Wales Guidelines and criteria for grading the quality of agricultural land. Second Revision Draft – December 1995	Revision of ALC criteria following ADAS reviews in 1994. Inclusion of specific guidance for disturbed land, identification of slightly gleyed horizon. No change to reference climate dataset. Note: the updated version of the ALC was never published and current official guidelines are still those from 1988.
ADAS, 2004	To improve the process of land use planning through the development of a modern, high resolution and robust climate database for use in Agricultural Land Classification. Defra project code: LE0216	Defra funded review of the climate data for the ALC.

Author	Title	Short summary of scope of work
Keay *et al*., 2014	The impact of climate change on the capability of land for agriculture as defined by the Agricultural Land Classification (SP1104) Defra project code: SP1104	A study for Defra and the Welsh Government to assess how future changes in climate might affect agriculture in England and Wales using the ALC as a surrogate measure. The project used the UKCP09 climate change scenarios.
Keay 2020	Rerun SP1104 with UKCP18 data Welsh Government Capability, Suitability & Climate Programme. Report CSCP06	This study repeated the modelling undertaken in SP1104 (Keay *et al*., 2014, above) using the UKCP18 climate change scenarios
Van Orshoven *et al*., 2014	Updated common bio-physical criteria to define natural constraints for agriculture in Europe	Definition and scientific justification for biophysical criteria chosen to define natural constraints. Includes soil texture, depth, stoniness and chemistry, slope and climatic factors.
Tompkins *et al*, 2015	Agricultural Land Classification Review	A review of the methods and data currently used to determine ALC grades and to identify alternative options for effective implementation. Three options considered in more detail, i.e., an automated system (combining ALC maps and soil data into a GIS system), zoning (by land classification) and updating climatic data and methods.
Rollett and Williams, 2019	ALC technical review (part 1) Welsh Government Soil Policy Evidence Programme 2018-2019. Report: SPEP2018-19/12	A review of the ALC criteria for slope, soil stoniness and depth and methods for determining soil texture.
Keay and Hannam, 2020	The effect of Climate Change on Agricultural Land Classification (ALC) in Wales Welsh Government Capability, Suitability & Climate Programme. Report: CSCP05.	Uses the most recent UK Climate projects (UKCP18) to investigate changes in land quality (as determined by ALC) for 2020, 2050 and 2080.
Rollett and Williams, 2020	ALC technical review part 2 – climate, site and interactive limitations. Welsh Government Soil Policy Evidence Programme 2019-2020. Report: SPEP2019-20/04	A review of the ALC criteria for aspect, frost, wind, micro-relief, flooding, irrigation and erosion.
Rollett and Williams, 2021	ALC technical review part 3: droughtiness Welsh Government Soil Policy Evidence Programme 2020-2021. Report: SPEP2020-21/02	A review of the ALC criteria for drought and validity of the current reference dataset

Author	Title	Short summary of scope of work
Nicholson, Williams and Hill, 2020	ALC technical review part 4: Grading of agricultural land with elevated PTE concentrations under the ALC system. Welsh Government Soil Policy Evidence Programme 2020-2021. Report: SPEP2020-21/05	A review on the potentially toxic element limit values to be used in the ALC system.
Rollett and Williams, 2022	ALC technical review part 5: soil wetness Welsh Government Soil Policy Evidence Programme 2021-2022. Report: SPEP2021-22/	A review of the ALC criteria for soil wetness.

6 ALC climate datasets

- The climatological data underpinning the ALC system and the origin and methodology for deriving it is described in the 1989 Meteorological Office publication: 'Climatological Data for Agricultural Land Classification', which was prepared in association with MAFF and the Soil Survey and Land Research Centre (SSLRC). The dataset comprises location, altitude, rainfall, temperature, soil moisture deficit and duration of field capacity datasets with a 5 km grid spacing.
- Climatic data are used in ALC for the assessment of climate, droughtiness and wetness limitations. To provide consistency in those assessments a standard data source was required for the calibration and operation of the system. Grid point datasets with a spacing of 5 km were assigned to the whole of England and Wales and standard methods were devised for estimating the value of each parameter at any location.
- The five agroclimatic parameters used in the ALC system (average annual rainfall, average summer rainfall, median duration of field capacity, median accumulated temperature >0°C, January to June and median accumulated temperature >0°C, April to September) and the associated limitation factors are listed in Table 4. The field capacity dataset was compiled by the SSLRC based on Meteorological Office data. The other datasets were compiled by the Meteorological Office and processed by the SSLRC prior to their incorporation in LandIS[5]. Datasets of altitude and of average annual rainfall change with altitude (i.e. lapse rate of AAR) are also held on LandIS for use in the interpolation from grid point values to site values.

Table 4. Agroclimatic parameters used in the ALC system. Source (Meteorological Office, 1989)

Limitation Factor	Parameter	Observation period
Climate	Average annual rainfall (AAR) Median accumulated temperature >0°C, January to June (AT0)	1941-1970 1961-1980
Soil wetness	Median duration of field capacity days (FCD)	1941-1970
Soil droughtiness	Average summer rainfall, April to September (ASR) Median accumulated temperature >0°C, April to September (ATS)	1941-1970 1961-1980

6.1 Rainfall data

- The ALC system uses rainfall data in the following ways, 1) AAR is used directly in the assessment of overall climate and 2) ASR is used in combination with temperature data to calculate moisture deficits that are used in the droughtiness assessment.
- The reference rainfall data for ALC is based on records from several thousand rain gauges for the years 1941-1970. Grid point AAR values (mm) were interpolated from unpublished rainfall maps at a scale of 1:250,000, on which the published 1:625,000 map for 1941-70 was originally based (Meteorological Office, 1977). Grid point ASR values (mm) were manually interpolated from an unpublished 1:625,000 scale map of average summer rainfall for 1941-70. The rate at which

[5] The Land Information System (LandIS) is a soils focused information system for England and Wales operated by Cranfield University. It contains soil and soil-related information for England and Wales including spatial mapping of soils at a variety of scales, as well as corresponding soil property and agro-climatological data. LandIS is recognised by UK Government as the definitive source of national soils information. https://www.cranfield.ac.uk/themes/environment-and-agrifood/landis

rainfall changes with altitude (lapse rate) is used to enable grid point values of AAR to be interpolated for intermediate locations between grid points.

6.2 Temperature data

- The ALC system uses temperature data in the following ways, 1) AT0 is used in the assessment of overall climate and 2) ATS is used in combination with rainfall data to calculate the moisture deficits that are used in droughtiness assessment.
- The AT0 dataset for the ALC is based on temperature data from the 94 stations in the Complete Agromet Database (Field, 1983), which had complete records over the period 1961-1980. Accumulated temperatures for the period January to June each year were computed for each station from daily measurements of maximum and minimum temperature, and the median value of AT0 in the period 1961-80 was determined. The median values were then extrapolated to grid points by means of a regression equation which related accumulated temperature, altitude, latitude (National Grid northing) and longitude (National Grid easting).

6.3 First review of ALC climatic datasets: ADAS, 1994

- Following the Met Office publication of rainfall and temperature data for the international standard climatological period of 1961-1990, ADAS (1994a,b) assessed the potential impact on ALC grading should the new dataset replace that in current use (the 1988 dataset[6]).
- The 1994 data reported that AAR had increased by 1-5% across England and Wales, in comparison to the 1988 ALC dataset. In most areas[7] reported rainfall volumes were similar for the two datasets (<50 mm differences) however larger changes were noted in high rainfall areas, particularly Cumbria and upland Wales. Across most areas of England accumulated temperatures in the 1994 dataset were greater than in the 1988 dataset. However, accumulated temperature for Wales was typically 0 to 50 day degrees lower in the 1994 dataset; according to ADAS (1994a,b) this reflected overestimation of temperatures in the earlier dataset.

6.3.1 ALC grade for climate

- ADAS (1994a,b) used the relationship between AT0 and AAR (Figure 6, page 36) to obtain the overall grade for climate. The impact of the new climate data on ALC grade for climate is shown in Table 5 for England and Table 6 for Wales. Overall, in England 11% of grid points were upgraded by 1 ALC grade, compared to Wales where 20% of grid points were upgraded by 1 ALC grade. However, it is important to note that the changes to climate grade will only change the overall ALC grade at the 6% of sites where climate is the most limiting factor climate.

[6] The 1988 dataset is used to assess the ALC grade for climate (and as part of the assessment of other limitations). However, note that the Met Office did not publish this data “Climatological Data for Agricultural Land Classification” until January 1989 and as a result, it is often referred to as the 1989 dataset.

[7] The areas used were old MAFF regions, i.e., Northern, Midlands and West, Eastern, Southeast, Southwest and Wales.

Table 5. England: change to overall climate grade from 1988 to 1994 climatic data at 5 km grid intersections (number of grid points). Blue: no change; green: upgrade (e.g. 2 to 1); orange: downgrade (e.g. 1 to 2). Source: ADAS, 1994a.

		1988 climatic data[1]					
	Grade	1	2	3a	3b	4	5
1994 climatic data	1	3716	350	4			
	2	81	425	92	20		
	3a		42	83	53	4	
	3b		7	27	121	58	
	4			1	31	304	38
	5					15	64

1. Met Office, 1989.

Table 6. Wales: change to overall climate grade from 1988 to 1994 climatic data at 5 km grid intersections (number of grid points). Blue: no change; green: upgrade (e.g. 2 to 1); orange: downgrade (e.g. 1 to 2). Source: ADAS, 1994a.

		1988 climatic data[1]					
	Grade	1	2	3a	3b	4	5
1994 climatic data	1	191	60				
	2	9	87	27	7		
	3a		19	31	29	4	
	3b		5	11	79	43	
	4			2	20	247	25
	5					6	13

1. Met Office, 1989.

6.3.2 Overall ALC grade

- Data from the National Soil Inventory (NSI) (data points at 5 km intervals across England and Wales) was used to compare differences in overall ALC grade using 1988 and 1994 climate data (ADAS, 1994a,b). ALC Grades were calculated for each point by assessing the grade for climate, gradient, flooding, soil depth, stoniness, chemistry, wetness, droughtiness and erosion. The most limiting factors were then identified, and the resulting grade applied to the data point. Overall, there was little difference in the distribution of ALC Grades using 1988 or 1994 climatic data (Table 7). The data showed that for England and Wales 17% (819) of the NSI datapoints changed ALC grade when the 1994 climate data was used. There was a noticeable downgrading from Grades 1 and 2 and subsequent increases (+25 NSI datapoints) in Grades 3a (mostly gains from Grade 2) and 3b (+194 NSI datapoints) (elevations from both 3a and 4) (Table 8).
- Analysis of the most limiting factor showed that wetness, drought, climate and slope were the most important individual factors (Table 9). Overall, for England and Wales, wetness was the most limiting factor for 39% and 37% of datapoints using the 1988 and 1994 datasets, respectively. In comparison, droughtiness determined ALC grade at 17% and 21% of the datapoints using the 1988 and 1994 datasets, respectively. Only in the Southeast region was there a change in the relative importance of the limiting factors with wetness the most limiting using the 1988 dataset and droughtiness the most limiting factor using the 1994 dataset.

Table 7. Proportion of land in each ALC grade (%) using 1988 or 1994 climatic data and the NSI dataset[1]. Blue: no change; green: upgrade (e.g. 2 to 1); orange: downgrade (e.g. 1 to 2). Source: ADAS, 1994a.

	Grade 1	Grade 2	Grade 3a	Grade 3b	Grade 4	Grade 5
1988 Data[2]						
England and Wales	2.3	16.9	19.3	35.4	15.0	11.1
Wales	0.0	4.8	10.9	25.9	29.4	29.1
English Regions						
Northern	1.6	12.0	13.5	31.1	17.5	24.4
Midland and West	3.3	20.3	17.9	41.1	12.2	5.1
Eastern	3.4	31.5	34.5	27.8	2.8	0.1
Southeast	4.0	22.7	22.3	43.0	6.9	1.2
Southwest	1.5	7.9	15.0	46.2	23.2	6.2
1994 Dataset						
England and Wales	2.0	14.0	19.9	39.4	14.7	10.1
Wales	0.0	3.9	10.3	28.2	29.8	27.9
English Regions						
Northern	1.4	12.0	13.5	33.7	18.9	20.5
Midland and West	2.9	16.8	21.1	44.2	10.1	4.9
Eastern	2.9	21.8	35.8	35.4	4.0	0.1
Southeast	3.4	18.9	23.4	45.9	7.2	1.2
Southwest	1.1	8.9	13.0	51.0	19.6	6.3

[1]The overall ALC grade (based on all limitations) was computed twice for each grid intersection at which an agricultural use was recorded, the first time using the 1988 climatic dataset and the second time using the 1994 climatic dataset.

[2.]Met Office, 1989.

Table 8. England and Wales: change to overall ALC grade using 1988 or 1994 climatic data and the NSI dataset (number of grid points)[1]. Blue: no change; green: upgrade (e.g. 2 to 1); orange: downgrade (e.g. 1 to 2). Source: ADAS, 1994a.

	Grade	**1988 climatic data[2]**					
		1	**2**	**3a**	**3b**	**4**	**5**
1994 climatic data	**1**	82	13				
	2	29	600	42	3	1	
	3a		200	693	64	2	1
	3b		3	199	1568	123	13
	4				77	591	41
	5			1		7	481

[1]The overall ALC grade (based on all limitations) was computed twice for each grid intersection at which an agricultural use was recorded, the first time using the 1988 climatic dataset and the second time using the 1994 climatic dataset.

[2.]Met Office, 1989.

Table 9. Most limiting factors (% of data points) for 1988[1] and 1994 climatic datasets and the NSI data[2]. Yellow: most limiting factor. Grey: second most limiting factor. Source: ADAS, 1994.

Limit	England & Wales		Wales		Northern		Midlands & West		Eastern		Southeast		Southwest	
	88	**94**	**88**	**94**	**88**	**94**	**88**	**94**	**88**	**94**	**88**	**94**	**88**	**94**
Wetness	39.0	36.6	38.9	40.2	43.1	38.1	45.7	44.5	28.1	27.9	35.6	29.6	41.9	38.5
Drought	16.7	21.2	2.7	3.4	8.3	9.2	13.4	18.4	36.9	43.0	26.6	36.1	11.3	17.3
Climate	5.8	6.1	13.7	13.1	11.9	16.1	5.0	3.3	0.0	0.0	0.5	0.0	3.1	2.4
Slope	5.1	5.4	9.7	11.2	2.9	3.2	5.7	5.8	0.7	0.5	4.3	3.6	9.1	9.6

[1]Met Office, 1989.

[2]The overall ALC grade (based on all limitations) was computed twice for each grid intersection at which an agricultural use was recorded, the first time using the 1988 climatic dataset and the second time using the 1994 climatic dataset.

6.3.3 Recommendations

- ADAS concluded that the introduction of the new climatic data would have a significant effect on overall grading; a decrease of 0.3 and 2.9 percentage points for ALC Grades 1 and 2 respectively and increases of 0.6 and 4 percentage points for ALC Grades 3a and 3b, respectively. They noted that the nature and magnitude of the effect would vary geographically with a tendency towards upgrading in the west (where wetness is the dominant limitation) and downgrading in the east (where the impact of droughtiness will increase). ADAS (1994a,b) concluded that there was “no credible reason for changing or recalibrating the grading procedures to lessen the impact of introducing new climatic data”.
- Subsequent work by ADAS (1995) mapping changes in soil droughtiness and wetness for 56 soil associations showed that about half of the soils had some significant change. Grade change was often concentrated at a local scale, which might be expected if there were consistent changes in the climate data. However, the changes were often interspersed with land that did not change grade leading ADAS to conclude that many of the changes were due to ‘noise’ in the dataset and likely to be due to climatic data processing methods and not real change. As a result, ADAS recommended that the ALC should continue to be based on the 1988 dataset.

6.4 Second review of ALC climatic datasets: ADAS, 2004

- In 2004, Defra commissioned ADAS to undertake another review of the climate data for ALC. This followed the recalculation of the climate averages for the UK for 1971-2000. The major change in this dataset was the "interpolate then calculate" principle whereby all the interpolations were performed on the climate averages (i.e. climate-based averages from many stations were used to derive the gridded data, rather than building the regression from a subset of stations then interpolating across England and Wales). In contrast the current ALC uses the “calculate then interpolate” principal using AT0 and ATS values that were calculated for a sub-set of weather stations before being interpolated across England and Wales.
- The larger size of the dataset used in the updated methodology (interpolate then calculate) should result in a better representation of current climatic conditions. In addition, the larger dataset will better capture the variability within the data (e.g., differences caused by altitude) than the data subset used to calculate the current (1988) ALC dataset. However, depending on the subject of interest a calculate then interpolate or interpolate then calculate approach may be most useful in a given situation (McVicar and Jupp, 2002). For example, some authors have noted that where sample sizes are small the calculate then interpolate procedures performed better

than interpolate then calculate procedures (Bosma *et al*., 1994). Other authors have highlighted the reduced computational cost of the calculate then interpolate approach compared to the interpolate then calculate approach (Leterme *et al*., 2007).

- ADAS (2004) noted that temperatures in the 1971-2000 period were on average 0.3°C warmer than in the 1988 climate dataset. The higher temperatures were predicted to result in an increase of 55°C days which was equivalent to a 4% increase on a typical AT0 total of 1350°C days. It was also noted that average summer rainfall had changed by between +2% and -5% and average winter rainfall by between +2% and +5%, although there was little change in overall AAR.

6.4.1 Calculation of AT0 and ATS

- ADAS (2004) suggested a new method to derive AT0 and ATS, based on the mean monthly accumulated temperature above 0°C for 24 climatological stations over the 30-year period 1971 to 2000.
    - ATj = (0.42 + 0.49 (Txj) + 0.48 (Tnj)) x day

      Where ATj is the daily mean temperature for month j, Txj and Tnj are the monthly mean maximum and minimum air temperatures and a, b and c are regression constants. r^2 = 99% and standard error = 0.13°C.

- To calculate AT0 the equation was summed for January to June and for ATS, for April to September. The results from the regression plotted against the observed values (for the 24 climatological stations) of accumulated temperature are shown in Figure 4.
- ADAS (2004) suggested that this method had two main advantages over the ALC method described above. Firstly, the equation could be applied directly to the interpolated values for mean monthly maximum and minimum air temperatures. Secondly the previous dependence of the ATS calculation on the AT0 value was removed.

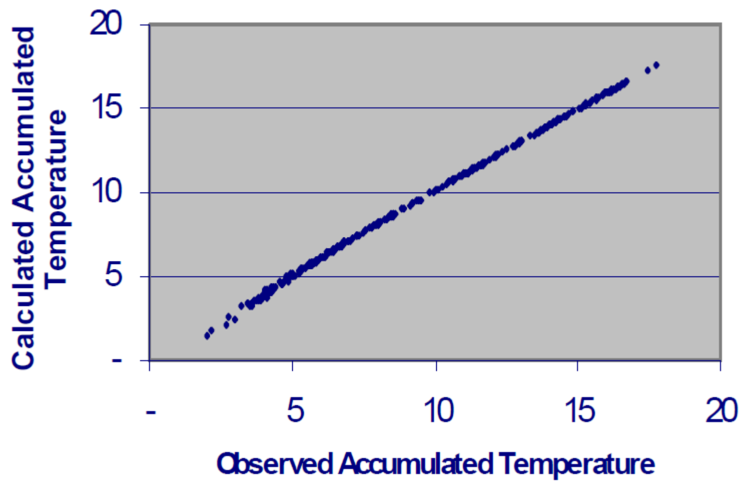

Figure 4. Daily mean accumulated temperature calculated compared to observed (Source: ADAS, 2004).

6.4.2 Calculation of field capacity days

- To calculate field capacity days, ADAS (2004) used a subset of 22 agroclimatic areas and values for return to and end of field capacity from Smith and Trafford (1976). The values were regressed against eastings, northings, altitude, average summer rainfall and average winter rainfall. Due to a measure of non-linearity the regressions were repeated separately for areas where the AAR was <800 mm (FCD_d) and >800 mm (FCD_w) (the authors noted that this approximately equated to above/below 175 FCD). The equations are:

- For areas with AAR<800 mm.

  FCD_d = -78.62+0.2221*ASR+0.3085*AWR+0.2152*ALT+0.00082*E+0.00794*N

- For areas with AAR>800 mm.

FCD_w = 47.50+0.0519*ASR+0.1856*AWR+0.1198*ALT+0.0054*E+0.00394*N

Where FCD is median field capacity duration (days), ASR is average summer rainfall (April to September, mm), AWR is average winter rainfall (October to March, mm), ALT is altitude in metres and E and N are eastings and northings.

- The predictive equation for the drier areas was tested against an additional sub-set of 11 agroclimatic areas to check on the accuracy of the estimated data, Figure 5. The mean error over the 11 areas was 3 days, suggesting the regression was able to accurately estimate FCD.

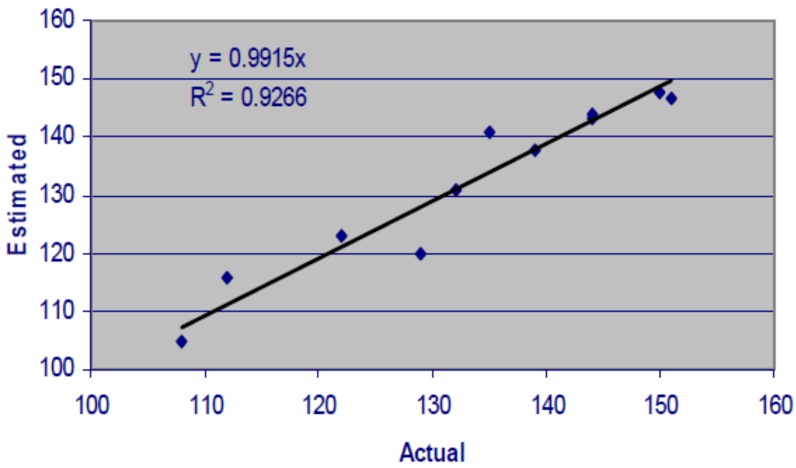

Figure 5. Check of FCD predictive equation. Actual: data from 11 agroclimatic areas from Smith and Trafford (1976) and estimated: calculated using ADAS equation for areas where AAR <800 mm. Source: ADAS, 2004.

6.4.3 Recommendations

- ADAS (2004) did not make any recommendations for updating the ALC dataset but noted that:
  - Higher temperatures will increase both AT0 and ATS
  - Moisture deficit values will be increased by lower ASR and higher ATS
  - FCDs will be reduced by lower ASR but increased by higher AWR.

6.5 Third review of ALC climatic datasets: Keay et al., 2014

- Keay *et al*. (2014) compared three methods for deriving January to June (AT0) and April to September (ATS) accumulated temperatures viz. (i) the original '1988 method' (MAFF, 1988), (ii) the '2004 method' (ADAS, 2004) and (iii) an improved '2010 method' (Table 10). Each method was applied to the same 1961-1990 dataset and the derived estimates of accumulated temperature were compared to the measured accumulated temperature for each of the stations for the 1961 to 1990 period. The comparison showed that the 1988 method underestimated the accumulated temperatures for both AT0 (-102°C) and ATS (-40°C), whereas the 2004 and 2010 method estimates were closer to the measured accumulated temperature.

- Keay *et al*. (2014) noted that when the original soil moisture deficit equations (from MAFF, 1988) for winter wheat and main crop potatoes (based on ATS and ASR) were extrapolated for future predictions the results were extreme with the whole of England and Wales assessed at ≤ALC Grade 4 for climate by 2080. As a result, the authors used the Met Office Rainfall and Evaporation Calculation System (MORECS) data to produce revised equations for soil moisture deficit, Table 11, below. The MORECS system uses input from daily observations (130 synoptic stations) and a modified Penman Monteith equation to calculate evapotranspiration, soil moisture deficit and excess rainfall over Great Britain. Outputs are averages over 40 x 40 km grid squares and daily estimates are available from 1961 to the present day.

Table 10. Methods for calculating accumulated temperature (Source: Keay *et al.*, 2014).

Year	Parameter	Equation	Summary
1988	Accumulated temperature (January to June) (AT0)	1708 - 1.14 (A) - 0.023 (E) - 0.044 (N)	A: altitude (m), grid intersection. E/N: national grid easting or northing
	Accumulated temperature (April to September)	611 + 1.11 (AT0) + 0.042 (E)	
2004	Daily mean accumulated temperature	ATj = (0.42 + 0.49 (Txj) + 0.48 (Tnj)) x NDIM	ATj: daily mean accumulated temperature Txj: mean max air temperature Tnj: mean min air temperatures for month j, NDIM: number of days in month
2010	Daily mean accumulated temperature	ATj >0°C =(0.4476 + (0.4854 *Tmax) + (0.4804*Tmin)) * NDIM	ATj: mean monthly accumulated temperature >0°C Tmax: daily mean max Tmin: daily mean min temperature all for month j. NDIM: number of days in month

Table 11. Equations for calculating soil moisture deficit for winter wheat (WWSMD) and main crop potatoes (MCPSMD) and average monthly summer temperature (AMST) (Source: Keay *et al.*, 2014).

Parameter	Equation	R^2
WWSMD	271.4754 + (-168.802 x LOG10 rainfall) + (10.00217 x temperature)	0.91
MCPSMD	337.8238 + (-185.614 x LOG10 rainfall) + (5.849057 x temperature)	0.90
AMST	0.00547 x ATS – 0.04	0.999

6.5.1 *Comparison of methods for field capacity days*

- Keay *et al*. (2014) used similar methodology to that used by ADAS (2004) (Table 12) but expanded the FC dataset to include 65 agroclimatic areas (from Smith and Trafford, 1976). In addition, data for ASR and AWR were normalised (using an inverse transformation) to eliminate the need for separate equations for wet and dry areas. The resulting equation (below) had an R^2 of 0.98 and small standard error of 6.4 days.
    - FCD = 367.14-(55007.8*INVASR) + (25867.3*INVAWR) + 0.000564*E + 0.004383*N + 0.1*ALT

    FCD is field capacity days
    INVASR is inverse transformation of average summer rainfall (April to September, mm)
    INVAWR is inverse transformation of average winter rainfall (October to March, mm)
    ALT, altitude in metres
    E and N are eastings and northings.

- The authors note limitations to these methods include the lack of temperature data, the use of area-based averages rather than climate station values, the estimate of altitude from a range (in the original source data) and the difficulty associated with accurate identification of the date of the end of field capacity.
- Keay *et al*. (2014) used MORECS estimates of FCDs to validate the FCDs estimates derived using the new FCD equation (above) for 1961-1990. The MORECS system uses input from daily observations from 130 synoptic weather stations to calculate evapotranspiration, soil moisture deficit and excess winter rainfall. The dataset was used to establish the end of FC (defined as the start date of a drying sequence of 10 days or more with a soil moisture deficit of ≥5mm) and the return to FC (defined as the start date of a wetting sequence of 10 days or more with a soil moisture deficit of <5mm). From these two dates, the median or 50th percentile value for the start and end dates were calculated for the 30-year period and used to validate the '2010 Method'.
- Initial validation was carried out by comparing values from the agroclimatic data from Smith and Trafford, 1976 and the FCD values calculated by Keay *et al*., 2014 for 10 agroclimatic zones (15 datapoints) for areas with AAR <1000 mm. The mean bias (comparison of the two datasets) was 17 days (i.e. the predicted values were 17 days higher than the reported values).
- The second stage of the validation compared the 2004 and 2010 methods with the MORECS estimates. In drier areas the MORECS estimates (based on soil moisture deficits) had a lower number of FCD than the 2004 and 2010 methods. However, where FCDs were >100, both predictive methods compared well with the MORECS data. A linear regression between the MORECS estimates and each of the predicted estimates of FCDs showed a strong relationship with an R^2 of approximately 0.93 for the '2010' method (the R^2 for the relationship between the 2004 method and the MORECS estimated was not reported).

6.5.2 *Recommendations*

- Keay *et al*. (2014) recommended that the climatic dataset underlying the ALC should be updated along with the equations that are used to calculate parameters such as AT0 and FCD. Specifically, that the "ALC system should be reviewed using contemporary weather and crop yield statistics to determine the significance of the droughtiness factor in the grading of agricultural land in England and Wales".

Table 12. Equations for calculation of field capacity day (FCD) used by ADAS (2004) and Keay *et al*. (2014).

Method	Parameter	Equation	Summary
ADAS 2004	FCD dry	-78.62+0.2221*ASR+0.3085*AWR+0.2152 *ALT+0.00082*E+0.00794*N	FCD: median field capacity duration (days) ASR: average summer rainfall (April to September) (mm) AWR: average winter rainfall (October to March) (mm) ALT: altitude in metres E and N: Easting and Northings
	FCD wet	47.50+0.0519*ASR+0.1856*AWR+0.1198 *ALT+0.0054*E+0.00394*N	
Keay *et al*., 2014	FCD	367.14-(55007.8*INVASR) + (25867.3*INVAWR) + 0.000564*E + 0.004383*N + 0.1*ALT	FCD: median field capacity duration (days) INVASR: inverse transformation of average summer rainfall (April to September) (mm) INVAWR: inverse transformation of average winter rainfall (October to March) (mm) ALT: altitude in metres E and N: Easting and Northings

7 The climate dataset

- The climate criteria used in the ALC system are average annual rainfall (AAR), average summer rainfall (ASR), median accumulated temperature >0°C from January to June (AT0) or from April to September (ATS) and median duration of field capacity days (FCD), Table 13. All the data are decades old, use dated spatial interpolation methods and the temperature datasets use non-standard climate reference periods[8]. In addition, several reviews of the datasets and methods have recommended that the data should be updated.

[8] 30-year periods are generally used to define climate averages because they are long enough to remove the influence of any inter-annual anomalies but short enough to be able to show longer climatic trends. 30-year time periods are also used as standard climate reference periods across the world, as recommended by the World Meteorological Organisation. The 30-year period refers to the most recent period ending with 0, e.g., 1981-2010 or currently 1991-2020 (WMO, 2017).

Table 13. Agroclimatic parameters used in the ALC system. Source (Meteorological Office, 1989)

Limitation Factor	Parameter	Observation period
Climate	Average annual rainfall (AAR) Median accumulated temperature >0°C, January to June (AT0)	1941-1970 1961-1980
Soil wetness	Median duration of field capacity days (FCD)	1941-1970
Soil droughtiness	Average summer rainfall, April to September (ASR) Median accumulated temperature >0°C, April to September (ATS)	1941-1970 1961-1980

7.1 The climate reference period

- The current climate reference period is 1991-2020 and the current baseline for historical comparison and climate change monitoring is 1961-1990 (WMO, 2017). The ALC datasets for rainfall pre-dates the historical baseline and the temperature dataset comprises of the first 20 years of the historical baseline, emphasising the need for updating.
- The ALC datasets were derived from average rainfall and temperature records collected over periods of either 20 or 30 years. The datasets were assembled using a combination of manual and computer methods. The rainfall data (from several thousand rain gauges) were obtained from small-scale rainfall maps (average annual rainfall values were plotted onto a topographic base map) for the period 1941-70. Temperature values for 1961-80 were computed using data from 94 climatological stations. An additional dataset for the median duration of field capacity (abbreviated to Field Capacity Days or FCD) was obtained from the Soil Survey of England and Wales (now Soil Survey and Land Research Centre or SSLRC). The FCD dataset was based on Met Office 1941-70 rainfall data.
- Climatic averages serve two major functions: as an implicit predictor of the conditions most likely to be experienced at any given location, and as a stable benchmark against which long-term changes in climate observations can be compared (WMO, 2017). Where a clear and consistent trend has been noted (e.g., increases in temperature), the predictive skill of climate averages is greatest if they are updated as frequently as possible. A 1991–2020 averaging period is more likely to be representative of conditions in 2021 than the 1961–1990 period. Conversely, there are clear benefits of using a stable benchmark as a reference point for long-term datasets, both in practical terms (not having to recalculate anomaly-based datasets every 10 years), and in terms of communication - an “above average” year does not suddenly become “below average” because of a change in reference period (WMO, 2017). As a result, WMO (2017) recommend that the average for both the most recent 30-year standard reference period (1991-2020) and the benchmark period (1961-1990) are calculated.
- In most countries, long-term datasets used for the monitoring of climate change are reported in spatially aggregated form (for example, a gridded dataset or an area-averaged anomaly derived from gridded data or the averaging of stations) (WMO, 2017). Consequently, averages from individual stations will most commonly be calculated as an intermediate step in the generation of a regional or gridded dataset, rather than used as standalone values.

7.2 Proposed new climate dataset for the ALC

- Weather and climate data for England and Wales is collated by the Met Office the national meteorological service for the UK. UK weather stations report a mixture of synoptic (snapshot hourly observations, e.g., hourly temperature) and climate (e.g. daily maximum and minimum temperature) observations.

- At the end of 2018 the Met Office made available the HadUK-Grid dataset which is a collection of climate variables derived from the network of UK weather stations[9]. It is suggested that this dataset could be used as the basis for updating the ALC climate dataset.
- HadUK-Grid differs from existing climate datasets in several key respects including higher spatial resolution, longer time series for some variables and improved consistency regarding the pre-processing of station observations (Hollis *et al*., 2019). The dataset includes key UK climate variables at up to 1 km resolution from 1862 for monthly rainfall, 1884 for monthly temperature, 1891 for daily rainfall, 1929 for monthly sunshine and a wider set of variables with start dates from the 1960s. To facilitate comparison of the observational dataset with the UKCP18 climate projections the dataset is also provided at 12 km, 25 km and 60 km resolution. All the gridded datasets use the same grid projection.
- The dataset interpolates weather station observations to a regular grid using methods developed for previous gridded datasets (Perry and Hollis, 2005a, 2005b and Perry *et al*., 2009). Daily, monthly, annual and long-term average datasets are available for a range of climate variables (Table 14). These include air temperature (maximum, minimum and mean), precipitation, sunshine, mean sea level pressure, wind speed, relative humidity, vapour pressure, days of snow lying, and days of ground frost. The number of stations used as input to the gridding varies with time; on average, air temperature is available from 540 and rainfall from 4400[10] stations, respectively.
- The long-term average (LTA) dataset, which uses climate data averaged over 30 years rather than annual data is of most relevance for the ALC. To calculate LTAs for HadUK-Grid the Met Office filled in any gaps in the 30-year period using linear regression against data from neighbouring stations; a weighted average of the estimates from six neighbours were used to determine the final estimate for the missing value. To generate the gridded datasets, the station LTAs were interpolated to a regular 1 km x 1 km grid of values covering the UK (the 'average then grid' approach). However, for some parameters (days of air frost, ground frost, thunder and snow cover) a different method was used which involved producing a grid of values for each month then obtaining the LTA by averaging the monthly grids (the 'grid then average' approach).
- Geographic effects were removed from the data prior to interpolation by using multiple regression with the station data as the dependent variable. The regression model was initially selected based on known relationships between topographical and geographical factors and climate and subsequently refined by adding/removing variables, changing the interpolation settings or changing the input data. The regression residuals[11] were then interpolated onto a regular grid using inverse-distance weighting (IDW). The value at each grid point was calculated as a weighted average of surrounding station values, the weighting function being 1/dp where d

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[9] https://www.metoffice.gov.uk/research/climate/maps-and-data/data/haduk-grid/haduk-grid
[10] https://www.metoffice.gov.uk/research/climate/maps-and-data/data/haduk-grid/faq#faq3
[11] Regression analysis produces a line of best fit describing the relationship between the dependant (the response variable being tested or measured) and independent (or explanatory) variables. Data points typically do not fall exactly on the regression equation line but are scattered around that line. Residuals are the difference between the observed value of the response variable and the value of the response variable predicted from the regression line (the predicted value). They are positive if they are above the regression line and negative if they are below the regression line. Residuals are sometimes called errors as they refer to the unexplained difference between the actual and predicted value. The sum of the residuals is 0.

is the distance and p is the power parameter. The method uses all data values within a specified search radius (which may be expanded if fewer than a predetermined number of stations are found).

Table 14. Available datasets in HadUK-Grid

Daily variables	**Definition**	**Start year**
Max air temperature	Max air temperature measured between 0900 UTC[12] on day D and 0900 UTC on day D+1 (°C)	1960
Min air temperature	Min air temperature measured between 0900 UTC on day D and 0900 UTC on day D+1 (°C)	1960
Precipitation	Total precipitation measured between 0900 UTC on day D and 0900 UTC on day D+1 (mm)	1891
Monthly, seasonal and annual variables		
Max air temperature	Average of daily max air temperature over the calendar month, season or year (°C)	1884
Min air temperature	Average of daily min air temperature over the calendar month, season or year (°C)	1884
Mean air temperature	Average of daily mean air temperature over the calendar month, season or year (°C)	1884
Precipitation	Total precipitation amount over the calendar month, season or year (mm)	1862
Sunshine	Duration of bright sunshine during the month, season or year (hours)	1929
Mean wind speed at 10 m	Average of hourly mean wind speed at a height of 10 m above ground level over the month, season or year (knots)	1969
Mean sea level pressure	Average of hourly (or 3-hourly) mean sea level pressure over the month, season or year (hPa	1961
Mean relative humidity	Average of hourly (or 3-hourly) relative humidity over the month, season or year (%)	1961
Mean vapour pressure	Average of hourly (or 3-hourly) vapour pressure over the month, season or year (hPa)	1961
Days of ground frost	Count of days when the grass minimum temperature is below 0°C (days)	1961
Days of snow lying	Count of days with greater than 50% of the ground covered by snow at 0900 UTC (days)	1971
Long term averages (LTA)		
1961 to 1990	Standard reference climatology period providing monthly, seasonal and annual averages for 1961 to 1990	
1981 to 2010	Standard reference climatology period providing monthly, seasonal and annual averages for 1981 to 2010	
1981 to 2000	20-year reference climatology period provided for use with UKCP18 products	

- The dataset is available for downloading via the Centre for Environmental Data Analysis (CEDA) archive[13] for registered users. Registration is straightforward and free. The data is available under

[12] Coordinated universal time or universal time coordinated. British summer time is UTC+1, Greenwich mean time is UTC+0
[13] https://archive.ceda.ac.uk/

open government licence which allows the information to be used "freely and flexibly with only a few conditions". Also, data may be copied, adapted and exploited both commercially and non-commercially[14]. The data are available in network common data format (netcdf) which can be manipulated and displayed using a variety of freely available and commercial or licensed software packages.

7.3 Proposed methods for updating ALC climatic parameters

7.4 Average annual rainfall

- The calculation of annual rainfall is the sum of the monthly totals. In the original ALC method AAR data was based on several thousand rain gauges for the 30-year period 1941-70. Average AAR values were plotted on to a 1:250,000 scale topographic base map and isohyets (lines connecting points with equal AAR) drawn manually. Grid point (5 km grid) values were obtained by interpolation using this base map. Similarly, ADAS (1994, 2004) used Met Office monthly mean rainfall data which had been interpolated to a 1 km grid (Perry and Hollis, 2005b).
- AAR for the most recent 30-year period of 1991-2020 based on the HadUK-Grid would be appropriate to update the rainfall data used in ALC. Rainfall averages for the 30-year reference periods (current and benchmark) derived from long-term average monthly gridded datasets at 1 km resolution are available.

7.5 Accumulated temperature

- For the original ALC dataset accumulated temperature was reported above the selected threshold (0°C) and over a specified period; AT0 is the median accumulated temperature above 0°C from January to June and ATS is the median accumulated temperature above 0°C from April to September. To calculate the daily weather station value for the original ALC data the daily mean temperature T_{mean} was calculated from the daily maximum temperature T_{max} and the daily minimum temperature T_{min} as $(T_{max} + T_{min})/2$. The degree-day value was estimated depending on which of T_{max}, T_{mean} or T_{min} were above the defined threshold (Table 15). Daily temperatures were then multiplied by the number of days in the month and accumulated over the required period. Median values were calculated for the period 1961-1980. Subsequently, a regression model with altitude, latitude and longitude was fitted to the AT0 weather station data to calculate grid point values.

  $AT0_g = 1708 - 1.14\ ALT_g - 0.023\ EAST_g - 0.044\ NORTH_g$
  ATO_g grid point value of AT0, ALT_g grid point value for altitude $EAST_g$ and $NORTH_g$ are the national grid easting and northing to 100 m

Table 15. Procedure for estimating degree-day value depending on which of T_{max}, T_{mean} or T_{min} were above 0°C

Daily T_{max}, T_{min} and T_{mean} above or below 0°C	Accumulated temperature
$T_{max} \leq T_{threshold}$	0
$T_{min} \geq T_{threshold}$	$T_{mean} - T_{threshold}$
$T_{mean} \geq T_{threshold}$ and $T_{min} < T_{threshold}$	$0.5\ (T_{max} - T_{threshold}) - 0.25\ (T_{threshold} - T_{min})$
$T_{measn} < T_{threshold}$ and $T_{max} > T_{threshold}$	$0.25\ (T_{max} - T_{threshold})$

[14] https://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/

- ADAS (1994) developed a new method for calculating mean accumulated temperature from monthly mean temperature values (the 1988 dataset used median AT0). However, there are no details of the method that was used to calculate AT0. Later, ADAS (2004) used a modified regression model to calculate the daily mean accumulated temperature. The equation was based on the relationship between the monthly mean, max and min temperature for 24 stations with complete temperature records over the 30-year period 1971-2000. This regression model was later updated by Keay *et al*. (2014) using data from 29 stations (the 2010 method). Keay *et al*. (2014) compared the estimated AT0 (calculated using either the ALC, 2004 or 2010 methods) with the measured AT0 for 29 weather stations for 1961-1990. The comparison showed that both the '2010' and '2004' methods performed significantly better than the '1988' method for the estimation of accumulated temperatures (i.e. the predicted AT0 was closer to the actual AT0).
- It is proposed that to update the AT0 for the ALC the accumulated temperature for the most recent 30-year climate period (1991-2020) should be calculated from the HadUK-Grid. In line with the methods used by ADAS (2004) and Keay *et al*. (2014) a subset of stations can be used to examine the relationship between the mean monthly AT0 and the mean maximum and minimum monthly temperatures (the January to June accumulated temperature is the sum of the six-monthly totals). The relationship (regression equation) can then be applied to the HadUK-Grid dataset following the interpolate then calculate principle. To validate the regression equation, derived estimates of AT0 should subsequently be compared to actual AT0 (for an earlier 30-year period).

7.6 Moisture deficit for wheat and potatoes

- The original ALC method for calculating moisture deficits for wheat (MDW) and potatoes (MDP) were based on methodology described by Jones and Thomasson (1985). The values for crop adjusted MD were obtained from MORECS based potential soil moisture deficit (PSMD) for the stations in the Complete Agromet Dataset. Subsequently the PSMD data was analysed to establish best fit multiple linear regression equations using ASR and ATS as the variables. This relationship was used to calculate grid point values. Both ADAS (1994) and ADAS (2004) used the ALC regression equation (combined with updated climate datasets) to derive a new MD dataset. Subsequently, Keay *et al*. (2014) used MORECS data to update the winter wheat and main crop potato predictive equations.
- Updating both the rainfall and temperature ALC datasets will require the regression equations for predicting MDW and MDP to be updated. New soil moisture deficit data can be obtained from MORECS for the most recent 30-year period (1991-2020). It will be necessary to regress the data against summer rainfall and temperature to produce an updated equation for predicting MDW and MDP.

7.7 Field capacity days

- The median duration of field capacity, measured in days, is used as the measure of climatic wetness in soil wetness assessment. The original ALC dataset is based on the work of Smith (1967), who used bi-weekly rainfall and monthly potential transpiration in a water abstraction model to estimate soil moisture status. The start of field capacity was defined as the date at which the soil moisture was no longer in deficit, and the end of field capacity was defined as the date when soil moisture deficit returned. The grid point values of FCD in the ALC dataset were produced by regression using a series of regional equations in which the climatic variable was average annual rainfall. Subsequently, ADAS (1994) calculated a new FCD dataset using updated

AAR data following the same principles as used in the ALC but using a national equation obtained from SSLRC. The equation is not defined in the ADAS (1994) report.

- The regression equation used to calculate FCD was modified by ADAS (2004) and Keay *et al.* (2014) using data on the start/end of field capacity from Smith and Trafford (1976) and based on relationships between ASR, AWR, altitude, easting and northing. ADAS (2004) derived regression equations for high (>800 mm)and low (≤800 mm) rainfall areas. In comparison, Keay *et al*. (2014) calculated a single equation for calculating FCD (rainfall components were normalised to eliminate the need for separate equations for wet and dry areas).

- It is proposed that the ALC data on the duration of FC is updated as it is currently based on 1941-70 climate data. However, the start and end of field capacity can be difficult to define. Based on the published methods of Francis (1981) and Smith and Trafford (1976), Keay *et al*. (2014) defined the end of field capacity as the start date of a drying sequence of 10 days or more with a soil moisture deficit of ≥5 mm. In contrast, the return to FC was defined as the start date of a wetting sequence of 10 days or more with a soil moisture deficit of <5mm. Alternatively, the JRC (in the guidelines for applying common criteria to identify agricultural areas with natural constraints) describe field capacity as zero soil moisture deficit (Jones *et al*., 2014). The authors identified the end of field capacity as the period when soil moisture content was >0 mm for ≥5 consecutive days (during the first part of the year – before summer). Conversely, the start of the field capacity period was defined when ≥5 consecutive days had a SMD <0 mm (during the second part of the year – after summer).

- As noted earlier, the published MORECS dataset calculates SMD and would enable the identification of the start/end of field capacity based on, for example, the number of days when SMD = 0 mm. The MORECS dataset uses data from synoptic weather stations which is then interpolated to a 40 x 40 km grid (approximately 200 grid squares cover the UK). The dataset is available on a daily, weekly or monthly timescale. The relationship between SMD and other climate or location variables would be appropriate to update the regression equation for predicting FCD.

7.8 Summary

- Table 16 below summarises the proposed datasets and sources for updating the ALC climatic parameters.

Table 16. Summary of proposed datasets and sources for updating the ALC climatic parameters

Dataset	Source	Details	Comments
Climate	Met Office HadUK-Grid dataset	Climate variables derived from the network of UK weather stations which have been interpolated to a regular grid. Daily, monthly, annual and long-term average datasets	The dataset includes key UK climate variables at up to 1 km resolution On average, air temperature is available from 540 and rainfall from 4400 stations, respectively. The long-term average (LTA) dataset, which uses climate data averaged over 30 years rather than annual data is of most relevance for the ALC Available for downloading via the Centre for Environmental Data Analysis (CEDA) Data is available under open government licence which allows the information to be used "freely and flexibly with only a few conditions".
Average annual rainfall (AAR)	Met Office HadUK-Grid	Total precipitation amount over the calendar month, season or year (mm)	Rainfall LTA monthly gridded dataset can be used to calculate AAR or ASR for the most recent 30-year period of 1991-2020
Average summer rainfall (ASR)			
Accumulated temperature January to June (AT0)	Met Office HadUK-Grid	Daily air temperature records. Maximum and minimum temperatures	A subset of stations can be used to examine the relationship between the mean monthly AT0 and the mean maximum and minimum monthly temperatures (the January to June accumulated temperature is the sum of the monthly totals). The relationship (regression equation) can then be applied to the HadUK-Grid dataset.
Accumulated temperature April to September (ATS)			

			To validate the regression equation, derived estimates of AT0 should subsequently be compared to actual AT0 (for an earlier 30-year period. The method can be repeated for ATS.
Field capacity days	MORECS dataset	Number of days when soil moisture deficit = 0 mm Start of the field capacity period (autumn): SMD <0 mm for ≥5 consecutive days End of field capacity (spring): SMD >0 mm for ≥5 consecutive days.	Data from synoptic weather stations interpolated to a 40 x 40 km grid (approximately 200 grid squares cover the UK). There is probably a cost for using the MORECs data.
Moisture deficit (wheat and potatoes)		July and August soil moisture deficit for wheat and main crop potatoes	It will be necessary to regress the data against summer rainfall and temperature to produce an updated equation for predicting MDW and MDP.

8 Climate extremes or episodic events

- A range of environmental factors can cause significant impact on crop yields and quality. Horticulture Research International (2008) assessed the vulnerability of UK agriculture to extreme climatic events. The authors categorised extreme events as one of two types. Firstly, low probability extreme weather events leading to critical physical and/or physiological thresholds being exceeded during sensitive stages of crop development, resulting in crop failure or significant loss of quality. Extreme weather events would include heat waves, periods of heavy or extended rain, gales or frosts. Secondly, extreme impacts where weather conditions affected crop growth or management resulting in substantial reduction in yield or quality. This could be a consequence of a single event, e.g. late spring frost, or prolonged weather conditions, e.g. warm winters or drier summers. Horticulture Research International (2008) concluded that most important factors affecting crop production were temperature (heat waves, frosts), water (drought, waterlogging) and storms (wind, hail, inundation).

8.1 Extreme events in land quality assessments

- In the assessment of land quality, dynamic variables (e.g. temperature which changes as the season progresses) are converted to static variables (i.e. a single value which stays the same). Hence, a key weakness in using summarised land qualities is that by treating dynamic variables in a static way much of the variability that is an essential property of the land and climate is removed (Hudson and Birnie, 2000). Whilst land evaluation methods based on this approach are of value in land use planning, it is more appropriate for land management decision making to have information on variability from which risk may be assessed (Hudson and Birnie, 2000).
- Previous work investigating changing land capability has focussed on shifts in long-term multi-year averages that are a feature of established classification systems (Brown and Castellazzi, 2014). However, shorter term variability also has a very important role in influencing the relative viability of different land-use systems (Hudson and Birnie 2000). In particular, inter-annual (between year) variability (IAV) is important for agriculture because of the key role of the annual cycle in both planning and management for crop or livestock systems (e.g. Reilly 2002).
- Shorter term variability influences land capability classifications because, although the established classification is based upon a long-term average, the results are sensitive to the period used to define the long-term average (Hudson and Birnie 2000; Brown *et al*. 2008). However, land that is significantly more variable from year to year should intuitively have a lower rating compared to equivalent land with the same average land capability but a more stable annual class (Brown and Castellazzi, 2014). High variability may effectively constrain some land use options due to the higher risks involved, meaning the land is less flexible in its uses. Currently, established classification systems do not incorporate this variability, despite its increasing relevance for adaptive resource management in a changing climate (Brown and Castellazzi, 2014).
- The work of Hudson and Birnie (2000) and Brown and Castellazzi (2014) highlighted the influence of annual changes in weather on LCA climate classes for Scotland. LCA classes for climate are based on the relationship between maximum potential soil moisture deficit (-250 to 0 mm) and accumulated temperature >0°C (up to 2000 day °C). In comparison, ALC classes for climate are based on the relationship between AAR (up to 5000 mm) and AT0 (up to 2000 day °C). Although the two systems use a different indicator of wetness (soil moisture deficit or rainfall) both are based on the principle that a warm dry climate should be graded more highly than a cool wet climate. Consequently, although the precise nature of the effects of episodic or extreme events

on land classification will be different in the two systems (LCA and ALC) the overarching trends will be similar.

- As noted, by Brown and Castellazzi (2014) during years of poor weather (i.e. too wet or too dry), climatic constraints will be more important factors than when the weather is good. When the weather is poor it is likely that land classified as ALC Grades 1 or 2 may experience management difficulties more commonly associated with land in lower Grades. During years of good weather, the constraints on land capability are likely to be dominated by intrinsic soil properties which will delimit the maximum extent for BMV land despite the favourable weather.
- Climate change predictions suggest that the weather is likely to become more extreme. This suggests that it will be more important to consider not just the average climatic conditions when allocating an ALC grade for climate but also the variation around that average. The World Climate Research Programme (WCRP) and WMO expert team on climate change detection and indices coordinate, organise and collaborate on climate extremes, indices and climate change detection (Met Office, 2018). This team have defined a set of 27 core indices which can be derived from land surface observations of daily temperature and precipitation (Table 17). A subset of these indices (highlighted in yellow in Table 17) have been calculated by the Met Office (2018) and could potentially be used as part of the ALC process to attempt to capture the risk of extreme events of relevance to agricultural crops.
- Further work is required to investigate how best to incorporate the influence of the probability of extreme events into the ALC methodology (e.g. frequency and severity of extreme events). Also to establish the methodology that would best capture the impact of weather extremes on agricultural land. Updates to the ALC could include the addition of new parameters (e.g., longest dry spell) or revision to current criteria (e.g. the use of percentiles rather than absolute values).

9 ALC climatic limitations

- Climate has a major and, in places, overriding influence on land quality by controlling both the range of agricultural uses and the cost and level of production. The most fundamental influence of climate is on the potential for plant growth, by determining the energy available for photosynthesis. However, climate also influences soil moisture, soil aeration, the number of field capacity days (i.e. when soils are wet enough for drainage to occur) and the ease of access to land to carry out field operations or for grazing by livestock (livestock are typically housed for longer when the climate is wetter/cooler to avoid damaging the soil/sward and for animal health/welfare).
- The main climatic factors currently considered in the ALC are temperature and rainfall, although account is also taken of seasonality (through the inclusion of summer temperature and rainfall) and of local factors such as exposure, aspect and frost risk which are considered on a site by-site basis. Climatic criteria are considered first when classifying land as severe limitations will restrict land to low grades irrespective of favourable soil or site conditions.

Table 17. Climate indices. Yellow highlighted indices were calculated by the Met Office and reported in 'State of the UK climate 2017: Supplementary report on climate extremes'. (Source: Met Office, 2018).

Index	Derived from	Resolution	Description
High temperature			
No of summer days	Daily max temperature	Monthly	No days when the daily max temperature >25°C
No of tropical nights	Daily min temperature	Monthly	No days when the daily min temperature >20°C
Highest max. temperature	Daily max temperature	Monthly	Highest daily max temperature during the month
Highest min. temperature	Daily min temperature	Monthly	Highest daily min temperature during the month
% of warm nights	Daily max temperature	Monthly	% of days when the daily min temperature is >90th percentile centred on a 5-day window for the base period of 1961-1990.
% of warm days	Daily max temperature	Monthly	% of days when the daily max temperature is >90th percentile centred on a 5-day window for the base period of 1961-1990.
Warm spell duration index	Daily max temperature	Monthly	Count of days with ≥6 consecutive days when daily max temperature >90th percentile.
Low temperatures			
No of icing days	Daily max temperature	Monthly	No of days when the daily max temperature is <0°C
No of frost days	Daily min temperature	Monthly	No of days when the daily min temperature is <0°C
Lowest max temperature	Daily max temperature	Monthly	Lowest daily max temperature during the month.
Lowest min temperature	Daily min temperature	Monthly	Lowest daily min temperature during the month
% of cool nights	Daily min temperature	Monthly	% of days when the daily min temperature is <10th percentile centred on a 5-day window for the base period of 1961-1990.
% of cool days	Daily max temperature	Monthly	% of days when the daily max temperature is <10th percentile centred on a 5-day window for the base period of 1961-1990.
Cold spell duration index	Daily min temperature	Monthly	Count of days with ≥6 consecutive days when daily min temperature <10th percentile.

Index	Derived from	Resolution	Description
Other temperature			
Growing season length	Daily mean temperature	Monthly	Count between first span of at least 6 days with mean temperature>5°C and the first span after July 1st of 6 days with mean temperature <5°C
Daily temperature range	Daily max and daily min temperature	Monthly	Average difference between daily max and daily min temperatures
Rainfall indices			
Max. 1-day precipitation	Daily Precipitation	Monthly	Highest value of daily rainfall
Max 5-day precipitation	Daily Precipitation	Monthly	Highest value of rainfall accumulated over 5 days
Simple precipitation intensity index	Daily Precipitation	Monthly	Total precipitation falling on wet days (≥1 mm) divided by no of wet days
Days of rain 1 mm	Daily Precipitation	Monthly	No of days with ≥1 mm rainfall
Days of rain 10 mm	Daily Precipitation	Monthly	No of days with ≥10 mm rainfall
Days of rain 20 mm	Daily Precipitation	Monthly	No of days with ≥20 mm rainfall
Longest dry spell	Daily Precipitation	Annual	Largest number of consecutive days with <1 mm rainfall
Longest wet spell	Daily Precipitation	Annual	Largest number of consecutive days with >1 mm rainfall
Rainfall from very wet days	Daily Precipitation	Annual	Total rainfall falling on days with daily rainfall total >95th percentile of daily rainfall
Rainfall from extremely wet days	Daily Precipitation	Annual	Total rainfall falling on days with daily rainfall total >99th percentile of daily rainfall
Total rainfall	Daily Precipitation	Annual	Annual total rainfall during the year

9.1 Temperature and rainfall

- Average annual rainfall (AAR), as a measure of overall wetness, and accumulated temperature, as a measure of the relative warmth of a locality are used to determine the grade according to temperature. Accumulated temperature is the excess daily air temperature above a selected threshold temperature, summed over a specified period. For the ALC climatic assessment, accumulated temperature is calculated (for temperature above 0°C), using an established algorithm (Meteorological Office, 1969, cited by Meteorological Office, 1989), for the period January to June (AT0) which is the critical growth period for most crops.
- The permitted combinations of AAR and AT0 for each ALC grade and subgrade are defined graphically in Figure 6 below. Land falls into progressively lower grades as the temperature decreases and rainfall increases.

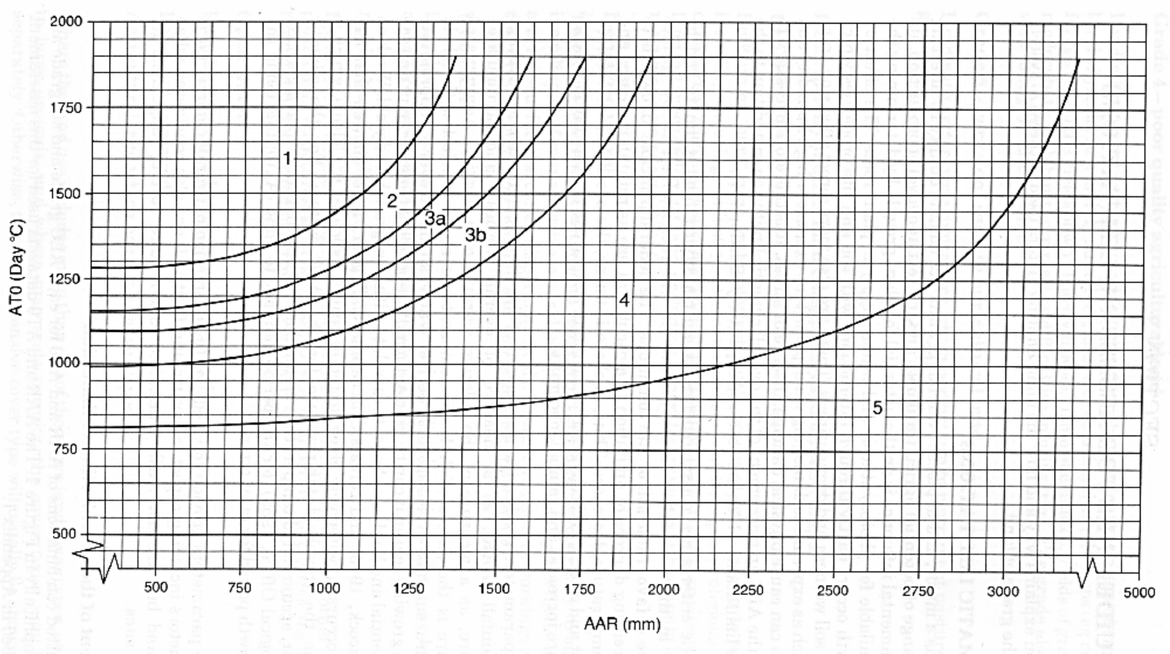

Figure 6. ALC grade according to climate (Source: MAFF, 1988).

9.1.1 Rationale for current guidance

- The ALC grading for climate is based on the premise that for crop and livestock production the least limited areas are those which are warm and dry (i.e., with high AT0 and low AAR). In comparison, the most limited areas are the wettest and coldest.

9.1.2 Recommendations from ALC related research.

- Rollett and Williams (2021) recommended that ALC grading according to climate should be reviewed. Currently, ALC grading by climatic factors alone is based on the premise that the warmer and drier the climate the better the grade, conversely the cooler and wetter the climate the worse the grade. This reflects the assumption that wetness was a more important determinant of yield and flexibility of use than droughtiness when the ALC was conceived (i.e. drought was less common). The general principal was to assign increasing limitation as rainfall increased and temperature increased. However, as the climate changes UKCP predictions suggest that parts of England and Wales could become too warm and too dry for some agricultural production. Consequently, Rollett and Williams (2021) suggested that it may be necessary to introduce maximum values for AT0 and minimum values for rainfall so that very warm and dry sites are not classed as Grade 1 for climate.

- At present the ALC climate grade is based on the relationships between AAR and AT0 and a curvilinear separation of grades is shown in Figure 1 of the ALC guidance document (reproduced as Figure 6, above). However, whilst the derivation of AAR and AT0 is clear, the way in which the curvilinear cut-offs between grades were derived is not clear. According to Keay *et al.* (2014), each of the curves shown in the 1998 guidance document were used to derive an equation separating the 6 classes. However, the equation used to derive the curves is not reported. As a result, Rollett and Williams (2021) recommended that any review of grading according to climate should clarify the basis for differences between grades.

9.2 Aspect

- The amount of solar radiation that a location receives depends on a variety of factors including latitude, season, time of day, cloud cover and altitude. At the local scale radiation is also controlled by surface slope, aspect and elevation (Allen *et al*., 2006). Aspect which is defined as the compass direction in which the land/slope faces (e.g. south or west) can have a marked influence on the amount of solar radiation that a site receives.
- The south side of a slope will receive more direct solar radiation than the north side (in the northern hemisphere). Daily and accumulated temperatures in spring and summer are higher on slopes with a southerly aspect than those facing in a northerly direction. Also, radiation intensity varies with slope angle such that differences due to aspect are more marked on steeper slopes.
- There is no definitive guidance on aspect in the current ALC guidelines; there are no limit values that relate to specific ALC grades. Current ALC guidance is that where the overall climate is liable to be modified significantly by local factors, the effect on grading should be assessed based on expert agrometeorological advice.

9.2.1 Rationale for current guidance

- At the local scale differences in aspect can modify the overall climate and have significant effects on crop performance or yield.

9.2.2 Recommendations from ALC related research.

- Rollett and Williams (2019) concluded that due to the complex relationship between aspect, slope and local topography it would be difficult to make any specific recommendations for accounting for aspect within the ALC guidelines. Also, aspect is likely to be a limiting factor only on those sites with a slope >11° (i.e. ALC grades 4 and 5) where other factors are likely to be more limiting (e.g. exposure or rainfall). For those reasons, the authors did not recommend any change to ALC guidance in relation to aspect.

9.3 Wind

- Wind speed is strongly influenced by topography. Upland areas, and land which stands above the surrounding countryside are often exposed, although the funnelling of winds along valleys, particularly in the uplands, may also result in consistently higher wind speeds.

- There is no definitive guidance on wind in the current ALC guidelines and there are no limit values that relate to specific ALC grades. Current ALC guidance is to seek expert agrometeorological advice[15] where the overall climate is liable to be modified significantly by local factors.

9.3.1 Rationale for current guidance

- Crop damage by wind may include leaf tearing, stem damage or uprooting. Wheat, oats, barley, maize, oilseed rape and shallow rooted brassica crops are particularly susceptible to wind damage by lodging (Gardiner *et al.*, 2016). Strong or cold winds can also cause stress to livestock, especially in wet weather.

9.3.2 Recommendations from ALC related research.

- Rollett and Williams (2020) noted that the Soil Survey of England and Wales (SSEW) produced a wind exposure map in 1980, based on the effect of wind on vegetation. They suggested that although the wind data (1960-1974) used in the SSEW is dated it is still indicative of the probable wind strength/direction in any area. As a result, Rollett and Williams (2020) proposed that the SSEW wind map for England and Wales could be made available online to provide an overview of the potential wind exposure for an area, albeit that wind speeds may vary greatly over short distances due to topography, aspect etc. However, they noted that where a more detailed assessment of wind exposure was required a period of on-site monitoring would be necessary.
- For annual crops, the risk of wind damage is particularly high in summer, when crops tend to be tallest and driest. Consequently, Rollett and Williams (2020) concluded that it would be useful to identify those areas at high risk of wind damage in summer. Bell *et al*. (2020) have produced a summer wind exposure map for Wales which categorises wind as weak, moderate or strong and has the potential to identify sites where crops maybe susceptible to wind damage. However, as noted above, map categories are only indicative of the wind risk at any site and onsite assessment will be required to take account of more localised wind conditions.

9.4 Frost risk

- Frost damage occurs when ice forms inside the plant tissue and injures the plant cells (Snyder and de Melo-Abreu, 2005). However, for crops that overwinter, including perennial fruit crops and certain vegetable crops such as cauliflower, the exposure to sufficiently cold temperatures is essential for subsequent development. Spring flowering bulbs such as daffodil and crocus also require a period of winter chilling.
- An 'air frost' occurs when the temperature at 1.25 metres above the ground falls below 0°C, whereas 'ground frost' refers to a temperature below 0°C measured on a grass surface. Spring frosts can cause serious damage to fruit crops and may check the growth of arable crops. The assessment of frost risk is more significant in relation to better-quality land (e.g. ALC Grades 1 and 2) where more sensitive crops are likely to be grown.
- Frost risk is closely related to topography and may be localised. Frost pockets (e.g. dips in the ground or valley bottoms) are areas that are particularly at risk from frost, especially where there is little direct solar radiation. Other factors that increase frost risk are elevation, lack of exposure to wind (i.e. still air) and soil type (sandy soils lose heat faster than other soil types).

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[15] Agrometeorological advice can be obtained from the Met Office (https://www.metoffice.gov.uk/services/business-industry/agriculture). Other potential sources of weather information are the AHDB weather hub (https://ahdb.org.uk/knowledge-library/weatherhub). However, this information may lack the site-specific detail needed for ALC assessment.

- The current ALC guidance is that where the overall climate is liable to be modified significantly by local factors, such as frost the effect on grading should be assessed based on expert agrometeorological advice.

9.4.1 Rationale for current guidance

- At the local scale differences in frost risk can modify the overall climate and have significant effects on crop performance or yield.

9.4.2 Recommendations from ALC related research.

- Climatic criteria are considered first when classifying land for ALC; and a single grade is given for overall climate limitations. The main parameters used are average annual rainfall and accumulated temperature (AT0). AT0 is the accumulated temperature >0°C for January to June (the critical growth period for most crops). Rollett and Williams (2020) suggested that these parameters provided a measure of frost risk at any site. Where winter or spring frosts occur more frequently or for long periods the AT0 will be lower than at warmer sites which are less prone to frost. However, in some cases land will be Grade 1 overall for climate despite the risk of frosts that could be potentially damaging to sensitive crops.
- Some of the crops grown on land classified as ALC 1 or 2 (e.g. potatoes, vegetables etc.) are more vulnerable to frost than crops grown on other ALC category sites. Consequently, Rollett and Williams (2020) concluded that there might be merit in including frost risk, as part of the climate assessment for land defined as ALC Grade 1 and 2. It was suggested that this could be based on the number of days of spring frost, which are potentially more damaging than winter frosts. For example, those areas with hardly any frost or weak, short-term frosts (<5 days) could be assessed as ALC 1 whereas sites that were subject to a greater risk of late frosts could be downgraded to ALC 2.
- In addition, Rollett and Williams (2020) suggested that for Wales, the use of high-resolution maps such as those produced by Environment Systems (Bell *et al*., 2020) was an effective method for assessing frost risk. However, Rollett and Williams (2020) noted that to ensure consistency further development of the frost risk map to include England would be required before any updates to ALC could be implemented.

10 Site limitations

- In the ALC the assessment of site factors is primarily concerned with the way in which topography influences the use of agricultural machinery and hence the cropping potential of the land. The factors that are considered are gradient, microrelief and flooding.

10.1 Gradient

- The gradient or slope of land has little or no direct influence on crop yields but influences the range of agricultural activities that may be safely and efficiently carried out. This is mainly because of the restrictions steeper slopes impose on mechanisation and on vulnerability to soil erosion. Where slopes are steeper, land management is more challenging and the types of crop that can be grown will be limited. The current ALC gradient limits are given in Table 18; the gradient limit for ALC Grades 1, 2 and 3a is ≤7°.

Table 18. ALC grade/subgrade according to gradient (Source: MAFF, 1988).

ALC grade/subgrade	Gradient limits (degrees)/[%]
1	7 [12.3]
2	
3a	
3b	11 [19.4]
4	18 [32.5]
5	>18 [>32.5]

10.1.1 Rationale for current guidance

- Grades according to gradient are based primarily on safe limits for a two-wheel 90 horsepower (hp) tractor and are also designed to minimise the risk of associated soil erosion.

10.1.2 Recommendations from ALC related research.

- As noted by Rollett and Williams (2019), the ALC grade cut-off points for gradient have evolved over time. In the 7-class Land Use Capability Classification (Bibby and Mackney, 1969) which preceded the ALC, only land with a slope of 0-3° was classified as Class 1 and more moderately sloping land (3-7°) was categorised as Class 2. The more restrictive grading reflected the effect of slope on mechanised farming in the 1960s.
- ALC grade limits in the current guidance reflect the increase in traction and power of tractors between the 1960s and 1980s. However, they do not reflect the current situation where two-wheel drive tractors are now uncommon. For example, it was estimated, that <1% of tractors that were sold in 2010 were two-wheel drive[16]. In addition, in 2020, the average horsepower of a tractor was 171 hp[17], almost twice that of the tractor on which the slope grade limits were originally based. As a result, most modern-day machinery can operate safely and efficiently on a slope of ≤7°. Based on the improvements in machinery design and power, along with systems that make working on a slope safer Rollett and Williams (2019) suggested that the gradient limit for ALC grade 1, 2 and 3a could be increased to 8°.
- Similarly, Van Orshoven *et al*. (2014) suggested that the severe threshold for the slope criterion should be ≥8.5°/15% (steeper than the current limit for ALC Grades 1-3a). Above the severe threshold, characteristics are considered to present a biophysical handicap to agriculture, without making agriculture impossible. The authors noted that at this angle the slope will limit mechanised cultivation and that specific equipment may be required to ensure safe and effective operation.
- The risk of soil erosion is high where slopes are >7° and soil is predominately sand or silty (i.e. sand, loamy sand, sandy loam, sandy silt loam, silt loam and silty clay loam). This may reduce the range of crops that can be grown or markedly increase production costs. For other mineral soils, the risk of soil erosion is lower, even at slope of >7°. Rollett and Williams (2019) did not recommend any changes to the ALC grades according to slope. However, the authors recommended that ALC guidance included notes on the high risk of erosion on light soil types when the slope gradient is >3°.

[16] https://www.fwi.co.uk/machinery/so-who-uses-two-wheel-drive-tractors
[17] https://aea.uk.com/industry-insight/tractor-statistics/

10.2 Microrelief

- Microrelief refers to complex changes of slope angle and direction over short distances, or the presence of boulders or rock outcrops, which even on level ground or gentle slopes, can severely limit the use of agricultural machinery (MAFF, 1988). The degree of limitation depends upon the distribution and severity of changes in slope direction and angle or frequency of rock outcrops. Microrelief is only considered in grading when it cannot be removed by normal management. For example, it may be possible to remove a boulder but not a rocky outcrop. Only, where the limitation cannot be removed, using normal agricultural equipment, should it be considered when grading land.
- In the current ALC, the effect of microrelief is considered in conjunction with overall gradient. However, detailed guidance on accounting for microrelief is not given and it is stated that "the degree of limitation should be assessed in relation to the hindrance to mechanical operations".

10.2.1 Rationale for current guidance

- Changes in microrelief can increase the effect of slope gradient on the efficiency and safety of machinery operations. For example, relatively few abrupt changes of slope angle on a site with a gentle overall slope may preclude the use of precision sowing or planting equipment.

10.2.2 Recommendations from ALC related research.

- Rollett and Williams (2020) suggested that microrelief could be used to modify the ALC grade according to gradient. It was suggested that where additional limitations were identified the ALC grade could be reduced by one grade or subgrade. Appropriate guidance could be included as a footnote to ALC Table 1 'grade according to gradient' to detail how microrelief should be used to modify the assessment. For example, where the gradient of the land is ≤7° but the land has many depressions or rocky outcrops (that cannot be remedied by normal agricultural operations) then it may be necessary to downgrade the ALC grade for slope to 3b (from 1, 2 or 3a) to reflect the level of hindrance to mechanical operations. However, where grade according to slope is already ≥4 (i.e. the gradient of the land is >11°) then downgrading according to microrelief is unlikely to be necessary. The footnote to ALC Table 1 could replace the current section on microrelief, which gives no specific guidance on how this limitation should be accounted for. Additional text could be used to clarify (or provide examples) of the types of microrelief that might cause sufficient hindrance to machinery operations to require downgrading.

10.3 Flooding

- The ALC guidelines for flooding (reproduced in Tables 19 and 20) consider frequency, duration and timing of flooding and apply to soils of good or moderate permeability. The assessment takes account of season by considering the impact of flooding in summer (mid-March to mid-November) and winter (mid-November to mid-March). The flood risk is assessed separately for each season and, in accordance with the most limiting principle, either can determine the ALC grade according to flooding.

Table 19. ALC grade according to flood risk in summer[1] (Source: MAFF, 1988).

Grade/subgrade	Flood limits	
	Frequency[2]	**Duration[3]**
1	Very rare	Short
2	Rare	Short
3a	Very rare Rare Occasional	Medium or long Medium Short
3b	Rare Occasional	Long Medium
4	Occasional Frequent	Long Short or medium
5	Frequent	Long

[1]Summer: mid-March to mid-November.

[2]Frequency, very rare: not more than once in 15 years, rare: once in 10 to once in 14 years, occasional: once in 3 to once in 9 years and frequent: more than once in 3 years. [3]Duration, short: ≤2 days; medium: >2 and ≤ 4 days and long: >4 days.

Table 20. ALC grade according to flood risk in winter[1] (Source: MAFF, 1988).

Grade/subgrade	Flood limits	
	Frequency[2]	**Duration[3]**
1	Rare	Short
2	Rare Occasional	Medium Short
3a	Rare Occasional Frequent	Long Medium Short
3b	Occasional Frequent	Long Medium
4	Frequent	Long

[1]Winter: mid-November to mid-March.

[2]Frequency, very rare: not more than once in 15 years, rare: once in 10 to once in 14 years, occasional: once in 3 to once in 9 years and frequent: more than once in 3 years. [3]Duration, short: ≤2 days; medium: >2 and ≤ 4 days and long: >4 days.

10.3.1 Rationale for current guidance

- The guidance in the ALC is based on the premise that it is a combination of the duration, frequency and timing of flooding that is important.
- As the duration of a flood increases so the damage to crops will increase. Within 48 hours, plants begin to suffer from oxygen deprivation (Jackson, 2004); 15 days is a critical threshold for arable crops in winter, with longer durations for 'improved' grass, and longer still for flood tolerant grass (Morris *et al*, 2008).
- More frequent flooding events increase the likelihood of soil damage and reduce opportunities for working the land and increase the impacts on crop yield. Flooded grassland is inaccessible to livestock and reduces opportunities for grazing and/or conserving grass for over winter feed. Where flooding occurs more frequently the range of crops that can be grown is often limited.
- The timing of flooding is also important in relation to cropping. Flooding at the time of planting (autumn or spring) can be detrimental to plant establishment, germination, nutrient uptake and

photosynthesis efficiency. It can also delay drilling and fertiliser/chemical applications. Autumn waterlogging can also result in poor rooting in winter cereal and oilseed rape crops leading to overwinter plant loss. Winter waterlogging (in isolation) has minimal impacts whilst summer flooding can destroy whole crops.

10.3.2 Recommendations from ALC related research.

- Rollett and Williams (2020), noted that the ALC categories for short (<48 hours) and medium (>2 days and <4 days) flood duration broadly aligned with literature values which suggested that 48 hours was the critical period after which plants started to suffer from oxygen deprivation. They noted that the long duration category (>4 days) would seem precautionary but recognised the wide-ranging effects of flooding, not just on plants but on workability and access.
- The ALC grade allocation according to flood risk suggests that summer flooding (mid-March to mid-November) is more damaging than winter flooding because active root systems are more likely to be affected by waterlogging and whole crops may be lost by summer floods. However, winter waterlogging has also been shown to have a significant effect on autumn sown crops such as cereals and oilseed rape (e.g., Gutierrez Boem *et al*., 1996). In addition, climate predictions suggest that changes to rainfall patterns are likely to increase the risk of winter flooding. As a result, Rollett and Williams (2020), suggested that there may be merit in a more in-depth review of the risks related to flooding at different times of the year.
- For simplicity, Rollett and Williams (2020), suggested that there could be a single grade relating to flood risk based on the stricter limits in the current grading system relating to summer flood risk. It was also suggested that the current additional recommendation for downgrading where soils of low permeability are present should be made more explicit as a footnote to the flood risk table.
- Rollett and Williams (2020) also noted that data on flood duration is not easy to access making it difficult to grade land according to the current ALC flood risk guidance. However, as data on flooding frequency is more accessible it may be possible to grade land on the risk of flooding in any one year, although it was noted that further investigation would be required to identify the most suitable data sources. For the estimated 10% of land that would not be ALC Grade 1 for flood risk more detailed data and information on localised flood risk may be required.
- A flood risk model could be developed for use with the ALC to enable the risk of flooding to be determined for agricultural production rather than the risk to property (which is the basis of most flood models).

11 Soil limitations

- The soil properties identified by ALC affecting the cropping potential and management requirements of land are texture, structure, depth, stoniness and chemical fertility (MAFF, 1988). These may act separately, in combination or by interactions with climate or site factors. The interactive limitations of soil wetness, droughtiness and erosion risk are discussed separately in Section 12.

11.1 Soil texture and structure

- Soil textural class is determined by the relative proportions of sand, silt and clay particles and the amount of organic matter in a soil horizon. Texture can be assessed in the field by hand texturing or measured in a laboratory by particle-size analysis.

- The mineral texture classes used for ALC are defined according to the soil textural triangle, which is based on the texture class intervals of the former Soil Survey of England and Wales. There are 11 major classes for mineral soil, which are defined by the relative proportions of clay (particle size fraction <0.002 mm), silt (particle size fraction 0.002-0.06 mm) and sand (0.06-2.0 mm) in the soil (Figure 7). Sand may be further sub-divided into fine: 0.06-0.2 mm, medium: 0.2-0.6 mm and coarse: 0.6-2.0 mm size fractions.
- Note that other classifications may include additional texture classes. For example, the FAO (2006) includes the subdivision heavy clay and also loam and silt texture classes but does not include a sandy silt loam texture class (Figure 7c).

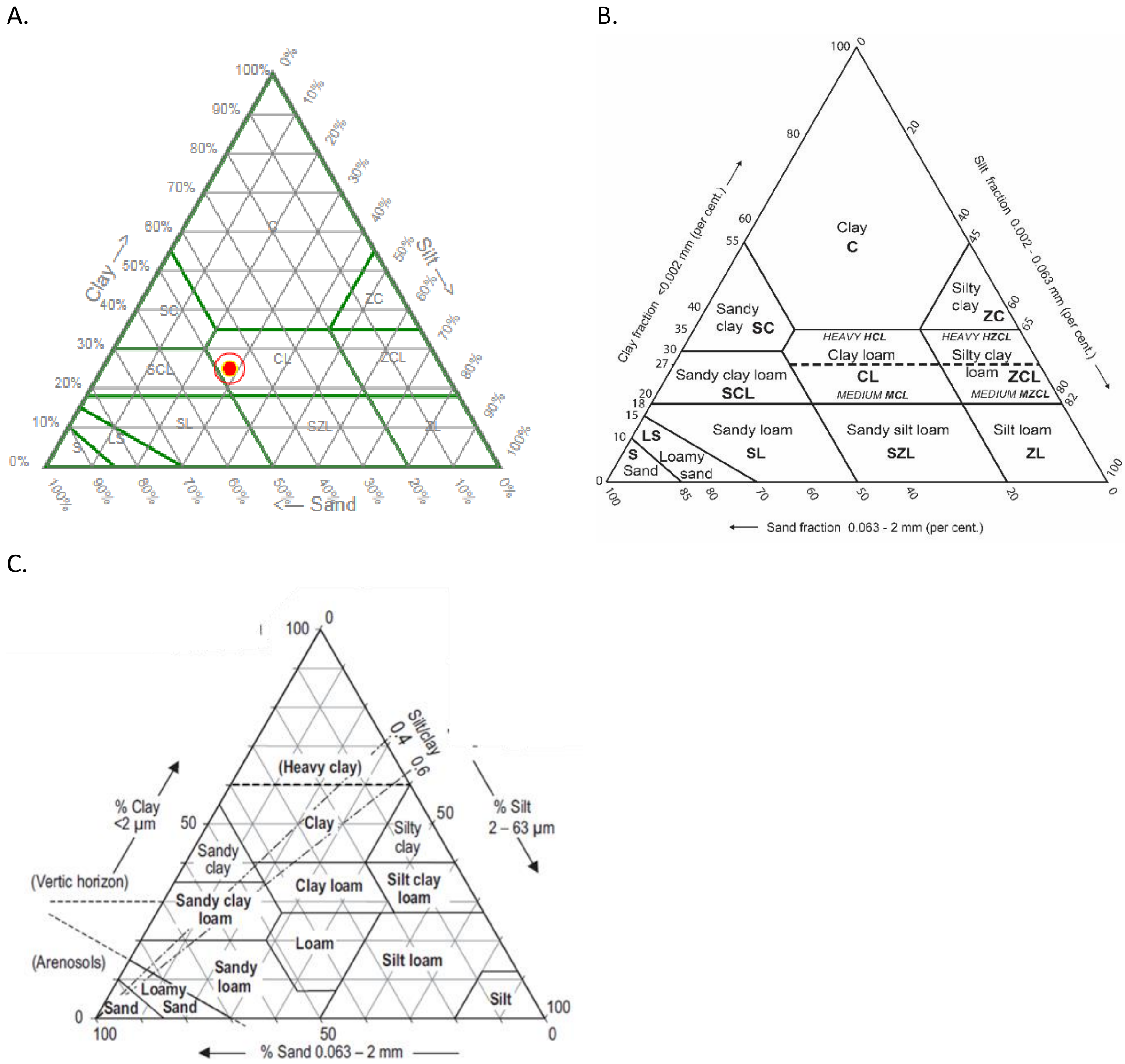

Figure 7. Soil textural triangle. A. Textural classes: particle size class estimator (available at https://www.landis.org.uk/services/tools.html). B. ALC textural classes showing division of clay loam (CL) and silty clay loam (ZCL) into MCL/HCL and MZCL/HZCL according to clay content Medium: <27% clay. Heavy: 27-35% clay (Hodgson, 2022) and C. FAO soil textural classes (FAO, 2006).

- Soil texture and structure are significant parameters in the assessments of droughtiness and wetness.

11.1.1 Rationale for current guidance

- Soil texture and structure have a major influence on water retention, water movement and aeration in soils. Texture also influences soil workability, trafficability, poaching risk, vulnerability to erosion and suitability as a medium for plant growth.

11.1.2 Recommendations from ALC related research.

- Based on literature reviewed, Van Orshoven *et al*. (2014) suggested that the severe threshold for unfavourable soil texture should be
    - Texture class in half or more (cumulatively) of 100 cm soil depth is sand or loamy sand (defined as % silt + 2x % clay = ≤30%) or
    - Dominant texture class of topsoil is heavy clay (≥60% clay; heavy clay is a subdivision of clay soil defined in the FAO soil triangle, Figure 7) or
    - Organic soil (organic matter ≥30% to 40 cm or more either from the surface or within the upper 100 cm of the soil) or
    - Topsoil contains ≥30% clay combined with the presence of soil with vertic properties (soil that experiences significant shrinking and swelling resulting from drying and wetting).
- These thresholds reflect the very limited water and nutrient holding capacity sandy soils. Also, that heavy clays are difficult to cultivate, and available water may be reduced by the presence of a high proportion of small pore sizes. In addition, clay soils are typically slowly permeable and susceptible to surface ponding/waterlogging. However, note that Van Orshoven *et al*. (2014) identified areas that did or did not meet criteria of natural constraint (for Less Favoured Area payments) rather than a series of grades as in the ALC system. As such, the criteria suggested by Van Orshoven *et al*. (2014) are probably only relevant for ALC Grades 4 and 5, i.e. poor and very poor-quality agricultural land.
- Also note that Defra (2010) testing of JRC biophysical constraints showed that only 0.3% of the UK was constrained by coarse or medium sand and heavy clay soil textures and no soils with vertic properties were identified in the UK.
- ALC does not consider soil texture as a standalone parameter rather it is an important component of the soil wetness and drought assessments.

11.2 Soil depth

- Soil depth affects a soil's capacity to function and is an important direct and indirect determinant of crop productivity. Shallow soils can physically restrict root growth reducing plant stability and increasing the risk of lodging. Crops also respond indirectly to soil depth through the availability (or otherwise) of vital resources such as water, oxygen and nutrients, which is also determined by soil depth.
- Standard tillage depth is typically 15-25 cm so soils that are shallower than this will have limited cropping options. Limiting depths in the ALC are given for soil overlying consolidated or fragmented rock which cannot be penetrated by cultivation implements (Table 21).

Table 21. ALC, limiting depths for soil overlying consolidated or fragmented rock (Source: MAFF, 1988).

Grade/Subgrade	Depth limits (cm)
1	≥60
2	≥45
3a	≥30
3b	≥20
4	≥15
5	<15

11.2.1 Rationale for current guidance

- Soil depth has a significant effect on the physical stability of the plant and can restrict root growth. Importantly soil depth is also an important determinant of soil available water and is used in the calculation of the soil drought limitation.

11.2.2 Recommendations from ALC related research.

- Van Orshoven *et al*. (2014) suggested two soil depth limit: ≤15cm (very severe limitations) and ≤30cm (severe limitations). The severe limit depth proposed by Van Orshoven *et al.* (2014) is the same as the limit value for ALC Grade 3a and any soil with a depth of <30 cm cannot be graded as BMV. Similarly, Rickson (2012) suggest that two soil depths, the critical and the crucial soil depth can be distinguished. The critical depth is a limit to cultivation whereas the crucial depth is the limit to plant growth. The critical depth is reported as between 25 and 30 cm (similar to the value for ALC Grade 3a) and is defined as the soil depth required for plant cover to be greater than 40%. The crucial depth is deeper and depends on the soil parent material.
- Soil depth can be classed as an inherent soil property unlikely to change, although erosion and change in land use may result in the removal of topsoil and a reduction in total depth of soil. Soil compaction caused by vehicle or animal traffic can also cause small reductions in soil depth over time. However, given the inherent nature of soil depth and the small number of soils where soil depth is less than <60 cm (the limit for ALC Grade 1 for soil depth) Rollett and Williams (2019) suggested that no changes to ALC grade categories are recommended.

11.3 Stoniness

In the ALC stony soils are classified according to the relative fraction of rock fragments in soil (soil stoniness) expressed as a relative volume. ALC specifies size limits for stones that will not pass-through sieves with 2 or 6 cm square mesh with either size determining the ALC grade (Table 22). The main effects of stones are to act as an impediment to cultivation, harvesting and crop growth and to reduce the available water capacity of a soil. Grade according to stoniness is based on mechanical limitations only; the effect on water capacity is considered as part of the droughtiness assessment.

Table 22. ALC grade according to stoniness (Source: MAFF, 1988).

Grade/subgrade	Limiting percentages (volume of hard stones in the top 25 cm of soil	
	*Stones >2 cm**	*Stones >6 cm***
1	5	5
2	10	5
3a	15	10
3b	35	20
4	50	35
5	>50	>35

*This column denotes the grade thresholds for *all* stones >2cm (including >6cm).

**This column is only used if stones >6cm create a *greater* limitation than the stones >2cm column.

- Large numbers of stones will prevent tillage and small stones wear on tillage implements, damage cultivation and harvesting equipment and can affect crop growth, most notably root crops such as potatoes and carrots. Production costs may also be increased due to the extra wear and tear on equipment. In addition, crop establishment may be poorer in stony soils, with crop yields and quality reduced because of impediment to rooting leading to poor establishment and restricted nutrient/water uptake.

11.3.1 Rationale for current guidance

- The limitation imposed by stones depends on their quantity, size, shape and hardness, which is reflected in the ALC guidance. Where stones are >6 cm the limiting percentages for each grade are lower than where stones are >2 cm reflecting the greater impediment to production caused by large stones. For example, the limit for ALC Grade 2 is 10% for stones >2 cm and 5% for stones >6 cm.
- Stones smaller than 2 cm, which have no or only minor effects on cultivation, are ignored when allocating ALC grade. Likewise, small numbers of large boulders or stones which can be removed easily are also ignored. Where the stones are of soft lithology, such as soft chalk, weakly cemented sandstones or siltstones, the ALC stone limits are reduced by one grade or subgrade.

11.3.2 Recommendations from ALC related research.

- Van Orshoven *et al*. (2014) suggested that soil texture is severely limiting to crop growth if the volume of coarse fragments of any kind in topsoil is ≥15% (volume/volume), including rock outcrops, boulders or large boulders. Note that Van Orshoven *et al*. (2014) define coarse fragments as >2 mm. The authors suggested that ≥15% coarse fragments reduced the water holding capacity of the soil by at least 40%; and increased the risk of damage to tillage equipment.
- Rollett and Williams (2019) noted that there was no rationale to suggest that the negative effects of stones on cultivation, harvesting and crop quality had reduced since 1988. For those reasons the authors did not recommend any changes to the ALC grades according to soil stoniness.

11.4 Chemical limitations

- The chemical status of a soil does not affect ALC grading where nutrient levels can be maintained or corrected by normal applications of fertiliser or lime (MAFF, 1988). Chemical factors will only affect grading where they have, or are likely to have, a detrimental long-term effect on the physical condition of the soil, the crop yield, the range of crops that may be safely grown, stocking rates or grazing management.

- Limitations may occur in sodium-rich clay and silty clay soils, which are potentially unstable when drained, where peat or marine alluvium rich in iron sulphide is drained, in soil over landfill or where high concentrations of potentially toxic elements occur.

11.4.1 Rationale for current guidance

- The effect of soil toxicity on grading is assessed in relation to the effects on plant growth and any limitations placed on the management or use of the land. These include restrictions on cultivation (which may bring contaminated material to the surface), stocking levels or grazing periods, or on the use made of produce obtained from it.
- Where chemical limitations prevent the growth of crops for direct human consumption the maximum grade is ALC 3b, where the use is limited to grass production (with some restrictions on management) the Grade is ≤4 and where only extensive grass production is possible land will be Grade 5.

11.4.2 Recommendations from ALC related research.

- ADAS (1993) proposed threshold values (defined as the level at or above which a detailed assessment of the effect of soil toxicity on ALC grade is required) for soil concentrations of the same nine PTEs subsequently included in the Code of Practice for Agricultural Use of Sewage Sludge (i.e., zinc, copper, nickel, cadmium, lead, mercury, chromium, molybdenum, selenium, arsenic and fluoride) plus boron. The thresholds were intended to apply to PTEs from all sources and for soils with pH <5.5. Limit values for each PTE were in line with those include in the Code of Practice for Agricultural Use of Sewage Sludge for soils with a pH of 5 to <5.5. However, where sewage sludge was the only contaminant the ADAS guidance recommended threshold values of 1000 mg/kg dry matter for zinc and 250 mg/kg dry matter for copper – limit values that are higher than those subsequently included in the Code of Practice for Agricultural Use of Sewage Sludge.
- The ADAS guidance advised that where values for a particular site were below the threshold values shown, then it was most unlikely that there would be any toxicity implications for ALC grading. In contrast, where values exceeded the relevant threshold there might, depending on circumstances, be a significant constraint on the agricultural use of the land and therefore on ALC grade. ADAS (1993) recommended the following gradings:
    - Extensive livestock grazing (short-term at low stocking levels): Grade 5
    - Inadvisable to plough/cultivate but intensive grazing ok: no better than Grade 4
    - Cropping for livestock feed but not human consumption: no better than Grade 3b
    - Cropping for human consumption but grazing inadvisable (due to toxic soil ingestion): no better than Grade 3b
    - No restrictions from soil toxicity: land graded following ALC procedure for disturbed/undisturbed land as appropriate.
- Nicholson *et al*. (2020) reported that there are no specific limit values for soil potentially toxic elements (PTE) concentrations included in ALC guidance, although an assessment is required of whether the land is "unsuitable for growing crops for direct human consumption". As a result, the authors suggested that additional guidance is required on how to assess whether the soil PTE concentrations are at a level where they are unlikely to be suitable for this purpose. They recommended that the soil PTE limit values included in the Code of Practice for Agricultural Use

of Sewage Sludge (DoE, 1996) are used as 'trigger values' to initiate further investigation before deciding on a final classification under the ALC system.

- Note that, where development of potentially contaminated sites is proposed, the planning system requires that PTE concentrations are assessed against Category 4 Screening Values (C4SVs[18]). These are based on modelled exposure pathways pertaining to residential, allotment, commercial and public open space land uses and indicate where there is no risk, or the level of risk is low. However, it is not appropriate to use C4SVs for ALC grading because these values were derived for non-agricultural land uses (Nicholson *et al*., 2020).

12 Interactive limitations

- The physical limitations which result from interactions between climate, site and soil are soil wetness, droughtiness and erosion. For ALC purposes wetness and droughtiness are assessed separately by relating soil profile characteristics to appropriate climatic parameters.

12.1 Soil wetness

- A soil wetness limitation exists when the soil water regime adversely affects plant growth or imposes restrictions on cultivations or grazing by livestock (MAFF, 1988). Rollett and Williams (2022) note that there are three main types of soil water regime, which give an indication of the overall mechanism and broad pattern of soil wetness:
    - Soils that are permeable and well drained
    - Soils that are permeable but waterlogged by a fluctuating groundwater table
    - Soils that are slowly permeable and seasonally waterlogged.
- The main factors that affect the duration of soil wetness are: (i) the presence of a fluctuating groundwater table, (ii) the presence of a slowly permeable layer or gleyed horizon (which inhibits the downward percolation of excess water causing seasonal wetness in and above the layer), (iii) the duration of the climatic field capacity period and (iv) whether there is artificial field drainage (Hollis, 1987). Overall, the duration of climatic field capacity has the biggest impact on soil wetness as it is a measure of the average period during which there is no potential soil moisture deficit, and any incident rainfall will produce excess soil water. During this period, soils affected by a groundwater table or with a slowly permeable layer at shallow depth are liable to be wet. Thus, the longer the field capacity period the longer the likely duration of waterlogging in the soil. However, any field assessment of soil wetness must consider all the factors above.
- The ALC wetness assessment considers two main factors:
    1. wetness of the cultivation zone or upper soil layers and
    2. wetness in the full rooting zone or whole soil profile

  The first factor requires a consideration of soil texture in the top 25 cm of the profile and field capacity days. The second requires the allocation of soil wetness class (I-VI).

[18] Statutory Guidance to support Part 2A of the Environmental Protection Act 1990 (which is the legislative framework for dealing with contaminated land) was published in 2012. This introduced a new four-category system for classifying land in terms of 'Significant Possibility of Significant Harm to human health' (Defra, 2012), where Category 1 includes land where the level of risk is clearly unacceptable, and Category 4 includes land where the level of risk posed is acceptably low.

12.1.1 Rationale for current guidance

- The current ALC wetness assessment considers the main factors that determine soil wetness (soil texture, climate and the soil water regime) and the subsequent effect on crop performance, cultivations and access by livestock.
- The wetness of the cultivation zone is influenced by the amount of water retained and the wetness of the climate. Soil texture is a major influence on the amount of water retained and for a given soil texture, the wetter the climate the greater the poaching risk and potential workability challenges.
- Waterlogging occurring below the cultivation zone is also important. Even if subsoil waterlogging does not reach up into the cultivation zone the wetness of the zone may be increased by upward movement of water by capillary action (Jones *et al*., 1992). The effect of subsoil waterlogging depends on both the depth and duration.

12.1.2 Recommendations from ALC related research.

- Rollett and Williams (2022) proposed that the ALC data on the duration of FC is updated as it is currently based on 1941-1970 climate data. The relationship between SMD and other climate or location variables could be used to update the regression equation for predicting FCD. It is likely that the 'best' regression for predicting FCD will include both summer and winter rainfall, rather than simply annual rainfall which forms the basis of the current equation. Analysis of climate data suggests that annual rainfall has not changed significantly over time whereas changes to seasonal rainfall patterns have been noted potentially resulting in delays to both the end of FC and return to FC.
- Rollett and Williams (2022) suggested several potential additions to the ALC text to complement the existing guidance and/or where signposting to additional resources or referenced documents would be useful, i.e.,
    - Additional text to define "mottles" and some accompanying illustrations. Also, further guidance on the identification of the frequency of mottles noting that the important distinction for ALC purposes is to identify if there are >2% mottles.
    - Additional guidance on how to use a Munsell colour chart (i.e. comparing a freshly extracted moist soil sample with standard Munsell soil colour charts in good natural light). Also, alternative methods for describing/measuring soil colour should be considered in future iterations of the ALC.
    - Updates to the ALC guidance should include definitions of soil structure types, biopores and soil consistence. Also, confirmation of the soil textures included in the fine to very coarse categories in ALC Figure 5 (diagrammatic representation of the combination of structure, texture and consistence which are characteristic of slowly permeable layers).
    - An assessment of soil consistence forms part of the ALC pedotransfer function for the identification of an SPL but knowledge of soil consistence is assumed rather than described. As a result, it is suggested that a table of soil consistence categories is added to the ALC.
- Soil workability and trafficability are implicit in the ALC rather than explicit. They are based on the interrelated factors of field capacity days, soil texture and characteristics (gleying and

permeability) and the duration of waterlogging. ALC grade according to wetness is highest where FCD are low, soil texture is light (e.g. sandy loam), and the duration of waterlogging is short. Similar conditions are likely to characterise sites that are workable and trafficable over long periods. In line with the Scottish Land Capability Classification (Bibby et al., 1991), Rollett and Williams (2022) noted that future iterations of the ALC should consider making the assessment of workability/trafficability more explicit. An additional Table (or Tables) could be included that identified the combination of criteria that identify workable soils or soils at low risk of poaching.

- Rollett and Williams (2022) also suggested that consideration should be given to the automation of the soil wetness assessment e.g. by using a spreadsheet calculator. This system would allow the user to input the parameters required to define the soil wetness class and subsequently the ALC grade for wetness. It would potentially speed up the process and reduce the risk of errors (e.g. from using the 'wrong' ALC Figure or Table to assess the final ALC grade for wetness). However, field assessment would still be required for data collection. An automatic system would also need careful caveats and warnings where values were near thresholds so that 'expert' knowledge could be used to override the system where required.

12.2 Soil droughtiness

- In the ALC system the method used to assess droughtiness is based on work by Thomasson (1979). It provides an indication of the average droughtiness risk based on two reference crops, winter wheat and maincrop potatoes. These crops have been selected because they are widely grown, have contrasting rooting depths and, in terms of their susceptibility to drought, are representative of a broad range of crops.
- Droughtiness limits for ALC grades and subgrades are defined in terms of moisture balances which are calculated separately for winter wheat and potatoes using the following formulae:
    - MB (wheat) = AP (wheat) – MD wheat
    - MB (potatoes) = AP (potatoes) – MD (potatoes)

  MB is moisture balance, AP is crop-adjusted water capacity of the soil profile and MD is moisture deficit.

12.2.1 Rationale for current guidance

- Soil moisture is a key driver for most soil processes and is instrumental in soil function. Soil moisture requirements vary considerably between crops due to different rooting and foliar characteristic and according to growth stage. For example, deeper rooted crops can utilise the moisture reserves of a larger volume of soil than shallow rooting crops.
- Droughtiness is most likely to be a significant limitation to crop growth in areas with relatively low rainfall or high evapotranspiration, or where the soil holds only small reserves of moisture available to plant roots. The severity of the limitation depends on the relationship between the soil properties and climatic factors and the moisture requirements of the crops grown. As a result, the calculation of moisture balance considers both the soil available water (based on soil texture, soil structural condition and crop rooting characteristics) and moisture deficit (the balance between water in (rainfall) and water out (evapotranspiration) of the soil).

12.2.2 Recommendations from ALC related research.

- Rollett and Williams (2021) reviewed the current methodology and datasets used to calculate soil droughtiness: rainfall, evapotranspiration, reference crops, available water capacity and crop rooting depth and suggested there was merit in expanding ALC guidance for a wider range of crops with different growing seasons and rooting depths. Both ADAS (2004) and Keay *et al*. (2014) have identified that temperature and summer rainfall data in the current ALC dataset may not reflect current values.

- Climate data is used in the calculation of moisture deficit values and Rollett and Williams (2021) suggested that the equation currently used to calculate moisture deficit required updating. Also, that the underlying assumptions about when crops realise full leaf cover may need revision considering changes to the climate since the ALC methodology was initially designed. However, the authors noted that it is unclear if any updates to the climate datasets, and resulting changes to the MD calculation methodology, will cause any changes to the overall ALC grade for droughtiness as MD is only one part of the droughtiness assessment. The areas that would potentially see a change in grade are those with low soil AWC where MD increases significantly. Also, sites close to the threshold between Grades are the most likely to see a change in grade, particularly in regions where moisture deficits are often high such as Southeast or Eastern England.
- When the values for crop available water capacity (AP) and moisture deficit (MD) are combined, positive values indicate an absence of moisture stress and negative values imply water availability is insufficient to sustain evapotranspiration and hence plant growth is restricted. In the original assessment of droughtiness and crop performance, Jones (1987) noted that AP did not account for variation in yield whereas MD explained 23% and moisture balance (AP-MD) explained 33% of the variation (significant at the 0.1% level). The dataset used by Jones (1987) included yields from 1973-1981 but the correlation was biased by the influence of drought in the dry years of 1975 and 1976 when the sum of AP-MD was <-40 mm. In non-drought years other factors such as differences in and weed pressure disease caused wide differences in yield at similar levels of MB. Rollett and Williams (2021) suggested it would be of value to examine the relationship between MB and crop yield using a more recent dataset to determine if the cut off points for ALC Grades currently in use are still valid.
- The relationship between soil texture and plant available water is generally acknowledged. Rollett and Williams (2021) reported that ALC tabulated values for the available water capacity of soils approximated to values published elsewhere and calculated in peer reviewed papers using pedotransfer functions. As a result, the authors concluded that there was no need to update the ALC methodology for assessing soil AWC. Also, that there was currently insufficient evidence to update the AWC values for rock listed in the ALC guidance.
- Current ALC guidance for calculating crop adjusted available water for wheat is based on a maximum root depth of 120 cm. Following a review of the literature, Rollett and Williams (2021) concluded that this depth continued to represent appropriate values for winter wheat. Likewise, although maximum potato root length can extend beyond the 70 cm depth used in the ALC the literature review suggested that most roots were found within this depth range. As a result, the authors concluded that the current guidance to calculate crop adjusted water for potatoes to 70 cm was valid.

12.3 Irrigation

- Irrigation regulates the amount and seasonal availability of water to match agricultural needs. Irrigation can potentially 'correct' any moisture deficit and enhance the potential of agricultural land. Consequently, current ALC guidance states that irrigation "should be taken into account in

ALC grading when it is current or recent practice”. However, as irrigation is likely to benefit only part of the full range of crops which could be grown, it will usually upgrade land by no more than one grade or subgrade.

- Current ALC guidance in relation to irrigation is not specific, i.e. there is no table of values that indicate the effect of irrigation on grading. It assumes that potatoes, field vegetable, fruit crops and sugar beet (in drier areas) would receive irrigation water. The ALC also recognises that irrigation will be of less benefit in wetter areas or where crops are grown on soils with high available water capacities. ALC guidance suggests that to determine the effect of irrigation on grade the following factors should be considered:
    - The adequacy of irrigation water supply
    - The range of crops to which water is usually applied
    - Climate and soil factors.
- Note that although irrigation is included in the 1988 ALC guidelines the 1997 changes to national planning guidance removed the potential to upgrade land where irrigation was available, and it is no longer used as a factor in grading land.

12.3.1 Rationale for current guidance

- Water stress caused by lack of rainfall can reduce plant performance. Irrigation can be used to ‘correct’ any moisture deficit and enhance the potential of agricultural land especially in drier areas.

12.3.2 Recommendations from ALC related research.

- Rollett and Williams (2020) suggested that ALC guidance for irrigation was only applicable to a small area of land growing a small range of crops Since over half of UK irrigated production is currently cropped in catchments defined as being ‘over-abstracted’ or ‘over-licensed’, there are understandably concerns regarding the environmental impact that any future increases in water demand might have on water resources (Knox *et al*., 2013).
- As noted, irrigation is no longer considered in ALC grading and will not be included in future updates to ALC guidance. Choices regarding which crops to irrigate typically reflect economic considerations rather than inherent physical conditions. For example, irrigation water may/may not be applied to adjacent fields or may/may not be applied to the same field in subsequent years depending on crop rotation. However, on-site water availability is likely to become more important due to predicted future increases in drought; a review of current/future water availability is suggested.

12.4 Soil erosion

- The incidence of erosion is determined by interactions between weather, soil type/condition, topography and the amount and type of vegetative cover. It is strongly influenced by agricultural management practices. There is no specific guidance in the ALC Guidelines in relation to erosion and it is acknowledged that several of the risk factors for erosion (i.e. soil depth or gradient) are considered by other parts of the ALC grading process.

12.4.1 Rationale for current guidance

- Soil erosion can impact land quality in two main ways:

- Direct effect on physical characteristics by, for example, reducing soil depth or creating conditions which inhibit the use of machinery or
- Constraints to management to a degree which reduces the range of crops or markedly raises production costs.

12.4.2 Recommendations from ALC related research.

- The effects of soil erosion on land quality are typically associated with rill/gully formation or loss of soil depth, particularly on sloping land. However, Rollett and Williams (2020) noted that these factors were considered in the ALC grades for gradient, microrelief and soil depth and only on rare occasions would erosion not be quantified by these other assessments of limitation. The authors suggested that the text on soil erosion included in ALC guidelines should be reviewed to include more detailed guidance on the factors that are likely to increase erosion risk. Alternatively, ALC guidance could include links to useful resources such as the Defra runoff and soil erosion risk assessment[19].

13 Review of limitations

- Table 23, below, summarises the scope of review suggested for each ALC limitation and the sub-components of the limitation where appropriate. Each limitation has been categorised as follows:
    - None. No change suggested.
    - Minor. Updating of ALC text suggested
    - Minimal. Some significant updates to ALC text suggested and/or additional criteria or resources proposed where information is easily available.
    - Moderate. More extensive reviewing of datasets or grade cut-offs suggested, for example, a reviewing of existing models.
    - Major. Updates to the background climate dataset or recommendations for new methodology suggested.
- In addition, the scope of test and trialling for validation is also listed and categorised using the same groupings so that:
    - None. No validation required
    - Minor. Validation to sense check any text added to the ALC guidance.
    - Minimal. Validation to sense check text and to test the usefulness or useability of any additional resources (e.g. frost risk or wind speed maps).
    - Moderate. Statistical assessment of the impact of new values at an England and Wales level.
    - Major. Statistical/spatial assessment of the impact of new data at an England and Wales level. Also, distribution of change and determination of uncertainty in the data. Cross checking by ALC surveyors to confirm that the model grading is representative of field conditions.

[19] https://www.gov.uk/guidance/complete-a-runoff-and-soil-erosion-risk-assessment

13.1 No, minor or minimal review suggested

- Four limitations (i.e., aspect, soil depth, soil stoniness and crop available water) were identified as requiring no review.
- Gradient, microrelief, erosion and irrigation were identified as requiring some minor reviewing. This mainly refers to improving the clarity of ALC guidance or the addition of extra information. In addition, it may relate to how the limit may be used to modify the overall ALC grade.
- Two climatic (frost and wind), one site (flooding), two soil (texture and chemical) and two sub-components of soil wetness (gleyed and slowly permeable layer) were identified as requiring minimal review. For these limitations the review process is outlined in Table 23 and includes the assessment of the potential addition of spring frost risk for land in ALC Grades 1 and 2, the use of online resources to identify the risks associated with frost, wind and flood, modification of the flood risk criteria and consideration of standalone limits for soil texture and the use of trigger values in relation to soil PTE concentrations.
- Limits in these categories should be simple or straightforward to review and update due to the limited scope of updates required. The relationship between the limitation and limits to crop production are well understood and the information or datasets required are easily available. However, note that depending on the extent of the review undertaken (e.g. developing a new model for agricultural flood risk) some more extensive work and more moderate review may be required.

13.2 Moderate review suggested

- Many of the limitations that require moderate review use data, or equations derived from relationships between factors in the current climate dataset, to determine the ALC grade (or sub-component of the grade calculation). As such these factors will need to be reviewed once the climate dataset has been updated.

13.3 Major review suggested

- The background climate dataset used in ALC is dated. Despite the recommendations of several previous reviews this has not been updated and is likely to be unrepresentative of current climatic conditions.
- The assessment of soil wetness and droughtiness is complicated, and consideration should be given to whether the methodology can be simplified or supported by an online tool to ensure that the correct ALC grade is allocated. In addition, consideration should be given to future-proofing the ALC so that farmer adaption to climate change is considered. For instance, Keay *et al*. (2014) noted the increasing importance of the ALC droughtiness factor in determining ALC grading in the future.

Table 23. Summary of suggested review, modification or updating suggested for ALC limitations. Scope of review: None (no change required), Minor (updating of text), Minimal (more significant updates to text, additional criteria or resources proposed where information is easily available), Moderate (more extensive reviewing of datasets or grade cut-offs, reviewing of existing models etc.), Major (updates to the background climate dataset or recommendations for new methodology). Scale of testing and trialling: None, minor, minimal, moderate and major.

ALC Limitations	Modification needed?	Summary of suggested review	Scope of review	Scale of testing and trialling
Climate limitations				
Climate (AT0/AAR relationship)	Yes	Review the introduction of maximum values for AT0 and minimum values for AAR in ALC grading so that very warm/dry sites are not classed as Grade 1 for climate. Review the basis for the current cut-offs for ALC grade by climate according to the curvilinear relationship between AAR and AT0 Review whether climatic averages are the best approach for ALC or if probabilistic approaches (like the ANC/Van Orshoven method) should be used. Review whether episodic climate events should be part of the ALC system.	Moderate	Moderate. Change in ALC grade for climate may result. Statistical assessment of the impact of new values at an England and Wales level based on an estimation of the grades using 'old' and 'new' climate cut-offs.
Aspect	No	None	None	Not applicable
Frost	Yes	Assess the potential for including frost risk (based on the number of days of spring frost), as part of the climate assessment for land in ALC grades 1 and 2. Review the potential for making available an online resource that can identify those areas at high risk from spring frost.	Minimal	Minimal. Could change the ALC climate grade for a very small number of sites.
Wind	Yes	Review the potential for making available an online wind map for England and Wales to provide an overview of the potential wind exposure for an area.	Minimal	None

ALC Limitations	Modification needed?	Summary of suggested review	Scope of review	Scale of testing and trialling
		Review the potential for making available an online resource that can identify those areas at high risk from summer wind. Recommendation for onsite wind assessment to take account of more localised wind conditions where required.		Additional resource. No grade changes.
Climate: sub-component				
Climate data	Yes	Review the reference climatic dataset used for the ALC. Update the temperature and rainfall dataset. Produce a free, publicly available and peer reviewed climate calculator and droughtiness calculator. Determine the best metric for capturing climatic variation within the ALC (i.e. it is not just the average climatic conditions that are important but the variation around that average).	Major	Major Changes could affect the ALC grade for climate, soil wetness or droughtiness. Statistical and spatial assessment of the impact of new climate data on climate, wetness and droughtiness gradings at an England and Wales level based on an estimation of the grades using ‘old’ and ‘new’ climate data. Assess distribution of change and determine uncertainty in the data, e.g., where land that changes grade is interspersed with land that does not change grade or changes that do not fit with field observations. A subset of samples will be graded by ALC surveyors to confirm that

ALC Limitations	Modification needed?	Summary of suggested review	Scope of review	Scale of testing and trialling
				the model grading is representative of field conditions.
Site limitations				
Gradient	Yes	Minor updating of text relating to the high risk of erosion on light soil types when the slope gradient is >3°.	Minor	None. Update to ALC text only.
Microrelief	Yes	Microrelief to be used as a modifier to the ALC grade according to gradient. Updating of text relating to ALC Table 1 'Grade according to gradient' to detail how microrelief should be used to modify the grading.	Minor	None Update to ALC text only.
Flooding	Yes	Review of the risks related to flood risk at different times of the year. Potential for a single grade relating to flood risk based on the stricter limits in the current grading according to summer flood risk. Creation of a new online resource (modelling) to identify areas at risk from agricultural flooding Review the requirement to include both flood duration and frequency. Minor updating of text relating to recommendation for downgrading when soils are of low permeability.	Minimal	Moderate. Grade according to flood risk could change if flood categories were updated. Statistical assessment of the impact of new values at an England and Wales level based on an estimation of the grades using 'old' and 'new' flood risk grade cut-offs.
Soil limitations				
Texture and structure	Yes	Soil texture/structure is not a standalone parameter in ALC rather it is an important component of the soil wetness and drought limits.	Minimal	None.

ALC Limitations	Modification needed?	Summary of suggested review	Scope of review	Scale of testing and trialling
		Consider if some standalone limits should be introduced into ALC.		
Depth	No	None	None	Not applicable
Stoniness	No	None	None	Not applicable
Chemical	Yes	Consider the use of the PTE limit values Code of Practice for Agricultural Use of Sewage Sludge as 'trigger values' to initiate further investigation before deciding on a final classification under the ALC system.	Minimal	Minimal Only concerns a small minority of soils.
Interactive limitations				
Soil wetness				
Final soil wetness limit	Yes	The methodology for allocating the overall ALC soil wetness grade is complicated and can be difficult to follow. It is complicated and there are lots of caveats hidden in the text which if ignored can result in significant grade differences. Consider if the methodology can be simplified or supported by an online tool to ensure that the correct ALC is allocated.	Major	Major. The changes to the climate dataset and any potential modifications to the soil wetness method could result in many grade changes.
Soil wetness: sub-components				
Field capacity days	Yes	In the ALC, FCD is a meteorological parameter which estimates the duration of the period when the soil moisture deficit is zero; current ALC FCD values are derived from a mathematical model (rainfall and evapotranspiration). Other authors have suggested alternative models to predict FCD. Considering the proposed changes to the reference climate dataset, the most appropriate method for determining FCD should be reviewed.	Moderate	Major The changes to the climate dataset, including the FCD dataset will influence final gradings for soil wetness. In addition, the FCD categories used in the soil wetness assessment may need updating.

ALC Limitations	Modification needed?	Summary of suggested review	Scope of review	Scale of testing and trialling
				Statistical and spatial assessment of the impact of new climate data on wetness gradings at an England and Wales level based on an estimation of the grades using ‘old’ and ‘new’ climate data. Assess distribution of change and determine ‘uncertainty in the data, e.g., where land that changes grade is interspersed with land that does not change grade or changes that do not fit with field observation. A subset of samples will be graded by ALC surveyors to confirm that the model grading is representative of field conditions.
Soil wetness class				
Gleyed horizon	Yes	Updating of the ALC text in relation to gleying and gleyed horizons to ensure this is straightforward to understand. Additional details, illustrations and diagrams may be required. Also, consideration of the addition of a slightly gleyed horizon.	Minimal	None/minor Updates to ALC text for clarification.
Slowly permeable layer	Yes	Updating of the ALC text in relation to slowly permeable layers to ensure this is straightforward to understand. Additional details, illustrations and diagrams may be required.	Minimal	None/minor Updates to ALC text for clarification

ALC Limitations	Modification needed?	Summary of suggested review	Scope of review	Scale of testing and trialling
		Link to videos/infographics /online tutorials. Again, ALC is being used more now for modelling and purposes other than the original BMV remit.		
Soil droughtiness				
Final droughtiness limit	Yes	Review the potential benefits of expanding the ALC guidance to include additional reference crops Determine the significance of the droughtiness factor in the grading of agricultural land in England and Wales using contemporary weather and crop yield statistics.	Major	Moderate/major The addition of extra reference crops adds complexity to the droughtiness (moisture deficit) limitation scoring and could result in grade changes.
Droughtiness: sub-components				
Crop adjusted available water capacity (AP)	No	None Current data on AWC in relation to soil texture and root depth has been reviewed and no updating is required.	None	Not applicable
Moisture deficit (MD) (Rainfall-potential evapotranspiration)	Yes	Review the equation currently used to calculate moisture deficit. The precise nature of the relationship is likely to change if the background dataset is updated. Due to changes in the climate since the ALC was designed, review the underlying assumptions of the current moisture deficit method in relation to the growing season and attainment of full crop cover. Review the text used to describe the MD term to ensure it is easy to follow.	Major	Moderate/major Changes to the moisture deficit equation may result in grade changes. Potentially the grade cut off for moisture balance (droughtiness) may need to be updated.
Potential evapotranspiration	Yes	Review the equation used to calculate potential evapotranspiration.	Moderate	Moderate Changes to the equation may result in grade changes. The grade cut off

ALC Limitations	Modification needed?	Summary of suggested review	Scope of review	Scale of testing and trialling
				for moisture balance (droughtiness) may also need to be amended.
Moisture balance (MB)	Yes	Examine the relationship between MB and crop yield for a more recent dataset to determine if the cut off points for ALC Grades currently in use are still valid.	Moderate	Moderate. Grade changes may result if cut-off points for ALC grades are changed.
Erosion	Yes	Updating of text relating to erosion.	Minor	None
Irrigation	Yes	Removal of text relating to irrigation.	Minor	None

14 Timescales, costs and risks

- The following Tables (25-27) outline the review suggested for the ALC along with potential methods for validation and expertise required to undertake each component of the review. In addition, the Table includes an indicative cost and timescale for the work described. Indicative costs are grouped into four categories: £. Cost <£500; ££. Cost £500 to £5,000; £££. Cost £5,000 to £15,000 and ££££. Cost >£15,000. Similarly, timescales for each aspect of the work have been estimated as ≤1 week, <1 month, 1-3 months or >3 months equating to ≤5 days, 20 days, 21-60 days and >60 days (this is intended as an estimation of the working days required for each task). However, note that the total time to carry out all aspects of the review would not be expected to be equal to the sum of all the parts. This is because work on one part of the review may also inform another part.

14.1 Priority

- Tables 25-27 also indicate whether the suggested review has high or low priority. Those with high priority include relatively simple updates to text in the ALC guidance (to improve clarity or understanding) and more complex changes to climate datasets (to update the underlying climate data) or climate metrics. The climate datasets are key components of the interactive limits (soil wetness and droughtiness) and as a result updates to these datasets (i.e., temperature, rainfall and field capacity days) will require concurrent updates to the methodology used to determine ALC grades for soil wetness and droughtiness. In comparison, optional updates (low priority) to the ALC system, i.e., those that would add to the resources available to identify frost, wind or flood risk or add extra complexity to the system (e.g. the use of additional crops in the moisture balance calculations or the addition of a very slowly permeable layer to the soil wetness assessment) have been classified as low priority. The ALC system would work without these optional updates, but assessments are likely to be more comprehensive if they were included.

14.2 Risk

- An assessment of the risk associated with each suggested update has also been included, risks have been categorised as:
    - None: no risk, this mainly applies to simple updates to the ALC guidance text to clarify ALC grading procedures or classifications. Very unlikely to result in grade changes or in unexpected outcomes or uncertainties.
    - Low risk: this applies to updates that expand the resources available to ALC assessors (e.g. online frost or wind resources or a new flood model). These updates will not change the ALC grade thresholds but will provide additional information to assist with grading. As such, they are unlikely to result in grade changes, unexpected outcomes or uncertainties.
    - Medium risk: this level of risk is applied to the addition of new assessment criteria (e.g. the addition of a slightly gleyed horizon) or the addition of new crops to the moisture deficit assessments. These add more complexity to the system and may result in grade changes or unexpected outcomes or uncertainties.
    - High risk: this level of risk applies to the updates in the climate dataset and variables that rely on that dataset. Also, to changes in grading thresholds that might result from a review of the climate criteria for ALC Grade 1, addition of climate variability criteria

or episodic events. Changes in grade both for individual limitations (e.g., soil wetness or climate) or overall ALC grade are highly likely. Also, due to the complex interactions between many of the parameters (e.g. soil wetness and workability and especially drought limitations) it is highly likely that unexpected outcomes or uncertainties will result. As a result, sufficient time will be required for data validation, ground-truthing, method comparisons etc before the updates can be published. Many of the updates that have been classified as high priority fall into the high risk category because they involve large-scale changes to the ALC dataset. However, many of these changes are considered important for the ALC to reflect current climatic conditions and continue to be of relevance in planning decisions.

14.3 Estimated costs/timescales

- It is not possible to give a precise cost for the suggested work but indicative costs for each component of the work are detailed below (Table 24). The estimated cost for the high priority review is £187,200 and for the low priority review is £98,000. However, the final cost and staff time required would depend on the precise nature and scope of the work undertaken.

Table 24. Review priority (high/low), description, duration (working days) and indicative costs

Review Priority	Description	Duration (days)	Cost (£)
High	Updates to ALC text (gradient, microrelief, flooding, slowly permeable layer etc.)	5	£2,500
	Flooding review	10	£6,500
	Update climate dataset (temperature, rainfall, field capacity days). Identify effects of grade changes. Data validation.	120	£76,800
	Change to climate cut-offs for ALC grades based on relationship between rainfall and temperature	10	£6,500
	Field capacity days (update dataset, assess effect on grading, threshold limits, validation)	30	£20,200
	Soil wetness (updates to FCD impacts on this dataset – confirm changes)	30	£19,200
	Changes to droughtiness assessment	35	£23,500
	Update moisture deficit equation	20	£12,800
	Crop yield and moisture balance relationship (current v old method)	30	£19,200
Total		**290 days (Over 2 years)**	***£187,200***
Low	Review climate metrics (grade variability, episodic events etc.) Identify effects of grade changes, data validation etc.	20	£15,700
	Additional wind and frost resources	25	£15,400
	Flooding model	40	£25,600
	Soil trigger values	6	£3,800

	Addition of very slowly permeable layer, consideration of standalone soil texture limits	3	£1,900
	Online resource for soil wetness Online resource for droughtiness or ALC climate	40	£25,600
	Expansion of drought assessment (additional crops, including modelling of affects)	15	£9,800
Total		***149 (Over 1.5 years)***	***£97,800***

Table 25. Minor and minimal review. Cost: £. <£500; ££. £500 to £5,000; £££. £5,000 to £15,000 and ££££. >£15,000. Time (estimation of the working days required for each task): ≤1 week (≤5 days); <1 month (20 days); 1-3 months (21-60 days) or >3 months (>60 days). Priority: High (essential) or low (optional). Risk: None; low (unlikely to result in grade changes, unexpected outcomes or uncertainties); Medium (may result in grade changes or unexpected outcomes or uncertainties) or High (changes in grade for individual limitations or overall ALC grade are highly likely along with unexpected outcomes or uncertainties).

ALC Limitations	Summary of review suggested	Validation	Expertise	Cost	Time	Priority	Risk
Site							
Gradient	Update text relating to the high risk of erosion on light soil types when the slope gradient is >3°.	None	ALC Soil science	£	≤1 week	High	None
Microrelief	Updating text relating to ALC Table 1 'Grade according to gradient' to detail how microrelief should be used to modify the grading.	None	ALC Soil science	£	≤1 week	High	None
Climate							
Frost	Assess the potential for including an assessment of frost risk (based on the number of days of spring frost), for land in ALC Grade 1 and 2.	Comparison of ALC grade with and without frost at a sub-set of sites currently ALC Grade 1 or 2. Number and distribution of sites that change ALC grade if spring frost is considered. Does this reflect the situation on the ground?	ALC assessors Crop physiology Climate GIS	££	<1 month	Low	Low
	Review the potential for providing an online resource that can identify areas at high risk from spring frost.	Comparison with grades identified on the ground. Ease of use/usefulness.	ALC assessors GIS Web-based resources	££	<1 month	Low	Low

ALC Limitations	Summary of review suggested	Validation	Expertise	Cost	Time	Priority	Risk
	Determine the spatial resolution required, the parameters to identify sites, and the appropriate metrics to identify risk (e.g. number of days, timing etc.)						
Wind	Review the potential for providing an online wind map for England and Wales to provide, 1) an overview of the potential wind exposure for an area and 2) identify areas at high risk from summer wind. Determine the spatial resolution required, parameters for site identification and the appropriate metrics to identify risk (e.g., number of days, timing etc.)	Comparison with Grades identified on the ground. Ease of use/usefulness.		££	<1 month	Low	Low
Flooding	Review of the risks related to flood risk at different times of the year. Assess the potential for a single grade relating to flood risk based on the stricter limits in the current grading according to summer flood risk. Review the requirement to include both flood duration and frequency.	Do flood risk/duration categories adequately reflect risk. Does the categorisation reflect the situation on the ground?	ALC Agricultural Plant physiology Water management	££	<1 month	Low	Low
	Minor updating of text relating to recommendation for downgrading flood risk when soils are of low	None	ALC Soil science	£	≤1 week	High	None

ALC Limitations	Summary of review suggested	Validation	Expertise	Cost	Time	Priority	Risk
	permeability. Guidance should be made more explicit as a footnote to the flood risk table.						
Soil limitations							
Texture and structure	Consider if some standalone soil texture/structure limits should be introduced into ALC.		ALC Soil science	£	≤1 week	Low	Low
Chemical	Consider the use of the PTE limit values from the Code of Practice for Agricultural Use of Sewage Sludge as 'trigger values' to initiate further investigation before deciding on a final classification under the ALC system.	Existing data on soil metal concentrations (Landis) could be used to determine how many sites would have triggered further investigation. And, what the ALC limiting factor was at these sites.	ALC Landis data Data manipulation Cranfield	££	<1 month	Low	Low
Soil wetness class sub-components							
Gleyed horizon	Updating of the ALC text in relation to gleying and gleyed horizons to ensure this is straightforward to understand. Additional details, illustrations and diagrams may be required. Alternatively, links to current references could be included.	Limited validation should be needed. The updates are designed to complement existing guidance.	ALC ALC assessors Soil science	£	≤1 week	High	Low
Slightly gleyed horizon	Consideration of the addition of a slightly gleyed horizon, although it is noted that this would add another layer of complexity to an already complex system.	Any new criteria or descriptions/definitions would need to be validated by ALC assessors for clarity and usefulness.				Low	Medium
Slowly permeable layer	Updating of the ALC text in relation to slowly permeable layers to improve the clarity of the	Limited validation should be needed. The updates are designed to complement existing guidance.	ALC ALC assessors Soil science	£	≤1 week	High	Low

ALC Limitations	Summary of review suggested	Validation	Expertise	Cost	Time	Priority	Risk
	description. Additional details, illustrations and diagrams may be required.						
	Links to videos/infographics/online tutorials etc which describe SPL (and gleyed horizons).	Validation by ALC assessors to confirm clarity and usefulness.	ALC ALC assessors Soil science Web-based resources Online content	££	<1 month	High	Low

Table 26. Moderate review. Cost: £. <£500; ££. £500 to £5,000; £££. £5,000 to £15,000 and ££££. >£15,000. Time (estimation of the working days required for each task): ≤1 week (≤5 days); <1 month (20 days); 1-3 months (21-60 days) or >3 months (>60 days). Priority: High (essential) or low (optional). Risk: None; low (unlikely to result in grade changes, unexpected outcomes or uncertainties); Medium (may result in grade changes or unexpected outcomes or uncertainties) or High (changes in grade for individual limitations or overall ALC grade are highly likely along with unexpected outcomes or uncertainties).

ALC Limitations	Summary of review suggested	Validation	Expertise	Cost	Time	Priority	Risk
Flooding	Creation of a new online model to identify areas at risk from agricultural flooding Provide appropriate spatial resolution, based on risk (of flooding), duration, timings/seasonality etc. Define the impact of flooding on agricultural production	Check that the tool correctly predicts flood risk using areas known to have flooded in the past. Confirm ALC grade according to flood risk. Note that Keay *et al*. (2014) found that flooding was only the most limiting factor at *c*.3% of sites	ALC Agricultural Modelling GIS CEH Environment Agency Natural Resources Wales Cranfield	£££	>3 months	Low	Medium
Climate	Review the introduction of maximum values for AT0 and minimum values for AAR in ALC grading so that very warm/dry sites are not classed as Grade 1 for climate. Review the basis for the current cut-offs for ALC grade by climate according to the curvilinear relationship between AAR and AT0.	Introduce maximum values for AT0 and minimum values for rainfall so that very warm and dry sites are not classed as Grade 1 for climate. Assess the effect of changes in climate grade on overall ALC grade using Landis database. Note that Keay *et al*. (2014) found that climate was the most limiting factor at *c*.17% of sites.	ALC Soil science Plant physiology Landis Cranfield	££	<1 month	High	High
	Review whether climatic averages are the best approach for ALC or if	To assess the effect of this change the grade according to climate	ALC Met Office data	£££	1-3 months	Low	Medium

ALC Limitations	Summary of review suggested	Validation	Expertise	Cost	Time	Priority	Risk
	probabilistic approaches should be used.	should be assessed based on a probabilistic approach	Statistics Data manipulation				
	Review whether episodic climate events should be part of the ALC system.	Investigate the addition of new parameters (e.g., longest dry spell or warm spell duration). Climate variability metric: how often does a site change ALC grade for climate. Identify whether the most variable sites should be downgraded for climate compared with sites with a more stable climate. Compare ALC grade for climate calculated based on averages (current approach) with those where sites are downgraded due to variable climate.				Low	Medium or high
Soil wetness: subcomponent							
Field capacity days	Identify the impact of the proposed changes to the reference climate dataset, on the FCD calculation and determine whether an alternative method for determining FCD is appropriate	Update the ALC dataset for the duration of field capacity. MORECS dataset calculates SMD and would allow the identification of the start/end of field capacity based on SMD = 0. The relationship between SMD and other climate (rainfall) or location variables (altitude, easting or	ALC MORECS data Met Office data Landis data Data manipulation Statistics	£££	1-3 months	High	High

ALC Limitations	Summary of review suggested	Validation	Expertise	Cost	Time	Priority	Risk
		northing) would be appropriate to update the regression equation for predicting FCD. FCD is only one component of the soil wetness assessment and to assess the impact of this change on ALC grading for soil wetness it could be calculated based on the revised and current FCD for a subset of sites. FCD cut-offs for soil wetness assessment may need to be revised.					
Droughtiness: subcomponents							
Potential evapo-transpiration	Review the equation used to calculate potential evapotranspiration (PE).	Where PE calculations are required for ALC the FAO-56 Penman-Monteith Method should be used. To assess the effect of changing the equation in the calculation of PE a subset of the Landis data should be used to compare results using the current ALC method and the FAO-56 Penman-Monteith Method. Note that PE is only one part of the ALC moisture deficit calculation, the other part is rainfall which is more variable. As such variations in rainfall are likely to have a larger effect on moisture deficit than PE.	ALC Landis Data manipulation Statistics	££	<1 month	Low High	Medium

ALC Limitations	Summary of review suggested	Validation	Expertise	Cost	Time	Priority	Risk
Moisture balance (MB)	Examine the relationship between MB and crop yield for a more recent dataset to determine if the cut off points for ALC Grades currently in use are still valid.	Moisture balance: crop adjusted water capacity minus moisture deficit. Winter wheat and potato yields should be compared with calculated MB for a dataset which covers multiple years. Yield data from the same site but in different years with different moisture contents should be included. Also, from sites with different soil types. Both the 'old' and 'new' methods for calculating MB should be used and compared.	ALC Soil science Landis Data manipulation Statistics	£££	1-3 months	High	High

Table 27. Major review. Cost: £. <£500; ££. £500 to £5,000; £££. £5,000 to £15,000 and ££££. >£15,000. Time (estimation of the working days required for each task): ≤1 week (≤5 days); <1 month (20 days); 1-3 months (21-60 days) or >3 months (>60 days). Priority: High (essential) or low (optional). Risk: None; low (unlikely to result in grade changes, unexpected outcomes or uncertainties); Medium (may result in grade changes or unexpected outcomes or uncertainties) or High (changes in grade for individual limitations or overall ALC grade are highly likely along with unexpected outcomes or uncertainties).

ALC Limitations	**Summary of review suggested**	**Validation**	**Expertise**	**Cost**	**Time**	**Priority**	**Risk**
Climate: sub-component							
Climate data	Review the reference climatic dataset used for the ALC. Update the temperature and rainfall dataset.	The updates to the climate dataset have been described in Table 16 along with the proposed new data sources and validation methods. The ALC grade for climate using old ALC data should be compared with the grade using the new climate data (HadUK-Grid). In this comparison, the climate dataset should be the only parameter that is changed. The overall ALC grade calculated using the old/new climate datasets should be compared. This will ascertain whether climatic conditions determine overall grade less/more frequently than in the past.	ALC Met Office data GIS Data manipulation Statistics	££££	>3 months	High	High

ALC Limitations	Summary of review suggested	Validation	Expertise	Cost	Time	Priority	Risk
Climate	Review whether climatic averages are the best approach for ALC or if probabilistic approaches should be used. Determine the best metric for capturing climatic variation within the ALC. Review whether episodic climate events should be part of the ALC system.	To assess the effect of this change the grade according to climate should be assessed based on a probabilistic approach Determine whether the average climatic conditions are important or the variation around that average. Climate variability metric: how often does a site change ALC grade for climate. The most variable sites could be downgraded for climate compared with sites with a more stable climate. ALC grade for climate could be calculated based on averages (current approach) and compared to grades where sites are downgraded where the climate is very variable. Investigate the addition of new parameters (e.g., longest dry spell or warm spell duration).	ALC Met Office data GIS Data manipulation Statistics Crop physiology Soil science	££££	>3 months	Low	Medium High
Online climate resource	Produce a free, publicly available and peer reviewed climate calculator and droughtiness calculator.	Once the new climate dataset is ready for use it can be used to develop an online resource for calculating ALC climate parameters (i.e. AT0, ATS, AAR, ASR and FCD). This would	ALC ALC assessor Web-based resources Online content	££££	>3 months	Low	Medium

ALC Limitations	Summary of review suggested	Validation	Expertise	Cost	Time	Priority	Risk
		remove the need for manual calculation of climate grades. Similarly, a droughtiness calculator (based on any updated methodology) would provide a simple online resource to assess the ALC grade for droughtiness. Although this system would be simpler for the user (ALC assessor) it would need to be carefully designed so that expert input was not lost.					
Soil wetness							
Final soil wetness limit	Consider if the methodology can be simplified or supported by an online tool to ensure that the correct ALC grade is allocated.	The final soil wetness grade is based on a range of factors, i.e., field capacity days, soil texture/type and the soil water regime (which is typically inferred from observed soil profile characteristics). Updates to many of the components of this method have been proposed, which could result in shifts in the ALC grade according to wetness. This is important because wetness is one of the main determinants of final ALC grade. To determine the effect of these changes a sub-set of sites from a	ALC ALC assessor GIS Data manipulation Statistics Web-based resources Online content	££££	>3 months	Low	Medium

ALC Limitations	Summary of review suggested	Validation	Expertise	Cost	Time	Priority	Risk
		range of climate, soil textures, soil groups and soil water regimes should be graded using the old and new methods/datasets. Results should be compared to determine changes to ALC grade for a) wetness and b) overall. The results of a smaller subset of sites should be checked 'on the ground'. Once the updated methodology/datasets have been tested the online resource can be developed.					
Soil droughtiness							
Final droughtiness limit	Review the potential benefits of expanding the ALC guidance to include additional reference crops	Further research could be carried out to determine the benefits of including additional crops. However, adding additional crops would increase the number of droughtiness limitation combinations increasing the likelihood of unforeseen contradictions between limitations for individual crops. This may be of more benefit for modelling purposes than ALC field assessments.	ALC Crop physiology	££	<1 month	Low	Medium High

ALC Limitations	Summary of review suggested	Validation	Expertise	Cost	Time	Priority	Risk
	Determine the significance of the droughtiness factor in the grading of agricultural land in England and Wales using contemporary weather and crop yield statistics agree	The ALC system should be reviewed using contemporary weather and crop yield statistics to determine the significance of the droughtiness factor in the grading of agricultural land in England and Wales. Updates to many of the components of this method have been proposed, which could result in changes to the ALC grade according to droughtiness. This is important because droughtiness is one of the main determinants of final ALC grade and as climate changes it is predicted to become an increasingly important factor in determining ALC grade To determine the effect of these changes a sub-set of sites from a range of climate, soil textures and soil groups should be graded using the old and new methods/datasets. Results should be compared to determine changes to ALC grade for a) droughtiness and b) overall. Farming adaptations to a changing climate also need to be factored in as it is necessary to understand the	ALC GIS Data manipulation Statistics	££££	>3 months	High	High

ALC Limitations	Summary of review suggested	Validation	Expertise	Cost	Time	Priority	Risk
		impact of increasing doughtiness on land capability.					
Droughtiness: subcomponent							
Moisture deficit (MD)	MD: Rainfall-potential evapotranspiration Review the equation currently used to calculate MD. The precise nature of the relationship is likely to change if the background dataset is updated.	Any changes to the methodology used to calculate PE would also require the regression analysis used for PSMD and crop specific MD to be reviewed.	ALC Soil science Crop physiology	£££	1-3 months	High	High

15 Testing and trialling

- The methods for validating the changes to the ALC grades allocated climate, site, soil and interactive limitations have been outlined in Table 25-27, above. Although, note that the scope of this report does not extend to a detailed discussion of validation methods.
- Any updates to the climate dataset will be far reaching as they will impact not only the climate limitation but also the interactive limitations of soil wetness and droughtiness. This is important because climate, wetness and drought were identified as the most limiting factors at >60% sites by ADAS (2004) and Keay *et al*. (2014). Consequently, any changes to these parameters are most likely to impact the overall ALC grade. In summary, the new climate dataset will be tested as follows:
    - Modelled outputs based on the Landis National Soils Inventory dataset, will be used to assess changes to ALC grade as a result of using an updated climate dataset. The NSI dataset will be checked and modified (where needed) by experienced soil scientists and ALC surveyors to remove erroneous or unrepresentative data and calculate any missing values.
    - Calculating relevant ALC climate parameters for selected NSI sites, e.g., AAR, AT0 etc using ALC climate data (Met Office 1989) and new climate data (Met Office, 2018).
    - Statistical assessment of the impact of new climate data on climate, wetness and droughtiness gradings at an England and Wales level based on an estimation of the grades using 'old' and 'new' climate data.
    - Statistical assessment of the impact of new climate data on overall ALC gradings at an England and Wales level based on an estimation of the grades using 'old' and 'new' climate data.
    - Spatial assessment of the impact of new climate data on climate, wetness and droughtiness gradings at an England and Wales level based on an estimation of the grades using 'old' and 'new' climate data.
    - Spatial assessment of the impact of new on overall ALC gradings at an England and Wales level based on an estimation of the grades using 'old' and 'new' climate data
    - Review spatial distribution of grade changes to assess distribution of change and determine 'noise' in the data, e.g., where land that changes grade is interspersed with land that does not change grade or changes that do not fit with knowledge 'on the ground'.
    - A subset of samples will be graded by ALC surveyors to confirm that the model grading is representative of field conditions.
    - Validation by a panel of ALC field specialists with good knowledge across all English and Welsh regions.
- The effect of other proposed changes to methodology, grade criteria etc. will also have important impacts on the allocation of ALC grades. These might include changes to the grade limit values for climate (maximum temperature and minimum rainfall) moisture balance (updated relationships between yield and soil moisture) or the inclusion of climate variability criteria.

- It will be important to model the change in each parameter independently to identify the effect of each single change before changes are combined.

16 Consequence of updates to ALC

- It is very likely that the overall ALC grade of some sites will change, particularly those that are close to the boundary between two Grades for a particular limitation. However, it should be noted that, downgrading for one parameter (e.g. climate) may not result in an overall reduction in grade if another parameter (e.g. slope, soil wetness etc.) is the most limiting factor.
- ALC grade for climate is likely to increase following updating to the climate dataset. Keay (2020) modelled change in ALC grade (for climate, soil wetness, drought and overall) using UKCP18 data for climate for *c.*6000 NSI sites. This work showed that 58% of sites were originally Grade 1 for climate (based on the Met Office 1989 data) compared to 73% under the medium scenario for 2020. These changes are indicative of the direction of change that can be expected once the ALC climate dataset is updated.
- Keay (2020) reported that 36% of sites were originally ALC grade 1 for droughtiness compared to 25% under the UKCP18 medium scenario for 2020; Grade 3a increased from 21% to 29% and Grade 3b from 11% to 19%. Keay (2020) also noted that 26% of sites were ALC Grade 1 for wetness using both the original dataset and under the UKCP18 2020 medium scenario. Again, these changes are indicative of the direction of change that can be expected for the ALC grade for droughtiness and wetness once the ALC climate dataset is updated.
- In comparison with the original data Keay (2020) reported that under the 2020 medium scenario the proportion of land in ALC Grades 1, 2 and 3a decreased whilst the proportion of land in Grades 3b, 4 and 5 increased (Figure 8).

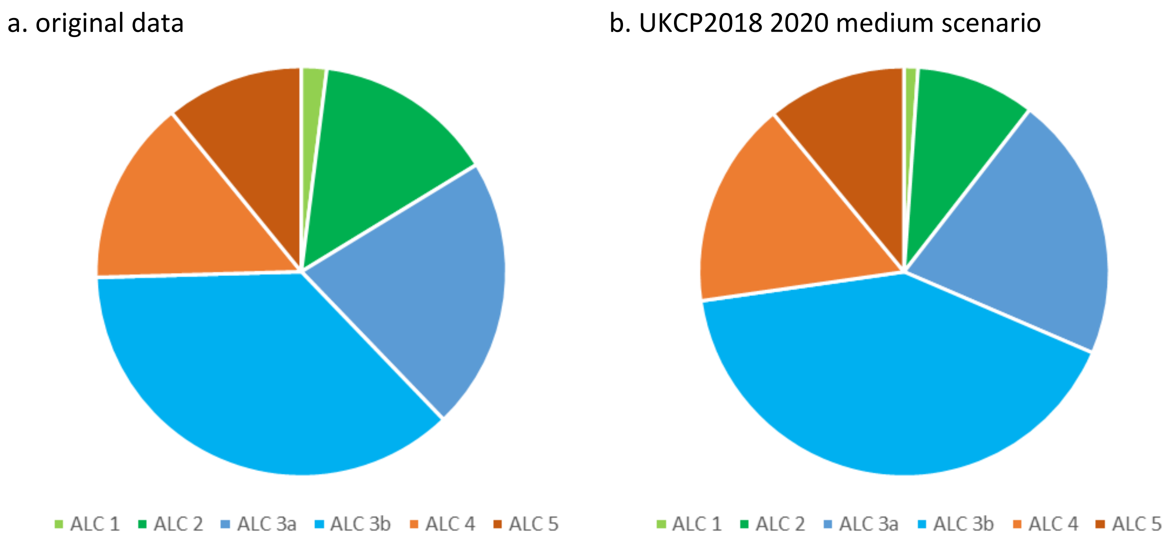

Figure 8. Proportion of land in each overall ALC grade, a) using the original dataset (Met Office, 1989) and b) using the UKCP18 climate dataset (2020 medium scenario) (Keay, 2020).

17 Conclusions

17.1 No, minor or minimal review required

- Limits in these categories should be simple or straightforward to review and update due to the limited scope of updates required. The relationship between the limitation and limits to crop production are well understood and the information or datasets required are easily available.
- Four limitations (i.e., aspect, soil depth, soil stoniness and crop available water) were identified as requiring no review.
- Gradient, microrelief, erosion and irrigation were identified as requiring some minor reviewing. This mainly refers to improving the clarity of ALC guidance or the addition of extra information. In addition, it may relate to how the limit may be used to modify the overall ALC grade.

17.1.1 Aspect

- Rollett and Williams (2019) concluded that due to the complex relationship between aspect, slope and local topography it would be difficult to make any specific recommendations for accounting for aspect within the ALC guidelines. Also, aspect is likely to be a limiting factor only on those sites with a slope >11° (i.e. ALC grades 4 and 5) where other factors are likely to be more limiting (e.g. exposure or rainfall). For those reasons, the authors did not recommend any change to ALC guidance in relation to aspect.

17.1.2 Soil depth

- Van Orshoven *et al*. (2014) suggested two soil depth limits: ≤15cm (very severe limitations) and ≤30cm (severe limitations). The severe limit depth proposed by Van Orshoven *et al.* (2014) is the same as the limit value for ALC Grade 3a and any soil with a depth of <30 cm cannot be graded as BMV. Soil depth can be classed as an inherent soil property unlikely to change, although erosion and change in land use may result in the removal of topsoil and a reduction in total depth of soil. Soil compaction caused by vehicle or animal traffic can also cause small reductions in soil depth over time. However, given the inherent nature of soil depth and the small number of soils where soil depth is less than <60 cm (the limit for ALC Grade 1 for soil depth) Rollett and Williams (2019) suggested that no changes to ALC grade categories were required.

17.1.3 Soil stoniness

- Rollett and Williams (2019) noted that there was no rationale to suggest that the negative effects of stones on cultivation, harvesting and crop quality have reduced since 1988. For those reasons the authors did not recommend any changes to the ALC grades according to soil stoniness.

17.1.4 Gradient

- The risk of soil erosion is high where slopes are >7° and soil is predominately sand or silty (i.e. sand, loamy sand, sandy loam, sandy silt loam, silt loam and silty clay loam). This may reduce the range of crops that can be grown or markedly increase production costs. For other mineral soils, the risk of soil erosion is lower, even at slope of >7°. Rollett and Williams (2019) did not recommend any changes to the ALC grades according to slope. However, the authors recommended that ALC guidance included notes on the high risk of erosion on light soil types when the slope gradient is >3°.

17.1.5 Microrelief

- Rollett and Williams (2020) suggested that microrelief could be used to modify the ALC grade according to gradient. Appropriate guidance could be included as a footnote to ALC Table 1 'Grade according to gradient' to detail how microrelief should be used to modify the assessment. For example, where the gradient of the land is ≤7° but the land has many depressions or rocky outcrops (that cannot be remedied by normal agricultural operations) then it may be necessary to downgrade the ALC grade for slope to 3b (from 1, 2 or 3a) to reflect the level of hindrance to mechanical operations. However, where grade according to slope is already ≥4 (i.e. the gradient of the land is >11°) then downgrading according to microrelief is unlikely to be necessary. The footnote to ALC Table 1 could replace the current section on microrelief, which gives no specific guidance on how this limitation should be accounted for.

17.1.6 Irrigation

- Rollett and Williams (2020) suggested that irrigation should not be considered in ALC grading given the negative impacts that abstraction can have on local water resources in areas where water is scarce. Taking irrigation out of ALC would help ensure that cropping is appropriate to local conditions.

17.1.7 Soil erosion

- The effects of soil erosion on land quality are typically associated with rill/gully formation or loss of soil depth, particularly on sloping land. However, Rollett and Williams (2020) noted that these factors were considered in the ALC grades for gradient, microrelief and soil depth and only on rare occasions would erosion not be quantified by these other assessments of limitation. The authors suggested that the text on soil erosion included in ALC guidelines should be reviewed to include more detailed guidance on the factors that are likely to increase erosion risk.

17.2 Minimal review required

- Two climatic (frost and wind), one site (flooding), two soil (texture and chemical) and two sub-components of soil wetness (gleyed and slowly permeable layer) were identified as requiring minimal review.

17.2.1 Wind

- Rollett and Williams (2020) proposed that the Soil Survey of England and Wales (SSEW) wind map for England and Wales could be made available online to provide an overview of the potential wind exposure for an area, albeit that wind speeds may vary greatly over short distances due to topography, aspect etc. However, they noted that where a more detailed assessment of wind exposure was required a period of on-site monitoring would be necessary.
- For annual crops, the risk of wind damage is particularly high in summer, when crops tend to be tallest and driest. Consequently, Rollett and Williams (2020) concluded that it would be of benefit to identify those areas at high risk of wind damage in summer. Bell *et al*. (2020) produced a summer wind exposure map for Wales which categorises wind as weak, moderate or strong and has the potential to identify sites where crops maybe susceptible to wind damage. However, this map does not currently include England.

17.2.2 Frost risk

- Some of the crops grown on land classified as ALC 1 or 2 (e.g. potatoes, vegetables etc.) are more vulnerable to frost than crops grown on sites with different ALC grades. Consequently, Rollett and Williams (2020) concluded that there might be merit in including frost risk, as part of the climate assessment for land defined as ALC Grade 1 and 2. It was suggested that this could be based on the number of days of spring frost, which are potentially more damaging than winter frosts. The use of high-resolution maps such as those produced by Environment Systems (Bell *et al*., 2020) could be an effective method for assessing frost risk. However to ensure consistency further development of the frost risk map to include England would be required.

17.2.3 Flooding

- For simplicity, Rollett and Williams (2020), suggested that there could be a single grade relating to flood risk based on the stricter limits in the current grading system relating to summer flood risk. The authors also noted that data on flood duration is not easy to access making it difficult to grade land according to the current ALC flood risk guidance. However, as data on flooding frequency is more accessible it may be possible to grade land on the risk of flooding in any one year, although it was noted that further investigation would be required to identify the most suitable data sources. For the estimated 10% of land that would not be ALC Grade 1 for flood risk more detailed data and information on localised flood risk may be required. It was also suggested that there may be merit in a more in-depth review of the risks related to flooding at different times of the year. A flood risk model could be developed for use with the ALC to enable the agricultural risk of flooding to be determined rather than the risk to property (which is the basis of most flood models).

17.2.4 Chemical limitations

- Nicholson *et al*. (2020) noted that there are no specific limit values for soil potentially toxic elements (PTE) concentrations included in ALC guidance, although an assessment is required of whether the land is "unsuitable for growing crops for direct human consumption". As a result, the authors suggested that additional guidance is required on how to assess whether the soil PTE concentrations are at a level where they are unlikely to be suitable for this purpose. They recommended that the soil PTE limit values included in the Code of Practice for Agricultural Use of Sewage Sludge are used as 'trigger values' to initiate further investigation before deciding on a final classification under the ALC system.

17.2.5 Soil wetness: soil gleying and slowly permeable layers

- Two sub-components of the soil wetness assessment require minimal updating relating to 1) soil gleying and 2) slowly permeable layers. The ALC text in relation to gleying and gleyed horizons should be updated to ensure this is straightforward to understand. Also, consideration should be given to the addition of a slightly gleyed horizon. Likewise the ALC text in relation to slowly permeable layers should also be updated to ensure this is straightforward to understand. Additional details, illustrations and diagrams may be required for both gleyed horizons, slowly and slightly permeable layers.

17.3 Moderate review required

- Many of the limitations that require moderate review (i.e. ALC climate grade, sub-component of ALC grade for soil wetness (field capacity days) and sub-components of ALC grade for droughtiness (moisture deficit, moisture balance)) use data, or equations derived from relationships between factors in the current climate dataset, to determine the ALC grade (or sub-component of the grade calculation). As such these factors will need to be reviewed once the climate dataset has been updated.

17.3.1 Climate

- Currently, ALC grading by climatic factors alone is based on the premise that the warmer and drier the climate the better the grade. This reflects the assumption that wetness was a more important determinant of yield than droughtiness when the ALC was conceived (i.e. drought was less common). However, as the climate changes UKCP predictions suggest that parts of England and Wales could become too warm and too dry for some agricultural production. Consequently, Rollett and Williams (2021) suggested that it may be necessary to introduce maximum values for AT0 and minimum values for rainfall so that very warm and dry sites are not classed as Grade 1 for climate.
- At present the ALC climate grade is based on the relationships between AAR and AT0. However, whilst the derivation of AAR and AT0 is clear, the way in which the curvilinear cut-offs between grades were derived is not clear. As a result, Rollett and Williams (2021) recommended that any review of grading according to climate should clarify the basis for differences between grades.

17.3.2 Soil wetness: field capacity days

- In the ALC, FCD is a meteorological parameter which estimates the duration of the period when the soil moisture deficit is zero; current ALC FCD values are derived from a mathematical model (rainfall and evapotranspiration). Other authors have suggested alternative models to predict FCD. Considering the proposed changes to the reference climate dataset, the most appropriate method for determining FCD should be reviewed.

17.4 Major review required

- Parameters that require major review are updates to the background climate dataset and recommendations for potentially more detailed updating of the overall soil wetness and soil droughtiness methodology.

17.4.1 Soil wetness

- The assessment of soil wetness is complicated, and consideration should be given to whether the methodology can be simplified or supported by an online tool to ensure that the correct ALC grade is allocated.

17.4.2 Soil droughtiness: moisture deficit and moisture balance

When the values for crop available water capacity (AP) and moisture deficit (MD) are combined to calculate moisture balance, positive values indicate an absence of moisture stress and negative values imply water availability is insufficient to sustain evapotranspiration and hence plant growth is restricted. The cut-off values for ALC grades for moisture balance are based on an assessment of droughtiness and crop performance between 1973-1981 (Jones. 1987). Given that this data is >40 years old Rollett and Williams (2021) suggested that the relationship between MB and crop yield should be determined for a more recent dataset to find out if the current delineation between ALC Grades is still valid. In comparison, following a review of the literature the authors concluded that there was no need to update the ALC methodology for soil or rock AWC and that the current root depths used to assess crop available water continue to be valid.

17.4.3 Climatic dataset

- The climate criteria used in the ALC system are average annual rainfall (AAR), average summer rainfall (ASR), median accumulated temperature >0°C from January to June (AT0) or from April to September (ATS) and median duration of field capacity days (FCD). All the data are decades old, use dated spatial interpolation methods and the temperature datasets use non-standard climate reference periods. Several reviews of the datasets and methods have recommended that the data should be updated (e.g. ADAS, 2004, Keay *et al*., (2014), Rollett and Williams (2020)).

- At the end of 2018 the Met Office made available the HadUK-Grid dataset which is a collection of climate variables derived from the network of UK weather stations. It is suggested that this dataset could be used as the basis for updating the ALC climate dataset for rainfall and temperature. The MORECS dataset is suggested as the basis for updating the field capacity days and moisture deficit (wheat and potatoes) datasets.

17.4.4 Extreme or episodic weather events

- Further work is required to investigate how best to incorporate the influence of the probability of extreme events into the ALC methodology (e.g. frequency and severity of extreme events). Work is also required to establish the methodology that would best capture the impact of weather extremes on the capability of agricultural land. Updates to the ALC could include the addition of new parameters (e.g., longest dry spell) or revision to current criteria (e.g. the use of percentiles rather than absolute values).

17.5 Prioritising the ALC system reviews

- Reviews with high priority include relatively simple updates to text in the ALC guidance (to improve clarity or understanding) and more complex changes to climate datasets (to update the underlying climate data) or ALC grade for climate limit values for rainfall and temperature.
- Lower priority for review are the climate metrics, additional wind and frost resources, a new agricultural flood model, soil PTE trigger values, the addition of guidance on a very slowly permeable layer, the expansion of the drought assessment to include additional crops and the development of online resources for soil wetness, droughtiness or climate grading.

17.6 Potential costs and timescales for review

- It is not possible to give a precise cost for the suggested work but an indicative cost for the high priority review is £187,200 and for the low priority review is £97,800. However, it should be noted that the final cost would depend on the precise nature of the work undertaken.
- Indicative timescales for the review and associated work are 2 years for the high priority work and 1.5 years for the low priority work.

17.7 Risks associated with updating ALC

- The risks that each suggested revision may have on the outcome of ALC grading have been categorised as none, low, medium or high. Updates in the low risk category (e.g. online frost or wind resources or a new flood model) are unlikely to change the ALC grade thresholds and will provide additional information to assist with grading. Revisions with the highest risk (e.g., updates to the climate dataset and variables that rely on that dataset) are highly likely to result in grade changes for interactive limitations (e.g., soil wetness and workability, droughtiness and overall climate). Also, due to the complex interactions between many of the parameters unexpected outcomes or uncertainties may result. Several of the high priority updates fall into the high risk category as they involve large-scale changes to the ALC dataset. Many of these are important for the ALC to reflect current climatic conditions and ensure that ALC continues to be of relevance in planning decisions.

17.8 Importance of testing and trialling

- Any updates to the climate dataset will be far reaching as they will impact not only the climate limitation but also the interactive limitations of soil wetness and droughtiness. This is important because climate, wetness and drought were identified as the most limiting factors at >60% sites by ADAS (2004) and Keay *et al*. (2014). Consequently, any changes to these parameters are most likely to impact the overall ALC grade.
- The proposed updates to the ALC will require thorough testing to quantify the impact of the changes on ALC grade for a range of sites. Each individual parameter will be tested independently to identify the effect of the revision on each ALC limitation before changes are combined to assess the impact on the overall grade. A statistical and spatial assessment of the impact of new climate data on climate, wetness and droughtiness gradings (and overall gradings) at an England and Wales level will be undertaken based on an estimation of the grades using 'old' and 'new' climate data. In addition, the spatial distribution of grade changes will be reviewed to assess the distribution of change and determine uncertainty in the data, e.g., where land that changes grade is interspersed with land that does not change grade or changes that do not fit with knowledge of field observations.
- To ground-truth the results a subset of samples will be graded by ALC surveyors to confirm that the model grading is representative of field conditions. Results will also be validated by a panel of ALC field specialists with experience across all English and Welsh regions.

17.9 Other considerations

- Future reviews of the ALC should consider whether it is appropriate to include a weighting system. Although the ALC recognises that "climate can be overriding in the sense that severe limitations will restrict land to low grades irrespective of favourable soil of site conditions" it is given equal weighting in the final grading. The lowest grade allocated to any limitation is the final grade.
- In the New Zealand Land Use Capability system, a LUC subclass is identified through which the main physical limitation or hazard to use is identified (Lynn et al., 2009). Four limits are recognised:
    - e: erodibility. Susceptibility to erosion is the dominant limitation
    - w: wetness. A high water table, slow internal drainage and/or flooding are the dominant limitations
    - s: soil. Dominant limitation is in the rooting zone (e.g., shallow soil, stoniness, low water holding capacity etc.)
    - c: climate. Dominant limitation might be summer drought, excessive rainfall, frequent frost, salt spray or strong winds.
- Other classification systems also identify the main limitation that applies in area through a sub-class or limitation type. For example, the SSEW Land Use Capability Classification identified the following subclasses, i.e., wetness (w), soil (s), gradient and soil pattern (g), erosion (e) and climatic (c) (Bibby and Mackney, 1969). The Scottish Land Capability Classification recognises the same five principal kinds of limitation (Bibby *et al*., 1991). It may be appropriate to use a subclass in the ALC to identify the dominant limitation.

- The ALC system was designed to identify land that is best suited to productive agriculture. The system does not consider the sustainability of production or the wider environmental or amenity value of any land. However, both the English and Welsh Government have set out plans to reward farmers and land managers for sustainable farming practices. In England, the Sustainable Farming Incentive (SFI) will pay farmers to provide public goods such as good water quality, biodiversity, animal health and welfare and climate change mitigation, alongside food production. Similarly, in Wales the proposed Sustainable Farming Scheme (due to begin in January 2025) will reward farmers for delivering sustainable land management outcomes (e.g. promoting carbon storage, soil and water quality, flood and drought risk mitigation). The increased emphasis on sustainability could potentially be reflected in the ALC if the remit of the scheme was expanded although this is outside the scope of the ALC as tool for planners.

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