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Llywodraeth Cymru
Welsh Government

# Capability, Suitability & Climate Programme

## Crop Requirements Report Part 2

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# Crop Requirements – Part 2

# Capability, Suitability & Climate Programme

**Submitted to:**

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Agricultural Land Use & Soil Policy

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## Introduction

This report builds on (and should be read in conjunction with) the previous report for Welsh Government, Part 1, completed in 2017, which considered the suitability of growing conditions in Wales for 21 crops (5 arable, 14 horticultural, 1 ornamental and grapes, Table 1). The assessment considered the climate (e.g. temperature or rainfall) and site limitations (e.g. aspect or gradient) or soil factors (e.g. soil depth, stone content, wetness/drainage or soil pH status) for the different crop types. The Agricultural Land Classification (ALC) grades that would potentially be suitable for each crop were also given. The report covered both land capability (i.e. the general assessment of, for example, climatic and soil factors without taking into consideration land use) and suitability (i.e. the fitness for the production of a specific crop). In this report the requirements of a further 101 crops are considered (Table 2, below).

**Table 1. List of crops in Part 1 2017 report.**

| Number | Crop |
|---|---|
| | **Arable** |
| 1 | Potatoes |
| 2 | Barley |
| 3 | Wheat |
| 4 | Oilseed rape |
| 5 | Maize |
| | **Horticulture** |
| 6 | Asparagus |
| 7 | Cauliflower |
| 8 | Squash |
| 9 | Courgettes |
| 10 | Parsnips |
| 11 | Carrots |
| 12 | Celeriac |
| 13 | Onions |
| 14 | Leeks |
| 15 | Rhubarb |
| 16 | Raspberries |
| 17 | Blackberries |
| 18 | Currants |
| 19 | Salad Crops |
| | **Viticulture** |
| 20 | Grapes |
| | **Ornamental** |
| 21 | Daffodils |

**Table 2. List of crops for Part 2**

| | **Crop** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **No** | **1. Arable** | **No** | **3. Field vegetables** | **No** | **4. Culinary herbs** | **No** | **7. Fruit (tree)** | **No** | **12. Other crops** |
| 1 | Seed potatoes | 21 | Artichokes | 41 | Mint | 61 | Apples | 82 | Comfrey |
| 2 | Sugar beet | 22 | Aubergine | 42 | Parsley | 62 | Cherries | 83 | Fennel |
| 3 | Beans: field | 23 | Beans: green, runner, broad | 43 | Rosemary | 63 | Pears | 84 | Herbage seed |
| 4 | Beans: soya | 24 | Beans: mung | 44 | Sage | 64 | Plums/Damsons | 85 | Hops |
| 5 | Beans: navy | 25 | Beetroot | 45 | Thyme | 65 | Greengages/Cherries | 86 | Juniper |
| 6 | Peas | 26 | Broccoli | | **5. Oil crops** | 66 | Olives | 87 | Poppy |
| 7 | Lentils | 27 | Brussels sprouts | 46 | Lavender | | **8. Other fruit** | 88 | Saffron |
| 8 | Lupins | 28 | Cabbages | 47 | Borage | 67 | Bilberries | 89 | Sunflowers |
| 9 | Millet | 29 | Celery | 48 | Calendula | 68 | Strawberries | 90 | Squill |
| 10 | Naked Oats | 30 | Chard | 49 | Camelina | 69 | Melons | 91 | Tea |
| 11 | Oats | 31 | Chicory | 50 | Echium | | **9. Forage/fodder crops** | | **13. Ornamental** |
| 12 | Rye | 32 | Garlic | 51 | Evening Primrose | 70 | Beets/Mangolds | 92 | Roses |
| 13 | Spelt Wheat | 33 | Horseradish | 52 | Linseed | 71 | Forage Rape | 93 | Tulip |
| 14 | Triticale | 34 | Kale | 53 | Flax | 72 | Lucerne | | **14. Trees** |
| | **2. Salad greens** | 35 | Radish | 54 | Cannabis | 73 | Birdsfoot Trefoil | 94 | Sitka Spruce |
| 15 | Komatsuna | 36 | Salsify | 55 | Lunaria | 74 | Sainfoin | 95 | Douglas Fir |
| 16 | Leaf radish | 37 | Spinach | 56 | Mustard | 75 | Typhon | 96 | Norway Spruce |
| 17 | Mibuna | 38 | Swedes | | **6. Nuts** | | **10. Green manure crops** | 97 | Western Red Cedar |
| 18 | Mizuna | 39 | Sweetcorn | 57 | Almonds | 76 | Black Medicks | 98 | Sessile Oak |
| 19 | Pak Choi | 40 | Turnips | 58 | Chestnut | 77 | Vetches | 99 | Beech |
| 20 | Rocket | | | 59 | Hazelnut | | **11. Biomass crops** | 100 | Wild Cherry |
| | | | | 60 | Walnuts | 78 | Reed Canary grass | 101 | Silver Birch |
| | | | | | | 79 | Miscanthus | | |
| | | | | | | 80 | Osiers | | |
| | | | | | | 81 | Willow | | |

***The crop tables***

Subsequent sections of the report detail the requirements of each crop and include a tabular summary of the crop requirements. The example table below is designed to facilitate understanding of the Tables that follow (Table 3).

**Table 3. Notes on crop requirement tables**

| Requirements | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 150 | 300 | For annual crops this the number of days from planting/sowing to harvest.<br>For perennial crops this is the number of days on which the crop is typically actively growing. |
| Air or ground frost | -3 | 0 | 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.<br>The minimum temperature is the temperature furthest from 0°C and the maximum temperature is the temperature closest to 0° at which freezing damage occurs. |
| Other | | | Frequent or strong winds can be damaging to crops.<br>Crops that have particular susceptibility to wind damage have been noted in the individual crop tables. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[7] | 24<br>[32] | This is the range of mean daily temperatures during the growing season which are optimum or [tolerable] for the crop, unless otherwise stated. |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | For the Agricultural Land Classification (ALC) system the period January to June is considered the critical growth period for most crops. Accumulated temperature (AT0) January to June is a measure of the relative warmth of a locality and is the excess of daily air temperature above 0°C (for the ALC system).<br>The AT0 ranges from *c.*600-800°C where the altitude is highest (*c.* 600-800 m) to >1200°C at altitudes of ≤200 m in, for example, Pembrokeshire.<br>Where there is no specific information on crop requirements, the minimum and maximum AT0 are based on the limit values for the appropriate ALC grades. |
| Rainfall (mm) Optimum & [tolerable] range | 500<br>[300] | 1000<br>[2500] | This is the annual rainfall which is optimum or [tolerable] for the crop, unless otherwise stated. |
| **Site** | | | |
| Aspect | | | The compass direction in which the land/slope faces (e.g. south or west). The south side of a slope will receive more direct solar radiation than the north side (in the northern hemisphere). Daily and accumulated temperatures are higher on slopes with a southerly aspect than those facing in a northerly direction. |
| Altitude (m) | | | Altitude (above mean sea level), affects, for example, soil wetness and temperature.<br>For the AT0, The lapse rate for temperature is 1.14 day °C/m (MAFF, 1988). For example, for two points which had the same National Grid |

| | | | |
|---|---|---|---|
| | | | easting and northing but a difference of 50 m in altitude the AT0 would be 57°C higher at the lower altitude.<br>Rainfall and frost risk increase at higher altitudes. |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed.<br>The gradient limit for each crop is given based on the categorisation used in the ALC: grade 1 to 3a 7°; grade 3b 11°; grade 4 18° and grade 5 >18°. |
| **Soil** | | | |
| Soil pH<br>Optimum & [tolerable] range | 7.0<br>[5.0] | 7.5<br>[8.3] | This is the soil pH which is optimum or [tolerable] for the crop, unless otherwise stated. |
| Topsoil texture | S | C | This indicates the range of suitable soil textures for the crop, e.g. min S to max C means that the crop can be grown on S, LS, SL, SZL, ZL, MZCL, MCL, SCL, HZCL, HCL, SC, ZC & C. Abbreviations for topsoil texture are listed Table 4, below. |
| Depth (cm) | 20-50 | 50-150 | Soil depth is often the limiting factor affecting water availability, anchorage or nutrient availability. The minimum depth is the most crucial and is that required for the crop plant to access sufficient water and nutrients from the soil profile.<br>Note that even where a soil has sufficient depth for crop growth other factors such as bulk density, soil structure, water table etc. can also impede root growth. |
| Stone content (%) | 0 | 5<br>[10] | Stones can impede cultivation, harvesting and crop growth. In line with the ALC the limits are given for stones in the top 25 cm of the soil for two size classes, i.e. >2 cm and >6 cm. Limiting percentages are based on the volume of hard stones; stones >6 cm have a more detrimental effect than those >2 cm. Hence the limiting percentages (for ALC grades) are lower for larger stones.<br>Where there is no specific information on crop requirements, the minimum and maximum stone limits are based on the limit values for the appropriate ALC grades for stones >2 cm [and >6 cm]. |
| Drainage | | | This is related to available water capacity, soil wetness, moisture balance and field capacity which are considered individually below. |
| ALC soil wetness class | I-III | I-II | For ALC purposes, soil wetness is assessed by a combination of the climatic regime, the soil water regime and the texture of the top 25 cm of the soil.<br>There are six soil wetness classes (I-VI) which are used in combination with topsoil texture and field capacity days to grade according to soil wetness.<br>A range of soil wetness classes are given for each crop as suitable classes depend on both soil texture and field capacity days. The most important is the minimum (i.e. wettest) soil wetness class. |
| Moisture balance (mm) | +5<br>[-10] | +30<br>[+10] | Droughtiness limits for ALC grades are defined in terms of moisture balances-MB (mm) for wheat and [potatoes], calculated as crop available water capacity-AP- moisture deficit-MD.<br>The moisture balance limits given are based on the ALC classes considered suitable for the crop, unless indicated otherwise. |

| | | | |
|---|---|---|---|
| Field capacity (days) | >225 | ≥151- | Field capacity days (FCD) is a meteorological parameter which estimates the number of days when the soil moisture deficit is zero.<br><br>The FCD categories in the ALC for assessing the climatic component of the wetness assessment are, <126, 126-150, 151-175, 176-225 and >225 days. For Wales, most sites will be in the highest two categories. |
| **Other** | | | |
| Environmental risks | | | Farmers manage 81% of the total Welsh land area and must sustain the balance between agricultural production and environmental management.<br><br>It has been assumed that crops are managed according to 'best practice' and only potential environmental risks specifically associated with a particular crop are listed. |
| ALC group | 2 | 1 | The Agricultural Land Classification of England and Wales (MAFF, 1988) provides a framework for classifying agricultural land "according to the extent to which its physical or chemical characteristics impose long- term limitations on agricultural use".<br><br>The limitations may affect the range of crops which can be grown, the level of yield, the consistency of yield and the associated cost of farming the land.<br><br>The minimum grade is indicative of the ALC grade where the crop may be potentially be grown subject to the limitations outlined in Table 5, below. |

**Table 4. ALC soil texture class abbreviations**

| Abbreviation | Soil textural class | Notes |
|---|---|---|
| S | Sand | |
| LS | Loamy sand | |
| SL | Sandy loam | |
| SZL | Sandy silt loam | |
| ZL | Silt loam | |
| MZCL | Medium silty clay loam | <27% clay content |
| MCL | Medium clay loam | <27% clay content |
| SCL | Sandy clay loam | |
| HSCL | Heavy silty clay loam | ≥27% clay content |
| HCL | Heavy clay loam | ≥27% clay content |
| SC | Sandy Clay | |
| ZC | Silty Clay | |
| C | Clay | |
| P | Peat | |
| SP | Sandy peat | |
| LP | Loamy peat | |
| PL | Peaty loam | |
| PS | Peaty sand | |
| MZ | Marine light silts | |

**Table 5. Agricultural Land Classification of England and Wales: grades 1-5.**

| Grade | Quality | Limits | Cropping |
|---|---|---|---|
| 1 | Excellent | No or very minor limits to agricultural use. | • Wide range of crops including fruit, salad crops and winter harvested vegetables. |

| | | | |
|---|---|---|---|
| | | | • High yields<br>• Low variation in yields |
| 2 | Very good | Minor limitations which might affect crop yield, cultivations or harvesting. | • Wide range of crops but may not be suitable for root crops or winter harvested vegetables.<br>• High yields<br>• More variation in yield. |
| 3a | Good | Moderate limitations which affect the choice of crops, timing and type of cultivation, harvesting or yield. | • Wide range of crops including cereals, oilseed rape, potatoes and less demanding horticultural crops<br>• Moderate yields |
| 3b | Moderate | | • Cereals: moderate yields<br>• Grass: high yields<br>• Other crops: lower yields |
| 4 | Poor | Severe limitations which restrict the range of crops and/or yield. | • Mainly grass with occasional arable crops (cereals or forage crops)<br>• Variable yields |
| 5 | Very poor | Very severe limitations. | • Restricted to permanent pasture or rough grazing. |

## Arable

***Crop 1. Seed potatoes***

In 2015, there were *c*.3,000 ha of potatoes grown in Wales (3% of total tillage land), with 60% grown in Pembrokeshire (Welsh Government, 2016), where land is well suited to potato production. Seed potatoes are generally confined to regions where a cool summer means a lower incidence of aphids and consequently less chance of aphid-transmitted virus disease (Jellings and Fuller, 1985). Land used for seed production must be free from potato cyst nematode and there must not have been any potatoes growing on the land in the preceding 5 to 7 years. Some seed potatoes are grown in Wales, for example, Sarpo Potatoes Ltd, has recently launched the 'Sustainable Potatoes Wales'[1] project, and is hoping to increase the number of Sarpo seed potato growers in Wales.

Potatoes are planted in ridges to ensure a well-drained aerated environment for strong growth. The duration of the growth cycle and total tuber production depends on cultivar, temperature and day length. Tuberisation comes before flowering and flowering is not necessary to produce tubers (Quiroz *et al*., 2012).

The shallow and sparse rooting system of potato plants (Opena and Porter 1999) make them sensitive to soil moisture stress (Onder *et al*. 2005) which can reduce yield and affect tuber quality. Potato crops require 0.35 to 0.8 $m^3$ of water to produce 1 kg of tuber dry matter. Under field conditions, this translates into a water requirement during the growing period of 350 to 650 mm, which is dependent on climate and cultivar (Sood and Singh, 2003 cited by Quiroz *et al*., 2012). Irrigation in England and Wales is mainly applied to enhance quality, e.g. size, shape, appearance, skin condition and delivery time to markets, rather than yield (Morris *et al*., 2004). The viability of commercial potato production is influenced by spatial and temporal variability in soils and agro-climate, and the availability of water resources where supplementary irrigation is required.

| Requirement | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing period (Days) | 120 | 150 | Short-lived annual.<br>Indeterminate varieties will carry on growing and require desiccation or haulm destruction to maximise yield and tuber quality. |

[1] http://sarpo.co.uk/sarpo-potatoes/

| | | | |
|---|---|---|---|
| | | | Determinate varieties stop producing new growth after tuber initiation.<br>Tuber initiation is triggered by short day length and temperatures of 15 to 20°C[2]. However, this response has been bred out of many commercially produced potatoes.<br>Plant: April (main crop) |
| Air or ground frost | | | ≤1°C may cause crop stress at any growth stage.<br>Frost will damage juvenile potato plants (emergence to 8 weeks)[3] as the foliage is very sensitive to frost.<br>Emergence should be timed so that the risk of frosts are minimised.<br>Mature tubers are susceptible to frost and must be lifted prior to autumn frosts. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[7] | 25<br>[30] | Optimum soil temperature 17-20°C<br>AT0 ≥1225°C required for potato production (Jones and Thomasson, 1985). |
| ALC accumulated temperature (day °C) | 1100 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 500<br>[250] | 800<br>[1750] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 8.5 | Limitations for de-stoning, planting and harvesting machinery (Daccache *et al*., 2012). |
| **Soil** | | | |
| Soil pH; optimum & [tolerable] range | 5<br>[4.2] | 7.0<br>[8.5] | |
| Topsoil texture | S | MCL | Wide range of soil types, medium soil type is optimal. |
| Soil depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 10 [15] | Stone free soil is preferred.<br>Stones may be mechanically removed providing they do not exceed 10% (volume).<br>Soils with >15% stones > 6 cm diameter in the top 25 cm are unsuitable (Knox *et al*., 2011). |
| Drainage | | | Free draining soils.<br>Water deficit during stolon formation and around tuber initiation can have an adverse effect on yield (Quiroz *et al*., 2012). |
| ALC soil wetness class | I-IV | I-II | |
| Moisture balance (mm) | -20<br>[-30] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Consider physical factors such as slope when bed forming and ridging. |

[2] http://www.yara.co.uk/crop-nutrition/crops/potato/key-facts/agronomic-principles/

[3] https://www.daf.qld.gov.au/plants/fruit-and-vegetables/vegetables/temperature-requirements-and-limitations

| | | | |
|---|---|---|---|
| | | | Soil compaction from the use of heavy machinery and/or soil loss through adherence. |
| ALC group | 3a | 1 | |

***Crop 2. Sugar beet***

Sugar beet (*Beta vulgaris*) is agriculturally important because of its ability to accumulate a large quantity of sugar in its storage root. It has been calculated that the yield potential for sugar beet in the UK's climate is 140 to 150 t/ha; the fact that this is not achieved is due to the weather, crop management, pests, diseases and weeds (Bayer Crop Science, 2011).

Sugar beet is grown under contract to British Sugar which is the sole processor of the UK's sugar beet crop and supplies around 60% of the UKs demand for sugar[4]. Growers are offered one or three-year contracts with a guaranteed minimum beet price plus a market bonus (linked to the EU market price for white sugar). Sugar is processed in four plants situated in East Anglia and the East Midlands; there is currently no processing plants in Wales or the west of England. From 1 October 2017 EU sugar policy became deregulated, with the abolition of national quotas and most other regulatory restrictions. This will allow the UK to grow more sugar beet potentially increasing opportunities for farmers to produce this crop.

| **Requirement** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 210 | 270 | Sugar beet is a long day plant and requires long days to promote stem extension and flowering (Draycott, 2006).<br>Plant: March (early March is optimum) to April.<br>Harvest: September to November. But harvesting season may be extended if lifting conditions are unsuitable. |
| Air or ground frost | | | Young seedlings can be damaged by frost. Severe frost can damage sugar beet left in the ground awaiting harvest in the autumn/winter (BBRO, 2018). |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 18<br>[7] | 26<br>[30] | Seed germination will start where soil temperatures are >3°C but will be slow at <5°C. Germination can be adversely affected if heavy rainfall occurs within 48 hours of drilling (BBRO, 2018). |
| ALC accumulated temperature (day °C) | 1100 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 400<br>[250] | 700<br>[1000][5] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 7.0<br>[6.5] | 7.5<br>[8.0] | Target pH varies according to soil type. Lower pH (6.0-) is tolerated on organic and peat soils (BBRO, 2018). |
| Topsoil texture | S | HCL | Wide range of soil types may be suitable, although medium soils often give the best crops (Jellings and Fuller, 1985). Clay soils may be unsuitable due to difficulties in seedbed preparation and harvesting. |
| Soil depth (cm) | 50-150 | >150 | |
| Stone content (%) | 0 | 10 [15} | |
| Drainage | | | Well drained. |
| ALC soil wetness class | I-IV | I-II | |

[4] https://www.britishsugar.co.uk/about-us/what-we-do/

[5] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=48742

| | | | |
|---|---|---|---|
| Moisture balance (mm) | -20 [-30] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Late harvesting increases the risk of compaction and soil loss by erosion.<br>Bare soil over winter (post-harvest) may increase nitrate leaching losses. |
| ALC group | 3a | 1 | |

***Crop 3. Beans: field***

Field beans (*Vicia faba*) are grown for harvesting dry for use in animal feed or export, mainly to Egypt, for human consumption (The Andersons Centre, 2015). In 2014, it was estimated that the UK accounted for about a third of all European bean production.

There are both winter and spring types which are suitable for different situations, yield and harvest dates are similar. However, winter beans are more frost hardy and form a taller thicker leaf canopy than spring types. Field beans are traditionally grown on heavy soils but a wide range of soil types are suitable where the risk of drought is minimised. Where summer drought is likely and/or spring sowing is problematic then winter beans are better.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 270[6]<br>[195] | 330<br>[240] | Winter beans: sown late October to early December.<br>Spring beans: sown late February to mid-March.<br>Both types are typically harvested in September. |
| Air or ground frost | -15 | -12 | Winter beans are hardy to -12-15°C.<br>Spring beans are not frost hardy; minimum temperature for germination is 5°C. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 18<br>[5] | 28<br>[32][7] | |
| ALC accumulated temperature (day °C) | 1100 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 650<br>[250] | 1000<br>[2600] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.8<br>[6.5] | 7.0<br>[7.5] | |
| Topsoil texture | MZCL | C | Medium to heavy soils. Light soils are unsuitable due to the risk of drought. Waterlogged soils should be avoided (Jellings and Fuller, 1985). |
| Depth (cm) | 20 | 150 | |
| Stone content (%) | 0 | 10 [15] | |
| Drainage | | | Not droughty or waterlogged (bean seeds are sensitive to poor aeration). |
| ALC soil wetness class | I-IV | I-II | |
| Moisture balance (mm) | -20<br>[-30] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | Bare soil over winter (before the establishment of spring beans) may be at risk of erosion and increased nitrate leaching losses. |

[6] 270-330 days for winter beans and 195-240 for spring beans

[7] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=2146

| | | | |
|---|---|---|---|
| ALC group | 3a | 1 | |

***Crop 4. Beans: soya.***

Around 2,000 hectares of soya beans (*Glycine max*) were grown in the UK in 2017 (Soya UK, 2017) and the area grown is expected to increase. Soya grown in the UK is non-GM and will attract a price premium from buyers who want traceable non-GM soya (*c.*80% of world plantings are GM).

| Requirements | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 120 | 150 | Sow late April/early May.<br>Soya beans respond to the length of days and begin to flower as nights become longer<br>Harvest September. |
| Air or ground frost | | | Soya bean is very sensitive to frost at seed emergence and pod filling. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 20<br>[10] | 33<br>[38] | Soya beans require soil temperatures of >10°C to germinate but between 13-16°C is optimal (Illinois Soybean Association, 2012).<br>Air temperatures of about 20°C.<br>1500-1600 degree days above 6°C. |
| ALC accumulated temperature (day °C) | 1100 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 600<br>[450] | 1500<br>[1800][8] | Excess moisture severely affects germination and early growth of soya bean. |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | 0 | 600<br>[1000] | Grows best at altitudes of less than 600 m above sea level.<br>Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.0<br>[5.8] | 8.0<br>[8.5] | Ideally, the soil pH values are neutral (pH 6–8) (Đorđević *et al*., 2017). |
| Topsoil texture | SL | C | Wide range of soil types except those that are very sandy. |
| Depth (cm) | 20-50 | 50-150 | Most roots in the upper 0.3 m of soil but can extend to 1.3 to 1.8 deep. |
| Stone content (%) | 0 | 10 [15] | |
| Drainage | | | Well drained (DAFF, 2010a). |
| ALC soil wetness class | I-IV | I-II | |
| Moisture balance (mm) | -20<br>[-30] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | Late harvesting increases the risk of compaction and soil loss by erosion.<br>Bare soil over winter (post-harvest) may increase nitrate leaching losses. |
| ALC group | 3a | 1 | |

[8] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=1150

***Crop 5. Beans: navy***

A number of pulses have already been considered in this report (e.g. lupins, lentils, peas etc.). However, navy (or haricot) beans (*Phaseolus vulgaris*) are used in the production of baked beans and are typically imported and there may be limited opportunity to grow these in Wales.

Navy beans are susceptible to frost and it is important that average soil temperature exceeds 10°C at sowing. Warm temperatures are required for optimum growth and harvesting is often not until late September/October. Suitable areas for production are most likely to be in parts of Wales where the mean minimum temperature in June is above 10°C and the average rainfall in September is below 75 mm (PGRO, 2017).

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 150 | 180 | Sow: Early to mid-May. Sowings made after 25 May can suffer from delayed harvest and reduced yields (PGRO, 2017).<br>Harvest: September-October. |
| Air or ground frost | | | Susceptible to frost. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 16<br>[7] | 25<br>[32] | Growth is optimal at temperatures of 18 to 24 °C. The maximum temperature during flowering should not exceed 30°C.<br>Day temperatures <20 °C will delay maturity and cause empty mature pods to develop (Liebenberg, 2002). |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 500<br>[300] | 2000<br>[4300] [9] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | Gentle slope for air drainage and to avoid frost pockets.<br>The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 5.5<br>[4] | 7.5<br>[9] | The optimum soil pH levels are 5.8-6.5 (Liebenberg, 2002). |
| Topsoil texture | SL | HCL | Sandy loam, sandy clay loam or clay loam with a clay content of between 15 and 35 % is suitable. |
| Depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Well drained soil |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5<br>[-10] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | Late harvesting increases the risk of compaction and soil loss by erosion.<br>Bare soil over winter (post-harvest) may increase nitrate leaching losses. |
| ALC group | 2 | 1 | |

[9] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=1668

***Crop 6. Peas***

Field peas also known as combinable peas (*Pisum sativum*) are grown for harvesting 'dry' whereas vining peas are grown for harvest as a green vegetable for processing. Peas may also be hand-picked for selling fresh in supermarkets etc. Combining peas are a valuable break crop used as a high protein component of pet and livestock feeds or canned for human consumption. Vining peas are grown under contract to provide a continuous supply of produce for the processing plants over the growing season (varieties and husbandry are likely to be dictated by the processor). Fresh peas are harvested as whole pods and are harvested by hand to minimize pod damage. The peas are stripped from the stems in the field and packed in boxes before being transported to the farm or pack house for packing.

Peas are traditionally grown in lower rainfall areas as they are not compatible with wet conditions particularly during the later stages of development when the canopy is vulnerable to disease and infection that will reduce both yield and quality (Jellings and Fuller, 1985). Heavy rainfall and wind in June and July can result in tall crops that are prone to lodging, growing peas on lighter soils reduces lodging risk.

Peas are most sensitive to soil moisture deficits at the beginning of flowering and during pod swelling. Irrigation during petal fall may increase the occurrence of Botrytis.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 150 | 180 | Sow: Mid-February onwards.<br>Harvest: late July to early September (field peas); where the crop is weedy or shows uneven ripening it may be desiccated prior to harvest. Vining peas are harvested at the optimum stage of maturity for rapid transport to the processing plants. |
| Air or ground frost | -6 | | Seedlings are tolerant of spring frosts to about -5 to -6°C, and if injured by frost, a new shoot will emerge from below the soil surface (Endres *et al*., 2016).<br>Although peas at early growth stages can survive frost, more advanced crops suffer damage (Red Tractor Assurance, 2016a, 2016b).<br>Damage from frost is unlikely if peas are sown after mid-February. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 10<br>[4] | 24<br>[30][10] | Peas do not grow at temperatures below 4.4°C (Red Tractor Assurance, 2016a, 2016b). |
| ALC accumulated temperature (day °C) | 1100 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 800<br>[350] | 1200<br>[2500] | Excessive rainfall during the later stages of pea growth is undesirable. Plant habit becomes indeterminate and flowering prolonged which may result in a humid microclimate that encourages fungal growth. |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | Gentle slope for air drainage and to avoid frost pockets.<br>The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 5.9<br>[4.5] | 6.5<br>[8.3] | pH >6.5 is acceptable but is likely to lead to manganese deficiency and a foliar manganese spray may be required. |

[10] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=1721

| | | | |
|---|---|---|---|
| Topsoil texture | LS | SCL | Deep, free-working loams are suitable for peas. Drought prone sands (unless irrigated) and heavy clay soils are unsuitable. |
| Depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Free draining soils are essential; peas are very sensitive to waterlogging (Red Tractor Assurance, 2016a, 2016b). |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5 [-10] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Late harvesting increases the risk of compaction and soil loss by erosion.<br>Bare soil over winter may increase nitrate leaching losses. |
| ALC group | 2 | 1 | |

***Crop 7. Lentils***

Lentils (*Lens culinaris*) are mostly used for human consumption; the two main types are red and green lentils. Worldwide, lentil production is *c*.5 million tonnes of which Canada and India are the major producers. Both spring and autumn lentil sowings have been trialled in the UK (Stone, 1991; Crook, 1999) and the first commercial crop of lentils was harvested in the UK in 2017[11].

Lentil does not tolerate flooding or waterlogged soils and free draining soils are essential. Waterlogging will result in flower and pod abortion and leaf senescence. This is a potential problem for UK crops. In many countries, lentils are indeterminate and drought forces maturation. However, severe drought is uncommon in the UK and determinate varieties will be essential (Crook, 1999).

Lentil is extremely sensitive to some residual herbicides, which can cause damage to the plant.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 120 | 310[12] | Sow: Autumn, e.g. October or spring, e.g. May.<br>Harvest: summer, e.g. mid-July to September.<br>When more than 90% of pods lose their green colour lentils are ready to harvest. The crop is typically desiccated when 60% of the pods in the top third of the canopy are appearing yellow-buff. |
| Air or ground frost | -7 | -2 | Frost tolerance at germination is -7/8°C, at flowering is -2/3°C and at podding -2/4 (GRDC, 2017). |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[5] | 29<br>[35] | Lentil can germinate at 5°C, although emergence will be increased at 7°C (GRDC, 2017). |
| ALC accumulated temperature (day °C) | ≥1300 | | |
| Rainfall (mm) Optimum & [tolerable] range | 600<br>[300] | 1000<br>[2500][13] | Lentil requires annual rainfall >300 mm (GRDC, 2017). |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1300°C). |
| Gradient (°) | 0 | 7 | Slightly sloping land is OK, providing that farming operations are still practicable.<br>The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.3 | 8.7 | Lentil is well suited to neutral to alkaline soils, preferring soils with a pH range of 6.3to 8.7 (GRDC, 2017). |
| Topsoil texture | SL | SCL | Sandy loams or heavier. |
| Depth (cm) | 50 | 150 | |
| Stone content (%) | 0 | 5 | Avoid stony fields, small stones can contaminate the harvest. |
| Drainage | | | Free draining. |

[11] https://hodmedods.co.uk/blogs/news/first-british-lentil-harvest-underway

[12] Large range includes crop grown in spring and autumn.

[13] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=7209

| | | | |
|---|---|---|---|
| | | | Lentil plants will die if exposed to even short periods of waterlogging or flooding (GRDC, 2017). |
| ALC soil wetness class | I-II | | |
| Moisture balance (mm) | +30 [+10] | | |
| Field capacity (days) | ≥151 | 225 | |
| **Other** | | | |
| Environmental risks | | | No specific risks. |
| ALC group | 1 | 1 | |

***Crop 8. Lupins***

Lupins are high protein, high energy, nitrogen-fixing grain legumes. There are currently three species of the lupin (*Lupinus* spp.) family available in the UK, the white lupin (*Lupinus albus*), the narrow leaved or blue lupin (*L. angustifolius*) and the yellow lupin (*L. luteus)*. Lupins have three main uses, 1) in animal feed, 2) in human consumption (lupin flour) and 3) to add N to soil in crop rotations.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Lupin is a long day plant, increasing day length provides a signal for the start of reproductive development.<br>Sow: mid-March to mid-April. |
| Air or ground frost | 0 | 2 | Lupin can be damaged by frost during vegetative growth, although the leaves enclosing the meristem give some protection to the vegetative shoot tips.<br>However, frost during the reproductive phase causes flower abortion (Walker *et al*., 2011). |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 10<br>[0] | 22<br>[40] | Optimum temperature for germination is 20°C.<br>The optimum temperature for photosynthesis is between 10 and 22°C. At temperatures >22°C the rate of photosynthesis is reduced and at <7°C, root nodulation and development is restricted; both extremes reduce plant growth (Walker *et al*., 2011). |
| ALC accumulated temperature (day °C) | 1100 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 400<br>[360] | 1000<br>[1800][14] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | Slightly sloping land is OK, providing that farming operations are still practicable.<br>The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 4.5 | 7/7.5 | Blue/yellow lupins are sensitive to alkaline soil and pH <7 is ideal. White lupins are more tolerant of alkaline conditions and grow well at pH 7 (PGRO, 2014). |
| Topsoil texture | S | SZL<br>[MCL][15] | Light sandy soils. White lupins can be grown on more heavy textured soils (PGRO, 2014). |
| Depth (cm) | 50 | 150 | |
| Stone content (%) | 0 | 10 [15] | |
| Drainage | | | Well drained, lupins are sensitive to waterlogging. |
| ALC soil wetness class | I-IV | I-II | |
| Moisture balance (mm) | -20<br>[-30] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |

[14] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=7431

[15] MCL for white lupins only.

| | | | |
|---|---|---|---|
| Environmental risks | | | Bare soil over winter may increase nitrate leaching losses. |
| ALC group | 3a | 1 | |

***Crop 9. Millet***

Millet (*Panicum miliaceum*) is an annual plant of the grass family grown for fodder, bird seed and for culinary uses. In the UK, selected species of millet are included in cover crops where it is valued for game and wildlife.

The variety 'Mammoth' has been specifically developed for UK conditions and is grown under full buy-back contracts with Soya UK[16]. Similarly, Sunshine millet, can be grown under contract with Premium Crop[17].

Millet is a C4 annual grass like Maize, meaning that it does not grow well at low temperatures, but does well as temperatures increase.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 130 | 135 | Sow: late April to May.<br>Harvest: early to mid-September.<br>Desiccation mid to late August is required to even out the maturity of seeds. |
| Air or ground frost | | | Susceptible to frost but is planted/harvested when the risk of frost is minimal. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 20<br>[15] | 32<br>[45] | At planting the soil temperature needs to be a minimum of 10°C, but 15°C is better to ensure a very rapid emergence and establishment. |
| ALC accumulated temperature (day °C) | 1000 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 500<br>[200] | 700<br>[1000][18] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1000°C). |
| Gradient (°) | 0 | 11 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land and for grade 3b it is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.0<br>[5.2] | 6.5<br>[8.2] | |
| Topsoil texture | S | SCL | Light and medium soils are best. |
| Depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 20 [35] | |
| Drainage | | | Avoid waterlogged soils. |
| ALC soil wetness class | II-IV | I-II | |
| Moisture balance (mm) | -50<br>[-55] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | Bare soil over winter may increase nitrate leaching losses. |

[16] http://www.soya-uk.com/mammoth-millet/

[17] http://www.premiumcrops.com/millet/agronomy.html

[18] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=8280

| | | | |
|---|---|---|---|
| ALC group | 3b | 1 | |

***Crop 10. Naked oats***

In 2017, *c.*5000 ha of oats (*Avena sativa*), was grown in Wales (*c.*6% of total tillage land) (AHDB, 2018); it is not known what proportion of that area (if any) was naked oats.

Oats generally tolerate acidic soils and moist climates better than either wheat or barley, making them ideally suited to Welsh growing conditions (Hackett, 2018). They are grown for both animal and human nutrition. Although the yield per unit area of naked oats is about 20 to 25% lower than those of conventional husked varieties, the higher oil and nutrient content of the grain attract a premium (CALU, 2005).There is a growing market for naked oats due to the premium price (30-45/t). There is particular interest in naked oats for non-ruminants like pigs and poultry because of the high energy content and crude protein values (McCalman and Little, 2013).

During the harvesting of husked oats the kernel remains tightly enclosed by a lignified lemma and palea, collectively termed the husk or hull. In naked oats, which are the same species as husked oats, the lemma is much less lignified and the kernel threshes free during harvesting. The value of the oat is in the grain and the removal of the fibrous husk at harvest makes the naked oat grain of premium value especially as it offers a nutrient dense grain with its higher protein and oil levels (Wadsworth, 2012). The yield of naked oats is lower than husked oats but the price premium and high nutritional value offset this difference.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 300 | 330 | Sow: Mid-September to mid-October is optimum but naked oats can been sown in November if necessary (winter varieties) or mid-March to the end of April (spring varieties).<br>Harvest: late July to September.<br>Long days (>12 hours) advance floral development. |
| Air or ground frost | | | Shallow sown winter oats can be susceptible to 'frost heave' over winter where roots are shallow.<br>Oats are the most susceptible cereal to frost lift and winter kill (Wade, 2012). |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 16<br>[5] | 20<br>[30] | |
| ALC accumulated temperature (day °C) | 1000 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 600<br>[250] | 1000<br>[1500] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1000°C). |
| Gradient (°) | 0 | 11 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. The limit for 3b land is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.5<br>[4.5] | 7.5<br>[8.5] | |
| Topsoil texture | LS | C | Light, medium or heavy soil types.<br>Poorly structured or shallow soils provide weak anchorage and increase root lodging risk. However, where shallow soil is over chalk then roots can penetrate the bedrock. |
| Depth (cm) | 20-50 | 50-150 | |

| | | | |
|---|---|---|---|
| Stone content (%) | 0 | 20 [35] | No specific limits but ALC gives limit values for Grade 3b of 20% and 35% (by volume) for stones >6 and 2 cm, respectively in the top 25 cm of soil. |
| Drainage | | | Well drained.<br>However, water stress may limit crop yield and late season drought can reduce grain filling. |
| ALC soil wetness class | II-IV | I-II | |
| Moisture balance (mm) | -50<br>[-55] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | Bare soil over winter may increase nitrate leaching losses on late winter and spring sown crops. |
| ALC group | 3b | 1 | |

***Crop 11. Oats***

In 2017, *c*.5000 ha of oats was grown in Wales (c.6% of total tillage land) (AHDB, 2018); the proportion of winter to spring plantings was not reported. Oats generally tolerate acidic soils and moist climates better than either wheat or barley, making them ideally suited to Welsh growing conditions (Hackett, 2018). They are grown for both animal and human nutrition; oats are also used in skin care products.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 300 | 330 | Sow: Mid-September to mid-October is optimum but can sow in November if necessary (winter varieties) or mid-March to the end of April (spring varieties).<br>Harvest: late July to September.<br>Long days (>12 hours) advance floral development |
| Air or ground frost | | | Shallow sown winter oats can be susceptible to 'frost heave' over winter where roots are shallow.<br>Oats are the most susceptible cereal to frost lift and winter kill (Wade, 2012). |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 16<br>[5] | 20<br>[30] | |
| ALC accumulated temperature (day °C) | 1000 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 600<br>[250] | 1000<br>[1500] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1000°C). |
| Gradient (°) | 0 | 11 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. The limit for 3b land is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.5<br>[4.5] | 7.5<br>[8.5] | |
| Topsoil texture | LS | C | Light, medium or heavy soil types.<br>Poorly structured or shallow soils provide weak anchorage and increase root lodging risk. However, where shallow soil is over chalk then roots can penetrate the bedrock. |
| Depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 20 [35] | No specific limits but ALC gives limit values for Grade 3b of 20% and 35% (by volume) for stones >6 and 2 cm, respectively in the top 25 cm of soil. |
| Drainage | | | Well drained<br>However, water stress may limit crop yield and late season drought can reduce grain filling. |
| ALC soil wetness class | II-IV | I-II | |
| Moisture balance (mm) | -50<br>[-55] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |

| | | | |
|---|---|---|---|
| Environmental risks | | | Bare soil over winter may increase nitrate leaching losses on late winter and spring sown crops. |
| ALC group | 3b | 1 | |

***Crop 12. Rye***

Rye (*Secale cereale*) was traditionally grown as a grain, a cover crop and a forage crop. More recently, hybrid rye has been grown as a feedstock for anaerobic digestion. Rye is more cold and drought tolerant than wheat, however, wheat and barley do better than rye in hot weather.

Winter types of rye require 40–60 days of cold temperatures, whereas the spring types require only 10–12 days to shift into the reproductive stage. Although rye comes into ear earlier than wheat, the grain takes much longer to mature. Rye is ready to harvest when the leaves are dead and the stems have turned yellow-brown.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 300 | 330 | Sow: mid to late September to November.<br>Harvest: timing and growth stage depends on the end-use of the crop.<br>Cereal rye is a long-day plant; that is, it requires increasing day length to induce flowering. |
| Air or ground frost | | | Cereal rye is one of the least susceptible cereals to frost. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[3] | 20<br>[31][19] | Germination can occur at 1°C but vegetative growth requires ≥3°C (GRDC, 2018).<br>Rye needs a cumulative soil temperature from the time of planting of 90°C for field emergence, provided sufficient water is present (GRDC, 2018). |
| ALC accumulated temperature (day °C) | 1000 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 600<br>[400] | 1000<br>[2000] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1000°C). |
| Gradient (°) | 0 | 11 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land and for 3b it is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 5.2 | 8.2 | The optimum soil pH for growth of cereal rye is *c*.5.2–8.2 (GRDC, 2018). |
| Topsoil texture | S | SCL | Light loams or sandy soils although it will grow in heavy clay and poorly drained soils. |
| Depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 20 [35] | |
| Drainage | | | |
| ALC soil wetness class | II-IV | I-II | |
| Moisture balance (mm) | -50<br>[-55] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | No specific risk. |
| ALC group | 3b | 1 | |

[19] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=1929

***Crop 13. Spelt wheat***

Spelt wheat (*Triticum spelta*) has unique gluten structure that makes it easier to digest than conventional wheat (Gillespie *et al*., 2014) and has recently becoming popular in artisan breads and cereals.

There is little agronomic data for the production of spelt wheat, particularly from a Western European or UK context. Hence it has been assumed that where no specific information exists, the crop requirements are the same as wheat (*Triticum aestivum*).

| Requirement | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 300 | 330 | Day length affects the duration of foundation and construction phases.<br>Long days (>12 hours) advance floral development in most varieties.<br>Sow: mid-September.<br>Harvest: July to August. |
| Air or ground frost | | | A period of cool temperature 0-12°C advances floral development.<br>Vernalisation reduces the duration of the foundation phase.<br>The apex is frost tolerant.<br>Frost risk highest when the ear is developing.<br>Frost risk falls significantly from April (AHDB, 2015). |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 10<br>[4] | 17<br>[24] | Warmth shortens all phases. More growth occurs in any phase during cool temperatures due to the increase in length of that phase (AHDB, 2015). |
| ALC accumulated temperature (day °C) | 1000 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 700<br>[300] | 1000<br>[1600] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | ~ | ~ | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1000°C). |
| Gradient (°) | 0 | 11 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. The limit for 3b land is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.5<br>[5] | 7.5<br>[8.3][20] | |
| Topsoil texture | LS | C | Medium or heavy soil types will allow optimal water capture, but wheat can be grown on lighter soils. |
| Soil depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 20 [35] | No specific limits but ALC gives limit values for Grade 3b of 20% and 35% (by volume) for stones >6 and 2 cm, respectively in the top 25 cm of soil. |
| Drainage | | | Well drained. |
| ALC soil wetness class | II-IV | I-II | |
| Moisture balance (mm) | -50<br>[-55] | +30 [+10] | |

[20] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=10591

| | | | |
|---|---|---|---|
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | No specific risk. |
| ALC group | 3b | 1 | |

***Crop 14. Triticale***

Triticale is a cross between wheat and rye that can be included in livestock feed, used by the bioethanol industry, harvested as a whole crop for silage or used as a feedstock for anaerobic digestion. Small amounts are used in human food products such as breakfast cereals. It was produced to combine the grain qualities of wheat with the low input requirements and hardiness of rye. However, it has had limited take-up in the UK, partly due to it often being seen as a low-yielding crop best suited to poor or marginal soils (Clarke *et al*., 2016a). The winter varieties grown have a vernalisation requirement and must be sown in the autumn or early spring (before mid-February) for them to produce flowering stems and grain (CALU, 2005).

Recent research in the UK has shown that triticale often out-yields wheat. The yield advantages of triticale come from a combination of a greater number of ears per $m^2$ and more grains per ear that are filled during a longer grain-filling period (Clarke *et al*., 2016b).

| Requirement | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 280 | 330 | UK trials have shown that Triticale begins stem extension and flowering earlier than wheat, but maturity date is only slightly earlier, giving a longer duration for grain-filling (Clarke *et al*., 2016b). |
| Air or ground frost | | | Triticale has been rated as susceptible to frost damage (GRDC, 2018b). |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15 [5] | 23 [27][21] | Four to eight weeks of low temperatures (>0°C and <9°C) are required for vernalisation as well as to ensure adequate development of cold tolerance (Salmon *et al*., 2004). |
| ALC accumulated temperature (day °C) | 1000 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 750 [300] | 900 [1600] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | ~ | ~ | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1000°C). |
| Gradient (°) | 0 | 11 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. The limit for 3b land is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 5 [4.5] | 7 [8.5] | Triticale performance under acid soils (in Brazil for example) has demonstrated excellent tolerance to low pH levels (Salmon *et al*., 2004). |
| Topsoil texture | LS | C | Medium or heavy soil types will allow optimal water capture, but Triticale can be grown on lighter soils.<br>As it is drought tolerant triticale can out-perform other cereals on sandy soils. |
| Soil depth (cm) | 50 | 50-150 | |
| Stone content (%) | 0 | 20 [35] | No specific limits but ALC gives limit values for Grade 3b of 20% and 35% (by volume) for stones >6 and 2 cm, respectively in the top 25 cm of soil. |
| Drainage | | | Well drained. |
| ALC soil wetness class | II-IV | I-II | |
| Moisture balance (mm) | -50 [-55] | +30 [+10] | |

[21] Porter and Gawith (1999).

| | | | |
|---|---|---|---|
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | No specific risk. |
| ALC group | 3b | 1 | |

## Salad greens/Asian vegetables

### *Crop 15. Komatsuna*

Young leaves, stalks and flower shoots of komatsuna (*Brassica campestris*) are used in salad and stir fry.

There is little information available on the commercial production requirements for this crop. It has been assumed that its requirements are similar to rocket.

| Requirements | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 20 | 80 | |
| Air or ground frost | | | |
| Other | | | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 17 [5] | 30 [41][22] | Soil temperature >5°C. |
| ALC accumulated temperature (day °C) | ≥1300 | | |
| Rainfall (mm) Optimum & [tolerable] range | 700 [400] | 1000 [3500] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1300°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 5.5 | 7.5 | |
| Topsoil texture | ? | ? | Wide range of soil types. |
| Depth (cm) | 20-50 | 20-50 | |
| Stone content (%) | 0 | 5 | |
| Drainage | | | |
| ALC soil wetness class | I-II | | |
| Moisture balance (mm) | +30 [+10] | | |
| Field capacity (days) | ≥151 | 225 | |
| **Other** | | | |
| Environmental risks | | | Assumed to be the same as for mibuna and mizuna, i.e.<br>High levels of local water abstraction where crop is irrigated.<br>Shallow effective rooting depth may lead to low N use efficiency increasing the risk of leaching.<br>Disposal of fleece or polythene crop covers if used.<br>Frequent trafficking due to successional harvesting/planting.<br>Bare soil over winter may increase erosion and nitrate leaching losses on spring sown crops. |
| ALC group | *1* | *1* | |

[22] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=3844

***Crop 16. Leaf radish***

Radish (*Raphanus sativus*) is a member of the Cruciferae (mustard family) it is often grown as a root vegetable but the leaves can also be eaten. Leaf radish varieties have less hairy leaves than those grown for roots making them more palatable in salads. As radishes have a very short growing period, several crops can be grown on the same piece of land during one season. However, this can lead to problems with disease and pest carry-over. When radishes are grown on soil with a light texture, irrigation is often required to assist germination and may be necessary throughout growth. Irrigation is thought to be of particular importance when the hypocotyl begins to swell especially if scab is likely to be a problem (Red Tractor Assurance, 2016l).

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 30 | 60 | Sowing at intervals during the spring will provide a continuous harvest.<br>Harvest: April to October, depending on the weather.<br>Long days induce bolting. |
| Air or ground frost | | | |
| Other | ~ | ~ | |
| Mean daily air temperature (°C).<br>Optimum & [tolerable] range | 12<br>[3] | 25<br>[30][23] | The minimum temperature for germination is 5°C[24]<br>The best quality and root shape are obtained when the crop grows and matures at moderate temperatures (10 to 18 °C) in intermediate to short day lengths. |
| ALC accumulated temperature<br>(day °C) | 1150 | ≥1300 | |
| Rainfall (mm)<br>Optimum & [tolerable] range | 800<br>[500] | 1000<br>[2800] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | Slightly sloping land is OK, providing that farming operations are still practicable.<br>The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH<br>Optimum & [tolerable] range | 6.0<br>[5.2] | 6.8<br>[8.3] | |
| Topsoil texture | S | SCL | A variety of soil types are suitable. Light textured or sandy soil and soils with a high OM or peat content produce crops with good colour and skin finish.<br>Soils with heavy texture and high clay content are unsuitable (Red Tractor Assurance, 2016l). |
| Depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Well drained. |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5<br>[-10] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |

[23] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=11291

[24] https://www.faa.gov.nl.ca/agrifoods/plants/pdf/radish.pdf

| | | | |
|---|---|---|---|
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Shallow effective rooting depth may lead to low N use efficiency, and increased risk of leaching.<br>Disposal of fleece or polythene crop covers if used.<br>Frequent trafficking due to successional harvesting/planting.<br>Bare soil over winter may lead to increased risks of soil erosion. |
| ALC group | 2 | 1 | |

***Crop 17. Mibuna***

Mibuna (*Brassica rapa*. Var. *japonica*) is a Japanese leafy vegetable used in salad mixes. It can be grown outside but will require the protection of horticultural fleece, depending on the season. However, more typically it will be grown in either a polytunnel or low field cloche (CALU, 2006). In the US salad crops may be grown using raised bed systems either with/without plastic coverings.

The crop can be sown directly or transplanted and it is essential to keep the soil moist until the crop is established (CALU, 2006).

Note: There is little information specifically referring to mibuna; the information below is taken from literature in relation to the similar crop mizuna.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 40 | 60 | Long day crop, flowering begins when day length is >12 hours.<br>Sow: in spring when the soil temperature ≥10°C. Only sow in autumn if the crop will be covered (Grahn *et al*., 2015). |
| Air or ground frost | | | Tolerant to light frosts (Masabni, Undated).<br>Avoid frost pockets and exposed sites.<br>Select areas where the risk of frost is low (i.e. coastal). |
| Other | | | Wind can help reduce pests and diseases by ensuring that the crop environment is not sufficiently humid for fungal development. However, the crop is easily damaged by strong winds. |
| Mean daily air temperature (°C).<br>Optimum & [tolerable] range | 7 | 18<br>[25] | Germination temperature 15-18°C.<br>Optimum temperature range 7-18°C (Ramu, 2012).<br>Temperatures >25°C can slow growth and reduce quality (Masabni, Undated). |
| ALC accumulated temperature<br>(day °C) | ≥1300 | | |
| Rainfall (mm)<br>Optimum & [tolerable] range | | | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1300°C). |
| Gradient (°) | 0 | 7 | Slightly sloping land is OK, providing that farming operations are still practicable. The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH<br>Optimum & [tolerable] range | 6.0<br>[5.5] | 6.8<br>[7.5] | pH 5.5-7.5 (Masabni, Undated) but soil with a pH of 6.0-6.8 results in maximum yield (Ramu, 2012). |
| Topsoil texture | SZL | HCL | Loamy soils with high water retention[25].<br>Will tolerate a wide range of soil types with proper management. Avoid excessively heavy soils that can cause root malformation (Masabni, Undated). |
| Depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 5 | |
| Drainage | | | Well drained. |
| ALC soil wetness class | I-II | | |

[25]https://www.daf.qld.gov.au/business-priorities/plants/fruit-and-vegetables/vegetables/asian-vegetables/mizuna-and-mibuna-greens

| | | | |
|---|---|---|---|
| Moisture balance (mm) | +30 [+10] | | |
| Field capacity (days) | ≥151 | 225 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Shallow effective rooting depth may lead to low N use efficiency, and increased risk of leaching.<br>Disposal of fleece or polythene crop covers if used.<br>Frequent trafficking due to successional harvesting/planting.<br>Bare soil over winter may increase soil erosion. |
| ALC group | 1 | 1 | |

***Crop 18. Mizuna***

Mibuna (*Brassica rapa*. Var. *nipposinica*) is a Japanese leafy vegetable used in salad mixes. It can be grown outside but will require the protection of horticultural fleece, depending on the season. However, more typically it will be grown in either a polytunnel or low field cloche (CALU, 2006). In the US salad crops may be grown using raised bed systems either with/without plastic coverings.

The crop can be sown directly or transplanted and it is essential to keep the soil moist until the crop is established (CALU, 2006).

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 40 | 60 | Long day crops, flowering begins when day length is >12 hours.<br>Sow: in spring when the soil temperature ≥10°C. Only sow in autumn if the crop will be covered (Grahn *et al*., 2015). |
| Air or ground frost | | | Tolerant to light frosts (Masabni, Undated).<br>Avoid frost pockets and exposed sites.<br>Select areas where the risk of frost is low (i.e. coastal). |
| Other | | | Wind can help reduce pests and diseases by ensuring that the crop environment is not sufficiently humid for fungal development. However, the crop is easily damaged by strong winds. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 7 | 18<br>[25] | Germination temperature 15-18°C.<br>Optimum temperature range 7-18°C (Ramu, 2012).<br>Temperatures >25°C can slow growth and reduce quality (Masabni, Undated). |
| ALC accumulated temperature (day °C) | ≥1300 | | |
| Rainfall (mm) Optimum & [tolerable] range | | | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1300°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.0<br>[5.5] | 6.8<br>[7.5] | pH 5.5-7.5 (Masabni, Undated) but soil with a pH of 6.0-6.8 results in maximum yield (Ramu, 2012). |
| Topsoil texture | SZL | HCL | Loamy soils with high water retention[26].<br>Will tolerate a wide range of soil types with proper management. Avoid excessively heavy soils that can cause root malformation (Masabni, Undated). |
| Depth (cm) | | | |
| Stone content (%) | 0 | 5 | |
| Drainage | | | Well drained. |
| ALC soil wetness class | I-II | | |
| Moisture balance (mm) | +30<br>[+10] | | |
| Field capacity (days) | ≥151 | 225 | |
| **Other** | | | |

[26]https://www.daf.qld.gov.au/business-priorities/plants/fruit-and-vegetables/vegetables/asian-vegetables/mizuna-and-mibuna-greens

| | | | |
|---|---|---|---|
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Shallow effective rooting depth may lead to low N use and increased risk of nitrate leaching.<br>Disposal of fleece or polythene crop covers if used.<br>Frequent trafficking due to successional harvesting/planting.<br>Bare soil over winter may increase risk of soil erosion. |
| ALC group | 1 | 1 | |

***Crop 19. Pak choi***

Pak choi (*Brassica chinensis*) can be grown throughout the UK, although wetter areas can increase the risk of the fungal infection ringspot (Red Tractor Assurance, 2016c). In drier areas irrigation may be required to main continuity of production. Plants can be direct drilled or transplanted. Seed for transplanting can be drilled under glass from mid-February or drilled without protection from early April to the end of August. Crops planted in the field may benefit from early protection under frost covers.

Irrigation may be required; rapid establishment can be achieved by irrigating immediately prior to sowing direct-drilled crops and after planting out of transplanted crops. Mature pak choi prefer growing in warm, moist conditions so the ability to irrigate the crop is essential.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 60 | 90 | Transplant in spring or direct sow in summer.<br>Harvest should be done before bolting and the first frost of autumn. |
| Air or ground frost | | | |
| Other | | | On light land windy areas should be avoided as soil particles can contaminate the head (Red Tractor Assurance, 2016c). |
| Mean daily air temperature (°C).<br>Optimum & [tolerable] range | 15<br>[10] | 21<br>[32] | Pak choi germinates best at temperatures between 7 and 20°C; optimal vegetative growth occurs between 15-21°C with uniform soil moisture (Nair and Irish, 2016).<br>Temperatures <13°C can lead to bolting. |
| ALC accumulated temperature<br>(day °C) | ≥1300 | | |
| Rainfall (mm)<br>Optimum & [tolerable] range | 900<br>[300] | 1400<br>[2000] [27] | |
| **Site** | | | |
| Aspect | | | Use of fields sloping to the South and West should be made for early production (Red Tractor Assurance, 2016c). |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1300°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH<br>Optimum & [tolerable] range | 7.0 | 7.3<br>[7.5] | A pH level of 7.0 to 7.3 is required, particularly where club root may be a problem (Red Tractor Assurance, 2016c). |
| Topsoil texture | S | MCL | Oriental brassicas can be grown on a wide range of soil types but lighter sandier soils will require irrigation.<br>Sandy-loam or clay-loams are best (Nair and Irish, 2016). |
| Depth (cm) | 20 | 150 | |
| Stone content (%) | 0 | 5 | |
| Drainage | | | Good drainage is essential. |
| ALC soil wetness class | I-II | | |
| Moisture balance (mm) | +30<br>[+10] | | |
| Field capacity (days) | ≥151 | 225 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion. |

[27] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=3878

| | | | |
|---|---|---|---|
| | | | Leafy vegetables accumulate nitrate in leaves so the N content of crop residues may be high increasing the risk of nitrate leaching.<br>Disposal of fleece or polythene crop covers if used.<br>Frequent trafficking due to successional harvesting/planting.<br>Bare soil over winter can increase soil erosion risk. |
| ALC group | 1 | 1 | |

***Crop 20. Rocket***

Rocket consists of two genera, *Eruca* and *Diplotaxis*. Wild rocket (*Diplotaxis tenuifolia*) is most popular in Europe whereas *Eruca sativa* (salad rocket) is the popular species in the US; however, often the terms are used interchangeably (Taylor, 2015). Rocket has increased in popularity over the last 20 years in the leafy salads market (Bennett *et al.,* 2007). In the UK, over 80 tonnes of rocket is consumed per week (Gill, 2008 cited by Taylor, 2015) which is sourced from Italy, Portugal, Spain, UK and USA.

An adequate water supply is needed in order to obtain high yield and good quality produce (Bianco, 1994).

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 26<br>[36] | 68<br>[99][28] | |
| Air or ground frost | | | |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[8] | 25<br>[29][29] | Plant when soil temperature reaches 10°C (Grahn *et al*., 2015).<br>Rocket bolts in response to high temperatures (>26°C) and long day lengths (>12 hours) (Morales *et al*., 2006). |
| ALC accumulated temperature (day °C) | ≥1300 | | |
| Rainfall (mm) Optimum & [tolerable] range | 500<br>[300] | 900<br>[1100] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1300°C). |
| Gradient (°) | 0 | 7 | Gentle slope for air drainage and to avoid frost pockets.<br>The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.2<br>[6] | 6.8<br>[8.5] | |
| Topsoil texture | S | ZL | Light textured soils such as silt and sandy loam. |
| Depth (cm) | 20-50 | 20-50 | |
| Stone content (%) | 0 | 5 | |
| Drainage | | | Well drained. |
| ALC soil wetness class | I-II | | |
| Moisture balance (mm) | +30<br>[+10] | | |
| Field capacity (days) | ≥151 | 225 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Rocket accumulates nitrate in leaves; limit values have been set of between 6000-7000 mg $NO_3$/kg (depending on harvest date) so the N content of crop residues may be high increasing the risk of nitrate leaching. |

[28] The longer growing period is for wild rocket which is slower to establish and germinate than salad rocket.

[29] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=5794

| | | | |
|---|---|---|---|
| | | | Shallow rooting leads to low N use efficiency, which increases risk of leaching.<br>Disposal of fleece or polythene crop covers if used.<br>Frequent trafficking due to successional harvesting/planting.<br>Bare soil over winter may increase soil erosion. |
| ALC group | 1 | 1 | |

## Horticulture (vegetables)

### *Crop 21. Artichokes*

Globe artichoke (*Cynara scolymus*) is grown for its tender edible immature flower buds. It is typically grown as an annual but can also be grown as a perennial when it is replanted every 5 to 10 years, however, it may be difficult to overwinter in the UK climate. Irrigation during the growing season will often be required.

Transplanted glasshouse plants are usually used instead of direct drilling, which are hardened before planting. Bud production occurs 60-100 days after transplanting.

| Requirements | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Perennial, but can be grown as an annual crop.<br>Harvest: October to May (excluding the coldest part of the winter). |
| Air or ground frost | -1 | 0 | Young globe artichokes transplants are tolerant of temperatures of -1 to 0°C. Mature plants usually survive heavy frosts, but their yield may be reduced. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[5] | 25<br>[30] | Vernalisation is required to induce bud formation (190 to 240 hours at ≤10°C) (Bratsch, 2014).<br>Globe artichokes grow best at 24°C daytime and 13°C night time temperature with a range of 7-29°C (DAFF, undated). |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 900<br>[300] | 1200<br>[1500][30] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. The limit for 3b land is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6<br>[5.5] | 6.5<br>[8.3] | |
| Topsoil texture | MZCL | SCL | Medium soils, not heavy clay or light sands. |
| Depth (cm) | 50 | 150 | Deep rooted, 90-120 cm |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Well drained |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5<br>[-10] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated or fertigation is used.<br>Irrigation may increase the risk of run-off and/or soil erosion. |
| ALC group | 2 | 1 | |

[30] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=847

Jerusalem artichoke (*Helianthus tuberosus*) are grown for their fleshy tubers and are native to temperate regions of North America.

| Requirements | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 210 | 240 | Perennial, but usually grown as an annual crop from tubers.<br>Sow: February to April<br>Harvest: after the first frosts |
| Air or ground frost | | | Frosts cause severe damage to young plants and planting should be delayed until after the normal time for the last frost. The plant requires a maximum of 140 frost-free days to produce good crops. The flavour of tubers in the ground can be improved by frosts (DAFF, 2011).<br><br>Generally the plant can tolerate sub-zero temperatures while the tubers can withstand freezing for several months even if the frost kills the stems and leaves (Yang *et al*, 2015). |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[7] | 27<br>[30][31] | The optimal soil temperature for planting is between 6 and 7 °C due to the fact that tubers become dormant at temperatures lower than 5 °C. The suitable average temperature range is 6.3–26.6 °C (Yang *et al.*, 2015). |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 700<br>[300] | 1500<br>[2000] | Suitable annual precipitation ranging from 310 to 2820 mm (Yang *et al.*, 2015). |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. The limit for 3b land is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6<br>[4.5] | 6.5<br>[8.3] | Slightly alkaline soils are favourable for Jerusalem artichoke production (Yang *et al.*, 2015). |
| Topsoil texture | LS | SCL | Light to medium soils. |
| Depth (cm) | 50 | 150 | |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Well drained |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5<br>[-10] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated or fertigation is used.<br>Irrigation may increase the risk of run-off and/or soil erosion. |

[31] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=1193

| | | | |
|---|---|---|---|
| | | | Bare soil over winter may increase the risk of soil erosion and nitrate leaching losses. |
| ALC group | 2 | 1 | |

***Crop 22. Aubergines***

Aubergines need warm soil and warm air temperatures to yield well (Saha *et al*., 2015) and do not perform well when exposed to low temperatures. In the UK, most aubergines are grown in polytunnels or glasshouses as they are susceptible to frost and growth of young plants is retarded when night temperatures are <16°C (Adamczewska-Sowińska, 2016). Most field grown aubergines are produced from plants that have been transplanted from a glasshouse rather than direct seeded. Market maturity will be reached about a month later in direct seeded plants than transplants.

In the US aubergine are cut back after the first crop is harvested to allow a second crop to develop. However, this may not be feasible under growing conditions in Wales.

Aubergine are likely to require irrigation to ensure the production of high quality fruit. The most critical period for irrigation is during flower and fruit formation (Kemble *et al*., 1998).

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | 120 days from transplants, longer from seed. |
| Air or ground frost | | | Susceptible. The optimum soil temperature for seed germination is 24-32°C (Ullio, 2003). |
| Other | | | Susceptible to wind damage; a trellis support system may be used to keep the fruit off the ground and to reduce wind damage (Ullio, 2003). |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 21 [16] | 29 [35] | Cool temperature and cloudiness can reduce fruit set (Chen *et al*., 2002). Transplanting must occur after all risk of frost has passed. Transplanting can be into raised bed for good drainage and only when the soil temperature is >20°C. |
| ALC accumulated temperature (day °C) | ≥1300 | | |
| Rainfall (mm) Optimum & [tolerable] range | 1200 [800] | 1600 [4000][32] | Can tolerate drought and excessive rainfall. |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1300°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. The limit for 3b land is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.5 [4.5] | 6.5 [8.5][32] | |
| Topsoil texture | SL | MCL | Sandy loam, loam or clay loam soils. Avoid heavy clay (Red Tractor Assurance, 2016d). |
| Depth (cm) | 50 | 150 | Deep. Root zone depth of 90 cm (Chen *et al*., 2002) |
| Stone content (%) | 0 | 5 | |
| Drainage | | | Well drained |
| ALC soil wetness class | I-II | | |
| Moisture balance (mm) | +30 [+10] | | |
| Field capacity (days) | ≥151 | 225 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated. Irrigation may increase the risk of run-off and/or soil erosion. |

[32] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=1965

| | | | |
|---|---|---|---|
| | | | Bare soil over winter may increase risk of soil erosion and nitrate leaching. |
| ALC group | 1 | 1 | |

***Crop 23. Beans: green, runner or broad beans.***

Green beans are a short season, late sown, cold sensitive crop that requires warm conditions for uninterrupted growth. Most suitable areas are south of the Wash. Green beans have shallow roots and a short growing season. Hence, for maximum yield the soil should be maintained close to field capacity throughout the growing season. Irrigation is most beneficial during flower initiation and pod development.

Runner beans are very susceptible to frost damage and high winds can be damaging to climbing runner beans causing pod scarring. They are dependent on insects for pollination and hives of honey bees may be introduced into the crop. Runner beans are also responsive to irrigation. Irrigation during early flower bud has been shown to the most important timing.

Broad beans can be grown successfully in most parts of the UK but high rainfall leads to excessive vegetative growth. However, drought stress during flowering and pod fill stages reduces yield. Irrigation from the beginning of flowering onwards can achieve large yield increases.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 50 | 90 | Sown in mid-May to avoid damage from late frosts. |
| Air or ground frost | | | Susceptible to frost and cold temperatures |
| Other | | | Runner beans need a sheltered site to avoid wind damage. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 16[33] [7] | 25 [32] | |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 500 [300] | 2000 [4300] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.5 [5.5] | 7.5 [9] | Broad beans require a pH of at least 6.0 to 6.5. |
| Topsoil texture | MZCL | SCL [HCL] | Medium soil types. Heavy clays are unsuitable for green and runner beans.<br>Broad beans can be grown on heavier soils than green or runner beans. |
| Depth (cm) | 20 | 150 | Shallow rooted. |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Free draining but moisture retentive soil. |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5 [-10] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Bare soil over winter can increase risk of soil erosion and nitrate leaching. |

[33] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=1668

| | | | |
|---|---|---|---|
| ALC group | 2 | 1 | |

***Crop 24. Beans: mung.***

Mung beans (*Vigna radiate*) are used for the production of bean sprouts or for processing. Mung beans are widely grown in Southeast Asia, Africa, South America and Australia but not in Europe. However, recent experimental work in Poland showed that it was possible to grown mung bean in the Polish summer (average daily air temperature June-September 18°C, rainfall *c.*300 mm) (Misiak *et al*., 2017). Crops are typically irrigated during flowering and early pod fill.

Pod maturity in mung bean is not uniform because the plants flower over an extended period. A desiccant is often used to kill green leaf and the few remaining green pods before harvest.

As a cover crop and soil improver, the mung bean can be sown before or after cereal crops. It makes good green manure. It is a nitrogen-fixing legume that can provide large amounts of biomass (7 t biomass/ha) and nitrogen to the soil (ranging from 30 to 250 kg/ha)[34].

| Requirements | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 90 | 120 | Seeds are best planted when the minimum air temperature is ≥15°C. Planted in late spring or summer. |
| Air or ground frost | | | Not frost tolerant. Requires 90-120 frost free days from planting to maturity (DAFF, 2010b). |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 25 [8] | 30 [40] | A typical mung bean cultivar requires a total of 1200°C day degrees in the days from sowing to maturity. |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 600 [500] | 1000 [1250][35] | Adequate rainfall from flowering to late pod fill to ensure good yield. |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | Reasonably steep gradients (Gentry, 2010). The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.3 [5] | 7.2 [8] | Mung beans require slightly acid soil for best growth (DAFF, 2010b). |
| Topsoil texture | SL | SZL | Fertile sandy loam. Heavy clay soils restrict growth and should be avoided (Mbeyagala *et al.,* 2017). |
| Depth (cm) | 20 | 150 | Mung beans are deep rooted. |
| Stone content (%) | 0 | 5 [10] | Avoid stony fields. |
| Drainage | | | Good |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5 [-10] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |

[34] https://www.integratedbreeding.net/743/communities/communities/facts-figures/mungbean-facts-figures

[35] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=2150

| | | | |
|---|---|---|---|
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Bare soil over winter may increase soil erosion and nitrate leaching risks. |
| ALC group | 2 | 1 | |

***Crop 25. Beetroot.***

Beetroot (*Beta vulgaris*) are grown for selling fresh, as cooked beet or as processed beet (e.g. in jars whole or sliced). Early crops require irrigation to ensure that a high growth rate is maintained and to achieve a good yield (Red Tractor, 2016e). Irrigation may also be required for main crops. Globe varieties are fairly shallow rooted and irrigation may be needed from June to August when the soil moisture deficit exceeds 25 mm (on sandy or sandy loam soils) or 50 mm (for other soil types) (MAFF, 1983).

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 120 | 180 | Early crops<br>Sown: February to early March and covered with film or fleece. Harvest: June to July<br>Main/late crops:<br>Sown: March to June. Harvest: July onwards.<br>Long day plant. A combination of long days and low temperature may induce flowering (bolting) although many varieties are now resistant to bolting. |
| Air or ground frost | | | Frost susceptible but will tolerate mild frosts. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[10] | 19<br>[25] | The majority of varieties grow best in a cooler climate with average daily temperatures between 15 and 19°C (Irving *et al*., 2012).<br>The minimum soil temperature for beetroot germination is 5°C (Schrader and Mayberry, 2003). |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 600<br>[500] | 800<br>[1000] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1150°C). |
| Gradient (°) | 0 | 7 | Limitations for de-stoning, planting and harvesting machinery.<br>The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.2<br>[5.8] | 7.0<br>[7.5] | |
| Topsoil texture | SL | MZCL | Sandy loams and silts to organic loams and fen peats (Red Tractor Assurance, 2016e). Very sandy soil is not suitable; under dry conditions variable germination and establishment can result. |
| Depth (cm) | 20 | 150[36] | |
| Stone content (%) | 0 | 5 [10] | Stone separation and burying will be required if soils are stony to avoid root damage and malformation.<br>Soils with a high content of gravel that cannot be removed are unsuitable.<br>No specific limits but ALC gives limit values for Grade 2 of 5% and 10% (by volume) for stones >6 and 2 cm, respectively in the top 25 cm of soil. |
| Drainage | | | |
| ALC soil wetness class | I-III | I-II | |

[36] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=514

| | | | |
|---|---|---|---|
| Moisture balance (mm) | +5<br>[-10] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Soil compaction from the use of heavy machinery (e.g. for de stoning) and/or soil loss through adherence.<br>Disposal of polythene and fleece crop covers.<br>Bare soil over winter may increase soil erosion and nitrate leaching. |
| ALC group | 2 | 1 | |

***Crop 26. Broccoli***

Broccoli (*Brassica oleracea var. italica*) is part of the cabbage family; the immature flower stalk is typically eaten fresh or following freezing. In wetter areas it can be advantageous for the crop to be exposed to prevailing winds, the crop dries out quickly and helps reduce the incidence of spear rot. However, in drier areas the crop may require irrigation as broccoli requires moisture throughout its growing period. Consequently, moisture retentive, alkaline soil are most suitable. Continuous production might be possible under the right conditions.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 75 | 90 | Early crops are obtained from module raised transplants whereas later crops are direct drilled into the field.<br>Sown: February to March under glass for transplanting in early to mid-April. Direct sown from mid-March to mid-August.<br>Harvest: usually occurs between June and August, although harvesting of late sown crops may be as late as November but is restricted to milder areas of the UK. Most crops need cutting two or three times since maturity within a crop is variable (Soffe, 1985). |
| Air or ground frost | | | |
| Other | | | Expose crop to prevailing wind in wetter areas but protect from strong damaging winds (Red Tractor Assurance, 2016c).<br>Avoid heavily wooded field margins and wasteland to minimise crop attack by rabbits, hares, pigeons etc. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[3] | 24<br>[35] | A soil temperature of 5-35°C is suitable for germination but it is most rapid between 20 to 28°C (Heisswolf *et al*., 2004).<br>Night temperatures between 10°C and 15°C.<br>Warm temperatures can cause poor head quality in broccoli. |
| ALC accumulated temperature | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 900<br>[350] | 1500<br>[2000] | |
| **Site** | | | |
| Aspect | | | Fields sloping to the South and West are best for early production (Red Tractor Assurance, 2016f). |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 7.0<br>[6.5] | 7.5<br>[8.5] | Particularly important when club root may be a problem. |
| Topsoil texture | S | MCL | Wide range of soil types, light sandy soils are good for early production but irrigation is essential to ensure good plant establishment, growth and development. |
| Depth (cm) | 50 | 150 | The plant in not deep rooted – most roots are in the top 35 cm. |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5<br>[-10] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated. |

| | | | |
|---|---|---|---|
| | | | Irrigation may increase the risk of run-off and/or soil erosion.<br>Potential soil structural damage caused by harvesting broccoli on heavier soils.<br>Disposal of perforated polythene crop covers.<br>Leafy vegetables accumulate nitrate in leaves so the N content of crop residues will be high.<br>Bare soil over winter may increase soil erosion and nitrate leaching. |
| ALC group | 2 | 1 | |

***Crop 27. Brussel Sprouts***

Brussels sprouts (*Brassica oleracea var. oleracea*) can be grown throughout the UK, although wetter areas in the west can increase the risk of foliar diseases. In drier areas of the south and east, irrigation may be required during periods of drought to maintain continuity. The greatest response is likely to be obtained by irrigating immediately pre-sowing in direct drilled crops. In transplanted crops irrigate soon after planting out to assist rapid crop establishment.

In earlier-maturing varieties due to be single-harvested in August and early September the crop is often 'stopped' by removing the growing point (or terminal bud) from the plant, or by destroying the bud with a sharp tap using a rubber hammer. This removes apical dominance and stimulates sprout growth producing a 5–10% higher yield.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Sow: Direct sowing, early March to late April, depending on variety. Transplanted crops are typically planted from April to late May. Harvest: September to December. |
| Air or ground frost | | | The young sprouts are at their best when hardened off by a sharp frost. |
| Other | | | Avoid heavily wooded field margins and wasteland to minimise crop attack by rabbits, hares, pigeons etc. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 12 [7] | 20 [25] | A soil temperature of 5-35°C is suitable for germination but it is most rapid between 20 to 28°C (Heisswolf *et al*., 2004). Night temperatures between 10°C and 15°C. If young plants are subjected to prolonged exposure to temperatures less than about 7°C, they frequently bolt to seed in autumn before making an economic crop. |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 900 [500] | 1600 [3000] | |
| **Site** | | | |
| Aspect | | | Fields sloping to the South and West are best for early production. |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 7.0 [6.5] | 7.5 [7.8] | Particularly important when club root may be a problem. |
| Topsoil texture | S | MCL | Well-structured calcareous clays and silts are the most suitable, although with irrigation a wide range of soils would be suitable. |
| Depth (cm) | 50 | 150[37] | |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Good drainage is essential. |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5 [-10] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated. |

[37] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=555

| | | | |
|---|---|---|---|
| | | | Irrigation may increase the risk of run-off and/or soil erosion.<br>Potential soil structural damage caused by harvesting sprouts on heavier soils.<br>Leafy vegetables accumulate nitrate in leaves so the N content of crop residues will be high.<br>Bare soil over winter may increase soil erosion and nitrate leaching. |
| ALC group | 2 | 1 | |

***Crop 28. Cabbage***

Cabbages (*Brassica oleracea var. capitata*) can be divided into six types, depending on leaf structure, density, colour and time of maturity, i.e. spring greens, early summer cabbage, late summer/autumn cabbage, winter cabbage, winter white and winter red storage cabbage and Savoy cabbage (Red Tractor Assurance, 2016g). Most varieties in current commercial use are hybrids. The crop can be grown throughout the UK, although wetter areas in the West can increase the risk of ringspot. Plastic film covers may be used for early production of summer and savoy cabbages but is only usually justified on crops that command a price premium.

The greatest response to irrigation is achieved after planting out with transplanted crops or immediately prior to direct drilling. Summer cabbages may benefit from watering during the growing period. In drier areas of the south and east, irrigation may be required during periods of drought to maintain continuity.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 150 | 300 | Sow: March to August<br>Harvest: May to November<br>Note: sowing/harvesting dates and growing season vary according to crop type. |
| Air or ground frost | -3 | 0 | Fairly resistant to frost but harvest should be before mid-November frosts to maximise storage life (Red Tractor Assurance, 2016g). |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[7] | 24<br>[32] | Cabbage plants that are exposed to temperatures of 10-13°C for prolonged periods may bolt (Delahaut and Newenhouse, 1997). |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 500<br>[300] | 1000<br>[2500][38] | |
| **Site** | | | |
| Aspect | | | Fields sloping to the South and West are best for early production. |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 7.0<br>[5.0] | 7.5<br>[8.3] | Particularly important when club root may be a problem. |
| Topsoil texture | S | MCL | Cabbage can be grown on a wide range of soil types, but lighter sandier soil types will require irrigation. However, heavier soil types may making harvesting difficult, particularly for winter types. |
| Depth (cm) | 20-50 | 20-50 | |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5<br>[-10] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |

[38] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=554

| | | | |
|---|---|---|---|
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Potential soil structural damage caused by harvesting winter cabbage on heavier soils.<br>Trafficking by harvest team.<br>Disposal of polythene covers sometimes used on early crops.<br>Leafy vegetables accumulate nitrate in leaves so the N content of crop residues will be high.<br>Bare soil over winter may increase soil erosion and nitrate leaching. |
| ALC group | 2 | 1 | |

***Crop 29. Celery***

Green celery (*Apium graveolens*) is the most popular type on the market, although there is still demand for blanched celery (where sunlight has been excluded from the developing stalks and the formation of chlorophyll has been inhibited). Because of its shallow root system, frequent, light irrigation is desirable, especially during the second half of crop growth. Nevertheless, prolonged periods when foliage is wet should be avoided, because such conditions favour development of foliage diseases.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 120 | 210 | Direct seeded or sown with transplants.<br>Sow: May-July<br>Harvest: July to December. |
| Air or ground frost | | | Plants can withstand very light frosts. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 13<br>[5][39] | 24<br>[25] | The crop requires high humidity and temperatures between 13°C and 24°C for plant development and high yields.<br>Temperatures remaining below 13°C will cause bolting and above 24°C will result in more fibrous and bitter stalks (DAFF, 2013a). |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 700<br>[500] | 1300<br>[1500] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | Level surface is most suitable.<br>The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6<br>[5.5] | 6.5<br>[7.5] | pH ranging from 6 to 6.5 (DAFF, 2013a). |
| Topsoil texture | S | MCL | Sandy to medium loam soils. |
| Depth (cm) | 20-50 | 20-50 | Plants are fairly shallow rooted, although deep soils are most suitable. |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Well drained. |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5<br>[-10] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Potential soil structural damage caused by harvesting on heavier soils.<br>Trafficking by hand-harvesting can cause soil structural damage.<br>Disposal of perforated polythene crop covers.<br>The nitrate content of the crop and, consequently crop residues can be high.<br>Bare soil over winter may increase soil erosion and nitrate leaching. |
| ALC group | 2 | 1 | |

[39] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=431

***Crop 30. Chard***

Chard (*Beta vulgaris var. vulgaris*) is a cool season crop which is half-hardy and can withstand light frosts (Red Tractor Assurance, 2016i). Prolonged exposure to temperatures <5°C will induce bolting, whereas during hot weather leaves remain small and are of poor quality.

Growing the crop in wet areas can increase the risk of disease; in drier areas irrigation may be needed in summer to maintain the crop. In dry areas of the country crops may require fairly frequent irrigation to ensure that the soil does not dry out to less than 50% available water.

Avoid heavily wooded field margins or wasteland which can be home to rabbits, hares and pigeons which may damage newly drilled crops.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 60 | 150 | Sow: March to August in frost free areas. In colder areas planting may be delayed until April. Early crops may be covered with polythene or fleece. |
| Air or ground frost | | | Can withstand light frosts (Red Tractor Assurance, 2016i).<br>Production of overwintered and late crops require relatively frost free areas. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C).<br>Optimum & [tolerable] range | 7<br>[4] | 25<br>[32] | Chard is a cool season crop that grows best at temperatures ranging from 7-25°C (Red Tractor Assurance, 2016i).<br>15-24°C days, 4-7°C nights (Masabni, undated a). |
| ALC accumulated temperature<br>(day °C) | 1150 | ≥1300 | |
| Rainfall (mm)<br>Optimum & [tolerable] range | 800<br>[500][40] | 1000 | |
| **Site** | | | |
| Aspect | | | South and west facing fields are best for early production. |
| Altitude (m) | | | Good access is necessary.<br>Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH<br>Optimum & [tolerable] range | 6.0<br>[5.5] | 7.0<br>[8.0] | Soil pH should be maintained at a level of 6.0 to 7.0 (Red Tractor Assurance, 2016i). |
| Topsoil texture | S | MCL | A wide range of soil types are suitable. Sandy soils will require irrigation but are best suited to direct drilled crops. |
| Depth (cm) | 50 | 150 | Chard has a moderately deep root system. |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Good drainage is essential. |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5<br>[-10] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion. |

[40] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=2474

| | | | |
|---|---|---|---|
| | | | Potential soil structural damage caused by cultivation or harvesting rig.<br>Trafficking by harvest team.<br>Disposal of polythene or fleece covers sometimes used on early crops.<br>Bare soil over winter may increase soil erosion and nitrate leaching. |
| ALC group | 2 | 1 | |

***Crop 31. Chicory***

Chicory (*Cichorium intybus* var. *sativum* (root chicory) or var. *foliosum* (cooked/salad chicory)) is grown in the field for its swollen taproot. Chicory root can be dried and use in pet foods, roasted and used in drink flavouring or processed to extract inulin (used as a sweetener, a source of soluble fibre or converted to ethanol for use as a biofuel). Chicory can also be used as a forage crop (broad-leaved varieties) for livestock; it has anthelmintic properties making it useful to ruminant livestock farmers (Rosenfeld and Rayns, undated). The crop should be ready to graze from eight weeks post-establishment.

Once the chicory root is harvested it can be put into cold storage to vernalise. Early crops of chicory require vernalisation by a minimum period of chilled storage for 10 days at 5°C. Crops forced before Christmas can be stored at 0-1°C. After Christmas, the temperatures should be brought down to -2°C. Following vernalisation the crop is forced in a controlled hydroponic environment in the dark to produce the chicon (which develop from apical buds on the taproots); the chicon takes 21 days to grow to the correct size for the UK's supermarkets. A single chicon is produced and once it has been harvested the remaining root may be used as animal feed.

Chicory is especially sensitive to any residue in the soil of a hormone herbicide. Such herbicides, including clopyralid, should be avoided in the previous crop. Particular care should be taken to minimise herbicide drift from neighbouring fields.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 180 | 210 | Sow: Mid-April to mid-August (later sowing is a part of a mixed sward for grazing).<br>Harvest: Late September to October.<br>Fodder crops: Persistency 2-5 years (AHDB, 2013). Chicory is dormant during winter. |
| Air or ground frost | | | Tolerates light frosts, however exposed sites with a history of light spring or early autumn frosts are best avoided.<br>A cold period is required to induce flowering. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 13<br>[7] | 24<br>[30] | The optimum temperature for chicory growth lies between 13°C and 24°C (Red Tractor Assurance, 2016j).<br>Growth ceases if temperatures are <7°C or >30°C.<br>Soil temperature should reach ≥10°C before planting in the spring (AHDB, 2013). |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 1500<br>[300][41] | 2500<br>[4000] | Requires well distributed rainfall (DAFF (2013b). |
| **Site** | | | |
| Aspect | | | Warm south facing fields are preferred. North facing fields should be avoided. |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.0<br>[4.8] | 6.8<br>[8.3] | Chicory will tolerate acid soil conditions (pH 5.0 to 6.8), although growth is better if pH lies between 6.0 and 6.8. Fields with a wide range of pH values can produce satisfactory crops if the cation exchange capacity (CEC) of the soil is above 10meq/g soil (Red Tractor Assurance, 2016j). |
| Topsoil texture | S | SCL | Most soil types. Medium to light soils are best. Clay soils may adhere to the roots and need removing before storage. |

[41] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=694

| | | | |
|---|---|---|---|
| Depth (cm) | 20-50 | 50-150 | Deep tap root. |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Well drained |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5 [-10] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | Soil compaction and poaching if crop is grazed in-situ. |
| ALC group | 2 | 1 | |

***Crop 32. Garlic***

Garlic (*Allium sativum*) is closely related to onions, leeks, shallots and chives and is grown for its bulbs which are used in cooking and for medicinal purposes. Irrigation is an essential requirement for production on sand-based soils (excluding silts). There is a marked growth response to irrigation on all light soils during dry periods. It leads to an increase in leaf number and size, which maximises bulb size and yield (Red Tractor Assurance, 2016k). Garlic crops should be separated by a minimum distance of 800 m from any commercial onion crop. Bulb formation is influenced by day length (requires 12-15 hour long days) and temperature and hence site selection is influenced by latitude.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 120 | 330 | Over wintered cloves are planted in late September/October for harvest the following June/July.<br>Spring planted cloves are planted in April-May for harvest in July/August.<br>Spring drilled from bulbils for harvest late August/September, producing a single round clove which if planted the following year will develop into a conventional bulb.<br>Note: Bulbing is influenced by day length. Only spring planting is recommended in the UK (Red Tractor Assurance, 2016k). |
| Air or ground frost | -12 | -6 | Garlic can withstand temperatures of -6°C but below -12°C can kill shoots and result in poor bulb development[42] ( |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 18<br>[7] | 30<br>[35][43] | Temperatures <5°C for 6-8 weeks required for vernalisation (Masabni, undated b).<br>Soil temperature >15°C for bulbing (day length >13 hours). |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 720<br>[500] | 1600<br>[2700] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | Avoid steep slopes where poaching and water/soil runoff may be a problem.<br>In addition, the safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.5<br>[6.0] | 7.0<br>[8.0] | |
| Topsoil texture | SL | SCL | Sandy loam, sandy clay loam, silts and some peat based soils are suitable. |
| Depth (cm) | 20 | 150 | Shallow rooting |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Well drained<br>Irrigation is essential on sand and lighter soil types. |
| ALC soil wetness class | I-III | I-II | |

[42] http://www.garlicworld.co.uk/reports/garlic%20cms.pdf

[43] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=367

| | | | |
|---|---|---|---|
| Moisture balance (mm) | +5<br>[-10] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Shallow rooting leads to low N use efficiency, which may lead to increased risk of leaching.<br>Risk of soil erosion due to bare soil particularly after seedbed preparation and during harvest. |
| ALC group | 2 | 1 | |

***Crop 33. Horseradish***

Horseradish (*Armoracia rusticana*) is a hardy perennial from the Mustard family that is grown for its fleshy white roots in annual (and occasionally perennial) production systems (Bratsch, 2009). It needs warm temperatures during the summer growing season and cooler temperatures in the late summer and autumn to enhance root development. The crop may require irrigation during dry periods in late summer or autumn.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 210 | 240 | Planted using root cuttings (sets) from the previous crop.<br>Plant: April to May.<br>Harvest: After tops have died due to frost. |
| Air or ground frost | | | Frost tolerant[44] |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 14<br>[6][45] | 20<br>[28] | |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 600<br>[390] | 900<br>[1700] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | Avoid steep slopes where poaching and water/soil runoff may be a problem.<br>In addition, the safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 5.5<br>[4.5] | 6.8<br>[8.7] | Horseradish tolerates a wide soil pH range of 5.5 to 6.8 (Bratsch, 2009). |
| Topsoil texture | SL | SCL | Loam or sandy loam soil rich in organic matter. |
| Depth (cm) | 50 | 150 | |
| Stone content (%) | 0 | 5 [10] | Avoid stony soils as roots will branch excessively. |
| Drainage | | | Well drained. |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5<br>[-10] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Horseradish can be difficult to control in subsequent crops.<br>Bare soil over winter may increase soil erosion and nitrate leaching. |
| ALC group | 2 | 1 | |

[44] https://www.growveg.co.uk/plants/uk-and-europe/how-to-grow-horseradish/

[45] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=3384

***Crop 34. Kale***

Kale (*Brassica oleracea var. sabellica*) can be produced for human consumption and/or animal fodder. Kale can be grazed in-situ by cattle or sheep, cut and feed to housed livestock or ensiled.

Kale (can be grown throughout the UK, although in wetter areas the risk of disease may increase and in drier areas irrigation may be needed during the summer. Also, irrigation immediately post planting when soil conditions are dry will improve evenness of establishment and crop continuity (Red Tractor Assurance, 2016l).

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Sow: (direct drill) early April to June or (transplants) February/March to late May.<br>Harvest: mid-June to the following February/March. Often individual leaves (rather than the whole plant) are cut so harvesting can continue over an extended period. |
| Air or ground frost | -15 | | Frost tolerant.<br>However, overwintered and late crops require relatively frost free areas. |
| Other | | | Avoid heavily wooded field margins and wasteland to minimise crop attack by rabbits, hares, pigeons etc. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[7] | 20<br>[30] | |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 450[46]<br>[300] | 1000<br>[2800] | Suitable for harvesting and spraying machinery.<br>Easy access. |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.5 | 7.0 | In soils where club root may be a problem the pH should be maintained at a level of 7.0 to 7.5 (Red Tractor Assurance, 2016l). |
| Topsoil texture | S | MCL | A wide range of soil types are suitable although sandy soils are likely to require irrigation but are best suited to direct drilled crops.<br>Heavy soils may limit opportunities for planting. |
| Depth (cm) | 20 | 50 | Deep rooted |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Well drained |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5<br>[-10] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion. |

[46] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=3867

| | | | |
|---|---|---|---|
| | | | Potential soil structural damage caused by harvesting winter kale on heavier soils.<br>Trafficking by harvest team.<br>Leafy vegetables accumulate nitrate in leaves so the N content of crop residues will be high.<br>Disposal of polythene covers sometimes used on early crops.<br>Soil compaction and poaching if livestock graze crop in-situ. |
| ALC group | 2 | 1 | |

***Crop 35. Radish***

Radish (*Raphanus sativus*) is a member of the Cruciferae (mustard family) it is often grown as a root vegetable but the leaves can also be eaten. As radishes have a very short growing period, several crops can be grown on the same piece of land during one season. However, this can lead to problems with disease and pest carry-over. When radishes are grown on soil with a light texture, irrigation is often required to assist germination and may be necessary throughout growth. Irrigation is thought to be of particular importance when the hypocotyl begins to swell especially if scab is likely to be a problem (Red Tractor Assurance, 2016m).

Bunched radishes are normally harvested by hand in the UK. Harvesting in the early morning when the temperature is cooler will often help to preserve shelf life.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 30 | 60 | Sowing at intervals during the spring will provide a continuous harvest.<br>Harvest: April to October, depending on the weather.<br>Long days induce bolting. |
| Air or ground frost | | | |
| Other | ~ | ~ | |
| Mean daily air temperature (°C).<br>Optimum & [tolerable] range | 12<br>[3] | 25<br>[30][47] | The minimum temperature for germination is 5°C[48].<br>The best quality and root shape are obtained when the crop grows and matures at moderate temperatures (10 to 18 °C) in intermediate to short day lengths. |
| ALC accumulated temperature<br>(day °C) | 1150 | ≥1300 | |
| Rainfall (mm)<br>Optimum & [tolerable] range | 800<br>[500] | 1000<br>[2800] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | Gentle slope for air drainage and to avoid frost pockets.<br>The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH<br>Optimum & [tolerable] range | 6.0<br>[5.2] | 6.8<br>[8.3] | |
| Topsoil texture | S | SCL | A variety of soil types are suitable. Light textured or sandy soil and soils with a high OM or peat content produce crops with good colour and skin finish.<br>Soils with heavy texture and high clay content are unsuitable (Red Tractor Assurance, 2016m). |
| Depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Well drained. |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5<br>[-10] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |

[47] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=11291

[48] https://www.faa.gov.nl.ca/agrifoods/plants/pdf/radish.pdf

| | | | |
|---|---|---|---|
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Shallow rooting can lead to low N use efficiency, which may increase risk of nitrate leaching.<br>Disposal of fleece or polythene crop covers if used.<br>Frequent trafficking due to successional harvesting/planting.<br>Bare soil over winter may increase soil erosion and nitrate leaching. |
| ALC group | 2 | 1 | |

***Crop 36. Salsify***

Information on the climatic, site or soil requirements for salsify is limited. The limited information available is related to gardeners (i.e. non-commercial growing). The advice to gardeners suggests that salsify needs a warm sunny site, preferably on stone-free, light well-drained soil and should be sown from March to May and harvested from late September onwards[49].

There is little commercial production of salsify in the UK. However, a major potato grower begun supplying home-grown salsify (from Cambridgeshire and Ayrshire) to 100 Waitrose stores in November 2018[50].

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Day length | | | |
| Growing season (Days) | | | |
| Air or ground frost | | | |
| Other | | | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | | | |
| ALC accumulated temperature (day °C) | | | |
| Rainfall (mm) Optimum & [tolerable] range | | | |
| **Site** | | | |
| Aspect | | | |
| Altitude (m) | | | |
| Gradient (°) | | | |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | | | |
| Topsoil texture | | | |
| Depth (cm) | | | |
| Stone content (%) | | | |
| Drainage | | | |
| ALC soil wetness class | | | |
| Moisture balance (mm) | | | |
| Field capacity (days) | | | |
| **Other** | | | |
| Environmental risks | | | |
| ALC group | | | |

[49] https://www.rhs.org.uk/advice/grow-your-own/vegetables/salsify

[50] http://wwpr.co.uk/2018/11/07/albert-bartlett-announces-it-will-supply-salsify-a-popular-victorian-vegetable-exclusively-to-waitrose-stores/

***Crop 37. Spinach***

Spinach (*Spinacia oleracea*) is marketed fresh (bagged or loose) or frozen; bagged spinach is often young leaves ('baby' spinach), whereas loose or frozen spinach will be from older plants. Spinach prefers growing in warm, moist conditions so the ability to irrigate the crop is essential (Red Tractor Assurance, 2016n). Sprinkler irrigators, either as static lines or mounted on a boom which moves within the crop, are preferred and will generally give better results than a rain gun (large droplets may damage leaves).

| Requirement | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 45 | 90 | Seeds germinate at 2-30°C, but 7-24°C is optimal.<br>Multiple harvests may be possible (Koike *et al*., 2011). |
| Air or ground frost | -9 | | Frost tolerant, spinach can withstand temperatures of ≤ -9°C. However, small seedlings and young plants can be harmed (Koike *et al*., 2011).<br>Bolting induced by long days (≥14 hours) following cold temperatures. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 13<br>[2] | 20<br>[27] | Spinach will grow from 5 to 30°C but growth is most rapid between 15 and 18°C (Koike *et al*., 2011). |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 800<br>[300] | 1200<br>[1700] [51] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | ~ | ~ | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.5<br>[6.0] | 7.5<br>[8.0] | Spinach will tolerate a wide range of loamy soils with pH range of 6.5-8.0 (Masabni, undated c). |
| Topsoil texture | SL | HCL | Wide range of loamy soils. |
| Soil depth (cm) | 20-50 | 20-50 | |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Well drained. |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5<br>[-10] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Spinach accumulates nitrate in leaves; limit values have been set of 3,500 mg $NO_3$/kg so the N content of crop residues will be high.<br>Disposal of fleece or polythene crop covers if used.<br>Frequent trafficking due to successional harvesting/planting. |

[51] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=1997

| | | | |
|---|---|---|---|
| | | | Bare soil over winter may increase soil erosion and nitrate leaching. |
| ALC group | 2 | 1 | |

***Crop 38. Swedes***

Swede (*Brassica napobrassica*) are a hardy vegetable well suited to the cool, damp conditions frequently found in Wales (CALU, 2007a). They can be grown for human consumption or as forage (grazed in situ) or fodder swede which are lifted and stored in clamps prior to feeding.

The most suitable areas are those with relatively cool summers, where neither extremes of drought or wetness are experienced (Red Tractor Assurance, 2015a). Adequate soil moisture is essential to give satisfactory plant establishment. Continuing soil moisture will ensure even growth and quality of crop avoiding growth cracks that are caused by periods of uneven growth. Swedes are particularly susceptible to club root infection. Therefore, a wide rotation of at least four to five years is recommended between swedes and any other brassica crop.

The quality and flavour of swede are much improved when the roots are fully matured and are exposed to frosts before harvest.

| Requirement | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 120 | 300 | A biennial grown as an annual, if seedlings are subject to temperatures <5°C this will trigger a flowering stem to develop (bolting).<br>Sow: April to June (fodder/forage) or later June-July for culinary swede.<br>Harvest: September to March. |
| Air or ground frost | | | Frost tolerant. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[5] | 20<br>[35] | The minimum temperature for germination is 5°C, with an optimum germination temperature of 15°C. |
| ALC accumulated temperature (day °C) | 1100 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 700<br>[300] | 1000<br>[1700][52] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 7.0<br>[6.5] | 7.3<br>[7.8] | Soil pH of 6.5 or above is required. This is of particular importance in the presence of club root (Red Tractor Assurance, 2015a). |
| Topsoil texture | LS | MCL | The most suitable soils for swedes are well-drained loams, silts and light clay loams, with up to 20% clay content (Red Tractor Assurance, 2015a). |
| Soil depth (cm) | 50-150 | 50-150 | |
| Stone content (%) | 0 | 10 [15] | |
| Drainage | | | Well drained but moisture retentive. |
| ALC soil wetness class | I-IV | I-II | |
| Moisture balance (mm) | -20<br>[-30] | +30 [+10] | |

[52] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=3861

| | | | |
|---|---|---|---|
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | Root crops are at risk from water erosion, due to large areas of bare soil.<br>Harvesting in late autumn/early winter is likely to increase the risks of soil compaction and erosion.<br>Bare soil over winter increases the risk of nitrate leaching losses. |
| ALC group | 3a | 1 | |

***Crop 39. Sweetcorn***

Sweetcorn (*Zea mays* var. *saccharata*) is a type of maize which is a sub-tropical plant and site selection is one of the most important factors to take into consideration when deciding whether and where to grow the crop. Factors such as temperature, soil type and topography, moisture and altitude are all important for crop growth. The cooling effect linked to increasing altitude limits maize growing to fields below 305 m (1000 feet) in most circumstances.

The most important criteria for the successful establishment of the crop is a soil temperature (at 5 cm) of at least 12°C and no frosts during the early development of the plant (Red Tractor Assurance, 2016o). In addition, over a complete growing season a maize crop needs a set amount of solar energy in order to develop from germination through to harvest (Phipps *et al.*, 1974). This is typically measured in Ontario Heat Units (OHUs) which are calculated by using the maximum daily air temperature above 10°C and the minimum daily air temperature below 5°C, between 1 May to 31 October 31 (University of Reading, 2014). OHU requirements for successful forage maize growth have been estimated to be about 2,300 units (Phipps and Wilkinson, 1985).

| Requirement | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 150 | 180 | Drilled between the first week of April and the first week of June depending on soil temperature and harvested August to September. |
| Air or ground frost | -3 | 0 | Avoid frost pockets. The crop is susceptible to frost damage.<br>A crop at the 2-6 leaf stage can be delayed 2-3 weeks by a late May frost.<br>Early frost: ≤-3°C death of growing point.<br>Late frost: ≤-0°C leaf necrosis. |
| Other | | | Sheltered from wind. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 18<br>[10] | 33<br>[47] | Maize seeds germinate at soil temperature of 8-10°C. (University of Reading, 2014).<br>2,300 OHU between 1 May and 31 October. |
| ALC accumulated temperature (day °C) | 1100 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 600<br>[400] | 1200<br>[1750] | |
| **Site** | | | |
| Aspect | | | Sweetcorn will always perform better on a south facing aspect, protected from wind and frost (Red Tractor Assurance, 2016s).<br>South facing sites best for early drilling.<br>North facing slopes are only suitable if they warm to 8°C by mid-May (Phipps and Wilkinson, 1985). |
| Altitude (m) | 0 | 305 | Site >180 m are marginal and only likely to be suitable with lighter, drier soils (Limagrain, 2010b). |
| Gradient (°) | 0 | 7 | Avoid steeply sloping fields.<br>The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6 | 8 | pH 6.5 is the target (Red Tractor Assurance, 2016o). |
| Topsoil texture | S | SCL | Wide variety of soil types but medium textured are best.<br>Heavy wet soils are slow to warm and can delay drilling; erosion risk is higher on sandy and light silty soils.<br>Soil type will influence drilling and harvest date. |
| Soil depth (cm) | 100 | >200 | Shallow soil will impair root development and yield.<br>Rooting depth is typically between 150 and 200 cm. |

| | | | |
|---|---|---|---|
| Stone content (%) | 0 | 10 [15] | No specific limits but ALC gives limit values for Grade 3a of 10% and 15% (by volume) for stones >6 and 2 cm, respectively in the top 25 cm of soil. |
| Drainage | | | Maize seeds and seedlings require moisture to enable germination and ongoing development.<br>Maize is sensitive to water stress and due to its high determinacy it cannot easily recover the loss of productivity (Hsiao and Fereres, 2012). |
| ALC soil wetness class | I-IV | I-II | |
| Moisture balance (mm) | -20<br>[-30] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | Ground cover is slow to establish after drilling increasing the risk of soil erosion and/or run-off. Buffer zones are required around all field margins.<br>Highest risk of erosion on sloping land with light soil.<br>Heavy harvest machinery can damage soil structure leading to compaction.<br>Late harvesting reduces the chance to establish a cover crop and bare soil over winter may increase soil erosion and nitrate leaching |
| ALC group | 3a | 1 | |

***Crop 40. Turnips***

Turnips (*Brassica rapa*) can be grown for human consumption or as stubble turnips which are grazed in situ. The most suitable areas for turnips are those with relatively cool summers, where neither extremes of drought or wetness are experienced (Red Tractor Assurance, 2015a). Adequate soil moisture is essential to give satisfactory plant establishment. Continuing soil moisture will ensure even growth and quality of crop avoiding growth cracks that are caused by periods of uneven growth. Turnips are particularly susceptible to club root infection. Therefore, a wide rotation of at least four to five years is recommended between turnips and any other brassica crop.

| **Requirement** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | A biennial grown as an annual, if seedlings are subject to temperatures <5°C this will trigger a flowering stem to develop (bolting).<br>Sow: Mid-April to August<br>Graze: 12-14 weeks after planting.<br>Or harvest: September to March. |
| Air or ground frost | | | Frost tolerant, although slight damage may occur. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[5] | 20<br>[35] | The minimum temperature for germination is 5°C, with an optimum germination temperature of 15°C.<br>The most vigorous root growth takes place during periods of low temperature (4-15°C) in autumn (Undersander *et al*., 1991). |
| ALC accumulated temperature (day °C) | 1100 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 900<br>[300] | 1400<br>[2000][53] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | ~ | ~ | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 11 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.5<br>[5.9] | 7.5<br>[7.8] | Soil pH of 6.5 or above is ideal. This is of particular importance in the presence of club root (Red Tractor Assurance, 2015a). |
| Topsoil texture | LS | MCL | The most suitable soils for turnips are well-drained loams, silts and light clay loams, with up to 20% clay content (Red Tractor Assurance, 2015a). |
| Soil depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 10 [15] | |
| Drainage | | | Well drained but moisture retentive.<br>Growth is reduced by excess water. |
| ALC soil wetness class | I-IV | I-II | |
| Moisture balance (mm) | -20<br>[-30] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion. |

[53] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=3881

| | | | |
|---|---|---|---|
| | | | Disposal of crop covers.<br>Root crops are at risk from water erosion, due to large areas of bare soil.<br>Bare soil over winter may increase soil erosion and nitrate leaching. |
| ALC group | 3a | 1 | |

## Culinary herbs

### *Crop 41. Mint*

Mint is used as a culinary herb which is dried to flavour food, make tea or for the production of mint oils to flavour, e.g. toothpaste, mouthwash, confectionery etc. The two most common types are peppermint (*Mentha piperita*) and spearmint (*Mentha spicata*).

Many herbs thrive in warm sunny locations and several (including mint) can be grown in an open field or field-bed system (covered or uncovered) (Red Tractor Assurance, 2015b). Cloches, polytunnels or glasshouse production gives greater environmental control, better crop quality and an extended growing season but increased costs. Mint is grown from vegetative propagules which are transplanted into the soil (Red Tractor Assurance, 2015b). Most UK grown herbs are short-term crops and an interrupted or uneven water supply will have an adverse effect on leaf growth.

A well-managed mint bed will last 2-3 seasons (CALU, 2006b), although in the US this is reported as up to 15 years (OSU, 2010).

| Requirements | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Sow: April to August.<br>Harvest: Mint for leaf production needs to be cut regularly to prevent flowering. Mint for oil production is cut as flowering commences when oil concentration and quality are peaking (DAFF, 2012a).<br>Long day plant, >10 hours initiates flowering. |
| Air or ground frost | | | |
| Other | | | Thrive best in warm soils. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[5] | 25<br>[36][54] | Soil temperature should be ≥10°C at sowing.<br>Temperature day: 15-25°C.<br>Temperature night: >5°C (Red Tractor Assurance, 2015b). |
| ALC accumulated temperature (day °C) | ≥1300 | | |
| Rainfall (mm) Optimum & [tolerable] range | 900<br>[600] | 1200<br>[2200] | Peppermint needs adequate rainfall on a regular basis in excess of 1000 mm (DAFF, 2012a). |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1300°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 4.5 | 7.5 | Optimum soil pH 4.5-7.5 (Red Tractor Assurance, 2015b). |
| Topsoil texture | S | ZL | Sandy and silt loam soils. |
| Depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 5 | |
| Drainage | | | Well drained, although mint will grow well in wet but well-aerated soil. |
| ALC soil wetness class | I-II | | |
| Moisture balance (mm) | +30<br>[+10] | | |
| Field capacity (days) | ≥151 | 225 | |
| **Other** | | | |

[54] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=7710

| | | | |
|---|---|---|---|
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Disposal of fleece or polythene crop covers. |
| ALC group | 1 | 1 | |

***Crop 42. Parsley***

Parsley (*Petroselinum crispum*) is a member of the carrot family, grown as a culinary or medicinal herb. Parsley prefers full sun and cool to warm temperatures. Parsley cultivars are available in flat leafed or curled forms and can be sown in spring and harvested 2-3 times or sown in August and over-wintered for early spring sales (Red Tractor Assurance, 2015b; CALU, 2006b). Parsley can be slow to germinate (taking up to one month) and some growers, especially organic tend to sow parsley in modules to transplant. The module can be planted out after 4-6 weeks, saving on the amount of time the crop is occupying field space. Good water supply and management is imperative for sustainable economic herb production in the UK.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Sow: Spring or August (for over-wintering).<br>Harvest: Summer or spring (if over-wintered). |
| Air or ground frost | | | Moderate tolerance to frost.<br>Temperatures <7°C for extended periods (>1 month) can cause bolting as the temperatures increase (Masabni, undated d). |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[5] | 25<br>[28] | Do not sow until soil temperature is ≥10°C or establishment will be uneven.<br>Temperature day: 15-25°C. Temperature night: >5°C (Red Tractor Assurance, 2015b). |
| ALC accumulated temperature (day °C) | ≥1300 | | |
| Rainfall (mm) Optimum & [tolerable] range | 900<br>[300][55] | 1500<br>[2800] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1300°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 5.0 | 8.0 | |
| Topsoil texture | SZL | MCL | Medium soil types are optimal. |
| Depth (cm) | 20 | 50 | |
| Stone content (%) | 0 | 5 | |
| Drainage | | | Well drained, herbs do not thrive under waterlogged conditions. |
| ALC soil wetness class | I-II | | |
| Moisture balance (mm) | +30<br>[+10] | | |
| Field capacity (days) | ≥151 | 225 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Disposal of fleece or polythene crop covers. |
| ALC group | 1 | 1 | |

[55] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=1661

***Crop 43. Rosemary***

Rosemary (*Rosmarinus officinalis*) is an evergreen shrubby herb which is used for flavouring food or for the extraction of oil that can be used in perfumes, soaps etc. Irrigation at planting is essential and supplementary irrigation is advised until the plants are well established. Where rainfall is >500 mm per year plants are unlikely to need further irrigation once established; in wetter areas rosemary may need to be grown in ridged beds to allow excess water to drain away (DAFF, 2012b).

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Plant from mid-April to the end of September.<br>Timing of harvest depends on the end market. For dried rosemary the crop is cut prior to flowering, whereas for oil plants should be in bloom. For the fresh market, rosemary is cut frequently at a young stage. |
| Air or ground frost | -5 | | Frost tolerant. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 20<br>15 | 25<br>30[56] | Should not be sown at soil temperatures <10°C or establishment will be uneven.<br>It grows well at day temperatures of 20 to 25°C (DAFF, 2012b). |
| ALC accumulated temperature (day °C) | ≥1300 | | |
| Rainfall (mm) Optimum & [tolerable] range | 600<br>[300] | 1400<br>[2700] | Annual precipitation range of 300 to 2700 mm (Simon *et al*., 1984). |
| **Site** | | | |
| Aspect | | | Full sun is best on south facing slopes. |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1300°C). |
| Gradient (°) | 0 | 7 | Gentle slope for air drainage and to avoid frost pockets.<br>The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.0<br>[5.0] | 7.0<br>[8.5] | pH range of 5.5 to 8.0 is required (DAFF, 2012b) or 5.0-8.5 (Red Tractor, 2015b). |
| Topsoil texture | S | SCL | Sandy to clay loam. |
| Depth (cm) | 20-50 | 20-50[57] | |
| Stone content (%) | 0 | 5 | |
| Drainage | | | Well drained. Rosemary will fail in waterlogged soil (Red Tractor, 2015b). |
| ALC soil wetness class | I-II | | Rosemary is tolerant of low soil moisture conditions (Red Tractor, 2015b). |
| Moisture balance (mm) | +30<br>[+10] | | |
| Field capacity (days) | ≥151 | 225 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Disposal of fleece or polythene crop covers.<br>Bare soil over winter may increase soil erosion and nitrate leaching. |
| ALC group | 1 | 1 | |

[56] Day time temperature; overnight temperature of >1°C is needed.

[57] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=9326

***Crop 44. Sage***

Sage (*Salvia officinalis*) is grown both as an essential oil and for culinary use (either fresh or dried). It may be grown from either seed or vegetative propagules and is often planted into a raised bed and sometimes grown through a polythene mulch. Sage plants will survive periods of drought due to their Mediterranean origin, so are unlikely to require irrigation unless water supply is limited over a long period.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Sow: Late February/early March.<br>Harvest: timing of harvest will depend on the end market (e.g. oil or culinary). Harvesting for the fresh market is typically done by hand. |
| Air or ground frost | | | |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[5] | 26<br>[30][58] | |
| ALC accumulated temperature (day °C) | ≥1300 | | |
| Rainfall (mm) Optimum & [tolerable] range | 500<br>[300] | 1000<br>[1500] | |
| **Site** | | | |
| Aspect | | | Full sun to achieve high production levels (Fraser and Whish, 1997). |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1300°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 5<br>[4.2] | 6.5<br>[8.3] | |
| Topsoil texture | ZL | SCL | Medium soil types. |
| Depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 5 | |
| Drainage | | | Well drained soil; sage will fail if the soil remains waterlogged (Red Tractor, 2015b). |
| ALC soil wetness class | I-II | | |
| Moisture balance (mm) | +30<br>[+10] | | Sage is tolerant of low soil moisture conditions (Red Tractor, 2015b). |
| Field capacity (days) | ≥151 | 225 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated, although irrigation is uncommon.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Disposal of fleece or polythene crop covers.<br>Bare soil over winter may increase soil erosion and nitrate leaching. |
| ALC group | 1 | 1 | |

[58] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=2412

***Crop 45. Thyme***

Thyme (*Thymus vulgaris*) is a perennial plant belonging to the Lamiaceae family. It is native to Europe and the Mediterranean basin and adaptable to a wide range of environmental conditions (Stahl-Biskup and Sáez, 2002). It is used as a culinary herb, as an essential oil and as a medicinal plant (Król and Kiełtyka-Dadasiewicz, 2015). A dry and sunny climate promotes leaf production.

Thyme may survive two to three years but is sometimes grown as an annual where winters are cold and plants may die over-winter. Thyme seeds are very small and consequently most Thyme is established from transplants. It may be grown in field bed systems, which may be covered with a biodegradable mulch or covered (e.g. with woven covers). Alternatively, crops may be grown under some form of protection such as a polytunnels.

As the annual variation in soil moisture in the UK is wide, irrigation should be available for high value crops.

| Requirement | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Sow: Spring.<br>Single harvest (first year); multiple harvests from the same planting (successive years); harvest before flowering.<br>The best time to harvest Thyme oil is around flowering as the oil concentration in the plant is then at its highest.<br>Thyme for the fresh market will be harvested by hand. |
| Air or ground frost | | | Limitedly tolerant to frost. |
| Other | | | Full sun is required for the best yield potential. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15 | 30 | Thyme should not be grown at soil temperatures <10°C or establishment will be uneven.<br>Optimum temperature: 15-30°C (day) and >1°C at night (Red Tractor Assurance, 2015b). |
| ALC accumulated temperature (day °C) | ≥1300 | | |
| Rainfall (mm) Optimum & [tolerable] range | 700 [400] | 1500 [2600][59] | Thyme does not like excessive moisture, which may make it prone to fungal diseases (DAFF, 2012c). |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1300°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 4.5 | 8 | Thyme prefers light, well-drained soils with a pH of 4.5 to 8.0 (Red Tractor Assurance, 2015b). |
| Topsoil texture | S | SCL | Sandy and loam soils. Plants cultivated in heavy wet soils are less aromatic (DAFF, 2012c). |
| Soil depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 5 | |
| Drainage | | | Well drained. Thyme will not thrive in waterlogged conditions. |
| ALC soil wetness class | I-II | | |
| Moisture balance (mm) | +30 [+10] | | |
| Field capacity (days) | ≥151 | 225 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated. |

[59] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=2441

| | | | |
|---|---|---|---|
| | | | Irrigation may increase the risk of run-off and/or soil erosion.<br>Disposal of fleece or polythene crop covers. |
| ALC group | 1 | 1 | |

## Oil crops

### *Crop 46. Lavender*

Lavender (*Lavandula* spp.) is a long-lived perennial, with a typical productive life of about 10 years grown for flower (fresh or dried) and oil production (Adam, 2006); lavender farms are often open to tourist visits. Oil is extracted from the flowers and to a lesser extent the leaves; the highest quality oil is from the flowers only (DAFF, 2009). Oil yield may increase with altitude as plants flower more abundantly in cooler conditions. Flowers are removed for the first couple of seasons to allow the plants to develop to their best potential.

| Requirements | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Sow: autumn to allow plants to establish before winter and benefit from fast growth in spring (unless risk of very harsh frosts).<br>Harvest:<br>Avoid harvesting in hot weather or very windy conditions as oil may be lost through evaporation. |
| Air or ground frost | | | Moderately frost tolerant but avoid frost pockets (Whiriskey and McCarthy, 2006). |
| Other | | | Sensitive to high humidity. Dry foliage and good air circulation around lavender plants helps reduce disease, which can reduce yields and foliage quality. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15[60]<br>[7] | 24<br>[28] | High summer temperatures reduce oil quality (DAFF, 2009). |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 500<br>[300] | 1000<br>[1400] | Lavender can produce well with an annual rainfall range from 300 to 1 400 mm per year (DAFF, 2009). |
| **Site** | | | |
| Aspect | | | South facing slight slopes are optimum. |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | Slightly sloping land is OK, providing that farming operations are still practicable.<br>The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.0<br>[5.3] | 8.0<br>[8.3] | |
| Topsoil texture | S | SL | Light, sandy or sandy loam soils are best. |
| Depth (cm) | 20 | >150 | |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Well drained. May be produced on raised beds (Ernst, 2017). |
| ALC soil wetness class | I-III | I-II | Moderately drought tolerant. |
| Moisture balance (mm) | +5<br>[-10] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |

[60] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=7172

| | | | |
|---|---|---|---|
| Environmental risks | | | No specific risks. |
| ALC group | 2 | 1 | |

***Crop 47. Borage***

Borage (*Borago officinalis*) is grown in the UK as a speciality oil crop. It is a recognised as a key source of gamma-linolenic acid (GLA) which is commonly used in personal care products and nutraceuticals (Laurence, 2004). GLA is an omega-6 essential fatty acid, found in many plants but in its most heavily concentrated form in borage (NNFCC, 2006). Borage oil is marketed as Starflower oil, uses include, skin care creams and anti-inflammatory treatments (e.g. for eczema). Borage can grow in a range of conditions and climates but will not tolerate excessively dry soils (Asadi-Samani *et al*., 2014). Around 7000 ha of borage is grown in the UK, from the south coast to mid-Scotland.

As bees are essential to pollination and thus crop productivity, beehives should be placed adjacent to borage crops.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 90 | 120 | Spring sown crop (around mid-April when the soil temperature has reached 6-7°C)[61].<br>To minimise seed loss swathing should be carried out once seed begins to shed from the second or third most forward flower/pod sets. The crop is harvested 7-10 days after swathing (usually in July to August). |
| Air or ground frost | | | Seedlings will survive light frosts, but older plants are easily damaged. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | | | Soil temperature ≥10°C for germination (NNFCC, 2006). |
| ALC accumulated temperature (day °C) | *1000* | *≥1300* | |
| Rainfall (mm) Optimum & [tolerable] range | | | Areas of low rainfall are preferred, owing to harvesting difficulties in wet conditions. |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1000°C). |
| Gradient (°) | 0 | 11 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land and 11° for grade 3b. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | | | |
| Topsoil texture | SL | C | All soil types except extremely acid and drought prone soils. |
| Depth (cm) | | | |
| Stone content (%) | 0 | 20 [35] | |
| Drainage | | | |
| ALC soil wetness class | *II-IV* | *I-II* | |
| Moisture balance (mm) | *-50 [-55]* | *+30 [+10]* | |
| Field capacity (days) | *>225* | *≥151* | |
| **Other** | | | |
| Environmental risks | | | Borage volunteers can be a problem in subsequent crops.<br>Bare soil over winter may increase soil erosion and nitrate leaching. |

[61] https://www.fwi.co.uk/arable/borage-area-set-to-rise-in-2014

| | | | |
|---|---|---|---|
| ALC group | *3a* | *1* | |

***Crop 48. Calendula***

Seeds of calendula (*Calendula officinalis*) are a rich source of calendic acid, which can be used to replace volatile organic compounds (VOC) as a drying agent in industrial chemicals (Gesch, 2012). Historically it was grown as an ornamental plant and for its pharmaceutical uses (e.g. as an anti-inflammatory used in topical burn and wound healing).

Calendula is a biennial, but is generally cultivated as an annual plant. It has irregular seed shapes (classified as nuggets, winged or hooked) which can make drilling difficult and field emergence can range from 40-60% (Froment *et al*., 2002). As Calendula is an indeterminate plant species (it produces flowers over an extended period), desiccation is required to aid harvesting.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 120 | 150 | Sown: Spring, usually early to mid-April<br>Harvest: Early to mid-August (5-7 days after desiccation). |
| Air or ground frost | | | In cold springs delay sowing until the latter half of April.<br>Seedlings tolerate light frosts. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 16<br>[8] | 25<br>[30] | |
| ALC accumulated temperature (day °C) | 1000 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 500<br>[300] | 800<br>[2500][62] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1000°C). |
| Gradient (°) | 0 | 11 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land and for grade 3b is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 5.5<br>[4.5] | 7.0<br>[8.3] | |
| Topsoil texture | S | MCL | Light to medium soil textures. |
| Depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 20 [35] | |
| Drainage | | | |
| ALC soil wetness class | *II-IV* | *I-II* | |
| Moisture balance (mm) | *-50*<br>*[-55]* | *+30 [+10]* | |
| Field capacity (days) | *>225* | *≥151* | |
| **Other** | | | |
| Environmental risks | | | Bare soil over winter may increase soil erosion and nitrate leaching. |
| ALC group | *3b* | *1* | |

[62] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=4040

***Crop 49. Camelina***

Camelina (*Camelina sativa*), a member of the mustard family, is a summer annual oilseed plant. It may be grown as a bio-fuel crop, for camelina meal (livestock feed), a component of cosmetic or industrial products or as a cooking oil or food supplement. Camelina oil has a high content (45% of the total fatty acid content) of the Omega-3 fatty acid alpha-linolenic acid (CALU, 2007b).

Unlike oilseed rape the pods are more or less shatter-proof, which makes the crop much less weather-dependent, resulting in more consistent harvested yields (Crowley and Fröhlich, 1998). The seed should be dried down quickly after harvest to around 8% moisture (max temperature 43°C) and stored to avoid deterioration of the oil.

There is little specific information available in relation to Camelina.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 90 | 130 | Sow: end of March to early May.<br>Harvest: mid-August to early September. |
| Air or ground frost | -14 | | Frost tolerant in the seedling and rosette stage (Putnam *et al*., 1993; Angelini *et al*., 1997). |
| Other | | | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | | | Camelina seeds germinate at soil temperatures of 2-3°C, although the best time to sow is when the soil has warmed to 10°C (CALU, 2007b). |
| ALC accumulated temperature (day °C) | 1000 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 300[63] | | Drought tolerant (Blackshaw *et al*., 2011). |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1000°C). |
| Gradient (°) | 0 | 11 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land and for grade 3b is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | | | |
| Topsoil texture | S | C | Light, medium and heavy soils[64] |
| Depth (cm) | | | |
| Stone content (%) | 0 | 20 [35] | |
| Drainage | | | |
| ALC soil wetness class | *II-IV* | *I-II* | |
| Moisture balance (mm) | *-50 [-55]* | *+30 [+10]* | |
| Field capacity (days) | *>225* | *≥151* | |
| **Other** | | | |
| Environmental risks | | | Bare soil over winter may increase soil erosion and nitrate leaching. |
| ALC group | *3b* | *1* | |

[63] https://www.agmrc.org/commodities-products/grains-oilseeds/camelina

[64] http://www.oilseedcrops.org/camelina/

***Crop 50. Echium***

Echium (*Echium plantagineum*) is a spring sown annual oilseed crop closely related to borage which grows to a height of 50-80 cm (Zahoor *et al*., 2017). Echium is a low input crop with agronomic characteristics similar to Borage. It is a source of Gamma Linoleic Acid and also contains the rarer stearidonic acid (SdA), which is an important intermediate in the production of a number of important compounds in the body (Hodsman, 2006). It also has anti-wrinkle properties and is currently used in the cosmetics. Stearidonic Acid is an omega-3 fatty acid that has been shown to exhibit strong anti-inflammatory properties. Echium oil contains between 12 and 14% stearidonic acid, compared to 2% found in the only other available commercial source, Blackcurrant seed oil.

Indeterminate growth habit results in uneven seed maturation with a consequent reduction in harvest efficiency and productivity. High levels of seed shattering have been reported and seed losses can exceed 75% (Zahoor *et al*., 2017).

There is limited information on the crop requirements of Echium.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Day length | | | Long day plant |
| Growing season (Days) | 120 | 180 | Sow: Late March to late April.<br>Harvest: mid-August to late September. The crop should be swathed, relatively close to the ground, when one third of the seed remains green, one third is black and one third is dark-grey. Approximately 10 days after swathing the crop should be combined (Hodsman, 2006). |
| Air or ground frost | | | |
| Other | | | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | | | 10 (4-6°C) for germination. |
| ALC accumulated temperature (day °C) | 1000 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | | | |
| **Site** | | | |
| Aspect | | | Open sunny position. |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1000°C). |
| Gradient (°) | 0 | 11 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land and for grade 3b is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | | | |
| Topsoil texture | S | SZL | Light soils. Thin dry soils are suitable. |
| Depth (cm) | | | |
| Stone content (%) | 0 | 20 [35] | |
| Drainage | | | |
| ALC soil wetness class | *II-IV* | *I-II* | |
| Moisture balance (mm) | *-20 [-30]* | *+30 [+10]* | |
| Field capacity (days) | *>225* | *≥151* | |
| **Other** | | | |
| Environmental risks | | | Bare soil over winter may increase soil erosion and nitrate leaching. |

| | | | |
|---|---|---|---|
| ALC group | *3a* | *1* | |

***Crop 51. Evening Primrose***

Evening primrose (*Oenothera* spp) seed is an important source of g-linolenic acid, a relatively rare fatty acid with value as a pharmaceutical and nutritional supplement (Fieldsend and Morison, 2000). In the UK, evening primrose crops ripen during a period of reducing day lengths, light levels and temperatures.

China is the major producer of evening primrose seed in the world through the combination of low cost hand labour and growing conditions which are ideally suited to the crop (Deng *et al*., 2001).

In temperate climates evening primrose is grown as either a winter or spring crop.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Sow: Mid-April (spring crop) or mid-August (winter crop).<br>Flowering: August (spring crop) or July (winter crop).<br>Harvest: October (spring crop) or September (winter crop) (Greiner and Köhl, 2014). |
| Air or ground frost | -22 | 0 | Over-wintering vegetative rosettes can survive temperature as low as -22°C (Deng *et al*., 2001). |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | | | 8°C is minimum soil temperature for seed germination (Granic, 1988 cited by Ghasemnezhad, 2007). |
| ALC accumulated temperature (day °C) | 1000 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | | | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1000°C). |
| Gradient (°) | 0 | 11 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land and for grade 3b is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 5.5 | 8.0[65] | |
| Topsoil texture | S | SCL | Sandy to sandy clays soils (Ghasemnezhad, 2007). |
| Depth (cm) | | | |
| Stone content (%) | 0 | 20 [35] | |
| Drainage | | | |
| ALC soil wetness class | *II-IV* | *I-II* | |
| Moisture balance (mm) | *-50 [-55]* | *+30 [+10]* | |
| Field capacity (days) | *>225* | *≥151* | |
| **Other** | | | |
| Environmental risks | | | Unknown but no specific risks identified. |
| ALC group | *3b* | *1* | |

[65] https://www.manitoba.ca/agriculture/crops/production/evening-primrose.html

***Crop 52. Linseed***

Both winter and spring linseed (*Linum usitatissimum*) will grow in all parts of the UK and on most soil types (Allen-Stevens, 2017). Linseed can be used for industrial, food and feed purposes; flax straw contains fibres that are used for making textiles, paper and insulation products, plastic composites etc. (see section on flax above). Linseed oil is a good source of the Omega-3 fatty acid, alpha-linolenic acid.

Flax plants are tall with few branches and low seed production, whereas linseed plants are shorter, with multiple branches and have been selected for high seed development. In the UK and Europe, flax grown for oil production is usually referred to as linseed, whereas flax refers to the fibre from the stems of *Linum usitatissimum* grown for fibre.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 150 | 180 | Sow: (winter varieties) September; (spring varieties) mid-March to mid-April once soil temperature is ≥7°C.<br>Harvest: (winter varieties) mid-July to mid-August September; (spring varieties) mid-August to mid-September.<br>The crop is desiccated 5-14 days prior to harvesting (dependent on the product that is used) (Allen-Stevens, 2017). |
| Air or ground frost | -4 | 0 | Seedlings can withstand temperatures of -4°C (DAFF, 2012d). |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 16<br>[5] | 24<br>[30][66] | High temperatures (≥32°C) shorten flowering thereby affecting seed yield (DAFF, 2012d). |
| ALC accumulated temperature (day °C) | 1000 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 450<br>[250] | 750<br>[1300] | Spread evenly throughout the growing season. |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1000°C). |
| Gradient (°) | 0 | 11 | Slightly sloping land is OK, providing that farming operations are still practicable.<br>The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land and for 3b it is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 5 | 7 | |
| Topsoil texture | SL | SCL | Wide range of soil types are suitable except heavy clay and light sands. Deep friable loams with a high OM content are optimum. |
| Depth (cm) | 20 | 50 | |
| Stone content (%) | 0 | 20 [35] | |
| Drainage | | | Well drained. |
| ALC soil wetness class | II-IV | I-II | |
| Moisture balance (mm) | -50<br>[-55] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |

[66] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=7336

| | | | |
|---|---|---|---|
| **Other** | | | |
| Environmental risks | | | No specific risks. |
| ALC group | 3b | 1 | |

***Crop 53. Flax***

Flax (*Linum usitatissimum*) seed can be used for industrial, food and feed purposes; flax straw contains fibres that are used for making textiles, paper and insulation products, plastic composites etc. Linseed oil is a good source of the Omega-3 fatty acid, alpha-linolenic acid. In the UK and Europe, flax grown for oil production is usually referred to as linseed, whereas flax refers to the fibre from the stems of *Linum usitatissimum* grown for fibre.

Flax plants are tall with few branches and low seed production, whereas linseed plants are shorter, with multiple branches and have been selected for high seed development. Flax for fibre is harvested by 'pulling' the entire crop (including the root) out of the ground. The straw is then laid on the ground in swathes to dry and ret for several weeks before being rolled into round bales.

The life cycle of the flax plant consists of a 45 to 60-day vegetative period; a 15 to 25-day flowering period; and a maturation period of 30 to 40 days (Dribnenki, undated).

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 90 | 125 | Sow: winter varieties in September and spring varieties in March to April once the soil temperature is ≥7°C.<br>Harvest: June to August (winter varieties) and August-September (spring varieties). |
| Air or ground frost | -8 | -4 | Flax seedlings can withstand temperatures down to -4°C (DAFF, 2012d). After the two-leaf stage the crop can tolerate -8°C for short periods. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 21<br>[5] | 26<br>[32] | High temperatures (>32°C) shorten flowering, thereby affecting seed yield (DAFF, 2012d). |
| ALC accumulated temperature (day °C) | 1000 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 450<br>[250] | 750<br>[1300][67] | Flax needs 450 to 750 mm of rain spread evenly through the growing season. |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1000°C). |
| Gradient (°) | 0 | 11 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land and for grade 3b is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 5 | 7 | Acidic soils (pH <6) must be avoided. |
| Topsoil texture | SL | SCL | Wide range of soil types are suitable, sandy loam to clay loams are best. Heavy clays are unsuitable, as are soils of a gravelly or dry, sandy nature. |
| Depth (cm) | 20 | 50 | Shallow rooted. |
| Stone content (%) | 0 | 20 [35] | |
| Drainage | | | |
| ALC soil wetness class | II-IV | I-II | |
| Moisture balance (mm) | -50<br>[-55] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |

[67] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=7336

| | | | |
|---|---|---|---|
| **Other** | | | |
| Environmental risks | | | No specific risks. |
| ALC group | 3b | 1 | |

***Crop 54. Cannabis sativa***

Cannabis (*Cannabis sativa*) cultivation was widely banned in the early 20th century because biotypes high in δ-tetrahydrocannabinol (THC, the principal narcotic component of cannabis) are the source of marijuana (Cherney and Small, 2016). However, more recently the licensed growth and processing of industrial hemp has been permitted. Only cultivars with less than 0.2% THC, may be grown for fibre and seed oil production in the EU (NNFCC, 2006).

In the UK, a licence from the Home Office is required to grow hemp in the UK at a cost of £580, which must be held before the crop is sown[68]. The licence will last for a single growing season and must be renewed before the crop can be grown for another season. In addition, a grower will be required to undergo a Disclosure and Baring Service (DBS) check to be eligible for a licence.

Hemp is grown widely as a fibre crop in Europe and is now also an established minor crop in the UK. The crop may be grown for both its fibre and oil. More recently there has been interest in using cannabis as a biomass crop and also as a source of cannabis resin for medicinal use.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 100 | 150 | Sow: late April onwards.<br>Cannabis is day-length sensitive and flowering is triggered with the onset of shorter days in late July. However, FINOLA, the most widely grown cultivar, is day-length insensitive (day neutral), although drought will hasten maturation (Cherney and Small, 2016).<br>Harvest: August-September.<br>For fibre production the crop is left in the field for 3-4 weeks to rett (removal of the pectin by natural exposure to the environment). The crop is then rowed up and baled (NNFCC, 2006). |
| Air or ground frost | -4 | | Susceptible to frost, so sow once risk of hard frosts has passed. However, seedlings may tolerate temperatures of about -4°C for a short period. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[6] | 27<br>[32][69] | A range of optimum soil temperature for germination is reported in the literature *c*.18°C for New Zealand (Cole and Zurbo, 2008) and 8 to10°C for Canada (Alberta Agriculture and Forestry, 2017). |
| ALC accumulated temperature (day °C) | 1100 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 350<br>[600] | 1200<br>[4000] | |
| **Site** | | | |
| Aspect | | | South facing slopes ensure maximum exposure to sunlight. |
| Altitude (m) | 0 | 1000[70] | Hemp grown in higher altitudes will have more seed production than quality fibre production Cannoy, 2015).<br>However, land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 3 [7] | 5% (*c*.3°) is considered to prevent standing water but not cause excess runoff (Cannoy, 2015).<br>The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |

[68] https://www.gov.uk/hemp-growing-licence

[69] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=4127

[70] Bouloc *et al*., 2013.

| | | | |
|---|---|---|---|
| Soil pH<br>Optimum &<br>[tolerable] range | 7<br>[6] | 7.5 | |
| Topsoil texture | S | C | A deep soil rich in organic matter is preferred but a wide range of soil types are suitable (Alberta Agriculture and Forestry, 2017). |
| Depth (cm) | | | The root is generally 30-60 cm, up to 2.5 m in light/loose soils and shorter in wet soils (Small *et al*, 2002). |
| Stone content (%) | 0 | 10 [15] | |
| Drainage | | | Well drained. |
| ALC soil wetness class | I-IV | I-II | |
| Moisture balance (mm) | -20<br>[-30] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | Bare soil over winter may increase soil erosion and nitrate leaching. |
| ALC group | 3a | 1 | |

***Crop 55. Lunaria***

Lunaria (*Lunaria annua*) is a biennial cruciferous oil seed crop. The seed contains 30-35% oil, which consists of 67% long chain fatty acids (44% erucic acid and 23% nervonic acid). The oil is suitable as a lubricant. In addition, recent developments indicate that nervonic acid may be used as raw material for the production of a medicine against multiple sclerosis (Mastebroek and Marvin, 2000). The crop has to be sown early in the summer (May-June) to achieve vigorous plant development required for vernalisation during the winter.

The biennial character of lunaria is the main constraint for an economically feasible production of Lunaria oil, although annual varieties are being developed. The production potential and agronomy of the crop requires further investigation as the crop often does not thrive in large open fields (Christou *et al*., 2012). Thus, at present Christou *et al*. (2012) concluded that the commercial production of lunaria is limited to seed multiplication for ornamentals.

There is very little information on the crop requirements for lunaria as, to date, the plant has been mainly used as an ornamental.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | |
| Air or ground frost | | | |
| Other | | | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | | | |
| ALC accumulated temperature (day °C) | | | |
| Rainfall (mm) Optimum & [tolerable] range | | | |
| **Site** | | | |
| Aspect | | | |
| Altitude (m) | | | |
| Gradient (°) | | | |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | | | |
| Topsoil texture | | | |
| Depth (cm) | | | |
| Stone content (%) | | | |
| Drainage | | | |
| ALC soil wetness class | | | |
| Moisture balance (mm) | | | |
| Field capacity (days) | | | |
| **Other** | | | |
| Environmental risks | | | |
| ALC group | | | |

***Crop 56. Mustard***

Mustard is a broadleaf, cool-season oilseed crop produced primarily for the condiment market. Two species of mustard are most often grown in the UK, white mustard (*Sinapsis alba*) and Brown mustard (*Brassica juncea*). Both have a very similar life cycle and growing pattern to oilseed rape (SASK Mustard, 2017).

Mustards are relatively resistant to pod shattering and straight combining is often the preferred harvest method. Shatter tolerance will allow the crop to be combined when plants are mature with little loss of seed during combining. For uneven crops swathing can be used to force the fields to ripen consistently. Desiccation is not commonly used for mustard.

Mustard can also be sown into cereal stubbles in July or August as a cover crop and/or for livestock grazing in October/November.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 150 | 180[71] | Increased day length and temperatures trigger bud formation.<br>Sow: early spring for seed production or August-September for grazing.<br>Harvest: late August to late September for seed. |
| Air or ground frost | | | Fairly frost tolerant (McKenzie, 2010). |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 10<br>[5] | 25<br>[30] | Soil temperature of 4.5°C required for germination (SASK Mustard, 2017). |
| *Brown mustard* | *15*<br>*[7]* | *28*<br>*[40]* | |
| ALC accumulated temperature (day °C) | 1000 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 700<br>[1100][72] | 1100<br>[1300] | |
| *Brown mustard* | 700<br>[2400][73] | 2400<br>[4200] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1000°C). |
| Gradient (°) | 0 | 11 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. The limit for 3b land is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.5<br>[5.5] | 7.5<br>[8.5] | |
| *Brown mustard* | 5.5<br>[5.0] | 6.5<br>[8.0] | |
| Topsoil texture | S | C | Medium or light soils are best, heavier soils are also suitable providing they are well drained. |
| Depth (cm) | 50 | 150 | |

[71] Growing season for seed crop.

[72] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=9787

[73] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=548

| | | | |
|---|---|---|---|
| Stone content (%) | 0 | 20 [35] | No specific limits but ALC gives limit values for Grade 3b of 20% and 35% (by volume) for stones >6 and 2 cm, respectively in the top 25 cm of soil. |
| Drainage | | | Well drained, waterlogged soils will result in stunted mustard plants. |
| ALC soil wetness class | II-IV | I-II | |
| Moisture balance (mm) | -50 [-55] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | No specific risks. |
| ALC group | 3b | 1 | |

## Nuts

### *Crop 57. Almonds*

The US is the largest producer of almonds, in particular, California where almonds thrive in a climate that has mild wet winters and hot dry summers. Almonds are a perennial deciduous tree, which begin to bear nuts after 3-4 years and have an economic life of about 20-25 years.

Almonds have a high requirement for water (Smith 2014); insufficient heat accumulation has also been shown to be a limiting factor for almond cultivation. However, almonds also need a winter chilling period of 0-700 hours below 7°C to break dormancy and mature the buds (Atkinson *et al*., 2004). Frost damage is known to be a primary limitation to almond cultivation, particularly early season frost damage occurring between bud swell and anthesis (Miranda *et al.* 2005). Flowering is early (February/March) meaning that spring frosts are potentially damaging and both blossoms and fruit can be killed by -1°C temperatures (OABS, 2017). While declines in frost risk have been shown to have positive effects on crop productivity (Lobell and Gourdji 2012) and could be expected to have a similar effect on almond yield, declines in winter chill may have detrimental effects on crop yields (Luedeling *et al*. 2009).

Almonds require cross-pollination to set fruit and many almond growers include bee hives to increase fruit set and final yield. Temperatures >12°C permit honey bees to fly and pollinate the almonds.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 180 | 240 | Perennial. Harvest August to October |
| Air or ground frost | -6 | 0 | Blossoms suffer damage at -2°C and vegetative buds at -4°C to -6°C. Mature trees are frost hardy. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 13 [35] | 35 [40] | |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 600 [250] | 900 [1500] | Rainfall during the harvesting season is undesirable. |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.5 [5.5] | 7 [8.5] | |
| Topsoil texture | SL | SCL | Medium, medium light. |
| Depth (cm) | 20 | 150 | |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Well drained. |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5 [-10] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated or fertigation is used.<br>Irrigation may increase the risk of run-off and/or soil erosion. |

| | | | |
|---|---|---|---|
| ALC group | 2 | 1 | |

***Crop 58. Chestnuts***

Sweet chestnut (*Castanea sativa*) is a deciduous tree growing to 30-35 m which can be grown for timber or nut production (Conedera *et al.,* 2016). Although sweet chestnut is a long-lived tree it is generally grown for timber on rotations of 50-70 years. It grows best in warm, sunny locations and optimum growth is often found on sheltered southerly aspects (Evans, 1984). Yield class ranges from 4 to 12, averaging 6 (Horgan *et al*., 2003).

Timber producing trees are easily grown from seed planted immediately it falls. Seed producing varieties are propagated by grafting selected strains and hybrids on to seedling rootstocks. Grafted trees begin to bear in two to four years, and seedlings will bear in five to seven years. The trees are primarily wind pollinated although insects may also aid in pollination.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 110 | 150 | Flowering to harvest. |
| Air or ground frost | | | Though chestnuts flower late, spring frosts can damage new growing shoots, and low-lying frost pockets should be avoided (Evans, 1984). |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 8 | 15 | Optimum mean yearly temperature ranging between 8°C and 15°C and monthly mean temperatures >10°C during 6 months (Conedera *et al*., 2016). |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 500 [600] | 800 [850] | Drought tolerant |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 4 | 5 | Soil pH should be acidic, between 4 and 5 (Horgan *et al*., 2003). |
| Topsoil texture | SL | MCL | Sandy loams are best and medium clay is ok. Avoid wet heavy clay and calcareous soils (Evans, 1984). |
| Depth (cm) | >150[74] | | |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Well drained |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5 [-10] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated or fertigation is used.<br>Irrigation may increase the risk of run-off and/or soil erosion. |
| ALC group | 2 | 1 | |

[74] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=2234

***Crop 59. Hazelnut***

The hazel (*Corylus avellana*) is typically a shrub reaching 4-8 m tall, occasionally more than 10 m, and the stem is usually branched (Enescu *et al.,* 2016). It is one of the most economically important tree nut crops worldwide (FAOSTAT, 2016). Turkey is the leading hazelnut producer, with approximately >500,000 tonnes nut in-shell per annum in recent years, (Baldwin, 2015).

Hazel trees are hardier than most nut bearing species and can be grown throughout Wales (CALU, 2006c). Trees to be used for nut production have usually been grafted onto non-suckering rootstocks. Trees are generally bought 1-2 years after grafting. Trees generally become commercially viable 5-6 years after planting, and can produce 2.5 tonnes/ha at this stage (CALU, 2006c). Once established, a hazel orchard can remain productive for around 100 years.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | |
| Air or ground frost | -15 | -5 | Dormant hazelnuts can tolerate temperatures as low as -15°C. However, frost hollows should be avoided as frost may damage flowers (≤-5°C). |
| Other | | | Hazelnuts do not tolerate windy conditions, combined with high summer temperatures and low humidity. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 10 [5] | 25 [35] | Chilling requirements vary for male catkins, female flowers and leaf buds but about 1200 hours between 5°C and 7°C is suitable (Mehlenbacher, 1991). |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 900 [600] | 1100 [1400] | Ideally >50 mm of rainfall in May, when trees are making active leaf and shoot growth (Baldwin, 2015). |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | Avoid steep slopes where poaching and water/soil runoff may be a problem.<br>In addition, the safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.0 [4.5] | 7.0 [8.5] | |
| Topsoil texture | LS | MCL | Deep loam soils are best, light sand or heavy clay soils should be avoided. |
| Depth (cm) | 50 | >150 | Deep soil |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Well drained. |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5 [-10] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated or fertigation is used.<br>Irrigation may increase the risk of run-off and/or soil erosion. |
| ALC group | 2 | 1 | |

***Crop 60. Walnuts***

The English walnut (*Juglans regia*) is a large deciduous tree; with correct management there is potential for walnut trees to be grown for dual usage i.e. nuts and wood. Walnut timber is valuable, although it will take ≥40 years before timber can be taken from a plantation. Walnut planting is best carried out during winter (November to February). Trees will produce fruit after 5-6 years and will need little management over that period. Walnut needs a warm and sheltered site and a long growing season (de Rigo *et al*., 2016).

Traditionally walnuts were planted in widely spaced orchards, however, more recently hedgerow systems have been adopted where trees are planted closer together. The hedgerow design brings early returns because the increased number of trees has a larger early combined canopy and yield[75].

| Requirements | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Harvest: September to October (or picked green in June for the pickling market). |
| Air or ground frost | | | Spring frosts can damage foliage and flowers.<br>Older trees are however able to withstand winter temperatures as low as -30°C (de Rigo *et al*., 2016). |
| Other | | | Avoid frost hollows and sites susceptible to high wind exposure (CALU, 2006c). |
| Mean daily air temperature (°C).<br>Optimum & [tolerable] range | 15<br>[7] | 30<br>[40] | Walnuts thrive in warm summers and planting should be confined to southern areas ((Hibberd, 1988).<br>600 and 800 hours of temperatures below 10 °C during winter (winter chill) (AWIA, 2009). |
| ALC accumulated temperature<br>(day °C) | 1150 | ≥1300 | |
| Rainfall (mm)<br>Optimum & [tolerable] range | 800<br>[1700] | 1700<br>[2200] | |
| **Site** | | | |
| Aspect | | | Sheltered with a southerly sunny aspect (Hibberd, 1988). |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | Gentle slopes near the valley bottom are optimal because cold air is drained away from the trees and water availability is high.<br>Also, the safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH<br>Optimum & [tolerable] range | 5.5<br>[4.5] | 7.5[76]<br>[8.0] | |
| Topsoil texture | SL | SCL | Medium textured, sandy to clay loams. Avoid very clayey or very sandy sites. |
| Depth (cm) | >150 | | Deep |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Well drained. |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5<br>[-10] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |

[75] http://fruitandnuteducation.ucdavis.edu/fruitnutproduction/Walnut/Walnut_Orchard_Establishment/

[76] https://www.walnuttrees.co.uk/walnut-trees/planting-and-care

| | | | |
|---|---|---|---|
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated or fertigation is used.<br>Irrigation may increase the risk of run-off and/or soil erosion. |
| ALC group | 2 | 1 | |

## Fruit (tree)

### *Crop 61. Apples*

In 2016, there was 354 ha of cider apples/perry pears grown in Wales; no dessert or culinary apples were recorded as having been commercially grown in Wales in the same year. Cider is normally made from 25-30% cider apples, the rest can be cull fruit, i.e. out grade eaters and cookers, but the fruit needs to be sound (CALU, 2007c). The Welsh climate is not generally considered suitable for the production of dessert/culinary apples as skin finish can be affected by scab (Creed *et al*., 2014).

Site selection is extremely important as the crop will be on the site for many years and yields are likely to be low until the trees are about seven years old. To ensure good yields growers must ensure that an adequate number of high quality flowers are produced, which will help to ensure fruit set. Particular attention needs to be given to the incidence of frost, likely wind speeds and daytime temperatures during the April and May flowering period.

In some seasons, considerable damage to flowers and young fruitlets is caused by frost. Desiccating winds at the time of flowering also serve to kill pollen and inhibit the activity of pollinating insects. Frost protection may be provided by the installation of water sprinklers, either under tree micro jets or over tree systems using spray nozzles. These raise the soil or air temperature sufficiently to avoid frost damage where the temperature is close to freezing. Natural windbreaks at regular intervals provide shelter for pollinators and regular gaps allow cold air flow to escape.

| Requirements | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 150 | 180 | Flowering to harvest<br>Harvest: September or October (depends on variety). |
| Air or ground frost | -2 | | The initiation of flowers and their early development in late summer and autumn is followed by a period of dormancy during the winter.<br>Avoid sites prone to spring frost.<br>Temperatures at flowering time of less than -2°C, (at approximately 0.5m above ground level) cause significant damage to the flowers if sustained for one hour or more. |
| Other | | | Avoid sites exposed to cold east or north winds and chose a site which is sheltered from strong winds (AHDB, 2018). |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 14<br>[8] | 27<br>[33] | Apples require a winter dormant period of 200-1,400 hours below 7°C (Atkinson *et al*., 2004). Without sufficient cold, leaf buds do not open.<br>Germination of pollen is temperature dependent with optimum temperatures between 15 and 25°C.<br>Although some varieties will set fruits when daytime temperatures are as low as 5°C (e.g. Falstaff), the majority of scion varieties require daytime temperatures of 12-15°C for successful pollen germination and growth (AHDB, 2018). |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 700<br>[500] | 2500<br>[3200] | Rain during the flowering period of apples reduces the potential for effective pollination and fruit set. Firstly, the rain inhibits the foraging activities of all bee species and thus reduces pollen transfer. Secondly, rain inhibits the germination and growth of pollen on the stigma and results in pollen death (AHDB, 2018).<br>During the summer mature apple orchards will use about 100-150 mm of water per month (Roper and Frank, undated). |
| **Site** | | | |
| Aspect | | | South facing slopes are optimal. North and east facing slopes adequate. |
| Altitude (m) | 0 | 125<br>[300] | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | Slight slope to allow the escape of cold air flows |
| **Soil** | | | |
| Soil pH | 5.6<br>[4.5] | 6.8 | |

| | | | |
|---|---|---|---|
| Optimum & [tolerable] range | | [8.0][77] | |
| Topsoil texture | S | MCL | Medium textured clay to gravelly sand. |
| Depth (cm) | 50 | >150 | |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Well drained, wet soils lead to poor aeration and increased risk of crown rot. |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5 [-10] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | Good water holding capacity to retain moisture and supply water to trees during dry periods. |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated or fertigation is used.<br>Irrigation may increase the risk of run-off and/or soil erosion. |
| ALC group | 2 | 1 | |

[77] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=1407

***Crop 62. Cherries***

In 2017 there was 731 ha of commercial cherry (*Prunus avium*) orchards in the UK producing about 6,500 t of cherries. The demand for cherries in the UK far exceeds domestic production and around 17,000 tonnes were imported into the UK in 2017 (Defra 2018). The UK cherry season is very short, with home-grown cherries widely available only during July (CALU, 2009).

Cherry trees need a period of rest or dormancy to produce fruit. Dormancy is broken once a variety's chilling requirement has been met. Every variety has its own individual chilling requirement.

Bee hives should be introduced to the orchard to ensure that bees are available for pollination.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Plant trees in early in the winter/spring period to allow trees to 'settle' before the spring growth begins. |
| Air or ground frost | | | Frost-free sites are best.<br>Frost tolerant, roots are more susceptible (-29°C) than above ground parts (-15°C).<br>Cherries are most susceptible to frost damage during flowering (-2°C). |
| Other | | | Low to moderate wind flow can help to reduce humidity and lessen disease and pest pressure. However, strong winds can damage trees and fruit or reduce fruit set (James, 2011). |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 18<br>[6] | 26<br>[40] | Sufficient winter chilling to ensure uniform and complete bud break in spring.<br>Temperature >13°C during flowering to ensure adequate bee activity (James, 2011). |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 500<br>[900] | 900<br>[1500] | For cherry production, the pattern of rainfall throughout the year is more important than the actual total annual rainfall for any locality. Low rainfall is required during flowering to ensure maximum pollination and fruit set (James, 2011). |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Good access is necessary.<br>Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.5<br>[5.5] | 7.0<br>[8.0] | |
| Topsoil texture | SL | MCL | Avoid very shallow or clay soils. Medium textured soils are best. Light sandy soils can be used provided irrigation is available. |
| Depth (cm) | 50-150 | >150 | |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Well drained, cherry trees will not tolerate waterlogging. |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5<br>[-10] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated or fertigation is used. |

| | | | |
|---|---|---|---|
| | | | Irrigation may increase the risk of run-off and/or soil erosion. |
| ALC group | 2 | 1 | |

***Crop 63. Pears***

Pear (*Pyrus communis*) is grown for eating fresh, canned or dried or processed into Perry. Pear wood can also be used in the production of furniture and also for woodwind instruments.

| Requirements | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 150 | 210 | Flower: April.<br>Harvest: Late August to late October.<br>From flowering to harvest depends on variety but is typically between 150 to 210 days. |
| Air or ground frost | -30 | -3 | Avoid areas with frequent spring frosts.<br>When trees are fully dormant they can withstand low temperatures (*c.*-30°C). Buds and flowers are more susceptible to frost (-3°C) (Marini, 2014). |
| Other | | | Avoid frost pockets.<br>Wind breaks may be required on windy sites. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 20<br>[10] | 35<br>[37][78] | Pear require a period of low temperature during the winter (1000-1200 hours at <7°C) to complete their dormant period (Marini, 2014). |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 600<br>[400] | 900<br>[2100] | |
| **Site** | | | |
| Aspect | | | South facing is ideal. |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | Gentle slope for air drainage and to avoid frost pockets.<br>The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.2<br>[4.5] | 6.8<br>[8.3] | Soil pH should be about 6.2 to 6.8 (Marini, 2014). |
| Topsoil texture | MZCL | C | Medium to heavy soils. |
| Depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 5 [10[ | |
| Drainage | | | Well drained. |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5<br>[-10] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated or fertigation is used.<br>Irrigation may increase the risk of run-off and/or soil erosion. |
| ALC group | 2 | 1 | |

[78] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=1832

***Crop 64. Plums/Damsons***

Around 80,000 tonnes of plums (*Prunus domestica*) valued at £60 million are consumed annually in the UK of which about 10% are produced nationally (Defra, 2018). However, the demand for home grown plums cannot currently be met due to unreliable and inefficient cropping systems. Ongoing research led by NIAB (February 2016 to April 2019) will address the sustainable intensification of UK plum production[79].

The Denbigh plum is the only plum variety native to Wales, which is grown in the designated geographical area of the Vale of Clwyd in Denbighshire either for culinary purposes or as a dessert plum. The designation of 'The Vale of Clwyd Denbigh Plum' by the EU as protected designation of origin (PDO) is in the final stages (EU, 2018).

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing seasons (Days) | | | Bud break: March to April.<br>Flowers: April to May.<br>Harvest: August to September, depending on a range of factors such as weather and intended market. Culinary plums are harvested before they are ripe whereas dessert plums are allowed to ripen on the tree. |
| Air or ground frost | -5 | -2 | Susceptible to spring radiation frosts.<br>The blossom is very susceptible to frost damage so the trees must be sited where damage from spring frosts is unlikely (CALU, 2007d).<br>90% of blossom may be killed following exposure to -5°C for 30 minutes (Murray, 2011). |
| Other | | | Wind breaks may be required, especially if plums are grown near the coast.<br>Avoid frost pockets (CALU, 2007d). |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 18<br>[6] | 33<br>[36][80] | Plum trees require sufficient low temperatures during the winter (<7°C for 800-1500 hours) to become dormant over winter (Atkinson *et al.,* 2004). |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 500 | 900 | Damsons will succeed in areas with higher rainfall, and less sunshine, than plums (CALU, 2007d). |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | Gentle slope for air drainage and to avoid frost pockets.<br>The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.0<br>[4.5] | 6.5<br>[7.4] | |
| Topsoil texture | SL | MZCL | Free draining medium textured soils. Sandy loam to sandy clay loam or well drained clays (DAFF, 2010d). |
| Depth (cm) | 50-150 | >150 | |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | |

[79] https://gtr.ukri.org/projects?ref=102133

[80] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=16203

| | | | |
|---|---|---|---|
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5<br>[-10] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated or fertigation is used.<br>Irrigation may increase the risk of run-off and/or soil erosion. |
| ALC group | 2 | 1 | |

***Crop 65. Greengages***

Greengages are a type of European plum (*Prunus domestica*) and as such have the same requirements as plums or damsons.

| Requirements | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing seasons (Days) | | | Bud break: March to April.<br>Flowers: April to May.<br>Harvest: August to September, depending on a range of factors such as weather and intended market. Culinary plums are harvested before they are ripe whereas dessert plums are allowed to ripen on the tree. |
| Air or ground frost | -5 | -2 | Susceptible to spring radiation frosts.<br>The blossom is very susceptible to frost damage so the trees must be sited where damage from spring frosts is unlikely (CALU, 2007d).<br>90% of blossom may be killed following exposure to -5°C for 30 minutes (Murray, 2011). |
| Other | | | Wind breaks may be required, especially if plums are grown near the coast.<br>Avoid frost pockets (CALU, 2007d). |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 18<br>[6] | 33<br>[36][81] | Plum trees require sufficient low temperatures during the winter (<7°C for 800-1500 hours) to become dormant over winter (Atkinson *et al.,* 2004). |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 500 | 900 | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | Gentle slope for air drainage and to avoid frost pockets.<br>The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.0<br>[4.5] | 6.5<br>[7.4] | |
| Topsoil texture | SL | MZCL | Free draining medium textured soils. Sandy loam to sandy clay loam or well drained clays (DAFF, 2010d). |
| Depth (cm) | 50-150 | >150 | |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5<br>[-10] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated or fertigation is used.<br>Irrigation may increase the risk of run-off and/or soil erosion. |

[81] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=16203

| | | | |
|---|---|---|---|
| ALC group | 2 | 1 | |

***Crop 66. Olives***

The olive (*Olea europaea*) is a small evergreen tree which grows slowly and is able to live over 1000 years (Guerrero Maldonado *et al*., 2016). Today, approximately 98% of olives are cultivated in Mediterranean Basin countries. However, olives have been grown commercially in England and Wales (e.g. Anglesey and Cardigan Bay) since *c*.2000, albeit in small quantities. Olives are processed following harvest to be consumed as table olives or pressed into olive oil.

Olives are traditionally grown in regions which have relatively cool, frost-free winters followed by hot, dry summers. They are less sensitive to wind than many other types of fruit tree (DAFF, 2010c). Trees can produce a crop when they are 6 years old and continue producing a commercial yield for the next 50 years[82]. It is, therefore, important to select the correct locality and to prepare the soil properly. Olive trees are genetically highly alternating in fruit production, yielding 7-8 t/ha one year and <0.5 t/ha the next.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | An evergreen long-day plant.<br>The trees should be planted during late winter or early spring.<br>Flowering in April-May is followed by fruit growth and ripening. Fruit is usually harvested 4 to 6 months after flowering.<br>Harvest: late summer to autumn. |
| Air or ground frost | -5 | | Late spring frosts can kill olive blossoms.<br>Buds and fruiting shoots can be damaged by temperatures <-5°C. Large branches and whole trees can be killed at -10°C. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[5] | 34<br>[40] | Olives need a period of winter chill of about two months at 1.5-10°C for optimum flower development.<br>The optimum temperatures for growth are 15 to 34°C. The most unfavourable temperatures are >40°C and <5°C (Taylor and Burt, 2007). |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 600<br>[200] | 900<br>[1200] | Good olive oil yields can be obtained without irrigation in growing areas where annual rainfall is greater than 600mm (Gucci and Fereres, 2012). |
| **Site** | | | |
| Aspect | | | Sunny position. |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.5 | 8.5 | |
| Topsoil texture | S | ZCL | Sandy to silty clay loams. |
| Depth (cm) | 50 | >150 | |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Well drained, trees cultivated on wet or waterlogged soils are susceptible to plant diseases (DAFF, 2010c). |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5<br>[-10] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |

[82] https://pfaf.org/user/Plant.aspx?LatinName=Olea+europaea

| | | | |
|---|---|---|---|
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated or fertigation is used.<br>Irrigation may increase the risk of run-off and/or soil erosion. |
| ALC group | 2 | 1 | |

## Other fruit

### *Crop 67. Bilberries*

The bilberry (*Vaccinium myrtillus*) also referred to as the European blueberry, is a long-lived ericaceous dwarf shrub that grows wild in Europe and Asia. Bilberry is harvested commercially from the wild in Finland and other European countries. Limited attempts have been made to grow the crop in cultivation. European blueberry grows wild in areas where summers are warm with long days and autumns and winters are cold with short days and abundant snowfall (Nestby *et al*., 2014).

Bilberry is a perennial species with a longevity between 15 to 30 years (Jensen and Ramborg, 2014 cited by Figal de Pedro, 2017) so it is essential to achieve the best possible conditions for cultivation and harvest. Long day conditions and increasing temperatures induce vegetative growth after winter and, when shoot elongation ceases in mid-summer, flower induction starts under long day conditions (Selås *et al*., 2015). High temperatures in later summer negatively affect the following years flowering.

Irrigation may be required in dry weather or when there are high levels of solar radiation to ensure that conditions remain humid.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Bilberry phenology is strongly influenced by photoperiod and temperature.<br>Long days increase berry production. |
| Air or ground frost | -3 | 0 | Spring frost with temperature below -3°C kills bilberry flowers and this is the main reason for low berry production (Nestby *et al*., 2014). Temperatures <10°C promote frost hardening so that plants can withstand low over winter temperatures (Figal de Pedro, 2017). |
| Other | | | Windbreaks are advisable to reduce frost damage and prevent damage by strong winds due to shallow rooting (Martinussen *et al*., 2009). |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 8<br>[5] | 17<br>[25] | |
| ALC accumulated temperature (day °C) | *≥1300* | | |
| Rainfall (mm) Optimum & [tolerable] range | 500<br>[250] | 700<br>[1700][83] | Slight slope to help drain cold air. |
| **Site** | | | |
| Aspect | | | South facing |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1300°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 4 | 5<br>[6] | Requires acidic soils with pH around 4-5 (Figal de Pedro, 2017). |
| Topsoil texture | ? | ? | No available information. |
| Depth (cm) | 20-50 | 50-150 | Shallow rooting system |
| Stone content (%) | 0 | 5 | |
| Drainage | | | Well drained |
| ALC soil wetness class | *I-II* | | |

[83] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=10714

| | | | |
|---|---|---|---|
| Moisture balance (mm) | *+30 [+10]* | | |
| Field capacity (days) | *≥151* | *225* | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Shallow rooting may lead to low N use efficiency, increasing the risk of nitrate leaching. |
| ALC group | *1* | *1* | |

***Crop 68. Strawberries***

Strawberries (*Fragaria ananassa*) are classed as 'everbearers' or 'June bearers'; under UK climatic conditions most 'June bearer' strawberry varieties will crop naturally over a period of 3 to 4 weeks and everbearers for 10 to 12 weeks (Red Tractor Assurance, 2016r). Most growers will grow a range of varieties and types to achieve continuous cropping over an extended period. Open field grown crops may be covered with floating crop covers to advance production, or covered whilst they are still dormant in late winter with straw to delay harvest.

Adequate soil moisture is essential to give satisfactory plant establishment, even growth and to promote quality, shape, size and yield of fruit. For most soil types in most seasons irrigation is essential for extended season cropping as well as during regrowth post-harvest. Strawberries may be grown on raised beds to improve drainage on soils where waterlogging may be a problem.

Commercial strawberry production is increasingly in polytunnels in table-top substrate systems, using bags or troughs filled with peat or coir based compost (CALU, 2007e). These bags or troughs are placed on the ground or on a variety of different support system. The increased popularity is due to the ease of picking and consistent cropping, plus it enables manipulation of the growing season through planting and fleecing crops, allowing crops to be grown from late May to November if desired (Creed *et al*., 2014).

| Requirement | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Plant: end of August to May. Depending on planting date, crop may not fruit in the first year.<br>Flowers are produced in May and June (earlier if protected). Flower initiation depends on day length and temperature.<br>Berries will be ripe 4-6 weeks after the flower is fertilised. |
| Air or ground frost | | | Avoid frost prone sites.<br>Strawberries are susceptible to spring frost which can lead to an increased risk of fungal disease (Red Tractor Assurance, 2016r). |
| Other | | | Sheltered from wind. Wind damage in the spring can lead to an increased risk of fungal disease.<br>High winds can be problematic if crops are covered by polytunnels. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 11<br>[11] | 24<br>[28][84] | |
| ALC accumulated temperature (day °C) | ≥1300 | | |
| Rainfall (mm) Optimum & [tolerable] range | 600<br>[300] | 900<br>[1700] | |
| **Site** | | | |
| Aspect | | | South west |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1300°C). |
| Gradient (°) | 0 | 7 | Gentle slope, avoid low lying areas where cold air collects (DAERA[85]). The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.5<br>[6.0] | 7.0<br>[8.0] | Strawberries thrive on well drained nutrient rich, slightly acidic (pH 6.0-6.5) soil (CALU, 2007f). |

[84] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=1112

[85] https://www.daera-ni.gov.uk/articles/field-strawberry-production

| | | | |
|---|---|---|---|
| Topsoil texture | LS | HZCL | A wide range of soils are suitable for strawberry growing including loamy sand, sandy loam, loam, silty loam, sandy silty loam, silt, clay loam and silty clay loam. However, very heavy clay soils are generally unsuitable due to poor aeration and drainage problems (Red Tractor Assurance, 2016r). |
| Soil depth (cm) | 20-50 | 20-50 | |
| Stone content (%) | 0 | 5 | No specific limits but ALC gives limit values for Grade 1 of 5% (by volume) for stones >2 and 6 cm, in the top 25 cm of soil. |
| Drainage | | | Well drained soils. Waterlogging in winter increases the spread of soil borne diseases. It will also increase root death (Red Tractor Assurance, 2016r). |
| ALC soil wetness class | I-II | | |
| Moisture balance (mm) | +30 [+10] | | |
| Field capacity (days) | ≥151 | 225 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Large areas of bare soil between rows or individual plants can lead to soil erosion.<br>Disposal of fleece crop covers. |
| ALC group | 1 | 1 | |

***Crop 69. Melons (Cantaloupe)***

Cantaloupe melons (*Cucumis melo*) are part of the cucurbitaceae family which includes squash, pumpkins etc.

In the US raised tilled beds are sometime used for planting and the beds may be covered with polythene sheets. Raised beds provide good drainage and increase the rate of soil heating. Irrigation may be necessary during early growth or during fruit formation, particularly where the crop is not grown on a moisture retentive soil. To achieve the best yields pollinators should be actively encouraged into the crop, for example by bringing hives into the crops or planting wildflower mixtures to attract bees (Orzolek *et al*., 2006).

The crop requirements listed below are for a field-grown crop. However, currently in the UK, melons are not typically grown outdoors for commercial production.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Melons can be direct-seeded or grown as transplants in a greenhouse.<br>Sow: outside after the risk of frost has passed when the soil temperature is >15°C.<br>Harvest: Late June onwards, depending on sowing date.<br>Note: fruit is often harvested at half-slip (when a growth crack develops at the joint where the fruit is attached to the stem which does not fully encircle the stem) over a period of 1-2 weeks. |
| Air or ground frost | | | Very frost sensitive, even a mild frost can damage the plant (Orzolek *et al.,* 2006). |
| Other | | | Avoid sites prone to high winds which can damage young seedlings (Motes *et al*., 2017). |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 18<br>[9] | 24<br>[35] | Optimum soil temperature range for germination is between 21° and 35°C (Kemble, 1996).<br>Temperatures >35°C or <10°C will slow the growth and maturation of the crop (Orzolek *et al*., 2006).<br>If they are exposed to cool temperatures (≤10°C) for short periods of time during the growing period, growth will be severely stunted (Rutledge, 2015). |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 1000<br>[900] | 1300<br>[2500][86] | |
| **Site** | | | |
| Aspect | | | Full sun. South facing slopes with good air drainage. |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C) |
| Gradient (°) | 0 | 7 | Slightly sloping land is OK, providing that farming operations are still practicable. The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.0<br>[5.0] | 6.5<br>[8.5] | Cantaloupe melons grow best at a pH level between 6.0 and 6.5 (Kemble. 1996). |
| Topsoil texture | S | MCL | Wide variety of soils but medium textured loams produce the best quality melons and yields (Rutledge, 2015). |

[86] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=815

| | | | |
|---|---|---|---|
| | | | Moisture retentive soils are suitable for the planted crop but can impair emergence of early direct drilled crops. |
| Depth (cm) | 50 | 150 | |
| Stone content (%) | 0 | 5[10] | Stony soils may be ok for crop establishment but will impair crop quality as the crop trails. |
| Drainage | | | Well drained sites that heat up quickly. |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5<br>[-10] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Bare soil over winter may increase soil erosion and nitrate leaching. |
| ALC group | 2 | 1 | |

## Forage/fodder crops

### *Crop 70. Beets/mangolds.*

Fodder beet (*Beta vulgaris*) are possibly the highest yielding forage crop for UK livestock farmers (Draycott and Hollies, 2001). Root yields of 50-75 t/ha are normal and when grown really well, can exceed 100t/ha. Consequently, the crops take up large amount of nutrients, in particular potash (580 kg/ha for a crop yielding 70-90 t/ha). Fodder beet is derived from wild beet growing on the shores of the Mediterranean and requires an adequate supply of sodium for optimum growth.

Fodder beet is a hybrid of mangels and sugar beets. It is a high energy, palatable crop that can be lifted and fed to livestock after cleaning (whole or chopped) after cleaning or grazed in situ.

| Requirements | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Drill: late March to April and lift October or November (before severe frosts). |
| Air or ground frost | | | |
| Other | | | All types require warm sunny conditions. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15 [4] | 25 [35] | Soil temperature should be at least 5°C before sowing (Limagrain, 2010) and some reports suggest that it requires at least five days of 10°C or higher before planting (Joordens, undated).<br>Sowing too early in cold conditions can lead to bolting. |
| ALC accumulated temperature (day °C) | 1100 | >1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 600 [500] | 800 [1000] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1150°C). |
| Gradient (°) | 0 | 7 | Limitations for de-stoning, planting and harvesting machinery.<br>The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.0 [5.5] | 7.0 [7.5] | A soil pH of 7 is the target (Limagrain, 2010). |
| Topsoil texture | S | MCL | Light sandy to medium clay loams and peats (Joordens, undated). Heavy soils make establishment and harvesting difficult. |
| Depth (cm) | 50-50 | 50-150 | Deep rooted crop. |
| Stone content (%) | 0 | 10 [15] | |
| Drainage | | | Well drained. |
| ALC soil wetness class | I-IV | I-II | |
| Moisture balance (mm) | -20 [-30] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | Soil compaction from the use of heavy machinery and/or soil loss through adherence.<br>Root crops are at risk from water erosion, due to large areas of bare soil. Bare soil over winter may increase soil erosion and nitrate leaching. |
| ALC group | 3a | 1 | |

***Crop 71. Forage rape***

Forage rape (*Brassica napus*) is a fast growing leafy catch crop with a high protein content. It has a flexible sowing period and can be grazed by sheep or cattle. Forage rape is able to survive and grow on relatively poor soils and on exposed sites.

As most crops are grazed in situ, a free draining light loam with a pH of 6-6.5 is ideal (Limagrain, 2016). In line with other brassica crops, feeding should be introduced gradually over a 2-week period. Ideally there should be an area of grassland to allow stock to 'run back' onto, along with access to hay, silage or straw (fibre). Limit crop to 50- 80% of total DM intake depending on what type of livestock are being fed and what long fibre is available.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 90 | 110[87] | Sow: March to August.<br>Feed: June to December.<br>Early sowing leads to higher yields but establishing too early will result in mature crops with low digestibility. |
| Air or ground frost | | | |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15[88]<br>[15] | 25<br>[41] | Crop is sown when soil temperature reaches 10°C. |
| ALC accumulated temperature (day °C) | 800 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 500<br>[400] | 1000<br>[1950] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <800°C). |
| Gradient (°) | 0 | 18 | Avoid steep slopes where poaching and water/soil runoff may be a problem.<br>In addition, the safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land, for grade 3b it is 11° and for grade 4 it is 18°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 5.8<br>[5.6] | 6.5 | |
| Topsoil texture | LS | SCL | A free draining light loam is ideal as most crops are grazed in-situ. Avoid heavy soils. |
| Depth (cm) | | | |
| Stone content (%) | 0 | 35 [50] | |
| Drainage | | | Well drained |
| ALC soil wetness class | III-V | I-II | |
| Moisture balance (mm) | <-50<br>[<-55] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |

[87] Number of days between sowing and the crop being ready to utilise for grazing.

[88]http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=549

| | | | |
|---|---|---|---|
| Environmental risks | | | Field poaching and compaction by grazing animals can lead to increased soil erosion. |
| ALC group | 4 | 1 | |

***Crop 72. Lucerne***

Lucerne (*Medicago sativa*), also known as alfalfa, is a widely grown leguminous forage crop globally. However, it remains a minority crop in Great Britain despite its high yields, protein content and zero nitrogen fertiliser requirement (Evans and McConnell 2015). Lucerne can be baled or clamped but is difficult to ensile under UK conditions (high humidity coupled with low sugar content). The crop can also be rotationally grazed but grazing can reduce crop persistency.

Lucerne is not suitable for heavy or waterlogged soils where conditions are likely to rot the deep taproot and it will be difficult to grow successfully in areas with high rainfall (AHDB, 2016)

It is slow to establish (putting energy into root development before leaf and stem production) and needs care in the early stages but given appropriate conditions can last 4-5 years (AHDB, 2016). Varieties vary in their winter hardiness and dormancy ratings are applied to the plants; higher dormancy ratings indicate greater winter activity. A dormancy rating of 4-5 is considered optimal for UK conditions. Flemish or Northern varieties of Lucerne are most suited to UK conditions being more tolerant of cold conditions than Provence (Southern) varieties.

Lucerne is auto-toxic, meaning that its seeds will not grow in a field of established Lucerne (a gap of 5-6 years is required between crops) (Undersander *et al*., 2011).

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Perennial with a period of winter dormancy.<br>Sow: late April to mid-August (as long as soil moisture is not limiting).<br>Cut: mid-May onwards (depending on location); 4-5 cuts are possible typically at 5-week intervals. Note: only 1-2 cuts may be harvested in the first year. |
| Air or ground frost | | | |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 21<br>[5] | 27<br>[45] | Will not grow when the soil temperature is <8°C (AHDB, 2016). |
| ALC accumulated temperature (day °C) | 1000 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 600<br>[350] | 1200<br>[2700][89] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1000°C). |
| Gradient (°) | 0 | 11 | Slightly sloping land is OK, providing that farming operations are still practicable.<br>The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land and for 3b it is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6 | 8.5 | Lucerne has a high requirement for calcium (McDonald *et al.*, 2003). |
| Topsoil texture | S | ZL | Suitable for a wide range of free draining soils; not suitable for heavy clay soils. |

[89] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=1428

| | | | |
|---|---|---|---|
| Depth (cm) | 50 | >150 | Very deep taproot (> 6m) (Undersander *et al*., 2011). There have been some reports of lucerne roots going down as far as 15 m in search of water (AHDB, 2016). |
| Stone content (%) | 0 | 20 [35] | |
| Drainage | | | Well drained soil. |
| ALC soil wetness class | II-IV | I-II | |
| Moisture balance (mm) | -50 [-55] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | No specific risks. |
| ALC group | 3b | 1 | |

***Crop 73. Trefoils (common Birdsfoot)***

Birdsfoot trefoil (*Lotus corniculatus*) is a perennial legume that provides good quality forage on soils considered unsuitable for other forage legumes (Collins *et al*., 2006). Currently, trefoil is not commonly grown in the UK, possibly because it is slow to establish and not very competitive with weeds or other crops. However, it has been found to be palatable to stock, non-bloating and to reduce internal parasites in sheep. Birdsfoot trefoil can be successfully ensiled, with evidence that the tannin concentration in the forage reduces protein degradation during the ensiling process (Salawu, 2001). Trefoil may be grown as a pure stand or in a mixture with grass; grass species should be carefully selected to ensure they do not out compete the trefoil.

| **Requirement** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Sow: spring when soil temperature at 10 cm is *c*.10°C.<br>Graze: two to three times annually (beginning at first flowering). The last grazing should end in late summer to allow plants to build reserves for overwintering.<br>Harvest: for hay or silage at early flowering for optimum yield and quality.<br>A day length of about 16 hours is required to initiate flowering (Undersander *et al*. 1993). |
| Air or ground frost | -7 | 1 | Frost tolerance varies according to variety. |
| Other | | | Requires a sunny site as it is not shade tolerant (Döring and Howlett, 2013). |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[3] | 25<br>[30][90] | |
| ALC accumulated temperature (day °C) | 800 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 600<br>[1000] | 1000<br>[1900] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <800°C). |
| Gradient (°) | 0 | 18 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land, for 3b it is 11° and for 4 it is 18°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6<br>[4.5] | 7<br>[8.2] | |
| Topsoil texture | S | C | Wide range of soil types |
| Soil depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 35 [50] | |
| Drainage | | | High drought tolerance and also tolerant to limited waterlogging. |
| ALC soil wetness class | III-V | I-II | |
| Moisture balance (mm) | <-50<br>[<-55] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | No specific risks. |

[90] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=7410

| | | | |
|---|---|---|---|
| ALC group | 4 | 1 | |

***Crop 74. Sainfoin***

Sainfoin (*Onobrychis viciifolia*) is a perennial forage legume which can be cut and made into hay or silage for livestock feed or grazed (sometimes as part of a grass/legume mix). It is highly palatable to livestock, does not cause bloat and is reported to have anthelminthic properties. Sainfoin leys last four years or more; it is often grown with grass species such as meadow fescue or cocksfoot. However, the seed rate of the grass has to be kept low to avoid out competing the sainfoin.

Sainfoin grows well in areas that are dry and drained or irrigated, but it grows very poorly on waterlogged land. In the UK, sainfoin has always been linked to calcareous chalky or limestone soils.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Sow: April to July.<br>Harvest: During the flowering period (May to October); the first cut is traditionally taken at the bud to mid-flowering stage (Carbonero, 2011). One to three cuts can be taken per year. The recommended interval between cuts is about 6 weeks. |
| Air or ground frost | | | There are very few studies into sainfoin frost tolerance; it is not believed to be especially sensitive to low temperatures (Ortiz and Smith, 2011). |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 18<br>[4] | 27<br>[34][91] | Sainfoin should be drilled between 10-20°C and not below 5°C (Ortiz and Smith, 2011). |
| ALC accumulated temperature (day °C) | 1000 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 330<br>[250] | 800<br>[1100] | In the absence of irrigation, annual rainfall should be at least of 330 mm (Ortiz and Smith, 2011). |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Optimum is 600 m above sea level, although it can grow between 100 and 2500 m (Ortiz and Smith, 2011).<br>Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1000°C). |
| Gradient (°) | 0 | 11 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land and for 3b it is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.6 | 8.0 | Sainfoin establishes well in alkaline and neutral soils with pH >6 (Döring and Howlett, 2013). Poor establishment is obtained on clay soil at pH 6 (Ortiz and Smith, 2011). |
| Topsoil texture | S | SCL | Chalk, limestone, medium loam and sandy soil (Hill, 2017). |
| Depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 20 [35] | It will thrive on very stony soils such as are found in the Cotswolds[92] |
| Drainage | | | Well drained; it does poorly on waterlogged soils. |
| ALC soil wetness class | II-IV | I-II | |
| Moisture balance (mm) | -50<br>[-55] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |

[91] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=8079

[92] https://www.cotswoldseeds.com/articles/132/growing-sainfoin

| | | | |
|---|---|---|---|
| Environmental risks | | | No specific risks. |
| ALC group | 3b | 1 | |

***Crop 75. Typhon***

Typhon (or Tyfon) is a stubble turnip x Chinese cabbage hybrid, which produces large palatable leaves. Typhon is ideally sown in the spring and utilised in the summer months when grass growth generally declines. It should not be sown too early as it is susceptible to bolting. Typhon's growth habit is very leafy with regrowth potential, providing up to three grazing's (Keady and Hanrahan, 2010).

The most suitable areas for turnips are those with relatively cool summers, where neither extremes of drought or wetness are experienced. Adequate soil moisture is essential to give satisfactory plant establishment. Continuing soil moisture will ensure even growth and quality of crop avoiding growth cracks that are caused by periods of uneven growth. Turnips are particularly susceptible to club root infection. Therefore, a wide rotation of at least four to five years is recommended between turnips and any other brassica crop.

| **Requirement** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 100 | 120 | Sow: Early summer (April to June) or after cereals (July to September).<br>Graze: summer (July to September) and autumn/winter (October to February). |
| Air or ground frost | | | Good frost resistance making it suitable for winter grazing. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[5] | 20<br>[35] | The minimum temperature for germination is 5°C, with an optimum germination temperature of 15°C.<br>The most vigorous root growth takes place during periods of low temperature (4-15°C) in autumn (Undersander *et al*., 1991). |
| ALC accumulated temperature (day °C) | 1000 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 900<br>[300] | 1400<br>[2000][93] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1000°C). |
| Gradient (°) | 0 | 11 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. The limit for grade 3b land is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.5<br>[5.9] | 7.5<br>[7.8] | Soil pH of 6.5 or above is ideal. This is of particular importance in the presence of club root (Red Tractor Assurance, 2015b). |
| Topsoil texture | LS | MCL | The most suitable soils for turnips are well-drained loams, silts and light clay loams, with up to 20% clay content (Red Tractor Assurance, 2015b). |
| Soil depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 20 [35] | |
| Drainage | | | Well drained but moisture retentive.<br>Growth is reduced by excess water. |
| ALC soil wetness class | II-IV | I-II | |
| Moisture balance (mm) | -50<br>[-55] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |

[93] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=3881

| | | | |
|---|---|---|---|
| **Other** | | | |
| Environmental risks | | | Root crops are at risk from water erosion, due to large areas of bare soil.<br>Soil compaction or poaching if the crop is grazed in-situ.<br>Bare soil over winter may increase soil erosion and nitrate leaching. |
| ALC group | 3b | 1 | |

## Green manure crops

### *Crop 76. Black Medick/yellow trefoil*

Black medick (*Medicago lupulina*) is grown as a green manure (i.e. a crop grown to improve the soil), fodder crop or a hay crop (Döring and Winkler, 2013). It is a low-trailing, annual plant that grows from a thick, shallow root. It is suitable as a short-term nitrogen fixer and may be under-sown with cereals or may be suitable for intercropping with vegetables. As legumes will only fix nitrogen when the soil is above 8°C they are effective between April and August.

Black medick can be sown in spring or summer; the plants from the later sowing will overwinter, flower the following year and then die off (Rayns and Rosenfeld, 2010). It sets large quantities of viable seeds which can lead to weed problems in the next crop. Regular mowing is essential (whenever it attains a height of 20 cm) to stop the plant seeding too soon (Rayns and Rosenfeld, 2010).

| Requirements | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Sown: March to May or late July to mid-August (NIAB, 2016). |
| Air or ground frost | | | Frost tolerant, will survive over winter and flower the following year. But spring sowing may be susceptible to frost. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 14 [3] | 25 [30][94] | Seeds germinate at temperatures from 10°C to 23°C, but the optimum temperature range for germination is between 16.5°C and 18°C (Alaska Natural Heritage Program, 2011). Warm and dry. |
| ALC accumulated temperature (day °C) | *1000* | *≥1300* | |
| Rainfall (mm) Optimum & [tolerable] range | 380 [300] | 1000 [1700] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1300°C). |
| Gradient (°) | 0 | 11 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land and 11° for grade 3b. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.0 | 7.5 | Optimum soil pH is between 6 and 7.5 (Döring and Winkler, 2013). |
| Topsoil texture | S | C | Light to heavy soils. Optimum are fine, well drained soils, low in OM (Kahnt, 2008 in Döring *et al*., 2013). |
| Depth (cm) | 20 | 50[38] | |
| Stone content (%) | 0 | 20 [35] | |
| Drainage | | | Well drained. |
| ALC soil wetness class | *II-IV* | *I-II* | |
| Moisture balance (mm) | *-50 [-55]* | *+30 [+10]* | |
| Field capacity (days) | *>225* | *≥151* | |
| **Other** | | | |
| Environmental risks | | | Green manure crops are largely beneficial for the environment but can increase pest disease and weed pressures in subsequent crops. |

[94] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=7654

| | | | |
|---|---|---|---|
| | | | Without careful management, the N conserved by the green manure, may be prone to leaching in the first winter after incorporation. |
| ALC group | *3b* | *1* | |

***Crop 77. Vetches.***

Vetches (common vetch (*Vicia sativa*) or hairy vetch (*Vicia villosa*)) are broadleaf legumes that are mainly used in fertility building mixes (green manures) and can be later sown than other legumes (NIAB TAG, 2016). Research by Aberystwyth University has shown that vetch was a useful source of forage protein for post lambing ewes (Marley *et al*., 2016). It may also be grown for fodder production (hay or silage) or as a grain to feed to livestock (20% of ration). There are a number of types of vetch available, with differences in vigour and frost susceptibility. Vetch is useful as a short term nitrogen fixer and is probably the 'best leguminous winter green manure' (Rayns and Rosenfeld, 2010) due to its ability to fix nitrogen at lower temperature than many other legumes.

When incorporated, vetch residues have an allelopathic effect, inhibiting germination of new seeds. This effect persists for around six weeks, and an adequate interval should be left if drilling direct sown crops after incorporating vetch (Rayns and Rosenfeld, 2010).

| **Requirement** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Sow: Spring (March onwards) or autumn (August to September). The crop dies after seed pods have developed. |
| Air or ground frost | | | Good frost tolerance and will retain a canopy over winter (Rayns and Rosenfeld, 2010). |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 14 [3] | 23 [28][95] | |
| ALC accumulated temperature (day °C) | 1000 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 700 [900] | 900 [1600] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1000°C). |
| Gradient (°) | 0 | 11 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. The limit for grade 3b land is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6 [4.5] | 7 [8.2] | |
| Topsoil texture | S | C | Range of soil types are suitable. |
| Soil depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 20 [35] | |
| Drainage | | | Well drained, does not tolerate waterlogging. Good drought tolerance. |
| ALC soil wetness class | II-IV | I | |
| Moisture balance (mm) | -50 [-55] | +30 [+10] | |
| Field capacity (days) | <230 | <200 | |
| **Other** | | | |

[95] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=238003

| | | | |
|---|---|---|---|
| Environmental risks | | | Green manure crops are largely beneficial for the environment but can increase pest and disease problems in subsequent crops. Without careful management, the N conserved by the green manure, maybe prone to leaching in the first winter after incorporation. |
| ALC group | 3b | 1 | |

## Biomass crops

### *Crop 78. Reed canary grass*

Reed canary grass (*Phalaris arundinacea*) is native to the UK and can be grown as an energy crop on marginal soils. The principal markets for the crop are electricity and heat production.

Reed canary grass can be grown from seed, once mature it reaches a height of 150-300 cm. It spreads underground by rhizomes approximately 1 cm thick, it can root to as deep as 3 m. Reed canary grass can be expected to reach full yield potential in the second or third year after sowing and can be expected to remain productive for up to eight years (Teagasc, 2007).

| Requirements | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Perennial grass.<br>Establishment: May.<br>Flowers are produced in early summer after which the crop matures.<br>Harvest: Spring (crops dry over winter avoiding the need for artificial drying). |
| Air or ground frost | | | Excellent frost tolerance and will withstand temperatures well below -1°C. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 17<br>[2] | 25<br>[38] | |
| ALC accumulated temperature (day °C) | 800 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 700<br>[300] | 1500<br>[2600] | It also exhibits excellent drought tolerance. |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <800°C). |
| Gradient (°) | 0 | 18 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land, for grade 3b it is 11° and for grade 4 18°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.0<br>[4.5] | 7.0<br>[8.3] | Optimum pH is 6-7 (Teagasc, 2007).<br>Reed canary grass tolerates a wide range of soil pH (4.9-8.3) (Bittman *et al*., 1988). |
| Topsoil texture | S | C | Range of soil types, with good organic matter content. |
| Depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 35 [50] | |
| Drainage | | | Tolerant to flooding and is also drought resistant. |
| ALC soil wetness class | III-V | I-II | |
| Moisture balance (mm) | <-50<br>[<-55] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | Although native to this country, reed canary grass is an invasive species and can spread to adjoining fields where it can be difficult to control. |
| ALC group | 4 | 1 | |

***Crop 79. Miscanthus***

Miscanthus species originate in Asia, they are perennial, rhizomatous grasses with lignified stems resembling bamboo. Once established (3-4 years) miscanthus can grow stems of >3 m in height within a single growing season (Caslin *et al*., 2011). Miscanthus plants can be productive for up to 15 years. Miscanthus is used as biomass crop for heat and power generation.

New shoots are produced from underground rhizomes annually, from July lower leaves senescence (as canopy closure prevents light penetration); following the first frost senescence accelerates, leaves are lost and the nutrients move back into the rhizome. By February only the leafless canes remain, which are harvested before the growth cycle begins again. Cane number will increase from 2-3 in year 1 to about 50 from year 3 onwards.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 180 | 210 | Perennial plant that remains in-situ for up to 15 years.<br>Plant: rhizomes March to early June (optimum time is March to April).<br>Harvest: March to early April.<br>Note: growth season is approx. April to September annually (depending on weather conditions). |
| Air or ground frost | -14 | 0 | Frost tolerant, surviving winter temperature of -14°C. However, spring frosts can damage early spring foliage and reduce the length of the growing season (Caslin *et al*., 2011). |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 10<br>[5] | 20 | Clifton-Brown and Jones (1997) |
| ALC accumulated temperature (day °C) | 800 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 700 | 800 | Between April and August a minimum of 250 mm of evenly distributed rainfall is required (Jodl *et al*., 2008 in Schorling *et al*., 2015). |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <800°C). |
| Gradient (°) | 0 | 11 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a, for grade 3b it is 11° and for grade 4 it is 18°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 5.5 | 7.5<br>[8.0] | Tolerant of a wide range of pH, but the optimum is between pH 5.5 and 7.5 (Defra, 2001). |
| Topsoil texture | S | MCL | Wide range of soil types from sand to high organic matter soils. However, as miscanthus is harvested in winter or early spring heavy clay soils may limit access to harvesting machinery. |
| Depth (cm) | 150 | >150 | Root to shoot ratio 1:1 |
| Stone content (%) | 0 | 35 [50] | |
| Drainage | | | Well drained.<br>Limited soil water availability will prevent the crop from reaching its full yield potential.<br>Miscanthus can survive drought (re-growing in subsequent years) but yield will be reduced in the dry year. |
| ALC soil wetness class | III-V | I-II | |
| Moisture balance (mm) | <-50<br>[<-55] | +30<br>[+10] | |

| | | | |
|---|---|---|---|
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | Soil compaction and/or erosion from winter harvesting especially in wet conditions. |
| ALC group | 4 | 1 | |

***Crop 80. Osiers***

Osier, basket willow or common osier (*Salix viminalis*) is a deciduous broadleaf tree native to the UK, Europe and western Asia. Osier withies (strong, flexible willow stems) are traditionally used for basket-making and weaving, and are becoming increasingly popular for use as willow screens and sculptures. It is now planted commercially for biofuel.

Willow coppice requires more water for its growth than any other conventional agricultural crop and hence requires a good moisture retentive soil (Caslin *et al.,* 2015).

Since willow will be in the ground for up to 25 years the selection of a suitable site is essential. Complete eradication of all invasive perennial weeds is essential prior to planting as the crop is poorly competitive against weeds whilst immature (NNFCC, 2010).

Planting rods of 1.5-2.5 m are usually harvested in January to February when the buds are fully dormant. Cutting material should be maintained in a refrigerated unit at -2 to -4°C prior to planting in early April to May. Traditionally the first year's growth is cut to within 10 cm of the ground before bud break (*c*.mid-February); subsequently the cropping cycle is 2-4 years.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Bud burst: *c*.mid-February/March. Leaf fall: autumn (around mid-October).<br>Harvest: December to March. |
| Air or ground frost | | | |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | | | The species is highly tolerant of the cold and can survive temperatures up to 54°C[96]. |
| ALC accumulated temperature (day °C) | 800 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 800 | 1100 | Areas with an annual rainfall of 800-1,100mm are best or areas where the crop has access to ground water (Caslin *et al.,* 2015). |
| **Site** | | | |
| Aspect | | | |
| Altitude (m) | 0 | 100 | Elevated sites can result in exposure problems and a reduction in the number of growing days per year. Therefore, production sites should generally be below 100 m above sea level (Caslin *et al.,* 2015). However, upland trials in Wales (≥300 m) recorded willow yields in the third year not dissimilar to those in lowland areas, although this was somewhat dependent on variety (Valentine *et al*., 2008). |
| Gradient (°) | 0 | 7 | Slopes in excess of 13% (7.4°) will provide difficulty for harvesting machinery, particularly in wet conditions, and should be avoided. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 5.5 | 7.0 | Soil pH should be in the range of 5.5-7 (NNFCC, 2010). |
| Topsoil texture | MCL | HCL | Medium to heavy clay loams are best. Light sandy soils may have insufficient moisture availability and highly organic or peaty soils will make initial weed control difficult. |
| Depth (cm) | | | |
| Stone content (%) | 0 | 35 [50] | |
| Drainage | | | Well drained but good moisture retentive soil. |
| ALC soil wetness class | III-V | I-II | |

[96] http://www.iucnredlist.org/details/61960656/0

| | | | |
|---|---|---|---|
| Moisture balance (mm) | <-50 [<-55] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | No specific risks. |
| ALC group | 4 | 1 | |

***Crop 81. Willow***

Willow (*Salix* spp.) are deciduous broadleaf trees native to the UK, Europe and western Asia which are planted commercially as biomass energy crop. Since willow will be in the ground for up to 25 years the selection of a suitable site is essential. However, willow is not a demanding species in terms of its site requirements and will thrive on a wide range of soil type and environmental conditions. Complete eradication of all invasive perennial weeds is essential prior to planting as the crop is poorly competitive against weeds whilst immature. Willow coppice requires more water for its growth than any other conventional agricultural crop and hence requires a good moisture retentive soil (Caslin *et al*., 2015).

Since willow will be in the ground for up to 25 years the selection of a suitable site is essential. Complete eradication of all invasive perennial weeds is essential prior to planting as the crop is poorly competitive against weeds whilst immature (NNFCC, 2010).

Planting rods of 1.5-2.5 m are usually harvested in January to February when the buds are fully dormant (these are typically supplied by a specialist producer). Cutting material should be maintained in a refrigerated unit at -2 to -4°C prior to planting in early April to May. Traditionally the first year's growth is cut to within 10 cm of the ground before bud break (c.mid-February); subsequently the cropping cycle is 2-4 years.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Bud burst: *c*.mid-February/March. Leaf fall: autumn (around mid-October).<br>Harvest: December to March. |
| Air or ground frost | | | |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | | | The species is highly tolerant of the cold and can survive temperatures up to 54°C[97]. |
| ALC accumulated temperature (day °C) | 800 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 800 | 1100 | Areas with an annual rainfall of 800-1100mm are best or areas where the crop has access to ground water (Caslin *et al*., 2015). |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | 0 | 100 | Elevated sites can result in exposure problems and a reduction in the number of growing days per year. Therefore, production sites should generally be below 100m above sea level (Caslin *et al.,* 2015). However, upland trials in Wales (≥300 m) recorded willow yields in the third year not dissimilar to those in lowland areas, although this was somewhat dependent on variety (Valentine *et al.,* 2008). |
| Gradient (°) | 0 | 7 | Slopes in excess of 13% (7.4°) will provide difficulty for harvesting machinery, particularly in wet conditions, and should be avoided. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 5.5 | 7.5 | Soil pH should be in the range of 5.5-7 (NNFCC, 2010). |
| Topsoil texture | MCL | HCL | Medium to heavy clay loams are best. Light sandy soils may have insufficient moisture availability and highly organic or peaty soils will make initial weed control difficult. |
| Depth (cm) | | | |
| Stone content (%) | 0 | 35 [50] | |
| Drainage | | | Well drained but good moisture retentive soil. |

[97] http://www.iucnredlist.org/details/61960656/0

| | | | |
|---|---|---|---|
| ALC soil wetness class | III-V | I-II | |
| Moisture balance (mm) | <-50 [<-55] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | No specific risks. |
| ALC group | 4 | 1 | |

## Other crops

### *Crop 82. Comfrey*

Comfrey (*Symphytum officinale*) is a perennial herb reputed to have medicinal properties (Wilkinson, 2003). The comfrey plant has a taproot up to 3 m in length, and can produce two to five crops per year (Bremness, 1988), which are often utilised as a source of organic fertiliser, either as green manure or as an ingredient of compost in home gardens. However, without additive treatment and extensive wilting, the fermentation of comfrey leads to poor quality silage (Wilkinson, 2003).

It is propagated from root cuttings, crown divisions and transplants. Comfrey plantings will last >20 years if weeds are adequately controlled and soil fertility is maintained. The plant yields best in full sunlight under cooler conditions (Teynor *et al*., 1992).

There is limited information on the crop requirements of comfrey.

| Requirements | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Early April onwards. Alternatively establish in autumn following harvest of the preceding crop. Plants need to be established before winter to ensure a high yield the following year (Teynor *et al*., 1992). |
| Air or ground frost | | | Frost resistant |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | | | |
| ALC accumulated temperature (day °C) | 1000 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | | | The deep root system ensures it is relatively drought resistant |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1000°C). |
| Gradient (°) | 0 | 11 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land and for grade 3b is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.0 | 7.0 | |
| Topsoil texture | S | C | Most soil types, except thin soils over rock. |
| Depth (cm) | | | Deep root system. |
| Stone content (%) | 0 | 20 [35] | |
| Drainage | | | |
| ALC soil wetness class | *II-IV* | *I-II* | |
| Moisture balance (mm) | *-50 [-55]* | *+30 [+10]* | |
| Field capacity (days) | *>225* | *≥151* | |
| **Other** | | | |
| Environmental risks | | | No specific risks |
| ALC group | *3b* | *1* | |

***Crop 83. Fennel***

Fennel is not usually grown outdoors in the UK because premature bolting can be caused by transplanting (Red Tractor Assurance, 2016h). Regular, adequate irrigation produces higher yields and flavourful crops.

| Requirements | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Sow: April to July.<br>Hot weather and long days encourage fennel to bolt so summer planting for autumn harvesting may be best. |
| Air or ground frost | | | Seedlings are frost tender, but mature plants tolerate light frost. |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[6] | 25<br>[32][98] | Soil temperature at planting needs to be ≥10°C. |
| ALC accumulated temperature (day °C) | ≥1300 | | |
| Rainfall (mm) Optimum & [tolerable] range | 700<br>[300] | 1500<br>[2600] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1300°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.5<br>[4.8] | 7.5<br>[8.2] | |
| Topsoil texture | S | SCL | Sandy to clay loam soil types |
| Depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 5 | |
| Drainage | | | Well drained |
| ALC soil wetness class | I-II | | |
| Moisture balance (mm) | +30<br>[+10] | | |
| Field capacity (days) | ≥151 | 225 | |
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated or fertigation is used.<br>Irrigation may increase the risk of run-off and/or soil erosion.<br>Bare soil over winter may increase soil erosion and nitrate leaching. |
| ALC group | 1 | 1 | |

[98] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=1107

***Crop 84. Herbage seed***

Most temperate grasses have a dual flower induction requirement. They require short days and/or low temperature in autumn followed by long days in spring/summer. This means than only tillers that have reached a certain size in autumn will become reproductive so that the number and size of tillers has a significant effect on seed yield in the following year. Herbage crops can be established as a pure stand or with a companion/cover crop (e.g. wheat or barley). Cover crops will have a negative effect on seed yield but may have a positive effect on weed competition.

Grass seed must be officially certified if it is produced or marketed. Agricultural grasses have three categories of seed production: Pre-basic (PB), Basic (BS) and Certified (CS). Some species may also be certified as higher voluntary standard (HVS) but this is a seed standard only and does not apply in the crop. Grass seed crops are approved on a single inspection at between 5 and 25% ear emergence (ear emergence is the most distinguishing characteristic).

Seed crop must be between 50 m (CS crops grown on an area >2 ha) and 200 (PB and BS crops grown on an area of ≤2 ha) away from sources of 'undesirable pollen' (other varieties of the same species). Variety purity is assessed based on numbers of off-type species in a specified area (ranging from 1/30 $m^2$ to 6/10 $m^2$) depending on grass species and category of seed production.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Sow: spring with cereal cover crop or mid-June to mid-July in a pure stand.<br>Harvest: late June to September (depending on type).<br>Most seed crops are established in the year prior to harvest. |
| Air or ground frost | | | |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 14<br>[4] | 25<br>[35] | Grass growth begins at 5°C. An increase in temperature up to 25°C increases the rate of leaf appearance as well as the rate of leaf extension. |
| ALC accumulated temperature (day °C) | 1100 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 700<br>[500] | 1750<br>[2300][99] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | Avoid steep slopes where poaching and water/soil runoff may be a problem.<br>In addition, the safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 5.0<br>[4.5] | 7.0<br>[8.4] | |
| Topsoil texture | | | Medium, heavy |
| Depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 10 [15] | |
| Drainage | | | |
| ALC soil wetness class | I-IV | I-II | |

[99] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=1362

| | | | |
|---|---|---|---|
| Moisture balance (mm) | -20 [-30] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | No specific risks. |
| ALC group | 3a | 1 | |

***Crop 85. Hops***

Hops (*Humulus lupulus*) are mainly grown for brewing, although minor uses are as a medicinal herb and for culinary purposes. Hop varieties for brewing purposes are loosely grouped according to their alpha acid percentage (bitterness) and essential oil content (aroma). As hop plants may be cropped for over 20 years and take 2-3 seasons to produce a commercial crop it is important that conditions are as optimal as possible. Also, that the plants are free from disease (use certified disease-free stock from PHPS registered nurseries). Of particular concern, is Hop Stunt Viroid, which is active in the USA and Asia and could have serious impacts on the hop industry if getting to the UK (Red Tractor Assurance, 2016j).

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 180 | 210 | Perennial, photoperiod sensitive crop, shorter days trigger the flowers to produce the burr and then the flower.<br>In spring, plant hops as rhizome cuttings, or rooted cuttings from the previous spring/summer.<br>April: first shoots emerge from the rootstock.<br>September to October: hop harvest. |
| Air or ground frost | | | When dormant, they withstand freezing; however, a severe frost will kill young, tender vines in spring. |
| Other | | | Hops are sensitive to wind, exposure to strong wind can cause leaf and cone damage (Dodd, 2017).<br>Grow in a sheltered site or utilise wind breaks. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[8] | 19<br>[35][100] | Hops become dormant in late summer/autumn in response to shortening days.<br>A sufficient period of chilling (30-60 days at 4-6°C) is required to break dormancy (Dodds, 2017).<br>Without adequate chilling the break of dormancy can be insufficient, resulting in poor spring growth. |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 400<br>[300] | 700<br>[1300] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | Avoid steep slopes where poaching and water/soil runoff may be a problem.<br>In addition, the safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6<br>[5] | 6.5<br>[8] | Although hops can tolerate acid soil conditions, lime should be applied to maintain a pH of 6.0 to 6.5 (Red Tractor Assurance, 2016j). |
| Topsoil texture | S | C | Hops will grow on light sandy to clay soils but light textured, deep soil is optimal (Dodds, 2017). |
| Depth (cm) | 20 | 150 | Deep rooted |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Well drained. |
| ALC soil wetness class | I-III | I-II | |

[100] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=6779

| | | | |
|---|---|---|---|
| Moisture balance (mm) | +5 [-10] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | No specific risks. |
| ALC group | 2 | 1 | |

***Crop 86. Juniper***

Common juniper (*Juniperus communis*), is a widely distributed slow-growing evergreen conifer, whilst the wood is rarely used commercially the berries are used to flavour gin and for culinary purposes (Enescu *et al*., 2016b). Although juniper populations are not threatened worldwide, declining production and disease in the wild population of the UK have reduced the juniper population.

Juniper is rarely cultivated commercially instead berries are harvested from the wild population. As a result there is a lack of information on the climatic, site or soil requirements for juniper.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Day length | | | |
| Growing season (Days) | | | |
| Air or ground frost | | | |
| Other | | | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | | | |
| ALC accumulated temperature (day °C) | | | |
| Rainfall (mm) Optimum & [tolerable] range | | | |
| **Site** | | | |
| Aspect | | | |
| Altitude (m) | | | |
| Gradient (°) | | | |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | | | |
| Topsoil texture | ? | ? | It can grow on acidic sandy or calcareous soils and favours free-draining soils and rocky outcrops (Enescu *et al*., 2016b). |
| Depth (cm) | 20-50 | 50-150[101] | |
| Stone content (%) | | | |
| Drainage | | | |
| ALC soil wetness class | | | |
| Moisture balance (mm) | | | |
| Field capacity (days) | | | |
| **Other** | | | |
| Environmental risks | | | |
| ALC group | | | |

[101] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=7022

***Crop 87. Poppy***

Poppies (*Papaver somniferum*) can be grown commercially for seed production for culinary use or for the extraction of morphine for use in pharmaceuticals. 92% of the morphine compounds are located in the capsule of the mature poppy plant and it is the poppy "straw" comprising the capsule and top 20 cm of the stem that is the target part. The seeds are a by-product of morphine poppy production and used in the culinary market[102].

All the morphine poppy crops in Britain are grown under licence for an Edinburgh-based pharmaceuticals company, Macfarlan Smith. The seed is provided to growers and drilled using a conventional drill at the end of March/beginning of April. Harvest is carried out using a combine harvester, typically in August supplied by the pharmaceutical company. Seed must be dried on-farm before supply to the contractor.

There is limited data available on the crop requirements of poppies.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 150 | 210 | Sow: March.<br>Harvest: mid-August. |
| Air or ground frost | | | Not frost tolerant |
| Other | | | Sensitive to strong wind and rain at harvest. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15<br>[3] | 24<br>[28][103] | Germination starts at 2-3°C. |
| ALC accumulated temperature (day °C) | 1000 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 800<br>[300] | 1200<br>[1700] | |
| **Site** | | | |
| Aspect | | | South facing slopes may be best. |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1000°C). |
| Gradient (°) | 0 | 7 | Gentle slope for air drainage and to avoid frost pockets.<br>The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.5<br>[6.5] | 7.5<br>[8.3] | |
| Topsoil texture | S | MZCL | Light, chalky, or medium free-draining soils |
| Depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | 0 | 20 [35] | |
| Drainage | | | Poppies do not tolerate waterlogging. |
| ALC soil wetness class | II-IV | I-II | |
| Moisture balance (mm) | -50<br>[-55] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | Unknown, but no specific risks identified. |
| ALC group | *3b* | *1* | |

[102] https://www.sruc.ac.uk/info/120186/novel_and_non-food_crops/175/poppy/1

[103] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=8296

***Crop 88. Saffron***

Saffron, the world's most expensive spice, is derived from the stigmas of the saffron crocus *(Crocus sativus*). The stigmas are dried and used in cooking to add colour, flavour and aroma to food.

Saffron is sterile and must be propagated by corm multiplication. Each corm only lasts a single season and is replaced by 1 to 10 cormlets, depending on the original size of the mother corm. In the first year flowers may be sparse but in the second and third years will increase in number.

According to 'Grown in Wales' (http://growninwales.co.uk/giw_grower/british-saffron/) there is a single saffron producer in Wales; it is also grown in England (e.g. http://www.norfolksaffron.co.uk/).

There is limited available information on the crop requirements of the saffron crocus.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | The crocus is actively growing between September and late April or May (Wales). When the soil temperature drops in the autumn the crocuses flower for about three weeks. Leaves may emerge simultaneously with the flowers or follow flowering. The leaves die back in the late spring prior to autumn flowering. |
| Air or ground frost | -10 | 0 | Saffron can withstand substantial frosts (-10°C), and can tolerate occasional snow in the winter but flowers can be damaged by frost (New Zealand Institute for Crop & Food Research, 2003). |
| Other | | | Full sun. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 7 [7] | 19 [23][104] | A mean temperature of 6 to 8°C at night and 15 to 20°c during the day (Menia *et al*., 2018). |
| ALC accumulated temperature (day °C) | 1000 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | 400 | 1500 | Saffron is grown in areas with a wide range of total annual rainfall (Gresta *et al*., 2008).<br>Rain during flowering spoils the saffron, whilst rain just before flowering encourages high flower yield. Spring rainfall encourages the production of new corms (New Zealand Institute for Crop & Food Research, 2003). |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1000°C). |
| Gradient (°) | 0 | 11 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land and for 3b it is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6 [5.5] | 7 [7.8] | |
| Topsoil texture | S | SCL | Sandy or loamy medium soils, although saffron is also reported to be grown on heavier soils in some countries (Gresta *et al*., 2008). |
| Depth (cm) | 20-50 | 20-50 | |
| Stone content (%) | 0 | 20 [35] | |
| Drainage | | | |
| ALC soil wetness class | II-IV | I-II | |

[104] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=4962

| | | | |
|---|---|---|---|
| Moisture balance (mm) | -50 [-55] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | Unknown, but no specific risks identified. |
| ALC group | *3b* | *1* | |

***Crop 89. Sunflowers***

Sunflowers (*Helianthus annuus*) are grown for their seed which is processed for oil or used whole for bird seed or human consumption. The UK is on the climatic fringe of the European growing area, but with the introduction of newer earlier ripening varieties the crop is becoming more viable, although yields can still be variable.

| Requirement | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 180 | 210 | Sow: mid-April to mid-May.<br>Harvest: by mid-September (later harvests can suffer as a result of damage by heavy rain or frosts). |
| Air or ground frost | -4 | -1 | Seedlings are relatively frost tolerant up to the four-leaf stage (-3.3°C).<br>At the bud and pollination stages temperatures of -1°C can cause damage to the anthers and stigmas.<br>After pollination, sunflowers are frost tolerant to -4°C (Berglund, 2007). |
| Other | | | Hail can result in plant death, injury or defoliation which can lead to yield loss (Berglund, 2007; GRDC, 2017b). |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 18<br>[8] | 28<br>[34] | The soil temperature at drilling should be 6-8°C in the top 10 cm of the soil. |
| ALC accumulated temperature (day °C) | 1150 | ≥1300 | Areas that achieve 1400 day degrees are best suited to sunflower production (above a base level of 6°C) (Cook *et al*., 1998). |
| Rainfall (mm) Optimum & [tolerable] range | 600<br>[300] | 1000<br>[1600][105] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1100°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.0<br>[5.0] | 7.5<br>[8.0] | The optimal pH range is from 6.0 to 7.5 (Cook, 2008). |
| Topsoil texture | S | SCL | A variety of soil types are suitable, however, a soil that will warm up rapidly in spring is preferred (e.g. sand silt or clay loams) (Cook *et al*., 1998). |
| Soil depth (cm) | 50-150 | >150 | Sunflowers have a deep tap root (1.5-1.8 m). |
| Stone content (%) | 0 | 5 [10] | |
| Drainage | | | Well drained. |
| ALC soil wetness class | I-III | I-II | |
| Moisture balance (mm) | +5<br>[-10] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | Sunflower seeds can be persistent so volunteers could be a problem in subsequent crops. |

[105] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=1191

| | | | |
|---|---|---|---|
| | | | Late harvested crops increase the risk of soil compaction/erosion and bare soil over winter increases the risk of nitrate leaching. |
| ALC group | 2 | 1 | |

***Crop 90. Squill***

Squill (*Drimia maritima*) is a perennial bulbous geophyte that is native to the Mediterranean region; there are two varieties red and white squill. In the Mediterranean squill has three distinct phases: 1) flowering in late summer; 2) leaf appearance and growth winter until late spring and 3) dormancy from late spring to later summer. The bulb contains several steroid glycosides (Bufadienolides) which are key compounds in many anti-cough medicines.

Information on the commercial production of squill are limited. It has been suggested that this is due to low rate of asexual multiplication by bulb offsets (El Grari and Backhaus, 1987). However, recent small scale research has shown that white squill can be grown in Gwynedd[106]. This was reported to contain twice the active constituents of squill grown overseas. In 2018, five farmers were involved in a project to understand the optimum growing conditions for squill across Wales.

Overall, there is a lack of available information on the climatic, site or soil requirements for squill

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | |
| Air or ground frost | -2 | | Leaves are hardy to -2°C; bulb is frost tolerant. |
| Other | | | The plant can tolerates strong winds but not maritime exposure [107] |
| Mean daily air temperature (°C). Optimum & [tolerable] range | | | |
| ALC accumulated temperature (day °C) | | | |
| Rainfall (mm) Optimum & [tolerable] range | 300 | 600 | May require an obligate dry period during dormancy. |
| **Site** | | | |
| Aspect | | | |
| Altitude (m) | | | |
| Gradient (°) | | | . |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | | | |
| Topsoil texture | S | SZL | Sandy and light free draining soils (Al-Tardeh, 2008). |
| Depth (cm) | | | |
| Stone content (%) | | | |
| Drainage | | | Well drained[107] |
| ALC soil wetness class | | | |
| Moisture balance (mm) | | | |
| Field capacity (days) | | | |
| **Other** | | | |
| Environmental risks | | | Unknown but no specific risks identified |
| ALC group | | | |

[106] https://businesswales.gov.wales/farmingconnect/feasibility-study-squill-production-north-wales

[107] https://pfaf.org/User/Plant.aspx?LatinName=Urginea+maritima

***Crop 91. Tea***

Tea is broadly divided into two groups/cultivars, China teas *Camellia sinensis* var *sinensis* and Indian teas *Camellia Sinensis* var *assamica* (DAFF, 2016). The Chinese tea plant is hardy and can survive cold temperatures and drought, it has a long lifespan. The Indian tea plant is less hardy and susceptible to frost and drought but can cope with heavy rainfall it would be unlikely to thrive in Wales.

Tea is an evergreen plant that will grow up to 16 m if left undisturbed, however, cultivated plants are trimmed to around 1-1.5 m for ease of picking.

It has been suggested that under Scottish conditions the time from planting to harvesting would be 5 years, 7 to 8 years to maturity with a commercial life of about 40 years (Melican, 2016); timescales for Wales are likely to be in a similar.

| **Requirement** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Dormancy is initiated by several continuous days of low night temperatures (<10-12°C depending on tea variety). Dormancy is broken and plants become active again when night temperatures exceed 10 to 12°C for several days.<br>Leaf production continues whenever the plant is not in a dormant state. |
| Air or ground frost | | | Avoid frost pockets to protect plants during the spring leaf flush.<br>Plants are frost tolerant when dormant but susceptible during early growth. |
| Other | | | Tea plants require at least 5 hours of sunshine daily.<br>Protect from cold drying winds. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 20<br>[8] | 30<br>[35] | Air temperatures between 20°C and 30°C are optimum; tea goes dormant if night temperatures are below 10°C (Melican, 2016).<br>Soil temperature ≥15°C to ≤25°C (Melican, 2016). |
| ALC accumulated temperature (day °C) | ≥1300 | | |
| Rainfall (mm) Optimum & [tolerable] range | 1400<br>[1000] | 2000<br>[5000] | Rainfall to be spread throughout the season.<br>Irrigation may be necessary to ensure even moisture supply.<br>Tea plant grows well in areas where annual rainfall varies from 1150 to 6000 mm (DAFF, 2016). |
| **Site** | | | |
| Aspect | | | Sloping southerly aspect to maximise light interception. |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1300°C). |
| Gradient (°) | 0 | 7 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 4.5<br>[4.0] | 5.5<br>[6.0][108] | Soil pH between 4.5 and 5.5 (Melican, 2016). |
| Topsoil texture | S | SCL | Sandy soil that is slightly acidic or loamy soils are best. |
| Soil depth (cm) | 50-150 | >150 | |
| Stone content (%) | 0 | 5 | |
| Drainage | | | Free draining but moisture retentive. |
| ALC soil wetness class | I-II | | |
| Moisture balance (mm) | +30 [+10] | | |
| Field capacity (days) | ≥151 | 225 | |

[108] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=4090

| | | | |
|---|---|---|---|
| **Other** | | | |
| Environmental risks | | | High levels of local water abstraction where crop is irrigated.<br>Irrigation may increase the risk of run-off and/or soil erosion. |
| ALC group | *1* | *1* | |

## Ornamental

### *Crop 92. Roses*

Climatic and soil factors play a vital role in the production of quality roses influencing both the growth/production and quality. The ideal temperature for rose production is 20-25°C during the day and 13-16°C at night along with 8 hours of sunlight (Shin *et al*., 2001) and <75% relative humidity. Below 15°C the interval between flowerings is increased and poor quality buds can result. Whereas at high temperatures (>30°C) poor quality flowers and petals can result.

Jawaharlal *et al*. (1999) reported that optimum conditions for large sized flower production were 15-21°C mean temperature, 55-80% relative humidity and 5-8 hour photoperiod while according to Damake and Bhattacharjee (2000) maximum flower production occurred at 21-31°C mean temperature, 60-80% relative humidity and 6.5-8 hour photoperiod.

Shin *et al*., (2001) observed that the number of days from bud to flowering increased from 21.6 to 63.0 days as temperature decreased from 30 to 15°C in *Rosa hybrida* cv. 'Kardinal'. Leaf area, stem length, chlorophyll contents and stem diameter generally increased with decreasing temperature, but the best quality stems were observed at 18°C.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | |
| Air or ground frost | | | Plant root stock in February.<br>Collect bud wood in June/July and insert into root stock.<br>The bud starts growing the following April. |
| Other | | | Sheltered from strong winds. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 15 | 21<br>[35] | |
| ALC accumulated temperature (day °C) | 1000 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | | | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude will be unsuited due to factors such as soil wetness and temperature (i.e. AT0 <1000°C). |
| Gradient (°) | 0 | 11 | The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 7° is the ALC limit for grade 1 to 3a land and for 3b it is 11°. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.0<br>[5.5] | 6.5<br>[8] | |
| Topsoil texture | | | Well drained loamy soil such as silty or sandy loam is best (Leghari *et al*., 2016). |
| Depth (cm) | | | |
| Stone content (%) | 0 | 20 [35] | |
| Drainage | | | |
| ALC soil wetness class | II-IV | I-II | |
| Moisture balance (mm) | -50<br>[-55] | +30<br>[+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | No specific risks. |
| ALC group | *3b* | *1* | |

***Crop 93. Tulips***

Tulips (*Tulipa* Spp.) can be grown for cut flower or bulb production, although many growers operate a combined system. Tulips are often planted in raised ridges similar to potatoes.

| Requirement | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Sow: autumn.<br>Harvest: spring flowers, summer bulbs.<br>Tulip bulbs develop roots in autumn, followed by leaf development and flowering in spring. Daughter bulb growth starts in spring and is completed by summer. Leaves will senesce in summer and bulbs can be harvested. |
| Air or ground frost | -12 | | Bulbs are frost hardy (-12°C)[109]. |
| Other | | | Full sun. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | | | Cold temperatures in winter trigger the biochemical processes which start flowering. |
| ALC accumulated temperature (day °C) | 1000 | ≥1300 | |
| Rainfall (mm) Optimum & [tolerable] range | | | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Land at high altitude may be unsuited due to factors such as soil wetness and temperature. |
| Gradient (°) | 0 | 11 | Limitations for planting and harvesting machinery.<br>The safe and efficient use of machinery on sloping land depends very much on the type and design of the machine and on the nature of the slope being farmed. 11° is the ALC limit for grade 3b land. |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | | | |
| Topsoil texture | S | C | Sandy to clay soils are suitable. |
| Soil depth (cm) | | | |
| Stone content (%) | 0 | 20 [35] | No specific limits but ALC gives limit values for Grade 3b of 20% and 35% (by volume) for stones >6 and 2 cm, respectively in the top 25 cm of soil. |
| Drainage | | | Well drained. Wet soil can rot bulbs and promote fungal diseases. Tulips have a high requirement for water whilst growing |
| ALC soil wetness class | II-IV | I-II | |
| Moisture balance (mm) | -50 [-55] | +30 [+10] | |
| Field capacity (days) | >225 | ≥151 | |
| **Other** | | | |
| Environmental risks | | | No specific risks. |
| ALC group | 3b | 1 | |

[109] https://pfaf.org/user/Plant.aspx?LatinName=Tulipa+gesneriana

## Trees

### *Crop 94. Sitka Spruce*

Sitka spruce (*Picea sitchensis*) originates from the USA and Canada (Houston Durrant *et al*., 2016b). The range of Sitka spruce is dependent on abundant moisture content during the growing season and its maximum development occurs when summer precipitation is high and there is no pronounced summer drought (Roche and Haddock, 1987). Unlike several other conifers it is tolerant of exposure and salt spray, making it particularly suitable for planting on wet coastal upland sites.

Sitka spruce forests make up 60% of the area of conifer forest in Wales (Forestry Commission 2017). The mean yield class[110] for Sitka spruce in Great Britain is 14 $m^3$/ha/year, although many sites are significantly more productive, having a predicted yield class of 16-20 $m^3$/ha/year (Bateman and Lovett, 1998; Sing *et al*., 2006).

The wood properties of Sitka spruce mean that it is suitable for a wide range of products including structural timber, pallets, fencing, structural poles, panel products and paper.

| Requirements | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | |
| Air or ground frost | -20 | -5 | Frost injury in young shoots can occur in late spring after budburst or in early autumn before stem elongation has ceased (Lucas *et al*., 1988). Sitka spruce undergoes a two-stage process of acclimation to freezing temperatures. The first stage is between September and November when the plant is hardy to -5°C. Deep winter hardiness (-20°C) occurs between November to March (triggered by first air frost) (Lucas *et al*., 1988). |
| Other | ~ | ~ | |
| Mean daily air temperature (°C). Optimum & [tolerable] range | | | Tolerates exposure better than any other common conifer. Mean daily temperatures at UK sites were reported as 7-10°C, with a maximum of 32°C and a minimum of -17°C (Samuel *et al*., 2007). |
| ALC accumulated temperature (day °C) | | | AT5 1190-1855 |
| Rainfall (mm) Optimum & [tolerable] range | 900 | 2000 | Avoid very dry sites in low rainfall areas (Horgan *et al*., 2003). It normally requires a minimum of 1000 mm of rainfall per year (Houston Durrant *et al*., 2016b). |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | Well suited to high elevations in the west and north of the UK. |
| Gradient (°) | 0 | >18 | |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | | | |
| Topsoil texture | | | |
| Depth (cm) | | | |
| Stone content (%) | | | |
| Drainage | | | |
| ALC soil wetness class | | | |
| Moisture balance (mm) | | | |
| Field capacity (days) | | | |
| **Other** | | | |

[110] The productivity of forest sites in Great Britain is usually expressed in terms of yield class, which is defined as the potential maximum mean annual volume (to a 7 cm top diameter) increment per hectare, irrespective of age of culmination or tree species (Hamilton and Christie, 1971).

| | | | |
|---|---|---|---|
| Environmental risks | | | Potential soil erosion if soil beneath trees lacks vegetation or if site is sloping.<br>Soil compaction from machinery used in forest management or tree felling. |
| ALC group | 5 | 1 | |

***Crop 95. Douglas fir***

Douglas fir (*Pseudotsuga menziesii*) is a large evergreen coniferous tree up to 60-80 m tall and with a trunk of up to 2 m in diameter which grows under a wide variety of climatic conditions (Da Ronch *et al*., 2016). In 2017, there was 9,000 ha of Douglas fir, 7% of the conifer area in Wales (Forestry Commission, 2017). Uses include telegraph poles, garden furniture, plywood and veneer. The typical yield class for Douglas fir is 16 $m^3$/ha/year (Horgan *et al*., 2003) and rotation length is 50-65 years.

Douglas fir withstands low winter temperatures very well, but can be damaged by late spring frosts in low-lying places. It is also intolerant of exposure, where it becomes badly deformed.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Day length | | | |
| Growing seasons (Days) | | | |
| Air or ground frost | | | Douglas fir is a frost tender species and can often suffer from late spring frost damage (Horgan *et al*., 2003). |
| Other | | | Avoid windy sites, which can result in a permanent curvature of the trunk which can have a negative effect on timber quality. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | | | |
| ALC accumulated temperature (day °C) | | | |
| Rainfall (mm) Optimum & [tolerable] range | >800 | 1200 | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | 0 | 3200 | Douglas fir in its native habitat occurs from 0 to 3200 m, altitudinal distribution increases from north to south, reflecting the effect of climate on distribution of the species (Da Ronch *et al*., 2016). |
| Gradient (°) | 0 | >18 | |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 5 | 6 | It does best on well-aerated, deep soils with a pH between 5 and 6 (Da Ronch *et al*., 2016). |
| Topsoil texture | S | SCL | A range of soil types are suitable except heavy types where it will become unstable due to restricted rooting (Horgan *et al*., 2003). Also, unsuited to alkaline soils. |
| Depth (cm) | | | |
| Stone content (%) | | | |
| Drainage | | | Well drained. |
| ALC soil wetness class | | | |
| Moisture balance (mm) | | | |
| Field capacity (days) | | | |
| **Other** | | | |
| Environmental risks | | | Potential soil erosion if soil beneath trees lacks vegetation or if site is sloping.<br>Soil compaction from machinery used in forest management or tree felling. |
| ALC group | 4 | 1 | |

***Crop 96. Norway spruce***

Norway spruce (*Picea abies*) is a large coniferous tree which can grow up to 50-60 m with a trunk of up to 150 cm in diameter, often reaching an age of 200-300 years in the wild (Caudullo *et al*., 2016). Norway spruce is normally grown over a rotation of between 45 and 60 years. In 2017, there was 8,000 ha of Norway spruce, 6% of the conifer area in Wales (Forestry Commission, 2017). The wood is used for joinery timber, furniture veneer and musical instruments (e.g. the bodies of guitars and violins). Norway spruce is also commonly used as a Christmas tree, although in recent years its popularity has declined in favour of non-shedding trees.

The root system is shallow and it can be easily blown down in high winds. It does not tolerate summer drought or waterlogged conditions and can be sensitive to salt winds in coastal regions (Horgan *et al*., 2003). Due to its preferences for cool and moist climatic conditions this economically very valuable species may become severely affected under global warming conditions (CH2014-Impacts, 2014).

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | |
| Air or ground frost | | | Avoid frost hollows.<br>Development of frost hardiness takes place in three steps,<br>1) onset of dormancy, 2) first stage of hardening at about 0°C, 3) second stage of hardening during a gradual lowering of the temperature below 0°C (Levitt 1980 cited by Aarrestad *et al*., 2014). |
| Other | | | Avoid exposed windy sites. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 5<br>[3] | 15<br>[25][111] | |
| ALC accumulated temperature (day °C) | | | |
| Rainfall (mm) Optimum & [tolerable] range | 400<br>[300] | 700<br>[900] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | |
| Gradient (°) | 0 | >18 | . |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 4<br>[3.7] | 5<br>[5.5] | Acid soils. |
| Topsoil texture | MZCL | C | A range of soil types but not coarse textured or peat soils (Horgan *et al*., 2003). |
| Depth (cm) | 20-50 | 50-150 | |
| Stone content (%) | | | |
| Drainage | | | Well drained but not droughty soils. |
| ALC soil wetness class | | | |
| Moisture balance (mm) | | | One of its main requirements is an adequate supply of soil moisture (Horgan *et al*., 2003). |
| Field capacity (days) | | | |
| **Other** | | | |
| Environmental risks | | | Potential soil erosion if soil beneath trees lacks vegetation or if site is sloping. |

[111] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=8571Norway

| | | | |
|---|---|---|---|
| | | | Soil compaction from machinery used in forest management or tree felling. |
| ALC group | 4 | 1 | |

***Crop 97. Western Red Cedar***

In its natural range western red cedar (*Thuja plicata*) is restricted to areas with abundant rainfall (or snow), high humidity and cool summers (Horgan *et al*., 2003). Despite its name it is related to the cypress family and has scale like leaves rather than needles. Western red cedar normally grows to heights of 45 to 60 m and diameters of 2.4 m. It is cold hardy throughout Britain, moderately frost tolerant, does not withstand exposure, but is moderately drought tolerant.

The typical yield class for Western red cedar is 17 $m^3$/ha/year (Horgan *et al*., 2003) and rotation length of 60-75 years. The wood is used for roofing, cladding, decking and garden furniture. It is shade tolerant and can be grown in a wide range of management systems.

| Requirements | Min | Max | Notes |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | |
| Air or ground frost | | | Susceptible to spring frosts (Aldhous and Low, 1974; Wilson *et al*., 2016). |
| Other | | | Performs best on sheltered sites. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | | | |
| ALC accumulated temperature (day °C) | | | |
| Rainfall (mm) Optimum & [tolerable] range | >800 | | Forest Research advise that the species is most suitable for intermediate climates with in excess of 800mm rainfall[112]. Within the natural range it tolerates rainfall of between 700 and >4000 mm (Klinka and Brisco, 2009). |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | |
| Gradient (°) | 0 | >18 | |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | | | It is one of the few conifers that will tolerate sites of high pH. |
| Topsoil texture | MZCL | C | Western red cedar occurs naturally on a very wide range of soils, including some gleys and peats (Wilson *et al*., 2016).<br>Wide range of soil types but it is most productive on heavier, lowland soils. Droughty soil types are not well suited to western red cedar. |
| Depth (cm) | | | |
| Stone content (%) | | | |
| Drainage | | | Freely drained yet moist soils. Avoid waterlogged soils. |
| ALC soil wetness class | | | |
| Moisture balance (mm) | | | Avoid very dry soils. |
| Field capacity (days) | | | |
| **Other** | | | |
| Environmental risks | | | Potential soil erosion if soil beneath trees lacks vegetation or if site is sloping.<br>Soil compaction from machinery used in forest management or tree felling. |
| ALC group | 4 | 1 | |

[112] https://www.forestresearch.gov.uk/tools-and-resources/tree-species-database/western-red-cedar-rc/

***Crop 98. Sessile oak***

Sessile oak (*Quercus petraea*) can live for up to 1000 years and grow to 30 to 40 m in height (Eaton *et al*., 2016). In 2017, there was 26,000 ha of oak woodland in Wales, representing *c.*20% of broadleaved trees grown in Wales; it is not known what proportion of that area was planted with Sessile oak (Forestry Commission 2017). The wood from oak is hard and durable and often used to make wine/spirit barrels and furniture. Typically Sessile oak grow slowly, only about 10-20 cm annually for the first 5-8 years (Evans, 1984). Fertile seed is produced after 20 (coppiced trees) to 50 years (closed stand); seed is not produced every year. The mean yield class for oak in Wales is 4 $m^3$/ha/year, reflecting the longer rotation than is typical for conifers.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | In the early years coinciding with rapid height growth there are usually two periods of shoot growth, the initial shoot elongating in May and June followed by lammas[113] growth in July and August. |
| Air or ground frost | -6 | -3 | Oak is sensitive to spring frosts, however, these are rarely a problem as the trees do not come into leaf until late April-early May. However, temperatures of -3°C can kill new foliage and sustained temperatures below -6°C in winter can kill acorns (Eaton *et al*., 2016). |
| Other | | | Avoid frost hollows and exposed windy sites. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | | | |
| ALC accumulated temperature (day °C) | | | |
| Rainfall (mm) Optimum & [tolerable] range | | | Over Great Britain as a whole there is evidence that oak does less well in high rainfall areas, but the effect is slight (Evans, 1984). |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) Optimum & [tolerable] range | 0 | 300 | Oaks prefer sites at elevations of less than 300 metres. |
| Gradient (°) Optimum & [tolerable] range | 0 | 18 | |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 4.0 | 6.0 | pH 4.0-6.0 (Horgan *et al*., 2003). |
| Topsoil texture | MZCL | C | Most textures are suitable; however, timber oak should not be established on lighter soils and sands unless this was little evidence of shake[114] in previous crops (Evans, 1984). |
| Depth (cm) | 60 | >100 | |
| Stone content (%) | | | |
| Drainage | | | Well drained. |
| ALC soil wetness class | | | |
| Moisture balance (mm) | | | |
| Field capacity (days) | | | |
| **Other** | | | |

[113] A second flush of shoot growth in late summer, named for Lammas Day (1 August).

[114] Shake is longitudinal fissuring or separation of wood found in freshly felled timber usually either radiating from the pith (star shake) or as a cleavage along an annual ring (ring shake).

| | | | |
|---|---|---|---|
| Environmental risks | | | Potential soil erosion if soil beneath trees lacks vegetation or if site is sloping.<br>Soil compaction from machinery used in forest management or tree felling. |
| ALC group | 3b | 1 | |

***Crop 99. Beech***

The European beech (*Fagus sylvatica*) is a large deciduous tree that commonly reaches 30-40 m and which can maintain a high rate of growth until late maturity (Houston Durrant *et al*., 2016a). It has a wide variety of uses including boat building, flooring, furniture, cooking utensils, pulp and can be coppiced for charcoal production. The mean yield class in Britain is 6 $m^3$/ha/year; rotation length is typically 100-130 years (Horgan *et al*., 2003). In 2017, there was 6,000 ha of beech woodland in Wales, representing c.4% of broadleaved trees grown in Wales (Forestry Commission, 2017).

Though not demanding of soil type, beech requires a humid atmosphere with precipitation well distributed throughout the year and a well-drained soil. It tolerates winter cold, but is sensitive to spring frost. It tolerates very shady situations.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | 140 | | Shoot elongation takes place in May and June which on young trees may be followed by lammas growth in July or occasionally by short, hairy shoots in late August (Horgan *et al*., 2003). |
| Air or ground frost | | | Frost tender species. Late spring frosts can damage young tree or flowers (von Wuehlisch, 2008). |
| Other | | | Can be vulnerable to windthrow[115] under unfavourable conditions. Avoid frost hollows and valley bottoms. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 10<br>[6] | 20<br>[35][116] | |
| ALC accumulated temperature (day °C) | | | |
| Rainfall (mm) Optimum & [tolerable] range | 500<br>[300] | 1000<br>[1500] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | 0 | 300 | It can tolerate altitudes > 300 m (Evans, 1984). |
| Gradient (°) | 0 | 18 | . |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 6.0<br>[3.5] | 7.5<br>8.5 | It grows best on moist, free-draining soils of pH 6.0-7.5 but will tolerate a lower pH if the moisture and nutrient status are adequate. |
| Topsoil texture | S | SCL | Wide range of soils are suitable but it grows best on deep well drained sandy to clay loams. Clay or silty clays with poor drainage are unsuitable (Evans, 1984). |
| Depth (cm) | >150 | | |
| Stone content (%) | | | |
| Drainage | | | Well drained; does not tolerate waterlogged soils (Houston Durrant *et al*., 2016a). |
| ALC soil wetness class | | | |
| Moisture balance (mm) | | | |
| Field capacity (days) | | | |
| **Other** | | | |
| Environmental risks | | | Potential soil erosion if soil beneath trees lacks vegetation or if site is sloping. |

[115] Windthrow refers to trees uprooted or broken by wind.

[116] http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=49181

| | | | |
|---|---|---|---|
| | | | Soil compaction from machinery used in forest management or tree felling. |
| ALC group | 3b | 1 | |

***Crop 100. Wild cherry***

Wild cherry (Prunus avium) is fast growing medium sized deciduous tree which grows to 15-32 m in height with a stem diameter of 90-120 cm. It shows a preference for warm and sunny sites and exposed sites should be avoided. Cherry trees start flowering and setting viable fruit at an early age, often under 10 years old, and good seed crops occur every 1 to 3 years (Gordon and Rowe, 1982). Yield classes of between 6 and 10 would be expected on most sites with a rotation length of between 70 and 80 years. Cherry wood is mainly used for the production of veneer but can also be used for parquet floors, musical instruments and wood panelling.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Flowering occurs from late March to May, with fruit following from late spring to summer. |
| Air or ground frost | | | Wild cherry is susceptible to damage by late spring frosts and may also suffer from severe winter frosts. |
| Other | | | Avoid exposed sites where the trees may become deformed or depressions where waterlogging may occur. |
| Mean daily air temperature (°C). Optimum & [tolerable] range | 18 [6] | 28 [40] | |
| ALC accumulated temperature (day °C) | | | |
| Rainfall (mm) Optimum & [tolerable] range | 500 [300] | 900 [1500] | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) | | | |
| Gradient (°) | 0 | 11 | . |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 5 [4.0] | 6.5 [7.0] | Soil pH should be between 5 and 6.5 (Evans, 1984). |
| Topsoil texture | S | SCL | The tree does not tolerate heavy clay soils.<br>Deep clay loams over chalk or limestone are particularly suitable. |
| Depth (cm) | 50-150 | >150 | |
| Stone content (%) | | | |
| Drainage | | | The tree does not tolerate heavy clays, waterlogged or poorly drained sites and can be sensitive to drought. |
| ALC soil wetness class | | | |
| Moisture balance (mm) | | | |
| Field capacity (days) | | | |
| **Other** | | | |
| Environmental risks | | | Potential soil erosion if soil beneath trees lacks vegetation or if site is sloping.<br>Soil compaction from machinery used in forest management or tree felling. |
| ALC group | 3a | 1 | |

***Crop 101. Silver birch***

Silver birch (*Betula pendula*) is a medium-sized tree, growing up to 30 m; the bark of young trees is brown only turning to silvery-white one the tree is mature (Beck *et al*., 2016). The wood is used to make plywood, veneer, flooring and birch pulp can be used to make paper. In 2017, there was 12,000 ha of birch woodland in Wales, representing *c*.9% of broadleaved trees grown in Wales; it is not known what proportion of that area was silver birch (Forestry Commission, 2017).

Productivity of up to 8 $m^3$/ha/year can be expected from silver birch on suitable sites, with rotation lengths of around 35 years (Horgan *et al.,* 2003). Yield class 4-6 is typical (although on better quality sites this can increase to 8), with a rotation length of 40-55 years (Price and MacDonald, 2012).

In the UK birch has often been seen as an unproductive scrub species with poor form (e.g. crooked stems), however, evidence from Scandinavia has shown that form and productivity can be improved with good silviculture. As a result the market for birch is not presently well developed.

| **Requirements** | **Min** | **Max** | **Notes** |
|---|---|---|---|
| **Climate** | | | |
| Growing season (Days) | | | Annual diameter growth begins in spring after the leaves have appeared and ceases in August. In favourable growing conditions, the annual ring width is 3-4 mm (Hynynen *et al.,* 2010). |
| Air or ground frost | | | Young trees can be damaged by late winter frosts (Horgan *et al*., 2003). |
| Other | | | Avoid exposed sites, young trees can be damaged by late winter frosts and/or cold winds (Horgan *et al*., 2003). |
| Mean daily air temperature (°C). Optimum & [tolerable] range | | | |
| ALC accumulated temperature (day °C) | | | >1200 day degrees (above 5°C) (Pyatt *et al.,* 2001). |
| Rainfall (mm) Optimum & [tolerable] range | | | |
| **Site** | | | |
| Aspect | ~ | ~ | |
| Altitude (m) Optimum & [tolerable] range | 0 | 350 [450] | Altitude should generally be below 300-350 m, though this may be increased by up to 100 m in very sheltered locations and should be reduced to 150 m or lower in more exposed and coastal areas (Price and MacDonald, 2012). |
| Gradient (°) | | | |
| **Soil** | | | |
| Soil pH Optimum & [tolerable] range | 3.5 | 7.0 | Birch tolerate a wide range of pH (3.5-7.0) but do not grow well on strongly calcareous soils unless there is an acid surface layer (Evans, 1984). |
| Topsoil texture | S | MZCL | Birch grows best on fairly fertile, light (sandy and silty loams), well-drained soils, particularly when soil conditions are acidic. Clay soils are often too compact for birch (Hynynen *et al.,* 2010). |
| Depth (cm) | | | |
| Stone content (%) | | | |
| Drainage | | | Well drained but not droughty. Waterlogged soils are not suitable. |
| ALC soil wetness class | | | |
| Moisture balance (mm) | | | |
| Field capacity (days) | | | |
| **Other** | | | |

| | | | |
|---|---|---|---|
| Environmental risks | | | Potential soil erosion if soil beneath trees lacks vegetation or if site is sloping.<br>Soil compaction from machinery used in forest management or tree felling. |
| ALC group | 4 | 1 | |

## References

### A


Aarrestad, P.A., Myking, T., Stabbetorp, O.E. & Tollefsrud, M.M. (2014). *Foreign Norway spruce (Picea abies) provenances in Norway and effects on biodiversity*. - NINA Report 1075. 39 pp.

Adam. K.L. (2006). *Lavender production, products, markets and entertainment farms*. National Sustainable Agriculture Information Service.

Adamczewska-Sowińska, K., Krygier, M. and Turczuk, J. (2016). The yield of eggplant depending on climate conditions and mulching. *Folia Horticulturae*, 28/1, 19-24.

AHDB (2013). *Using Chicory and Plantain in Beef and Sheep Systems*. AHDB Beef & Lamb.

AHDB (2015). *Wheat Growth Guide*. AHDB Cereals & Oilseeds.

AHDB (2016) *Growing and Feeding Lucerne*. AHDB Beef & Lamb.

AHDB (2018). *Apple Best Practice Guide*. http://apples.ahdb.org.uk/agronomy-pollination-additional-information.asp.

AHDB (2018b). *AHDB planting and variety survey results 2018*. https://cereals.ahdb.org.uk/media/1407437/ahdb-planting-and-variety-survey-results-2018-final.pdf

Alaska Natural Heritage Program (2011). *Black medick* (*Medicago lupulina* L.). University of Alaska, Anchorage.

Alberta Agriculture and Forestry (2017). *Industrial hemp enterprise*. Alberta Government. Agdex 153/830-1.

Aldhous, J.R. and Low, A.J. (1974). *The Potential of Western Hemlock, Western Red Cedar, Grand Fir and Noble Fir in Britain (The 'Minor Species' Project).* Forestry Commission.

Allen-Stevens, T. ed., (2017). *Linseed. A grower's guide*. A Premium Crops booklet produced in association with CPM.

Al-Tardeh, S.M. (2008). *Morphological and anatomical adaptations of the perennial geophyte Urginea Maritima (L.) Baker (Liliaceae) to the Mediterranean climate*. Doctoral Dissertation submitted to the School of Biology, Faculty of Sciences, Aristotle University of Thessaloniki.

Angelini, L.G., Moscheni, E., Colonna, G., Belloni, P. and Bonari, E. (1997). Variation in agronomic characteristics and seed oil composition of new oilseed crops in central Italy. *Industrial Crops and Products* 6, 313–323.

Asadi-Samani, M., Bahmani, M., Rafieian-Kopaei, M. (2014). The chemical composition, botanical characteristic and biological activities of Borago officinalis: a review. *Asian Pacific Journal of Tropical Medicine*, 7, Supplement 1(0), S22-S28.

Atkinson, D.J., Sunley, R.J., Jones, H.G., Brennan, R., Darby, P. (2004). *Desk Study on winter chill in fruit.* Defra Report CTC0206.

AWIA (2009). *Best Practice Management for Establishing a Walnut Orchard*. Australian Walnut Industry Association (AWIA) and Horticulture Australia Limited (HAL).


### B


Baldwin, B. (2015). *The Growth and Productivity of Hazelnut Cultivars (Corylus Avellana L.) in Australia*. A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy, Faculty of Rural Management, University of Sydney, July 2015.

Bateman, I.J. and Lovett, A.A. (1998). Using geographical information systems (GIS) and large area databases to predict Yield Class: a study of Sitka spruce in Wales. *Forestry* 71, 147–168.

Bayer Crop Science (2011). *Expert Guide: Sugar Beet*. Bayer CropScience Ltd.

BBRO (2018). *Sugar Beet Reference Book*. British Beet Research Organisation.

Beck, P., Caudullo, G., de Rigo, D. and Tinner, W. (2016). *Betula pendula, Betula pubescens and other birches in Europe: distribution, habitat, usage and threats*. In: San-Miguel-Ayanz, J., de Rigo, D., Caudullo, G., Houston Durrant, T., Mauri, A. eds., European Atlas of Forest Tree Species. Publ. Off. EU, Luxembourg, pp. e010226+.

Berglund, C.R. ed., (2007). *Sunflower Production*. NDSU Extension Service. North Dakota Experiment Station.

Bennett, R.N., Carvalho, R., Mellon, F.A., Eagles, J. and Rosa, E.A.S. (2007). Identification and quantification of glucosinolates in sprouts derived from seeds of wild Eruca *sativa L. (salad rocket) and Diplotaxis tenuifolia* L. (wild rocket) from diverse geographical locations. *Journal of Agricultural and Food Chemistry*, 55, 67-74.

Bittman, S., Waddington, J., Coulman, B., Bonin, S. (1988). *Reed Canarygrass a Production Guide*. Communications branch, agriculture Canada. https://archive.org/details/reedcanarygrassp805cana.

Blackshaw, R.E., Johnson, E.N., Gan, Y., May, W.E., McAndrew, D.W., Barthet, V., McDonald, T. and Wispinski, D. (2011). Alternative oilseed crops for biodiesel feedstock on the Canadian prairies. *Canadian Journal of Plant Science* 91, 889–896.

Bouloc, P., Allegret, S., and Arnaud, L. (2013). *Hemp: Industrial Production and Uses*. Wallingford, Oxfordshire, UK: CABI.

Bratsch, A. (2009). *Speciality Crop Profile: Horseradish*. Virginia Cooperative Extension. Publication 438-104.

Bratsch, A. (2014). *Speciality Crop Profile: Globe Artichoke*. Virginia Cooperative Extension. Publication 438-108.

Bremness, L. (1988). *The Complete Book of Herbs*. Dorling Kindersley, London, UK.

**C**

Cannoy, D.C. (2015). *Green Gold –a Cannabis Sativa L. Lucis Suitability Analysis for West Virginia*. Master of Science Thesis, Marshall University. Theses, Dissertations and Capstones, Paper 964.

CALU (2005). *Triticale and naked oats*. CALU Technical Notes (Ref 030101).

CALU (2006). *Production of exotic winter salad leaves*. CALU Technical Notes (Ref 020104).

CALU (2006b). *Field Grown Herbs*. CALU Technical Notes (Ref 020502).

CALU (2006c). *Hazelnut and walnut production*. CALU Technical Notes (Ref 050402).

CALU (2007a). *Crop Production Guides. Swede*. CALU (Ref 020108).

CALU (2007b). *Alternative crops: Camelina*. CALU Technical Notes (Ref 030201).

CALU (2007c). *Cider Production*. CALU Technical Notes (Ref 02042).

CALU (2007d). *Horticulture. Growing plums and damsons*. CALU Technical Notes (Ref 020403).

CALU (2007e). *Horticulture. Protected Strawberry Production*. CALU Technical Notes (Ref 020203).

CALU (2007f). *Horticulture. Field Grown Strawberries*. CALU Technical Notes (Ref 020202).

Carbonero, C.H. (2011). *Sainfoin (Onobrychis viciifolia), a Forage Legume with Great Potential for Sustainable Agriculture, An Insight on its Morphological, Agronomical, Cytological And Genetic Characterisation*. A thesis submitted to The University of Manchester for the degree of Doctor of Philosophy in the Faculty of Life Sciences.

Caslin, B., Finnan, J. and Eassson, L. (2011). *Miscanthus Best Practice Guidelines*. Teagasc and the Agri-Food and Bioscience Institute.

Caslin, B., Finnan, J., Johnston, C., McCracken, A. and Walsh, L. (2015). *Short Rotation Coppice Willow. Best Practice Guidelines*, Teagasc and the Agri-Food and Bioscience Institute.

Caudullo, G., Tinner, W. and de Rigo, D. (2016). *Picea abies in Europe: distribution, habitat, usage and threats*. In: San-Miguel-Ayanz, J., de Rigo, D., Caudullo, G., Houston Durrant, T., Mauri, A. eds., European Atlas of Forest Tree Species. Publ. Off. EU, Luxembourg, pp. e012300+.

CH2014-Impacts (2014). *Toward Quantitative Scenarios of Climate Change Impacts in Switzerland*, published by OCCR, FOEN, MeteoSwiss, C2SM, Agroscope, and ProClim, Bern, Switzerland, 136 pp.

Chen, N.C., Kalb, T., Talekar, N.S., Wang, J.F. and Ma, C.H. (2002). *Suggested cultural practices for eggplant*. Asian Vegetable Research and Development Centre.

Cherney, J.H. and Small, E. (2016). Industrial Hemp in North America: Production, Politics and Potential. *Agronomy*, 6, 58; doi:10.3390/agronomy6040058.

Christou, M., Alexopoulou, E, Pages, X., Alfos, C., Monti, A. and Nissen, L. (2012). *Non-food Crops-to-Industry schemes in EU27. WP1. Non-food crops, D1.1 Oil crops that can be produced in EU27*. Crops 2 Industry. EU Seventh Framework Programme. Grant agreement no. 227299.

Clarke, S., Roques, S., Weightman, R. and Kindred, D. (2016a). *Understanding Triticale*. AHDB.

Clarke, S., Roques, S., Weightman, R. and Kindred, D. (2016ab). *Modern triticale crops for increased yields, reduced inputs, increased profitability and reduced greenhouse gas emissions from UK cereal production*. Project Report No. 556. AHDB.

Clifton-Brown, J.C. and Jones, M.B. (1997). The thermal response of leaf extension rate in genotypes of the C-4-grass Miscanthus: An important factor in determining the potential productivity of different genotypes. *Journal of Experimental Botany* 48, 1573–1581.

Cole, C. and Zurbo, B. (2008). *Industrial hemp – a new crop for NSW*. Primefact 801.

Collins, R., Marshall, A.H., Ribaimount, F., Michaelson-Yeates T.P.T., Williams T.A., Olyott P. and Abberton M.T. (2006). *Developing the role of Lotus species in UK grasslands*. In: Lloveras, J., González-Rodríguez, A., Vázquez-Yáñez, O., Piñeiro, J., Santamaría, O., Olea, M. and Poblaciones, M.J. eds., (2006). Sustainable Grassland Productivity. Proceedings of the 21st General Meeting of the European Grassland Federation Badajoz, Spain 3-6 April 2006.

Commender, K.E., Munsell, J.F. and Ares, A. (2017). *Commercial Chinese Chestnut Production in Virginia*. Publication ANR-279P. Virginia Cooperative Extension, Virginia State University.

Conedera, M., Tinner, W., Krebs, P., de Rigo, D., Caudullo, G. (2016). *Castanea sativa in Europe: distribution, habitat, usage and threats*. In: San-Miguel-Ayanz, J., de Rigo, D., Caudullo, G., Houston Durrant, T., Mauri, A. eds., European Atlas of Forest Tree Species. Publ. Off. EU, Luxembourg, pp. e0125e0+.

Creed, C., Roberts, H. and Birkenshaw. J. (2014). *An economic analysis of the potential returns achieved from growing 10 specific horticultural crops in Wales*. ADAS.

Crook, D.G. (1999). *The introduction of autumn-sown lentil (Lens Culinaris) into UK arable cropping*. A thesis submitted for the degree of Doctor of Philosophy. University of Reading.

Cook, S.K. (2008). *Sunflowers - a growers guide*. Defra Innovation Network.

Cook, S.K., McCartney, H.A., Fletcher, B., Hutley-Bull, P.D., Barrie, I., Harris, D. (1998). *The role and position of sunflower in UK agriculture*. Report on MAFF review (project code ST01130), ADAS Boxworth.

Crowley, J.G. and Fröhlich, A. (1998). *Factors affecting the composition and use of Camelina*. Teagasc.

**D**

Daccache, A., Keay, C., Jones, R.J.A., Weatherhead, E.K., Stalham, M.A. and Knox, J.W. (2012). Climate change and land suitability for potato production in England and Wales: impacts and adaptation. *Journal of Agricultural Science*, 150, (2), 161-177.

Da Ronch, F., Caudullo, G. and de Rigo, D. (2016). *Pseudotsuga menziesii in Europe: distribution, habitat, usage and threats.* In: San-Miguel-Ayanz, J., de Rigo, D., Caudullo, G., Houston Durrant, T., Mauri, A. eds., European Atlas of Forest Tree Species. Publ. Off. EU, Luxembourg, pp. e01a4f5+.

de Rigo, D., Enescu, C. M., Houston Durrant, T., Tinner, W. and Caudullo, G. (2016). *Juglans regia in Europe: distribution, habitat, usage and threats*. In: San-Miguel-Ayanz, J., de Rigo, D., Caudullo, G., Houston Durrant, T., Mauri, A. eds., European Atlas of Forest Tree Species. Publ. Off. EU, Luxembourg, pp. e01977c+.

DAFF (Undated). *Globe artichoke Cynara scolymus*. Department Agriculture, Forestry and Fisheries, South Africa.

DAFF (Undated b). *Production guidelines for Swiss chard*. Department Agriculture, Forestry and Fisheries, South Africa.

DAFF (2009). *Lavender production*. Department Agriculture, Forestry and Fisheries, South Africa.

DAFF (2010a). *Soya beans. Production guideline*. Department Agriculture, Forestry and Fisheries, South Africa.

DAFF (2010b). *Mung bean. Production guideline*. Department Agriculture, Forestry and Fisheries, South Africa.

DAFF (2010c). *Olives. Production guideline*. Department Agriculture, Forestry and Fisheries, South Africa.

DAFF (2010d). *Plums. Production guideline*. Department Agriculture, Forestry and Fisheries, South Africa.

DAFF (2011). *Jerusalem artichoke Helianthus tuberosus*. Department Agriculture, Forestry and Fisheries, South Africa.

DAFF (2012a). *Peppermint production*. Department Agriculture, Forestry and Fisheries, South Africa.

DAFF (2012b). *Rosemary production*. Department Agriculture, Forestry and Fisheries, South Africa.

DAFF (2012c). *Thyme production*. Department Agriculture, Forestry and Fisheries, South Africa.

DAFF (2012d). *Production guidelines for flax (Linum usitatissimum L.).* Department Agriculture, Forestry and Fisheries, South Africa.

DAFF (2013a). *Celery. Apium graveolens L*. Department Agriculture, Forestry and Fisheries, South Africa.

DAFF (2013b). *Chicory (Chicorium intybus)*. Production Guidelines. Department Agriculture, Forestry and Fisheries, South Africa.

DAFF (2016). *Black Tea Production Guidelines.* Department Agriculture, Forestry and Fisheries, South Africa.

Dean, S., Garthwaite, D.G. and Thomas, M/R. (2000). *Pesticide Usage Survey Report 173. Hops in Great Britain*. Department for Environment, Food & Rural Affairs.

Deng, Y-C., Hua, H-M., Li, J. and Lapinskas, P. (2001). Studies on the cultivation and uses of Evening Primrose (*Oenothera* spp.) in China. *Economic Botany*, 55 (1), 83-92.

Defra (2001). *Planting and growing Miscanthus. Best Practice Guidelines for Applicants to DEFRA'S Energy Crops Scheme*. Department for Environment, Food and Rural Affairs.

Defra (2018). *Horticultural Statistics*.

Delahaut, K.A. and Newenhouse, A.C. (1997). *Growing broccoli, cauliflower, cabbage and other cole crops in Wisconsin: A guide for fresh-market growers*. A3684. University of Wisconsin Extension.

Dodds, K. (2017). *Hops a guide for new growers*. First edition 2017. New South Wales Department of Primary Industries.

Đorđević, V., Đorđević, G., Vidić, M., Milovac, Z. and Šeremešić, S. (2013). *Best Practice Manual for soya bean cultivation in the Danube region.* Austrian Development Cooperation.

Döring, T. and Howlett, S. (2013). *Manifold green manures – Part I: Sainfoin and birdsfoot trefoil*. The Organic Grower - No 22 spring 2013.

Döring, T. and Winkler, L.R. (2013). *Manifold green manures – Part III: Black medic and Lucerne*. The Organic Grower No 24 - autumn 2013.

Döring, T.F., Baddeley, J.A., Brown, R., Collins, R., Crowley, O., Cuttle, S., Howlett, S.A., Jones, H.E., McCalman, H., Measures, M., Pearce, B.D., Pearce, H., Roderick, S., Stobart, R., Storkey, J., Tilston, E.L., Topp, K., Watson, C., Winkler, L.R. and Wolfe, M.S. (2013). *Using legume-based mixtures to enhance the nitrogen use efficiency and economic viability of cropping systems*. Project Report No. 513. HGCA.

Draycott, A.P. and Hollies, J.D. (2001). *Fodder Beet fertiliser requirements*. The Potash Development Association.

Draycott, A.P. ed., (2006). *Sugar beet*. Blackwell Publishing Ltd.

Dribnenki, J.C. ed., (undated). *Growing Flax. Production, Management and Diagnostic Guide*. Flax Council of Canada.

**E**

EU (2018). Commission Implementing Decision on 21 August 2018 on the publication in the Official Journal of the European Union of the application for registration of a name referred to in Article 49 of Regulation (EU) No 1151/2012 of the European Parliament and of the Council ('The Vale of Clwyd Denbigh Plum' (PDO)) (2018/C 303/05). *Official Journal of the European Union*, C303/12-16.

Eaton, E., Caudullo, G., Oliveira, S. and de Rigo, D. (2016). *Quercus robur and Quercus petraea in Europe: distribution, habitat, usage and threats*. In: San-Miguel-Ayanz, J., de Rigo, D., Caudullo, G., Houston Durrant, T., Mauri, A. eds., European Atlas of Forest Tree Species. Publ. Off. EU, Luxembourg, pp. e01c6df+.

El Grari, R. and Backhaus, R.A. (1987). In vitro propagation of red squill, *Urginea maritima* Baker. Plant Cell, *Tissue and Organ Culture*, 10 (1), 65-71.

Endres, G., Forster, S., Kandel, H., Pasche, J., Knodel, J. and Hellevang, K. (2016). *Field Pea Production*. NDSU Extension Service.

Enescu, C. M., Houston Durrant, T., de Rigo, D. and Caudullo, G. (2016). *Corylus avellana in Europe: distribution, habitat, usage and threats.* In: San-Miguel-Ayanz, J., de Rigo, D., Caudullo, G., Houston Durrant, T., Mauri, A. eds., European Atlas of Forest Tree Species. Publ. Off. EU, Luxembourg, pp. e015486+.

Enescu, C. M., Houston Durrant, T., Caudullo, G. and de Rigo, D. (2016b). *Juniperus communis in Europe: distribution, habitat, usage and threats*. In: San-Miguel-Ayanz, J., de Rigo, D., Caudullo, G., Houston Durrant, T., Mauri, A. eds., European Atlas of Forest Tree Species. Publ. Off. EU, Luxembourg, pp. e01d2de+.

Ernst, M. (2017). *Lavender*. CCD-CP-127. Lexington, KY: Center for Crop Diversification, University of Kentucky College of Agriculture, Food and Environment.

Evans, C. and McConnell, D.A. (2015). In: van de Pol-van Dasselaar, A., Aarts, H.F.M., De Vliegher, A., Elgersma, A., Reheul, D., Reijneveld, J.A., Verloop, J., Hopkins, A. eds., (2015). Grassland and forages in high output dairy farming systems. Proceedings of the 18th Symposium of the European Grassland Federation Wageningen, the Netherlands 15-17 June 2015.

Evans, J. (1984). *Silviculture of Broadleaved Woodland*. Forestry Commission Bulletin 62. Her Majesty's Stationery Office.

**F**

FAOSTAT (2016). *Food and Agriculture Organization of the United Nations Crop statistics*. http://www.fao.org/faostat/en/#data/QC.

Figal de Pedro, S. (2017). *Characterization of variation in plant growth and fruit production in a Danish clonal genepool of European blueberries (Vaccinium myrtillus L.) as a basis for identification of superior genotypes for future cultivation*. MSc Thesis.

Forestry Commission (2017). *Forestry Statistics 2017*.

Fraser, S. and Whish, J.P.M. (1997). *A Commercial Herb Industry for NSW – an Infant Enterprise*. Rural Industries Research and Development Corporation Research Paper Series No 97/18.

Froment, M., Masterbroek, D and van Gorp. K. (2002). *A Growers Manual for Calendula Officinalis. L*.

**G**

Garthwaite, D., Barker, I., Mace, A., Parrish, G., Frost, S., Hallam, C., MacArthur, R. and Lu, Y. (2015). *Pesticide Usage Survey Report 270. Outdoor Vegetable Crops in the United Kingdom 2016*.

Garthwaite, D., Barker, I., Ridley, L., Mace, A., Parrish, G., MacArthur, R. and Lu, Y. (2016). *Pesticide Usage Survey Report 273. Orchards in the United Kingdom 2016*.

Garthwaite, D., Barker, I., Ridley, L., Mace, A., Parrish, G., MacArthur, R. and Lu, Y. (2016a). *Pesticide Usage Survey Report 271. Arable Crops in the United Kingdom 2016*.

Garthwaite, D., Barker, I., Ridley, L., Mace, A., Parrish, G., MacArthur, R. and Lu, Y. (2016b). *Pesticide Usage Survey Report 274. Soft Fruit in the United Kingdom 2016.*

Gentry, J. ed., (2010). *Mung bean management guide*. 2nd Edition. Department of Employment, Economic Development and Innovation.

Gesch, R.W. (2012). Growth and yield responses of calendula (Calendula officinalis) to sowing date in the northern U.S. *Industrial Crops and Products*, 45, 248-252.

Ghasemnezhad, A. (2007). *Investigations on the effects of harvest methods and storage conditions on yield, quality and germination of evening primrose (Oenothera biennis L.) seeds.* Dissertation Submitted for the degree of Doctor of Agricultural Science (Dr. agr.) to the Faculty of Agricultural Sciences, Nutritional and Environmental Management Justus Liebig University Giessen.

Gill, M. (2008). *Wild Rocket Sales on the Up*. In: The Vegetable Farmer. January, 27-28. ACT Publishing.

Gillespie, G., Brennan, L., Burke, J. and Forristal, D. (2014). *Spelt Wheat Food Potential*. CROPQUEST.

Grahn, C., Benedict, C., Thornton, T. and Miles, C. (2015). *Baby-leaf salad green production guide for Western Washington*. Washington State University Extension.

Granic, P. (1988). *Evening Primrose Cultivation*. In: Oleagineux, 43 (3): 123 – 124 in Ghasemnezhad, A. (2007).

GRDC (2017). *Lentil. GrowNotes™*. Grain Research and Development Corporation.

GRDC (2017b). *Sunflowers. GrowNotes™*. Grain Research and Development Corporation.

GRDC (2018). *Cereal Rye. GrowNotes™*. Grain Research and Development Corporation.

GRDC (2018b). *Triticale. GrowNotes™.* Grain Research and Development Corporation.

Greiner, S. and Köhl, K. (2014). Growing evening primroses (*Oenothera*). *Frontiers in Plant Science*, 5 (38). doi: 10.3389/fpls.2014.00038.

Gresta, F., Lombardo, G.M., Siracusa, L. and Ruberto, G. (2008). Saffron, an alternative crop for sustainable agricultural systems. A review. *Agronomy for Sustainable Development*, 28, 95-112.

Gucci, R., and Fereres, E. (2012). Fruit trees and vines. Olive. In: Steduto, P., Hsiao, T.C., Fereres, E. and Raes, D. eds., Crop Yield Response to Water. FAO Irrigation and drainage paper 66 (Rome: Food and Agriculture Organization of the United Nations), 300–313.

Guerrero Maldonado, N., López, M.J., Caudullo, G. and de Rigo, D. (2016). *Olea europaea in Europe: distribution, habitat, usage and threats*. In: San-Miguel-Ayanz, J., de Rigo, D., Caudullo, G., Houston Durrant, T., Mauri, A. eds., European Atlas of Forest Tree Species. Publ. Off. EU, Luxembourg, pp. e01534b+.

**H**

Hackett, R. (2015). A comparison of husked and naked oats under Irish conditions. *Irish Journal of Agricultural and Food Research*, 57, 1-8.

Heisswolf, S., Carey, D. and Walsh, B. (2004). *Brassica grower's handbook*. Queensland Government.

Hibberd, B.G. ed., (1988). *Farm Woodland Practice*. Forestry Commission.

Hill, R. (2017). *Growing Sainfoin*. Cotswold Seeds Ltd.

Hochmuth, R.C., Wallace, R.D. van Blokland, P.J. and Williamson, J.G. (2015). *Production and Marketing of Chestnuts in the Southeastern United States.* UF/IFAS Department of Food Resource Economics. University of Florida.

Hodsman, L. (2006). *An assessment of non-food crop opportunities in the south east of England*. National Non-Food Crops Centre.

Horgan, T., Keane, M., McCarthy, R., Lally, M. and Thompson, D. (2003). *A Guide to Forest Tree Species Selection and Silviculture in Ireland*. Ed. O'Carroll, J. COFORD, Dublin.

Houston Durrant, T., de Rigo, D. and Caudullo, G. (2016a). *Fagus sylvatica and other beeches in Europe: distribution, habitat, usage and threats*. In: San-Miguel-Ayanz, J., de Rigo, D., Caudullo, G., Houston Durrant, T., Mauri, A. eds., European Atlas of Forest Tree Species. Publ. Off. EU, Luxembourg, pp. e012b90+.

Houston Durrant, T., Mauri, A., de Rigo, D. and Caudullo, G. (2016b). *Picea sitchensis in Europe: distribution, habitat, usage and threats.* In: San-Miguel-Ayanz, J., de Rigo, D., Caudullo, G., Houston Durrant, T., Mauri, A. eds., European Atlas of Forest Tree Species. Publ. Off. EU, Luxembourg, pp. e0137a1+.

Hsiao, T.C. and Fereres, E. (2012). *Maize*. In: Hsiao, T.C. ed., 3.4 Herbaceous Crops. http://www.fao.org/docrep/016/i2800e/i2800e07.pdf.

Hynynen, J., Niemistö, P., Viherä-Aarnio, A., Brunner, A., Hein, S. and Velling, P. (2010). Silviculture of birch (*Betula pendula* Roth and *Betula pubescens* Ehrh.) in northern Europe. *Forestry*, 83 (1), 103-119.

**I**

Illinois Soybean Association (2012). *Illinois soybean production guide*. Systematic strategies to increasing yields.

Irving, D., Boulton, A. and Wade, S. (2012). *Beetroot Stand Management*. Final Report for the HAL Project VG 06117. Horticulture Australia Ltd.

**J**

Joordens Zaden (undated). *Brigadier Fodder beet grower guide*.

James, P. (2011). *Australian Cherry Production Guide*. Cherry Growers of Australia Inc.

Jellings, A.J. and Fuller, M.P. (1985). *Arable cropping*. In: Halley, R.J. and Soffe, R.J. eds., Primrose McConnell's The Agricultural Notebook. 18th Edition. Butterworths & Co (Publishers) Ltd, 151-193.

Jensen, M., Ramborg, S. (2014). *Dyrkningsvejledning for almindelig blåbær*. Institute for Fødevarer. Aarhus Universitet.

Jodl, S., Eppel-Hotz, A. and Kuhn, W. (2008). Miscanthus als nachwachsender Rohstoff – Ergebnisse aus 20-jähriger Forschungsarbeit in Kurzfassung. Veitshöchheimer Berichte, 126, 1–36 (in German).

Jones, R.J.A. and Thomasson, A.J. (1985). *An Agroclimatic Databank for England and Wales*. Soil Survey Technical Monograph No. 16.

**K**

Kahnt, G. (2008). *Leguminosen im konventionellen und ökologischen Landbau*. Frankfurt a.M., Germany: DLG Verlag, 2008. (German).

Keady, T. and Hanrahan, S. (2010). *Reseeding Pasture: Should you consider Chicory or Tyfon?* Teagasc. https://www.teagasc.ie/media/website/publications/2010/ReseedingPastureChicoryOrTyfon.pdf.

Kemble, J.M. (1996). *Guide to commercial production of muskmelon (Cantaloupe) and related melons*. ANR-974. Alabama Cooperative Extension System.

Kemble, J.M., Sikora, E.J., Simonne, E.H., Zehnder, G.W. and Patterson, M.G. (1998). *Guide to commercial eggplant production.* Alabama Cooperative Extension System.

Klinka, K. and Brisco, D. (2009). *Silvics and silviculture of coastal Western Red Cedar: a literature review.* British Columbia Ministry of Forests and Range, Forest Science Programme, Victoria, B.C. Spec. Rep. Ser. 11. www.for.gov.bc.ca/hfd/pubs/Docs/Srs/Srs11.htm.

Knox, J.W., Daccache, D.A., Weatherhead, E.K. and Stalham, M. (2011). *Climate Change Impacts on the UK Potato Industry*. AHDB.

Koike, S.T., Cahn, M., Cantwell, M., Fennimore, S., Lestrange, M., Natwick, E., Smith, R.F. and Takele, E. (2011). *Spinach Production in California*. UC Vegetable Research & Information Center Publication 7212. University of California Agriculture and Natural Resources.

Król, B. and Kiełtyka-Dadasiewicz, A. (2015). Yield and Herb Quality of Thyme (*Thymus vulgaris* L.) Depending on Harvest Time. *Turkish Journal of Field Crops*, 20 (1), 78-84.

**L**

Laurence, R. (2004). *Borage production for oil and gamma-linolenic acid*. A report for the Rural Industries Research and Development Corporation.

Levitt, J. (1980). *Factors related to freezing tolerance*. In: T.T. Kozlowski, T.T. ed., Physiological Ecology, Academic Press, Inc., Stanford, California, pp. 160-227.

Liebenberg, A.J. (2002). ed., *Dry Bean Production*. Department Agriculture, Forestry and Fisheries, South Africa.

Limagrain (2010). *The Forage Crops Guide*. Limagrain UK Limited.

Limagrain (2010b). *Maize: A Grower's Guide*. Limagrain UK Limited.

Limagrain (2016). *The Essential Guide to Forage Crops*. Limagrain UK Limited.

Lloveras, J., González-Rodríguez, A., Vázquez-Yáñez, O., Piñeiro, J., Santamaría, O., Olea, M. and Poblaciones, M.J. (2006). *Sustainable Grassland Productivity*. Proceedings of the 21st General Meeting of the European Grassland Federation Badajoz, Spain 3-6 April 2006.

Lobell, D.B., Gourdji, S.M. (2012). The influence of climate change on global crop productivity. *Plant Physiology* 160(4), 1686-1697.

Lucas, P.W., Cottam, D.A., Sheppard, L.J. and Francis, B.J. (1988). Growth responses and delayed winter hardening in Sitka spruce following summer exposure to ozone. *New Phytologist*, 108, 495-504.

Luedeling, E., Zhang, M. and Girvetz, E.H. (2009). Climatic changes lead to declining winter chill for fruit and nut trees in California during 1950–2099. *PLOS One* 4(7):e6166.

**M**

MAFF (1983). *Beetroot.* Booklet 2444. MAFF Publications.

Marini, R. (2015). *Growing Pears in Virginia*. Publication 422-017. Virginia Cooperative Extension. Virginia Polytechnic Institute and State University.

Martinussen, I., Nestby, R. and Nes, A. (2009). Potential of the European wild blueberry *(Vaccinium myrtillus*) for cultivation and industrial exploitation in Norway. *Acta Horticulturae*, 810, 211-216.

Marley, C., Theobald, V., Fychan, A., Thomas, B., Gethin, A., Scott, M., Sanderson, R. and McCalman, H. (2016). Utilising common vetch (*Vicia sativa*) as a source of forage protein for grazing ewes. In: M Höglind, A.K. Bakken, K.A. Hovstad, E. Kallioniemi, H. Riley, H. Steinshamnm and L. Østrem eds., The multiple roles of grassland in the European bioeconomy: Proceedings of the 26th General Meeting of the European Grassland Federation, Trondheim, Norway , 04/09/2016.

Masabni, J. (Undated). *Mustard Greens*. AgriLIFE Extension.

Masabni, J. (Undated a). *Swiss Chard*. AgriLIFE Extension.

Masabni, J. (undated b). *Garlic*. Texas AgriLife Extension Service.

Masabni, J. (Undated c). *Spinach*. AgriLIFE Extension.

Masabni, J. (Undated d). *Parsley*. AgriLIFE Extension.

Mastebroek, H.D. and Marvin, H.J.P. (2000). Breeding prospects of *Lunaria annua* L. *Industrial Crops and Product*, 11, 139-143.

Mbeyagala, K.E., Amayo, R., Obuo, J.P., Pandey, A.K., War, A.R. and Nair, R.M. (2017). *A manual for mungbean (greengram) production in Uganda.* National Agricultural Research Organization (NARO), 32 pages.

McCalman, H. and Little, T. (2012). *Linking farmers: Growing and feeding oats for poultry in Wales*. Organic Centre Wales.

McDonald, W., Nikandrow, A., Bishop, A., Lattimore, M., Gardner, P., Williams, P. and Hyson, L. (2003). *Lucerne for pasture and fodder*. Agfact P2.2.25 third edition, New South Wales Agriculture.

McKenzie, R.H. (2010). *Mustard Production for Alberta*. Agdex 143/20-1. Alberta Agriculture and Rural Development.

Mehlenbacher, S.A. (1991). Chilling requirements of hazelnut cultivars*. Scientia Horticulture*, 47 (3-4), 271-282.

Melican, N. (2016). *Tea Growing Feasibility Study. Study Report undertaken to examine the feasibility of growing tea commercially in Scotland*. Community Food Fund.

Menia, M., Iqbal, S., Zahida, R., Tahir, S., Kanth, R.H., Saad. A.A. and Hussian, A. (2018). Production technology of saffron for enhancing productivity. *Journal of Pharmacognosy and Phytochemistry*, 7(1), 1033-1039.

Miller, R.L. (1991). *Hemp as a Crop for Missouri Farmers: Markets, Economics, Cultivation, Law*. Report to Agriculture Task Force, Missouri House of Representatives. www.naihc.org/hemp_information/content/millerhemp.html.

Miranda, C., Santesteban, L.G. and Royo, J.B. (2005). Variability in the relationship between frost temperature and injury level for some cultivated Prunus species. *HortScience* 40(2), 357-361.

Misiak, K., Górna, B., Król, E. and Hołubowicz, R. (2017). *Yield and Quality of Mung Bean (Vigna radiata (l.) R. Wilczek) Seeds Produced in Poland*. Bulletin UASVM Horticulture 74(2). DOI:10.15835/buasvmcn.

Morales, M.R., Maynard, E. and Janick, J. (2006). 'Adagio': A Slow-Bolting Arugula. *HortScience* 41(6), 1506-1507.

Morris, J., Weatherhead, E.K., Knox, J.W., Vasileiou, K., de Vries, T.T., Freeman, D., Leiva, F.R. and Twite, C. (2004). *The Case of England and Wales*. In: Vecino, J.B. and Martin, C.G. (Eds). Sustainability of European Irrigated Agriculture under Water Framework Directive and Agenda 2000. WADI. European Commission.

Motes, J., Roberts, W., Edelson, J., Damicone, J. and Duthie, J. (2017). *Cantaloupe Production*. HLA-6237. Oklahoma Cooperative Extension Service. Oklahoma State University.

Murray, M. (2011). *Critical Temperature for Frost Damage on Fruit Trees*. Utah State University Cooperative Extension.

**N**

Nair, A. and Irish, L. (2016). *Commercial Production of Pak Choi*. Iowa State University Extension and Outreach.

NNFCC (2006). *Borage (Borago officinalis)*. Crop Fact Sheet. National Non Food Crop Centre.

NNFCC (2010). *Short Rotation Coppice Willow (SRC).* Crop Fact Sheet. National Non Food Crop Centre.

Nestby, R., Krogstad, T., Joner, E. and Vohník, M. (2014). The effect of NP fertilization on European blueberry (*Vaccinium myrtillus L.*) development on cultivated land in mid-Norway. *Journal of Berry Research,* 4(3), 147-157.

Nestby, R., Percival, D., Martinussen, I., Opstad, N. and Rohloff, J. (2011). The European Blueberry (*Vaccinium myrtillus L.*) and the potential for cultivation. A review. *The European Journal of Plant Science and biotechnology*, 5(1), 5-16.

New Zealand Institute for Crop & Food Research (2003). *Growing saffron - the world's most expensive spice.* Crop & Food Research.

NIAB-TAG (2016). *Cover Crops*. A practical guide to soil and system improvement.

**O**

OABS Development (Pty) Ltd, (2017). *Study on the market potential for the commercial viability of almond production in South Africa*.

Onder, S., Caliskan, E., Onder, D. and Caliskan, S. (2005). Different irrigation methods and water stress effects on potato yield and yield components. *Agricultural Water Management*, 73, 73-86.

Opena, G.B. and Porter, G. A. (1999). Soil management and supplemental irrigation effects on potato: II. Root growth. *Agronomy Journal*, 91, 426–431.

Orzolek, M.D., Bogash, S.M., Kime, L.F. and Harper, J.K. (2006). *Agricultural Alternatives. Cantaloupe Production.* The Pennsylvania State University.

Ortiz, M.M. and Smith, L. (2011). *Sainfoin. Surprising science behind a forgotten forage*. Project Number PITN-GA-2011-289377. Cotswold Seeds Ltd.

**P**

PGRO (2014). *Lupin Agronomy Guide*. Processors and Growers Research Organisation.

PGRO (2017). *PGRO Pulse Agronomy Guide*. Processors & Growers Research Organisation.

Phipps, R.H., Fulford, R.J. and Crofts F.C (1974). Relationships between the production of forage maize and accumulated temperature, Ontario heat units and solar radiation. *Agricultural Meteorology*, 14(1-2), 385-397.

Phipps, R.H. and Wilkinson, M. (1985). *Maize Silage*. Great Britain, Chalcombe Publications.

Price, A., and MacDonald, E. (2012). *Growing Birch in Scotland for Higher Quality Timber*. The Research Agency of the Forestry Commission. Timber Development Programme. Forest Research.

Pryor, S.N. (1988). *The Silviculture and yield of Wild Cherry*. Bulletin 75. Forestry Commission.

Putnam, D.H., Budin, J.T., Field, L.A. and Breene, W.M. (1993). *Camelina: a promising low input oilseed*. In: Janick, J. and Simon, J.E. (eds) New Crops. Wiley, New York, pp. 314–322.

Pyatt, G., Ray, D. and Fletcher, J. (2001). *An Ecological Site Classification for Forestry in Great Britain*. Bulletin 124. Forestry Commission, Edinburgh.

**Q**

Quiroz, R., Chujoy, E. and Mares, V. (2012). *Potato*. In: Hsiao, T.C. (Ed) 3.4 Herbaceous Crops. http://www.fao.org/docrep/016/i2800e/i2800e07.pdf.

**R**

Ramu, S. (2012). *Ethnic herbs and greens crop production manual*. Rutgers University.

Rayns, F. and Rosenfeld, A. (2010). *Green manures – species selection*. Factsheet 25/10. Horticulture Development Company.

Red Tractor Assurance (2015a). *Crop module: Swede, Turnip and Kohlrabi*. Effective 1st September 2015. Assured Food Standards.

Red Tractor Assurance (2015b). *Crop module: Herbs*. Effective 1st September 2015. Assured Food Standards.

Red Tractor Assurance (2016a). *Crop module: Peas (vining, processed)*. Effective from 1st June 2016-31st May 2018: version 3.2 (Crop Risk Category 2). Assured Food Standards.

Red Tractor Assurance (2016b). *Crop module: Peas (picking, fresh).* Effective from 1st June 2016-31st May 2018: version 3.2 (Crop Risk Category 2). Assured Food Standards.

Red Tractor Assurance (2016c). *Crop module: Chinese cabbage, Pak Choi, Choi Sum (outdoor)*. Effective from 1st June 2016-31st May 2018: version 3.2 (Crop Risk Category 2). Assured Food Standards.

Red Tractor (2016d). *Crop module: Aubergines*. Effective from 1st September 2015-31st May 2018: version 3.2 (Crop Risk Category 3). Assured Food Standards.

Red Tractor Assurance (2016e). *Crop module: Beetroot*. Effective from 1st June 2016-31st May 2018: version 3.2 (Crop Risk Category 2). Assured Food Standards.

Red Tractor Assurance (2016f). *Crop module: Broccoli*. Effective from 1st June 2016-31st May 2018: version 3.2 (Crop Risk Category 2). Assured Food Standards.

Red Tractor Assurance (2016g). *Crop module: Cabbage*. Effective from 1st June 2016-31st May 2018: version 3.2 (Crop Risk Category 2). Assured Food Standards.

Red Tractor Assurance (2016h). *Crop module: Celery*. Effective from 1st June 2016-31st May 2017: version 3.2 (Crop Risk Category 1). Assured Food Standards.

Red Tractor Assurance (2016i). *Crop module: Chard*. Effective from 1st June 2016-31st May 2018: version 3.2 (Crop Risk Category 2). Assured Food Standards.

Red Tractor Assurance (2016j). *Crop module: Chicory*. Effective from 1st June 2016-31st May 2017: version 3.2 (Crop Risk Category 1). Assured Food Standards.

Red Tractor Assurance (2016k). *Crop module: Garlic*. Effective from 1st June 2016-31st May 2018: version 3.2 (Crop Risk Category 2). Assured Food Standards.

Red Tractor Assurance (2016l). *Crop module: Kale*. Effective from 1st June 2016-31st May 2018: version 3.2 (Crop Risk Category 2). Assured Food Standards.

Red Tractor Assurance (2016m). *Crop module: Radish*. Effective from 1st June 2016-31st May 2017: version 3.2 (Crop Risk Category 1). Assured Food Standards.

Red Tractor Assurance (2016n). *Crop module: Spinach*. Effective from 1st June 2016-31st May 2018: version 3.2 (Crop Risk Category 1). Assured Food Standards.

Red Tractor Assurance (2016o). *Crop module: Sweetcorn*. Effective from 1st June 2016-31st May 2018: version 3.2 (Crop Risk Category 2). Assured Food Standards.

Red Tractor Assurance (2016p). *Crop module: Strawberries*. Effective from 1st June 2016-31st May 2017: version 3.2 (Crop Risk Category 1). Assured Food Standards.

Red Tractor Assurance (2016q). *Crop module: Fennel*. Effective from 1st June 2016-31st May 2018: version 3.2 (Crop Risk Category 2). Assured Food Standards.

Red Tractor Assurance (2016r). *Crop module: Hops*. Effective from 1st September 2015-31st May 2018: version 3.2 (Crop Risk Category 3). Assured Food Standards.

Roche, L. and Haddock, P.G. (1987). *Sitka spruce (Picea sitchensis) in North America with special reference to its role in British forestry*. Proceedings of the Royal Society of Edinburgh 93B, 1–12.

Roper, T.R. and Frank, G.G. (Undated). *Planning and establishing commercial apple orchards in Wisconsin*. A3560. University of Wisconsin Extension.

Rosenfeld, A. and Rayns, F. (Undated). *Sort out your soil. A practical guide to Green Manures*. Cotswold Seeds and Garden Organic.

Rutledge, A. D. (2015). *Producing Cantaloupes in Tenn*essee. PB962. Agricultural Extension Service. The University of Tennessee.

**S**

Saha, S.K. ed., Pfeufer, E., Bessin, R., Wright, S. and Strang, J. (2015). *2016-17. Vegetable production guide for commercial growers.* Cooperative Extension Service. University of Kentucky College of Agriculture, Food and Environment.

Salmon, D.F., Mergoum, M. and Gómez Macpherson, H. (2004). *Triticale* production and management. In: Mergoum, M. and Gómez Macpherson, H. eds., (2004) Triticale improvement and production. FAO Plant Production and Protection Paper 179.

Samuel, C.J.A, Fletcher, A.M. and Lines, R. (2007). *Choice of Sitka spruce seed origins for use in British forests.* Forestry Commission Bulletin 127. Forestry Commission, Edinburgh, i-xii + 1 -1 12pp.

SASK Mustard (2017). *Mustard Production Manual*. Saskatchewan Mustard Development Commission. Government of Saskatchewan.

Schorling, M., Enders, C. and Voight, C.A. (2015). Assessing the cultivation potential of the energy crop *Miscanthus x giganteus* for Germany. *Global Change Biology Bioenergy,* 7, 763-773.

Schrader, W.L. and Mayberry, K.S. (2003). *Beet and Swiss Chard Production in California*. Publication 8096. University of California.

Selås, V., Sønsteby, A., Heide, O.M., Opstad, N. (2015). Climatic and seasonal control of annual growth rhythm and flower formation in *Vaccinium myrtillus* (*Ericaceae*), and the impact on annual variation in berry production. *Plant Ecology and Evolution*, 148(3), 350-360.

Simon, J.E., Chadwick, A.F. and Craker, L.E. (1984). *Herbs: An Indexed Bibliography 1971-1980.* The Scientific Literature on Selected Herbs, and Aromatic and Medicinal Plants of the Temperate Zone, Archon Books, 770pp.

Sing, L., Pearce, A., Ray, D. and Brown, T. (2006). *Modelling Sitka spruce yield in southern Scotland*. In: Sustainable forestry in theory in practice: recent advances in inventory and monitoring, statistics and modelling, information and knowledge management, and policy science, K M Reynolds, ed., Edinburgh.

Small, E., Pocock, T. and Cavers, P.B. (2002). The biology of Canadian Weeds. 119. *Cannabis sativa* L. *Canadian Journal of Plant Science*, 83, 217-237.

Snare, L. (2008). *Hazelnut production*. Primefact 765. New South Wales Department of Primary Industries.

Soffe, R.J. ed., (1985). *The Agricultural Notebook. 19th edition*. John Wiley & Son.

Sood, M.C. and Singh, N. (2003). Water Management. In: Khurana, S.M.P., Minhas, J.S., Pandey, S.K., eds. The potato: Production and utilization in Sub-Tropics. New Delhi, India, Mehta Publishers, pp. 111-120.

Soya UK (2017). *Soya is now a commercial reality in the UK*.

Stahl-Biskup, E. and Sáez, F. (2002). *Thyme: the genus Thymus*. London: Taylor & Francis.

Stone, A. (1991). *The adaptation of chickpea (Cicer arietinum) & lentil (Lens culinaris) to the United Kingdom.* A thesis submitted to the University of Reading for the degree of Doctor of Philosophy.

**T**

Taylor, J.L. (2015). *Delayed Bolting in Rocket for Improved Quality and Greater Sustainability*. PhD Plant and Environmental Sciences. University of Warwick.

Taylor, R, and Burt, J. (2007). *Growing olives in Western Australia*. Department of Agriculture and Food, Western Australia, Perth.

Teagasc (2007). *Reed Canary Grass*. Fact Sheet. Tillage No. 7.

Teynor, T.M., Putnam, D.H., Doll, J.D., Kelling, K.A., Oelke, E.A., Undersander, D.J. and Oplinger, E.S. (1992). *Comfrey*. Field Crops Manual. https://hort.purdue.edu/newcrop/afcm/comfrey.html

The Andersons Centre (2015). *Revealing the opportunities for growing peas and beans in the UK*.

**U**

Ullio, L. (2003). *Eggplant growing*. NSW Agriculture.

Undersander, D., Kaminski, A.R., Oelke, E.A., Smith, L.H., Doll, J.D., Schulte, E.E. and Oplinger, E.S. (1991). *Turnip*. Alternative Crops Field Manual. University of Wisconsin.

Undersander, D., Cosgrove, D., Cullen, E., Grau, C., Rice, M.E., Renz, M., Sheaffer, C., Shewmaker, G. and Sulc, M. (2011). *Alfalfa Management Guide*. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.

Undersander, D., Greub, L., Leep, R., Beuselinck, P., Wedberg, J., Smith, D., Kelling, K., Doll, J., Cosgrove, D., Grau, C., Peterson, S., Wipfli, M. and English, J. (1993). *Birdsfoot trefoil for grazing and harvested forage*. North Central Region Extension Publication 474.

University of Reading (2014). *Growing and feeding forage maize – a review.* Research Partnerships: Grasslands, Forage and Soil. Work Package 3b: Alternative forages. Report prepared for AHBD Dairy.

**V**

Valentine, J., Duller, C.J., Hinton-Jones, M., Tubby, I., Fry, D.A., Slater, F.M., Sherborne, A., Jones, E., Heaton, R., Farrell, J., Horne. B., Green, C.G. and Powell, H. (2009). *The development of sustainable heat and power fuelled by biomass from short rotation coppice in Wales*. Aberystwyth University Report of the Helyg i Gymru / Willow for Wales 2004-2008 project. 92pp. http://www.willow4wales.co.uk/.

van de Pol-van Dasselaar, A., Aarts, H.F.M., De Vliegher, A., Elgersma, A., Reheul, D., Reijneveld, J.A., Verloop, J., Hopkins, A. eds., (2015). *Grassland and forages in high output dairy farming systems.* Proceedings of the 18th Symposium of the European Grassland Federation Wageningen, the Netherlands 15-17 June 2015.

von Wuehlisch G. (2008). *EUFORGEN Technical Guidelines for genetic conservation and use for European beech (Fagus sylvatica).*Bioversity International, Rome, Italy. 6 pages.

**W**

Wadsworth, E. (2012). *Naked Oats – the story so far*. In: Oats from breeder to market. SENOVA-+.

Walker, J., Hertel, K., Parker, P. and Edwards, J. (2011). *Lupin growth and development*. New South Wales Government Industry and Investment.

Wani, S.P., Heng, L.K. and Vajja, N.R. (2012). *Soybean* In: Hsiao, T.C. (Ed) 3.4 Herbaceous Crops. http://www.fao.org/docrep/016/i2800e/i2800e07.pdf

Wikinson, J.M. (2003). A laboratory evaluation of comfrey (*Symphytum officinale L*.) as a forage crop for ensilage. *Animal Feed Science and Technology*, 104 (1-4), 227-233.

Wilson, S. McG., Mason, B., Jinks, R., Gil-Moreno, D. and Savill P. (2016).The Redwoods and Red Cedar Coast redwood (*Sequoia sempervirens*), giant redwood (*Sequoiadendron giganteum*) and western red cedar (*Thuja plicata*) – species, silviculture and utilisation potential. Species Profile. *Quarterly Journal of Forestry*, 110 (4), 244-256.

Whiriskey, J. and McCarthy, P. (2006). *Lavender Production*. Fact Sheet No 52. Teagasc.

**X**

**Y**

Yang, L., He, Q.S., Corscadden, K. and Udenigwe, C.C. (2015). The prospect of Jerusalem artichoke in functional food ingredients and bioenergy production. *Biotechnology Reports*, 5, 77-88.

**Z**

Zahoor, F., Forristal, D, and Gillespie, G. (2017). *Minor Crops Report*. CROPQUEST.

https://www.teagasc.ie/media/website/crops/crops/Potential-for-minor-crops-as-break-crops.pdf