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Barley growth guide

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Contents

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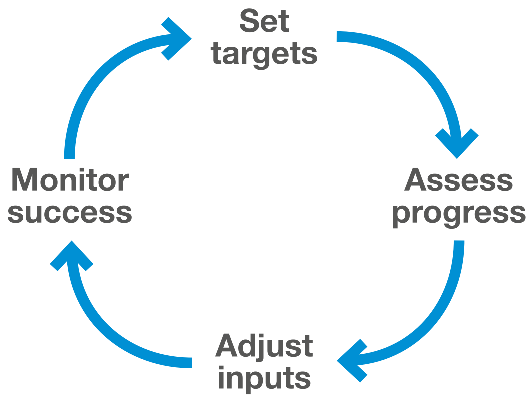
Introduction

This guide aims to support understanding and enhancement of barley production through improved management.

The steps in any cycle of management are to:



Measurements are vital for good management and learning. As well as assessing weeds, pests and diseases, crop managers must assess the crop itself. Crop progress, structure and final performance can then be compared with benchmarks or new targets.

A crop's growth best relates to the natural resources that it captures. By knowing available resources, managers can tell whether better or worse than expected growth was due to weather or husbandry.

Crop assessments should be objective and, where possible, measured. This guide presents metrics by which production targets can be set and crop progress monitored. It also explains how the metrics interrelate and can be influenced.

This growth guide presents a series of benchmarks for barley. Benchmarks are a quantitative reference point against which a crop's progress, structure and final performance can be compared.

The guide can be used to understand the factors that affect crop growth, including the relative importance of variety, natural environment and husbandry.

Capturing natural resources

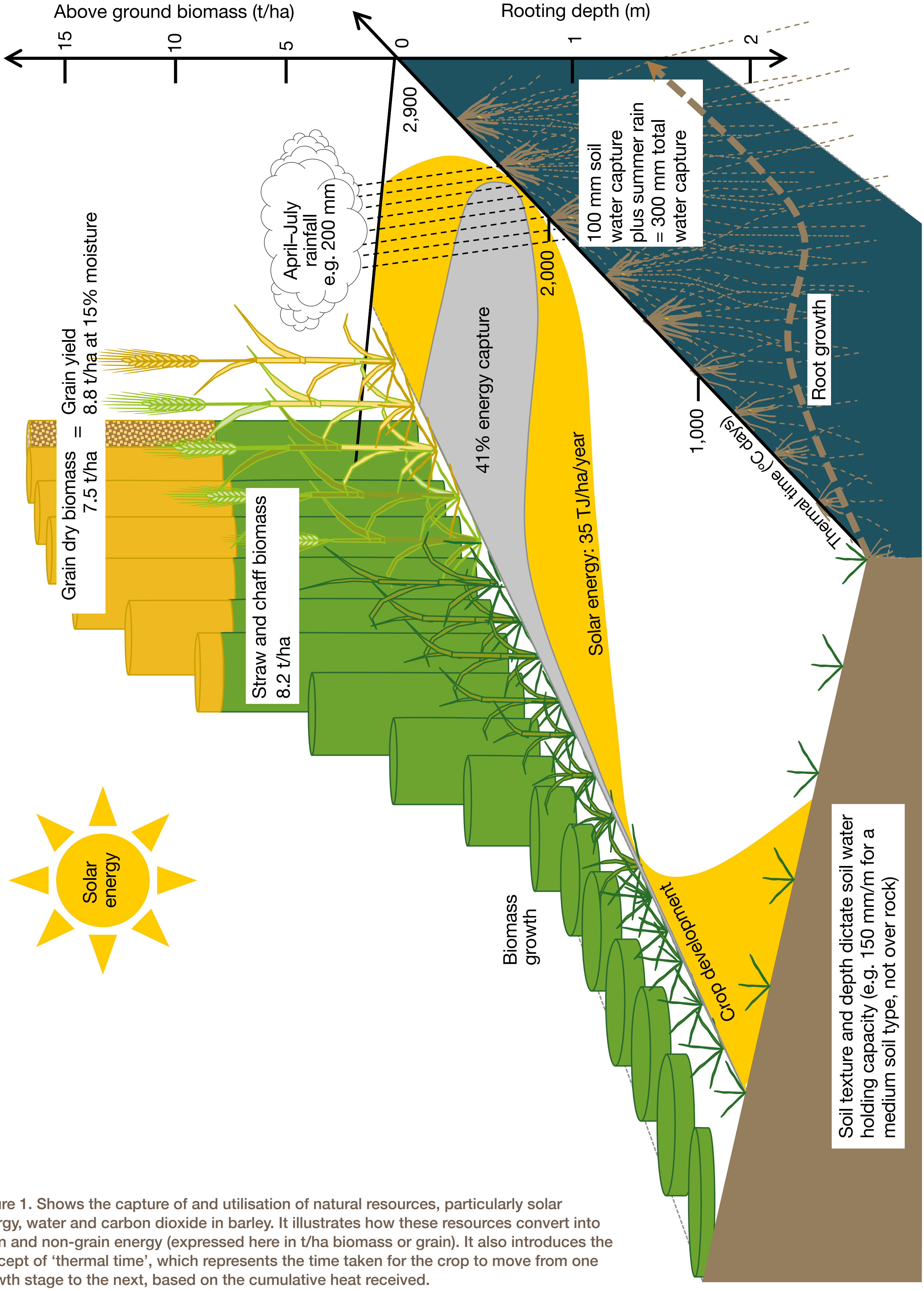


Figure 1. Shows the capture of and utilisation of natural resources, particularly solar energy, water and carbon dioxide in barley. It illustrates how these resources convert into grain and non-grain energy (expressed here in t/ha biomass or grain). It also introduces the concept of 'thermal time', which represents the time taken for the crop to move from one growth stage to the next, based on the cumulative heat received.

Source: ADAS

Understanding barley yields

Yield determination

Crops harvest energy – they convert natural resources (solar energy, carbon dioxide and water) into edible and other forms of energy. Water is required in proportion to the energy captured.

Cereal yields depend on the following:

- Available natural resources
- Their capture
- Their conversion to harvestable grain

If light is limiting

Yield (t/ha) = Light energy (TJ/ha) x Capture (%) x Conversion (t/TJ) x Harvest index

If water is limiting

Yield (t/ha) = Available water* (mm) x Capture (%) x Conversion (t/ha/100 mm) x Harvest index

***The sum of summer rainfall and soil-held water.**

In the UK, light limitation of barley yields is more common than water limitation. Water limitation becomes more common as yields increase.

Available natural resources cannot generally be controlled, so yields must be managed primarily through influencing their capture.

Light capture depends mainly on green canopy longevity. Each five extra days of full light capture by a green canopy should be associated with 1 t/ha of extra crop growth. Average long-term (1981–2010) annual solar radiation map for the UK is shown in Figure 2.

Average long-term (April–July, 1981–2010) rainfall map for the UK is shown in Figure 3.

Water capture depends mainly on rooting depth. On a soil holding 15% available water, an increase in rooting depth of 14 cm should provide an extra 20 mm of water, which should support one extra t/ha of biomass growth.

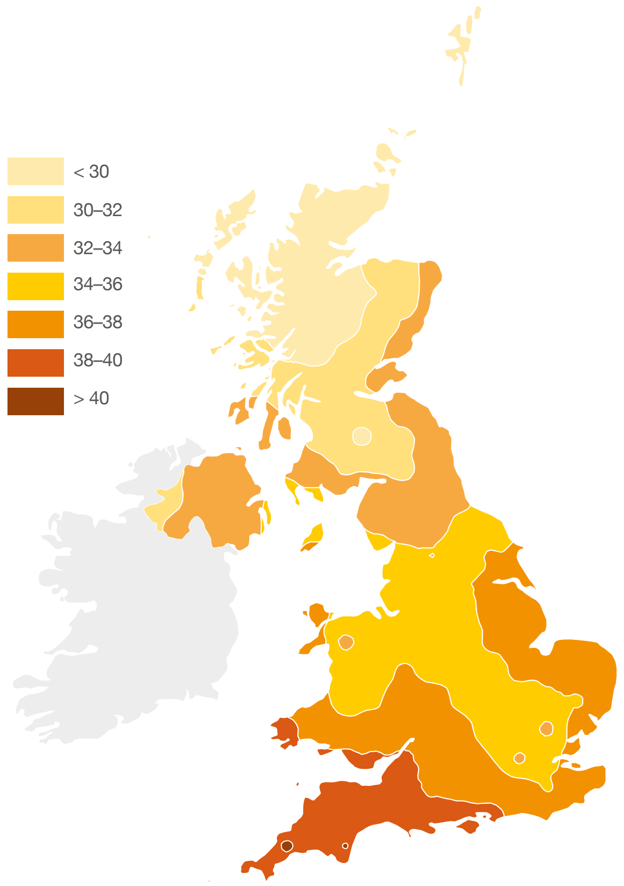


Figure 2. Average annual solar radiation 1981–2010 (TJ/ha)
Source: ADAS

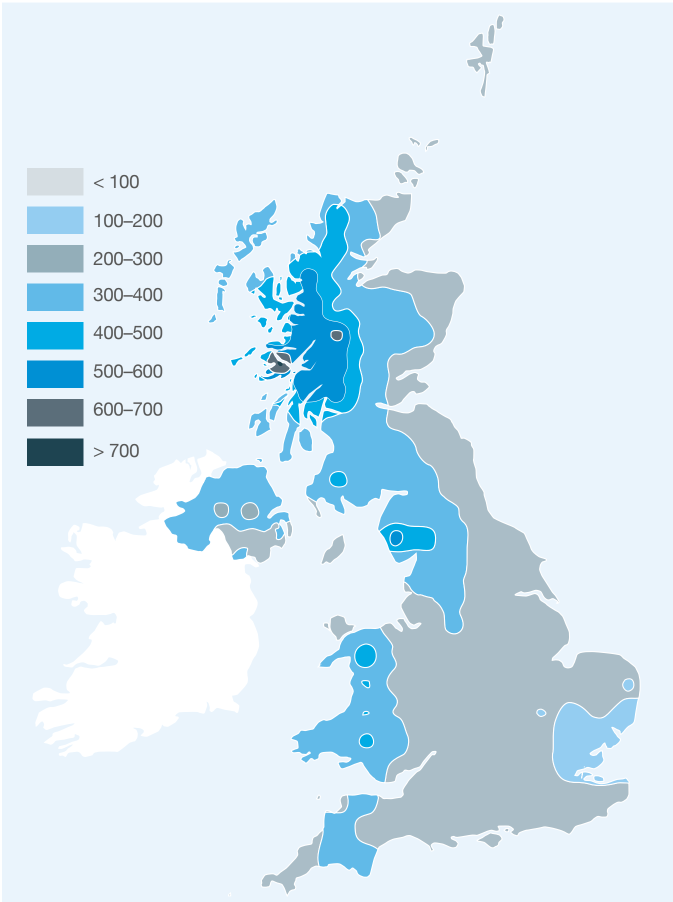


Figure 3. Average rainfall April–July, 1981–2010 (mm)
Source: ADAS

The harvest index is the proportion of total crop biomass growth that is harvested as grain (Figure 4). The benchmark for grain is 51% at harvest. Stem, leaf material and chaf make up 49% of the total above ground biomass.

Grain biomass arises from all growth after flowering, plus some biomass (proteins and sugars) transferred from the straw.

Harvest index is thought to be influenced more by variety choice than by husbandry.

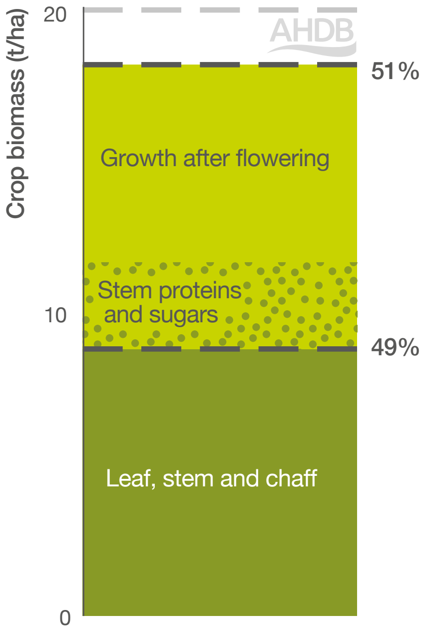


Figure 4. Crop biomass distribution in barley (%)
Source: ADAS

Barley types

Barley spikes (or 'ears') can produce either one or three grains per node, giving 'two-row' or 'six-row' varieties (Figure 5), whereas wheat is more flexible, producing several grains per node (depending on the assimilates available during ear development).

Figure 5. Two- and six-row barley varieties

Sink limitation

The number of grains set and the potential size of each grain determine a crop's 'sink capacity' for new assimilates. Unlike wheat, barley commonly has insufficient grains to store all assimilate formed during grain filling, i.e. it is 'sink-limited', as shown in Figure 6.

Sink capacity in barley crops is largely determined by fertile shoot number. As six-row barley varieties have more grains per ear than two-row varieties, they may be less sink-limited.

In sink-limited crops, grain yields relate more to factors affecting early growth and less to factors affecting late growth. Sink limitation can be reduced by maximising ear number. This is more important for barley than wheat.

Hybrid barley varieties are now commonly grown across the UK. All hybrids are six-row varieties. When grown at recommended seed rates and recommended nitrogen supply, hybrid barley can produce greater yields than two-row barleys, through the production of a larger number of smaller grains.

Sink-limited grains appear plump. Source-limited grains may appear 'pinched' because their capacity has not been fulfilled. Plant breeding for high-specific weight may favour sink-limitation, which may also compromise resource conversion.

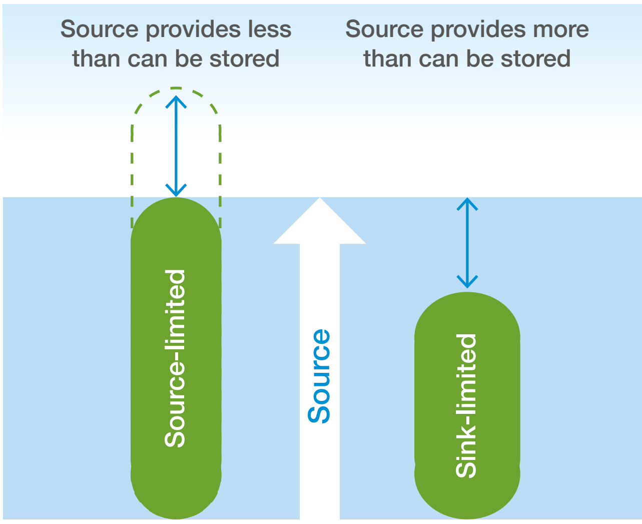


Figure 6. A comparison between source- and sink-limited crops
Source: ADAS

Resource capture and conversion

Rates of energy absorption, carbon dioxide fixation and water transpiration by leaf canopies (Figure 7) are inherently linked, so light use, water use and biomass formation are roughly proportional.

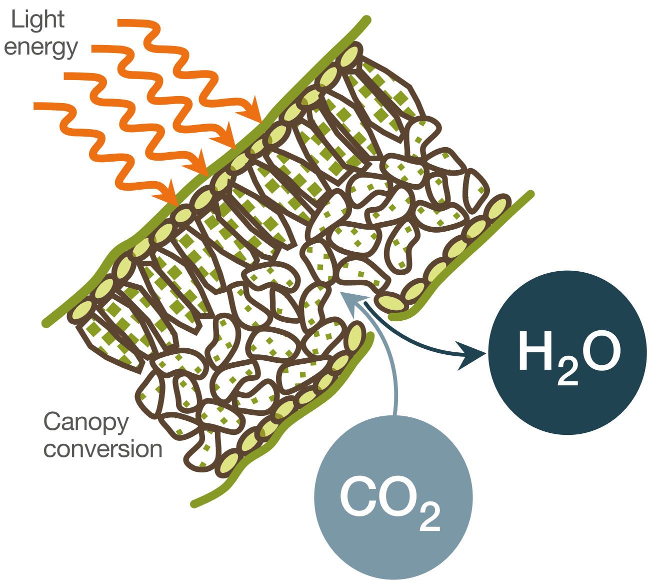


Figure 7. Canopy capture and conversion of natural resources

Source: ADAS

Estimated rates of conversion by barley canopies are 1.1 t of dry plant biomass per terajoule (TJ) of energy intercepted and 4.6 t/ha biomass per 100 mm of water captured and transpired.

Conversion rates are less than for wheat, probably because barley is more sink-limited.

Biomass production can be monitored to indicate the success of resource capture and conversion.

Resource conversion is thought to be influenced more by variety choice than by crop management.

Mapping yield potentials

Although the benchmark yield for UK barley is 8.8 t/ha, potential grain yields could be as high as around 20 t/ha. This higher figure is based on average resources available, management to maximise resource capture and a variety that is not sink-limited. Potentially, this can result in maximum rates of conversion to grain biomass.

What are benchmarks?

This symbol identifies a benchmark – a quantitative reference point against which a crop's performance can be compared. By assessing crops against benchmark values, growers can determine how best to manipulate husbandry. Some targets and husbandry responses are suggested, but this guide is not an agronomy manual.

'At-a-glance' benchmark values are provided at the back of this guide.

Each benchmark represents a median (middle) value derived from measurements made on the two-row winter barley variety 'Pearl' during three harvest years (2002 to 2004). Trials were sown between 15 September and 10 October at six trial sites across the UK. Full crop protection and lodging control were applied to minimise potential crop losses. Fertiliser use was for feed quality grain (rather than for malting).

Other varieties and sowing dates may reach key stages earlier or later than the benchmark date. Where known, differences for six-row and hybrid winter barley and spring barley are highlighted.

Some graphs to illustrate growth processes are based on example crops and may give data that differs from benchmarks. Some benchmark data for modern varieties can be found within the AHDB Recommended Lists datasets: **ahdb.org.uk/rl**

Varietal influence

Benchmarks vary in the extent to which they are affected by genetics (heritability). Benchmarks with high heritability are strongly influenced by choice of variety, whereas benchmarks with low heritability are principally controlled by husbandry choices.

The heritability of each benchmark is indicated as High, Medium or Low and the other management choices with a significant effect are listed.

Crop life cycle

Throughout the growing season, a crop changes in form (development) and accumulates dry matter (growth).

Key facts

- The rate at which barley develops is highly influenced by variety choice and sowing date
- Some phases of development and growth have more effect on harvestable yield than others
- Management should maximise growth in those phases that influence yield most, particularly ear number
- Spring barley crops pass through growth stages much faster than winter barley crops

Growth

Growth, which is the increase in crop size or weight, results from photosynthesis. It depends on:

- Light energy falling on the canopy
- Size of green canopy and, hence, light interception
- Capacity of the crop to utilise light energy and store dry matter

Growth is maximised by bright, cool weather because:

- High light energy maximises photosynthesis
- Cool temperatures slow development and increase the length of any phase

Summer light levels (Figure 8a) and temperatures (Figure 8b) are both lower in the North than in the South.

On cloudy days, light energy is less than half that intercepted on sunny days.

In the North, lower temperatures slow crop development and maximise growth. This results in higher average yields, despite more cloudy days.

Site and season effects can, therefore, be explained by variation in both light and temperature.

The key development phases

Crop development is measured by progress through growth stages. Crop processes 'switch on' or 'off' at key stages (GS21, GS31, GS39, GS59, GS71 and GS87).

Detailed information on the growth stages is published near the back of this guide.

Development can only be altered by variety choice and sowing date. Subsequent management decisions aim to influence growth during development (e.g. by controlling disease or applying fertiliser).

The speed at which a crop progresses through each developmental stage is governed by:

Temperature: Warm conditions speed up development

Vernalisation: Cool, not freezing, temperatures advance the start of flower initiation in the majority of winter barley varieties

Day length: Long days advance floral development

Key management action timings

It is important to maximise ear number to achieve yield potential in both winter and spring barley. In particular, the tillering phase must not be limited by disease or a lack of nutrients.

Advisers who are BASIS-qualified (for crop protection products) or FACTS-qualified (for fertiliser) should be consulted for specific rate and timing recommendations.

Key developmental phases, with important management action timings, are shown in Figure 9.

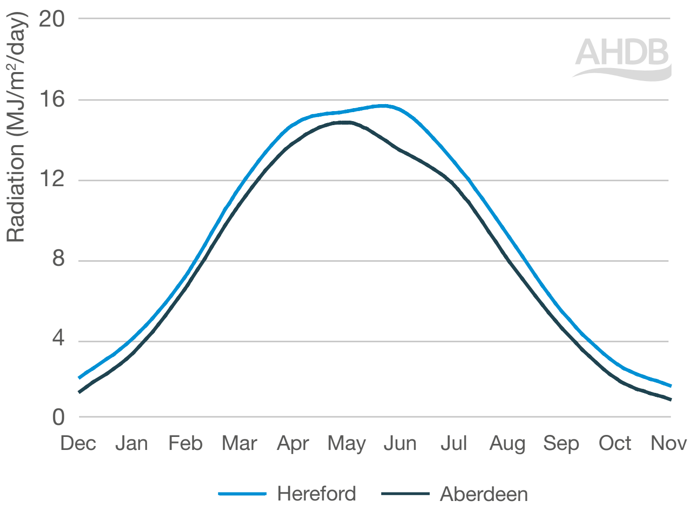


Figure 8a. Daily incident radiation in Hereford and Aberdeen
Mean of 30 years – Met Office data

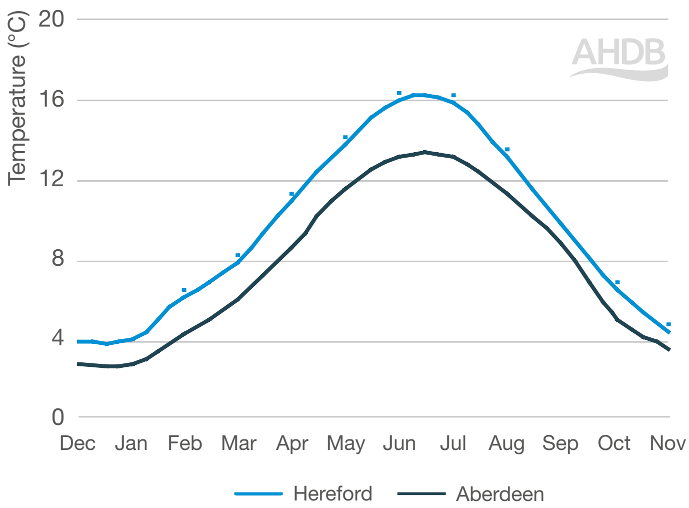


Figure 8b. Daily temperature difference in Hereford and Aberdeen
Mean of 30 years – Met Office data

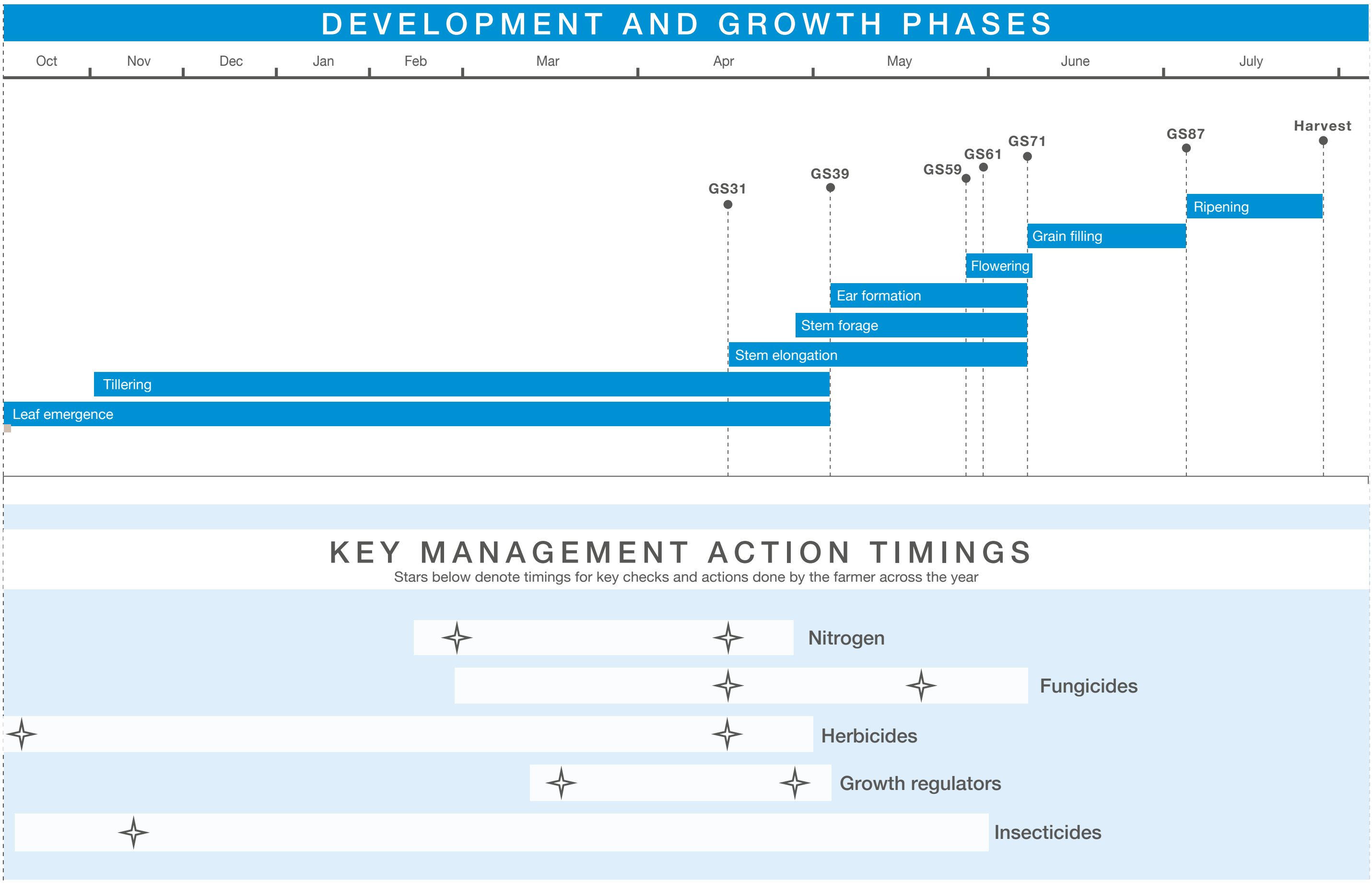


Figure 9. Barley developmental phases and key management action timings

Cereal growth stages

Germination: GS00–GS09

Seedling growth: GS10–GS19

Tillering: GS20–GS29

Stem elongation: GS30–GS39

Booting: GS40–GS49

Ear emergence: GS50–GS59

Flowering: GS60–GS69

Milk development: GS70–GS79

Dough development: GS80–GS89

Ripening: GS90–GS99

For more information on cereal growth stages, see the last section of this guide, 'Cereal growth stages and benchmarks'.

Sowing date

Sowing date has the greatest influence on early crop development. Later-sown crops pass through their developmental stages faster and complete each stage more quickly than crops sown earlier. Typically, crops sown several weeks apart will mature within days of each other.

In an average season, winter barley crops sown after 10 October reach key developmental stages later than the benchmark date. Any differences diminish over the season.

The window for sowing winter barley is narrower than for winter wheat. A low vernalisation requirement means barley is less suited to very early sowing, while yield declines faster when it is sown after mid-November.

Spring barley

Spring barley is typically sown from December until late April.

The crop is relatively frost-sensitive, so early sowing is not common in the North.

In a spring-sown crop, the three main phases (canopy formation, canopy expansion and grain filling) all last from six to eight weeks.

Speed of development differs little between varieties. Some varieties produce fewer tillers, making them less suited to late sowing.

Establishment

Establishment includes germination, emergence and overwinter survival.

Key facts

- Barley has limited ability to compensate for reductions in seed rates
- Germination is driven by adequate soil moisture, temperatures above 0ºC and oxygen
- Speed of emergence is governed by soil temperature and sowing depth
- Overwinter survival can be highly variable, depending on the site and season

Sowing to emergence

B Thermal time to 50% emergence = 150ºC days

Varietal influence: Low

Other influences: Sowing depth, soil conditions, temperature, seed quality

If soil moisture, temperature and oxygen levels are adequate, seeds will normally germinate. Germination rate is then controlled directly by soil temperature.

Initially, water penetrates the seed coat (imbibition), softening the hard, dry tissues inside. Good contact between seed and soil speeds up water transfer, which is particularly important in drier seedbeds. Water uptake activates the embryo and allows plant hormones to be transported through seed tissues.

Very wet or near-saturated soil conditions reduce the oxygen diffusion rate. In such conditions, despite normal imbibition, oxygen becomes limiting and reduces germination.

Temperature affects the rate of both germination and emergence (Figure 10). Accumulated mean daily temperature from sowing can be used to measure the 'thermal time' (ºC days) taken for crops to emerge.

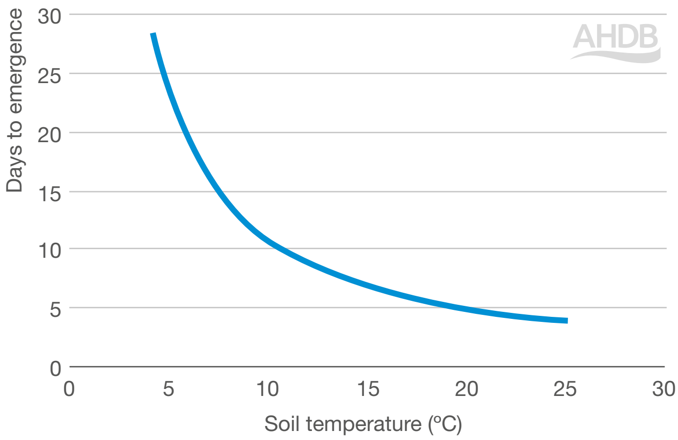


Figure 10. Seedling emergence (days) at various soil temperatures

Mean of all sites
Source: ADAS

At the reference sites, crops reached 50% emergence in 150ºC days. The thermal time to emergence was greater where dry soil limited germination. In autumn, as daily temperatures decline, crops take longer to emerge but emergence accelerates as temperatures rise in spring. In the South, the threshold of 150ºC days is reached sooner than in the North (Table 1).

Table 1. A comparison of time to reach 150°C days in the South and the North

	*Days to accumulate 150°C days	
Sowing date	North (Aberdeen)	South (Hereford)
15 September	13	11
15 October	18	15
15 November	34	25
15 December	48	34
15 January	48	35
15 February	38	28
15 March	28	21
15 April	21	16

Source: Met Office data
*Mean of 30 years

Establishment

B 85% of seeds sown established

Varietal influence: Low

Other influences: Cultivations, seed treatments, sowing depth, soil conditions, temperature, pests

Seed rates and plant populations

B Spring population = 305 plants/m^2

Compared to wheat, there is less scope for barley to compensate against low plant populations by increasing grain number in each ear, as each spikelet holds only one or three florets.

For hybrid barley varieties, lower seed rates are used than for conventional varieties, with approximately 200 seeds/m^2 being common. A target spring population for hybrids would be approximately 180 plants/m^2.

Barley is generally more susceptible to overwinter plant loss than wheat. Overwinter survival is site-dependent.

Losses can occur from frost heave or waterlogging, as well as pests. Seedbed consolidation reduces the risk of frost heave. Winter hardiness ratings of winter barley varieties are given in the AHDB Recommended Lists.

The risk of losses is increased by:

- Late and shallow sowing
- Manganese deficiency

How to measure plant populations

Seed rate calculations should be carried out to achieve a target plant population in spring, adjusting for expected establishment after losses.

$$\text{Seed rate (kg/ha)} = \frac{\text{Target plant population/m}^2 \times \text{Thousand grain weight (g)}}{\text{Expected establishment (\%)}}$$

Plant populations can be counted when the crop is fully established. Place a 0.5 m x 0.5 m (0.25 m^2) quadrat (or four 0.5 m long rods placed as a square) diagonally so that one row goes vertically from one corner to the opposite corner in 10 representative areas of a field and count the number of plants within the quadrat. Take the average of all counts and then multiply by four to get the number of plants per m^2.

For overwinter survival, count the plant population (as per the method above) after winter but before significant warming and growth occurs. At this stage, it can be hard to tell separate plants from tillers and plants may need to be dug up to determine actual numbers.

Implications for management

Consolidate seedbeds in dry conditions to improve seed-to-soil contact, water uptake and germination.

At drilling:

- Avoid late and shallow drilling
- Increase seed rate, when sowing after optimal dates, to offset poor establishment or tillering
- Consider pests, such as slugs and leatherjackets, when determining seed rates
- If appropriate, control aphid vectors to manage barley yellow dwarf virus (BYDV) risk in winter crops
- In autumn, correct any manganese deficiency, which can decrease winter hardiness
- Select varieties with good winter hardiness for northern and exposed sites

Spring barley

Ideally, the seedbed for spring barley should be fine and well-drained.

Early sowing or poor seedbeds may lead to reduced establishment, but early-sown crops often tiller well to compensate.

In a good seedbed, typical plant establishment is between 80% (early-sown) and 95% (late-sown). In a poor seedbed, establishment can vary from 55% (early-sown) to 70% (late-sown). Late spring drought may reduce establishment further.

Spring barley is less winter-hardy than winter barley. Site selection is important when considering sowing spring barley early.

Seed rate

Spring barley, especially when drilled late, compensates less well than winter barley for reduced plant populations, so there is less potential to reduce seed rate.

Drilling late-sown crops (after optimal date) at an increased seed rate reduces the risk of low ear numbers from poor tillering or establishment.

Leaf emergence and tillering

Tillering is one of the most important processes governing canopy development and crop yield. Seed rates and nitrogen influence tiller numbers.

Key facts

- Temperature drives the speed of leaf appearance (rates differ between varieties and sowing dates)
- Thermal time controls the number of leaves initiated
- Tiller production and survival are affected by climate and husbandry
- Final ear-bearing shoot number is a key component of yield

Leaf emergence

B 108°C days/leaf (phyllochron)

Varietal influence: Medium

Other influences: Sowing date, temperature

Leaves and tillers grow from initials (buds) produced by the stem apex before it switches to reproductive development in response to vernalisation and day length changes. The first leaf emerges from the coleoptile soon after drilling. Leaves then emerge continuously on main stems and tillers, until the final (flag) leaf emerges.

Temperature drives leaf emergence (Figure 11). The time period, measured in thermal time (°C days above a base temperature of 0°C), between the emergence of two successive leaves is called the phyllochron. Initially, winter barley leaves emerge rapidly during autumn. The rate slows over winter, then accelerates in spring until the final leaf emerges in May at GS39 (Figure 12).

Late-sown winter crops accumulate less thermal time to GS39. However, the phyllochron is smaller in later-sown crops so the rate of leaf emergence is more rapid.

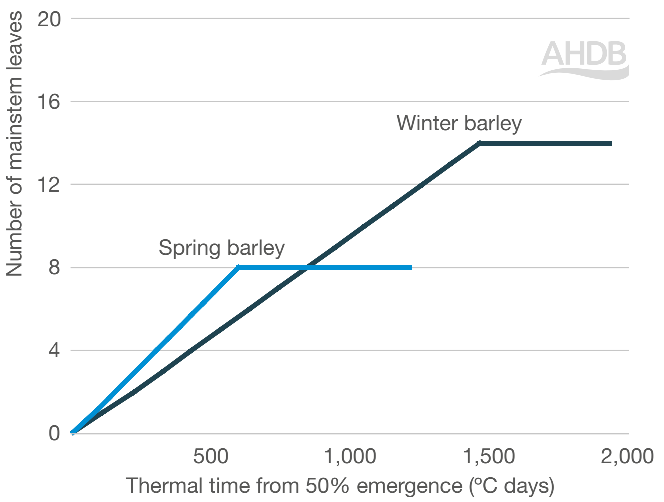


Figure 11. Effect of thermal time on leaf emergence in winter and spring barley

Winter barley data source: AHDB-funded research. Spring barley data source: SRUC

How to measure the phyllochron

The phyllochron can be measured by tagging the youngest, fully emerged leaf when plants have three fully emerged leaves, and again when they have seven fully emerged leaves. The proportion emerged of the next partially emerged leaf is noted at the same time, as well as the date of tagging. The tagged plants are monitored and at GS39 the number of leaves that have emerged since the last tag was attached are counted. Daily temperature data is then used to calculate the thermal time taken for each leaf to emerge.

Leaf number

B Average number of leaves = 14 (North = 13, South = 15)

Varietal influence: Low

Other influences: Sowing date, latitude

Late-sown winter crops have less time to initiate leaves before ear formation is triggered by cool weather in winter. For the same reason, crops usually produce fewer leaves at northern sites than at southern sites (Figure 12).

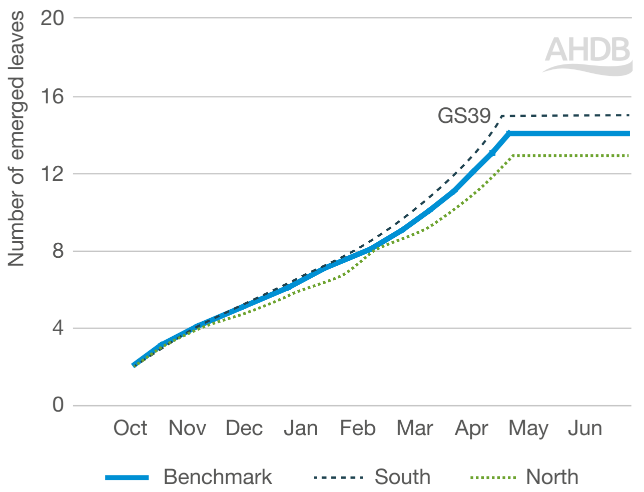


Figure 12. Leaf emergence in winter barley

Spring barley

Spring barley produces fewer leaves than winter barley and the phyllochron can be more than 20% shorter (e.g. 82°C days) depending on variety and sowing date.

Final ear numbers can be similar in spring and winter varieties; however spring crops tend to produce fewer tillers.

Maximising growth of tillers before stem extension increases their chance of surviving to form ears. Tiller production and survival are the most important factors determining yield in spring barley.

Tiller production

B Shoot numbers by GS30 (2 April) = 1,180 shoots/m^2

Varietal influence: Medium

Other influences: Sowing date, plant population, nitrogen supply

Tillering, which refers to the production of shoots in addition to the main stem, occurs after leaf 3 emerges and determines ears/m^2 – an important yield component.

Tillering starts rapidly in the autumn, slows over winter and can resume in the spring as temperatures and nutrient availability improve. Tillering may occur later, during stem extension, if spring drought restricts water and nutrient availability before moist conditions return.

Reference crops tiller equally well at northern and southern sites. The process of tiller death begins earlier at southern sites but final ear numbers are usually similar at all locations (Figure 13).

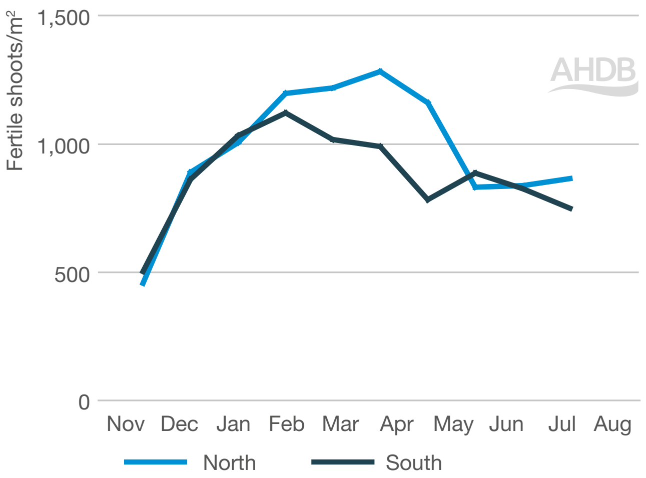


Figure 13. Tiller development of winter barley grown in northern and southern sites

How to measure tiller numbers

Tiller numbers/m² are counted using quadrats as per the plant population counts described in the Establishment section (page 11).

Final shoot number

B Final shoot number = 775/m^2 (3 shoots/plant)

Varietal influence: High

Other influences: Sowing date, plant population, nitrogen supply

Over the season, the maximum shoot number usually exceeds final shoot number. Increasing competition for both light and nutrients results in smaller and younger tillers dying, which makes way for the main yield-forming shoots.

Generally higher dry matter at GS31 contributes to better survival rate of the shoots (Figure 14).

The maximum fertile shoot number is similar throughout the UK, but is reached earlier in the South.

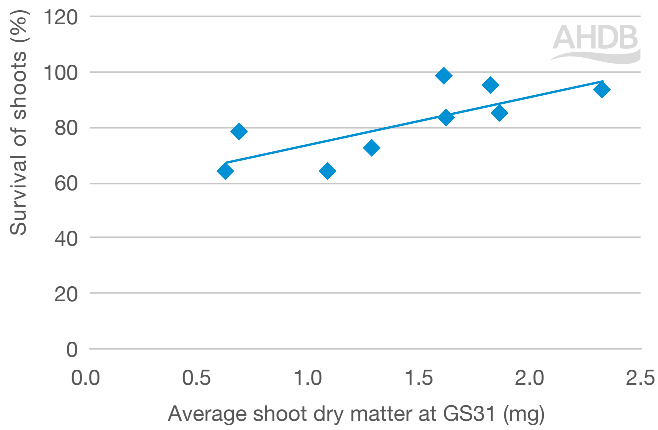


Figure 14. Correlation between average shoot biomass and survival percentage in spring barley
Source: SRUC and Teagasc

Implications for management

- For winter barley, review nitrogen timing and rate to remedy low tiller numbers in spring
- For spring crops, promote rapid early growth to maximise tiller production and survival
- Ensure good weed control to reduce competition and maximise tiller production and survival
- Ensure fungicide strategies are implemented to prevent diseases from restricting shoot number

Root growth and distribution

Soil structure, management and drainage have major effects on root growth and distribution.

Key facts

- A mature root system has 20 or more main roots per plant, with many branches
- Root distribution through the soil profile determines water and nutrient capture
- Good rooting, especially deep rooting, will enhance crop growth when water is limited

Roots begin to grow at germination, with three to six seminal roots emerging from the seed. These can grow deep and persist throughout the crop's life.

The number of crown roots, which develop from the stem base, relates to leaf and tiller numbers. Once the main shoot has three to four leaves, crown roots appear with thickened upper regions to anchor the plant. The mature root system has 20 or more roots on each plant, plus numerous root branches.

In well-drained and well-structured soil, the rate of root extension depends on temperature (Table 2).

Table 2. Typical main root daily extension rates in deep and well-structured soil

Season	Extension rate (mm/day)
Autumn	12 mm
Winter	6 mm
Spring	18 mm

The relative distribution of roots down the soil profile changes little between GS31 and anthesis. Over 70% of root length is found in the top 30 cm.

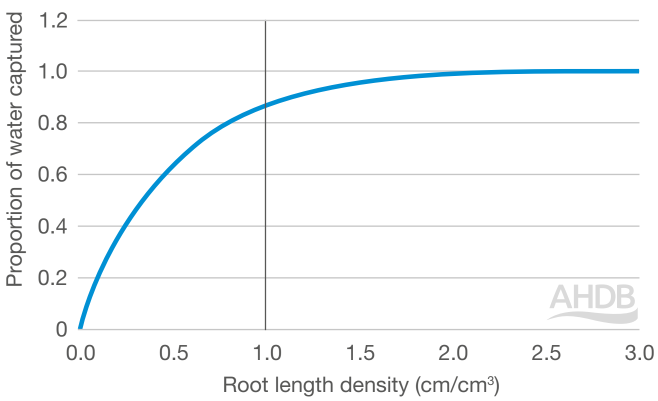


Figure 15. Effect of root length density on captured water

Source: ADAS

High uptake rates of less mobile nutrients, such as phosphorus (P), only occur when root length density exceeds 5 cm/cm^3 of soil. Lower root length densities are adequate for potassium (K) uptake. Proportion of water uptake increases with higher root length densities (Figure 15) and about 1 cm/cm^3 is required for an optimum uptake of nitrogen and water.

Root growth up to stem extension

Varietal influence: Medium

Other influences: Sowing date, plant population, soil structure, phosphorus availability

Root growth after stem extension

Varietal influence: Medium

Other influences: Sowing date, plant population, soil structure, PGRs, fungicides

Implications for management

Soil structure has a major impact on root growth and distribution. In some clay-rich soils, moisture extraction by roots promotes cracking, which improves soil structure and root access in following seasons. Hence, deep rooting can be self-sustaining, unless wheelings or cultivations destroy soil structure. With minimal tillage, enhanced earthworm activity creates long, continuous pores in the subsoil to aid root penetration.

- Early sowing and some PGRs may help to increase rooting but the main ways root systems can be managed is indirectly, through improved soil structure and drainage
- Varietal differences in crown root spread and low plant population can be used to help maximise anchorage strength

How to measure rooting

The established method for measuring root length involves taking soil cores, washing the soil from the roots and using a scanner to measure the roots. This method is time-consuming and requires specialist equipment.

An early visual assessment of rooting can be made by digging up representative plants with a spade within a couple of months of planting, measuring rooting depth with a ruler and weighing the washed roots to obtain root biomass. If a soil core is available, soil can be extracted to 90 cm in the spring and before harvest to assess changes in soil moisture as a proxy for rooting depth. Sampling from representative areas of the field is important, either based on soil type or crop growth.

Alternatively, soil structure can be assessed as a proxy for rooting, as good soil structure will allow the roots to penetrate to depth more easily and capture available water.

The Visual Evaluation of Soil Structure (VESS – details available at **ahdb.org.uk/vess**) involves soil removal (to 30 cm depth), assessment and scoring, and can be carried out at any time of year (but preferably when the soil is moist).

Nitrogen uptake

The majority of nitrogen is taken up by the time the crop reaches flowering.

Key facts

- Soil rarely supplies all the nitrogen required by the crop
- Nitrogen fertiliser applications can be used to manage canopy size
- Over the season, nitrogen affects different aspects of canopy growth

Pattern of nitrogen uptake

Nitrogen uptake by the crop determines canopy size, primarily by affecting shoot number.

Varietal influence: Low

Other influences: Nitrogen supply, temperature, sowing date

Overwinter to mid-March

Early-sown crops are likely to experience good autumn growing conditions with increased nitrogen uptake, assuming soil nitrogen availability is not limiting.

Mid-March to GS31

B Rate of nitrogen uptake = 1.2 kg/ha/day

B Total uptake = 65 kg/ha by GS31

Rate of nitrogen uptake increases in mid-March as warmer conditions stimulate canopy expansion through more rapid leaf emergence and tillering (Figure 16).

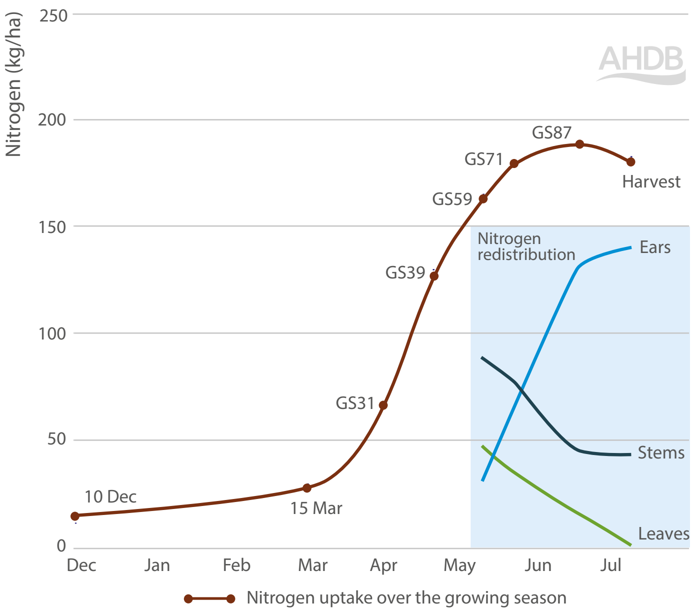


Figure 16. Uptake of nitrogen and its distribution in above-ground tissues in winter barley crop

GS31 to GS39

B Rate of nitrogen uptake = 3.1 kg/ha/day

B Total uptake = 128 kg/ha by GS39

Rapid nitrogen uptake continues as canopy size increases through leaf emergence and tiller survival.

GS39 to GS59

B Rate of nitrogen uptake = 1.8 kg/ha/day

B Total uptake = 163 kg/ha by GS59

Nitrogen uptake slows as canopy size peaks and ears begin to form (Figure 16).

Canopy nitrogen requirement

B 28 kg nitrogen/ha per GAI unit

B Total nitrogen uptake = 181 kg nitrogen/ha at harvest

Varietal influence: Medium

Other influences: Nitrogen supply

Barley is usually grown after winter wheat (a crop with a high nitrogen demand), often on lighter, low nitrogen status soils, which are more prone to nitrate leaching.

Soil nitrogen is rarely sufficient for crop requirement. Unless adequate nitrogen is made available, shoot numbers and yield will be restricted.

After ear emergence, relatively little nitrogen is taken up and nitrogen is redistributed within the plant. Protein in leaves and stems is transferred to form grain protein (Figure 16).

However, root systems remain active after flowering and will take up nitrogen if the soil is moist and there is mineral nitrogen in the soil profile.

Spring barley

The nitrogen offtake in spring barley at harvest is typically 25–30% less than that of winter barley (i.e. 130 kg nitrogen/ha at harvest), but it depends on fertiliser management and target end use. Crops grown for feed, rather than for malting, have higher fertiliser nitrogen applications and greater nitrogen offtakes.

If nitrogen is available after flowering, it will be taken up and accumulated in both straw and grains. Spring barley grains have the capacity to store up to around 1 mg of nitrogen per grain at a concentration of 2.4%.

Yield is strongly dependent on timing and rate of nitrogen fertiliser applications.

Response to fertiliser nitrogen

When the supply of nitrogen from the soil is insufficient to meet crop nitrogen requirement, fertiliser nitrogen applications should increase yield. There is, typically, a steep yield response to the initial nitrogen fertiliser dose, before plateauing near the optimum rate and sometimes decreasing at super-optimal rates, due to lodging.

Fertiliser nitrogen increases the grain nitrogen concentration as shown in Figure 17.

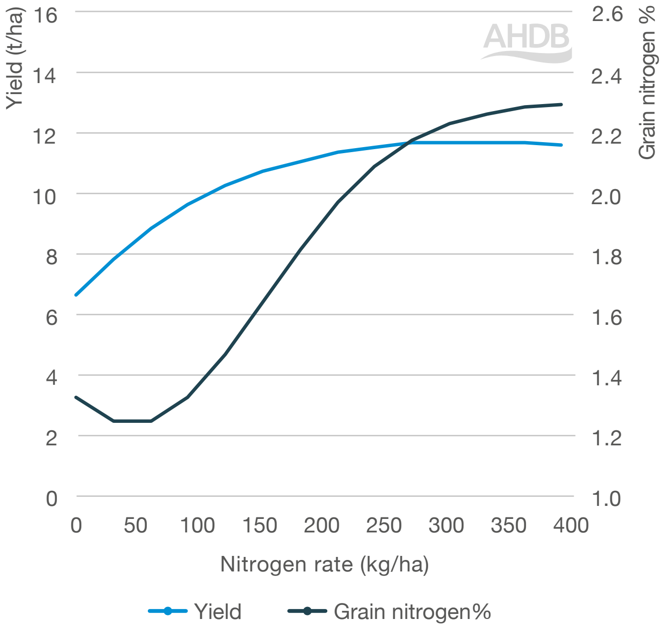


Figure 17. Relationship between yield and grain nitrogen concentration for winter barley (variety: Venture)

Implications for management

Where soil nitrogen residues may be large (>120 kg nitrogen/ha) or uncertain, soil mineral nitrogen analysis is a better predictor of available soil nitrogen than the field assessment method. It should include an estimate of crop nitrogen content at the time of soil sampling.

Early spring nitrogen during tillering is important for most barley crops and has been shown to increase yield.

- Apply early nitrogen to encourage tillering, especially after poor establishment or to overcome root restrictions where there is soil compaction or a risk of take-all
- Applying more of the nitrogen early in spring reduces the grain nitrogen concentration
- More early nitrogen also increases crop height, straw yield and lodging risk. Where large amounts of early nitrogen are used, plant growth regulators (PGRs) should be considered

Late spring nitrogen after tillering is needed by most crops. It encourages rapid canopy expansion, mainly through better tiller survival.

- Use late spring nitrogen before the canopy turns pale and tillers start to die
- Nitrogen applied during late stem extension or later increases the grain nitrogen concentration

How to measure soil nitrogen

Soil nitrogen supply can be estimated by a field assessment method (FAM) described in the **AHDB Nutrient Management Guide (RB209)** or, if the soil nitrogen level is potentially high (>120 kg nitrogen/ha) or uncertain, by a soil mineral nitrogen (SMN) measurement. SMN is often measured down to a depth of 90 cm in the spring (before any nitrogen is applied).

How to measure crop nitrogen uptake

Nitrogen uptake can be measured any time during the season using a quadrat (see Establishment section for details). For each quadrat, cut the plants at ground level, dry them and weigh them, then send a subsample to a lab for grinding and percentage nitrogen determination. To determine the total amount of nitrogen on an area basis, the percentage nitrogen in the crop needs to be multiplied by total dry weight of the crop. To determine the nitrogen redistribution to the grain, this assessment needs to be done just before harvest, the grain separated from the straw/chaff and percentage nitrogen measured for both samples.

Nitrogen guidance

For the latest information, see the **Nutrient management guide (RB209) at ahdb.org.uk/RB209**

Canopy expansion and senescence

Canopy refers to all the crop's green surface area (leaves, stems, ears and awns), with leaf blades forming the largest area. Canopy size is determined by both leaf emergence/expansion and shoot numbers.

Key facts

- Canopies go through three distinct phases:
  - Slow expansion
  - Rapid expansion
  - Senescence and death
- Canopy size determines the proportion of sunlight intercepted and subsequent dry matter increase
- Canopy growth and lifespan is responsive to crop management

Canopy size can be expressed as Green Area Index (GAI) – the ratio of total green area (one side only) to the ground area occupied (Figure 18).

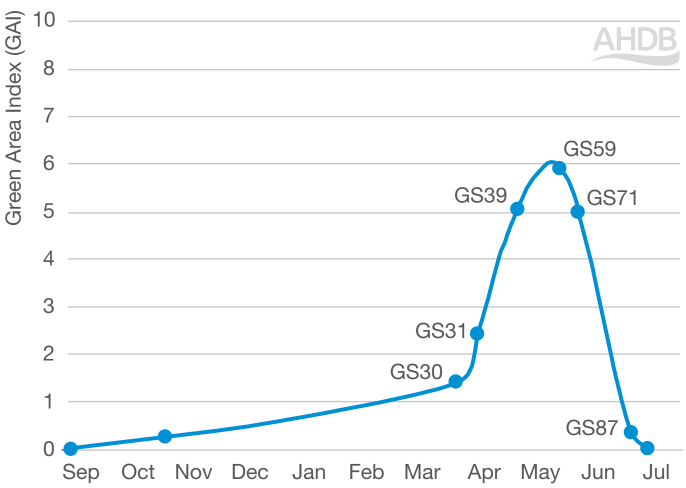


Figure 18. Change in Green Area Index (GAI) over the growing season for winter barley

Early canopy expansion

B GAI = 1.4 by GS30 (2 April)

Varietal influence: Medium

Other influences: Temperature

Leaves and tillers emerge through the autumn and winter. At this time, the crop is small and there is relatively little light to intercept. Cooler temperatures and low light levels will slow leaf emergence, tillering and growth during this period. For further details, see Figure 18 above.

Rapid canopy expansion

B Canopy closure* (GAI 3) = 21 April

*5 days after GS31

B Peak GAI at GS59 = 5.8

Varietal influence: Medium

Other influences: Temperature

From GS30, canopy expansion accelerates as tillering continues and leaf emergence increases with rising spring temperatures. Canopy expansion continues until shortly after ear emergence.

Between GS30 and ear emergence (GS59), crop growth equates to an average of one unit of GAI every 12 days. Growth is most rapid from GS30 to GS39, when GAI increases by one unit every week (Figure 18). Canopy closure occurs when the ground is completely shaded by leaves.

As the canopy becomes thicker, each increase in GAI contributes less additional intercepted light energy, until full light capture is achieved (Figure 19). For example, an increase from GAI 2 to 3 captures 15% more light, whereas only 2% extra is captured as GAI rises from 6 to 7 (Figure 19).

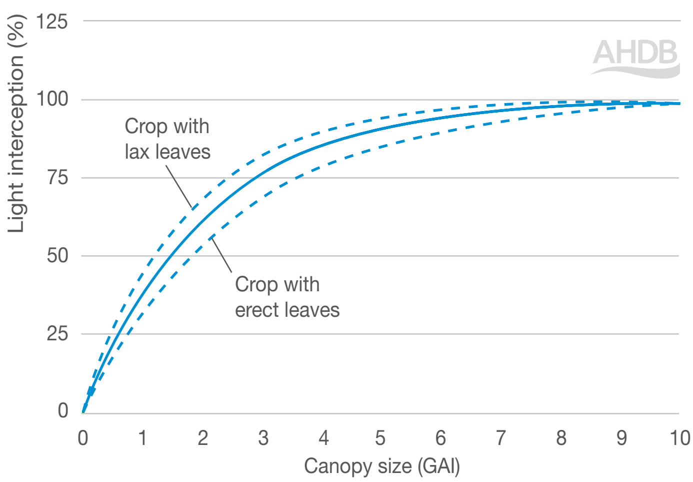


Figure 19. Light interception by crop with different canopy sizes

Canopy senescence

B GAI = <0.5 by 5 July

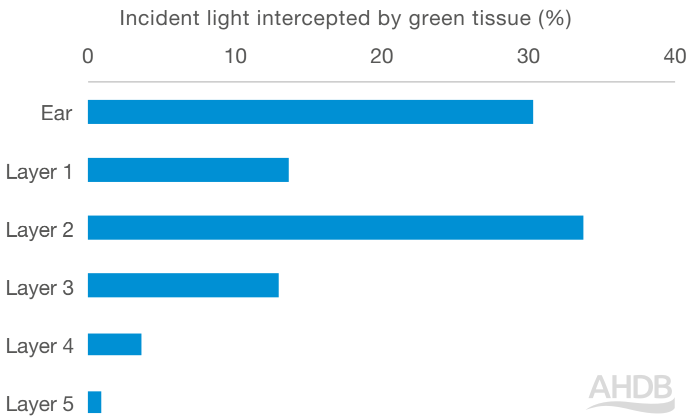
Varietal influence: Medium

Other influences: Nitrogen supply, temperature, rainfall

Loss of canopy green area begins soon after ear emergence as lower leaves progressively die. GAI falls from 3 to less than 1 in just 10 days.

Spring barley

Canopy expansion tends to be more rapid in spring barley and peak GAI is often around 10–15% less than winter barley (i.e. GAI around 5 at GS59). However, canopy size is highly dependent on crop management.



Source: SRUC

Figure 20. Light interception by ears and different leaf layers in spring barley crop at flowering

Light interception

Unlike wheat, the flag leaf of barley is small and intercepts relatively little light. Most of the light is intercepted by the ear and leaf layer 2 (leaf 2 plus the stem immediately above it). See Figures 20 and 21. Ears (including awns) and stem also contribute to the photosynthesis of the canopy.

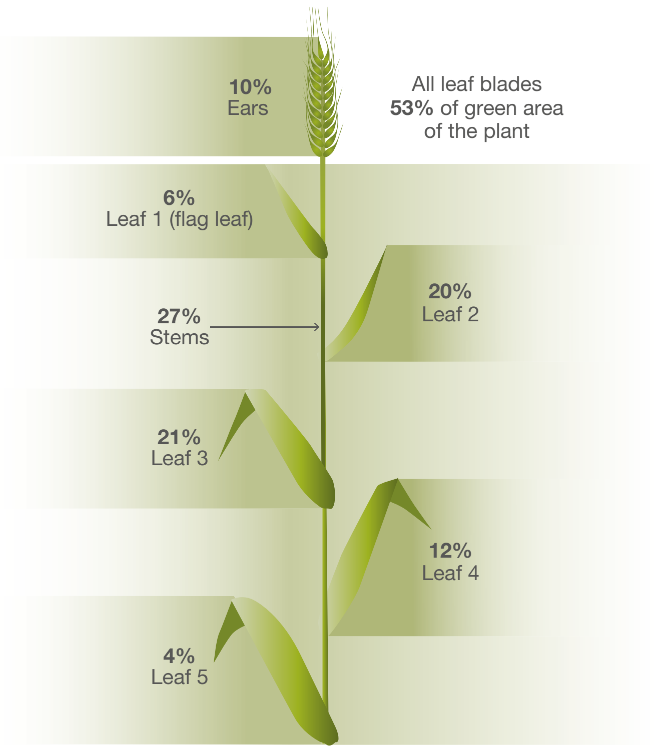


Figure 21. Distribution of green area for different leaf layers in winter barley

Implications for management

- Ensure crops have adequate nitrogen to achieve benchmark canopy size at GS59 (GAI 5.8)
- Maintain adequate levels of soil potassium
- Protect early canopy against disease (T1 timing is more important in barley compared with wheat)
- Consider options to increase shoot number and canopy size:
  - Sow earlier
  - Use higher seed rates
  - Apply spring nitrogen earlier

How to measure GAI

GAI can be measured in several ways.
The simplest is to assess the green leaf area compared to the ground area by eye. A more accurate method involves cutting a known area of crop (e.g. 1 m^2), removing the leaves and feeding them through a leaf area meter.

Some apps are now able to measure GAI from a photo taken vertically above the crop. Multiple photos should be taken to get an average for a field. Apps are most accurate for growth stages up to early stem extension (around GS32).

Sensors (handheld, tractor-mounted, on drones or satellites) measure reflectance of different wavelengths of light. Various vegetation indices are then calculated, usually using near infrared or red wavelengths, which indicate crop cover.

Biomass growth

Biomass growth represents the net effect of photosynthesis after losses from respiration and leaf fall. It can be assessed by measuring changes in above-ground dry matter over time.

Key facts

- Growth is slow before the canopy closes
- Greatest growth occurs once the canopy has closed after early stem extension
- Crop dry weight gain slows midway through grain filling after considerable canopy senescence
- Barley growth is maximised in bright, cool weather

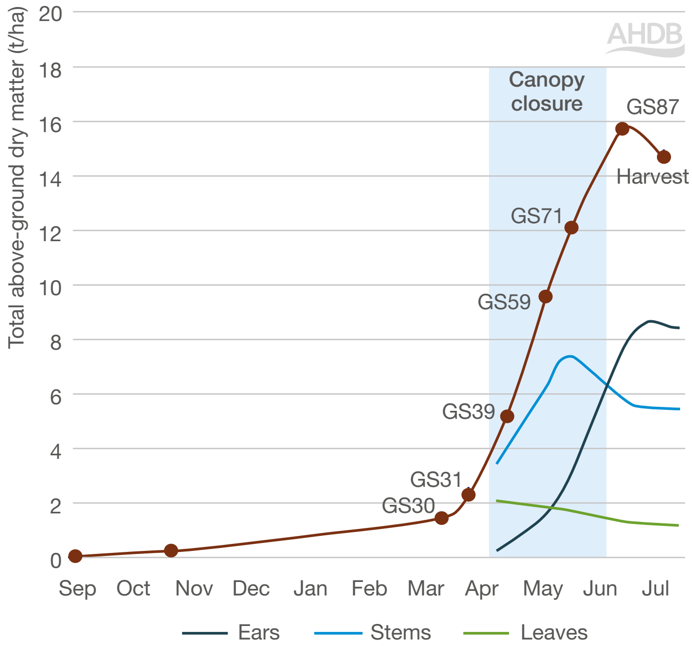


Figure 22. Changes in crop dry matter over a growing season

Growth up to canopy closure

B Growth before canopy closure = 2.7 t/ha by 21 April

Varietal influence: Medium

Other influences: Nitrogen supply, sowing date, plant population, temperature

Between sowing and canopy closure (about five days after GS31), some 18% of total dry matter is produced. Growth is slow during this period which can extend up to 200 days as the canopy is incomplete (Figure 22).

Growth after canopy closure

B Growth after canopy closure (GAI >3) = 0.2 t/ha/day dry matter (an extra 11 t/ha by 20 June)

Varietal influence: Medium

Other influences: Nitrogen supply, light, temperature, water

A GAI of over 3 is maintained for eight weeks. During this period (early stem extension to late grain fill), the crop generates about 70% of its total dry matter. The length of this phase is largely governed by temperature.

During this phase, the crop intercepts more than 70% of available light for photosynthesis. Light availability affects the rate of dry matter accumulation. Cloud cover can reduce light energy by 75%.

The canopy begins to senesce at GS59 but dry matter gain hardly decreases until midway through grain filling.

Dry matter redistribution during grain filling

Varietal influence: Medium

Other influences: Nitrogen supply, plant population

Dry matter accumulates in the ear until GS87 (Figure 22) when maximum crop dry weight occurs. During this period, stems and leaves lose weight through respiration and translocation of carbohydrate reserves and nitrogen into the developing grain. Stems don't lose soluble reserves until after GS71 when final internodes stop extending. After GS87, as leaf tissue is shed before harvest, the crop dry weight falls (Figure 22).

Spring barley

Between GS31 and ear emergence, the crop accumulates biomass at 0.2 t/ha/day.

Final total biomass in spring barley (12.5 t/ha at GS87) is about 80% of winter barley.

How to measure dry matter

Crop dry matter can be measured at any time during the season.

Sample, dry and weigh the crop from a 0.5 m x 0.5m (0.25 m^2) quadrat (see nitrogen uptake section) and multiply the weight by four to determine the weight in 1 m^2.

Alternatively, crop vegetation indices – calculated from spectral reflectance measurements taken by crop sensors – can be used as a proxy for crop dry matter (see Canopy expansion and senescence section, page 18).

Diseases

Stem and root diseases

Take-all, eyespot and other stem-base diseases may restrict water and nutrient uptake and curtail crop growth. Barley usually follows wheat in arable rotations, increasing pressure from these diseases. Growing barley as a first cereal helps to reduce yield losses.

Foliar diseases

Foliar diseases, such as rhynchosporium, net blotch and mildew, all reduce canopy size and also curtail growth. Disease control measures help protect leaf area and minimise disease impact on shoot number, grain number/ear and grain weight.

Implications for management

- Control rabbits and slugs to protect young tillers in autumn and winter
- Adopt measures to hasten canopy closure in spring if necessary
- Control diseases to preserve green leaf area
- For future years, consider earlier drilling if canopy develops late

Figure 23. Ramularia leaf spot can also lead to yield losses in barley

Stem elongation

Crop height is a reflection of variety and growing conditions.

Key facts

- Stem height is determined by the extension of the last five internodes
- Variety and growing conditions affect height
- Height influences lodging risk, which can be reduced by plant growth regulator (PGR) use and careful management of nitrogen fertiliser

Height and node number

B Nodes in extended stem = 4 (5 internodes)

Varietal influence: High

Other influences: Sowing date, PGRs, nitrogen supply

B Final height* = 93 cm
North = 89 cm; South = 98 cm

*Barley height is measured from soil level to collar of ear.
PGRs = chlormequat at GS30–31, Terpal at GS37–39

At GS39, barley reaches nearly half of its final potential height (Figure 24). Agronomic conditions and crop management influence its final height. After GS59, only small increases in crop height occur.

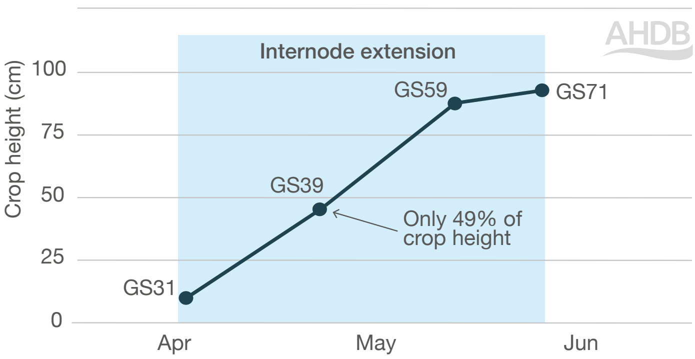


Figure 24. Barley grows taller as internodes extend

Spring barley

Spring barley varieties are 10–20 cm shorter than winter barley varieties. At flag leaf emergence, spring barley reaches only 57% of its final height.

Lodging risk

Barley can lodge as a result of anchorage failure (root lodging), buckling of the stem base (stem lodging) or buckling of the upper half of the stem (brackling or necking). In general, barley is more prone to stem buckling than root lodging.

Lodging resistance scores, measured on a 1–9 scale (9 is very lodging-resistant), are described in the AHDB Recommended Lists. Resistance generally ranges from ‘lodging-prone’ (4) to ‘lodging-resistant’ (8).

The following factors also influence lodging risk:

- Soil mineral nitrogen at high levels promotes thick, dense canopies susceptible to stem lodging
- Fertiliser nitrogen applied early, or in excessive amounts, increases tiller numbers and reduces stem strength
- High plant populations increase lodging risk, mainly due to reduced anchorage strength
- Crops with a large canopy (GAI >1.5) at the start of stem extension (GS30) tend to have a greater lodging risk due to weaker stems
- Plant growth regulators (PGRs) reduce lodging risk primarily by shortening the crop. Reducing height by 5 cm increases lodging resistance by the equivalent of one varietal lodging resistance score

PGRs can be applied between late tillering and GS45. PGRs that inhibit gibberellic acid are usually most effective when applied at early stem extension. PGRs containing 2-chloroethyl phosphonic acid are usually most effective when applied during late stem extension up to GS45. The PGR chlormequat is less effective in barley than in wheat. Sequences of PGR types can reduce height by up to 15 cm.

Implications for management

- Consider varietal lodging risk and note that tall varieties are not always the most lodging-prone
- Assess lodging risk early in the season, before GS30, by considering GAI and variety
- Late-season growth regulators have a significant effect on final crop height, but can be damaging if the crop is under stress

How to measure stem elongation

Height can be measured any time during the season by placing the end of a metre ruler on the ground and measuring the height to the tip of the stem, base of ear or top of ear (the ear adds around 10 cm). At least 10 shoots should be measured and an average taken. Before GS39, the height of the main-stem (largest stem) of a plant should be measured, but after this stage any tiller can be measured.

The proportion of a crop that is lodged can be assessed from its first occurrence. A % lodging index can be calculated:

Lodging Index = % Crop leaning (10 to 45° from vertical) ÷ 3 + % Lodging (>45° from vertical but not flat) ÷ 2 + % Lodged flat to ground

Stem carbohydrate storage

Stem reserves, mainly sugars (fructans), reach a maximum shortly after flowering.

Key facts

- Stem reserves buffer the crop against poor growing conditions at grain filling
- Grain fill depends on photosynthesis and stem reserves

Stem reserves

B Reserves at flowering = 1.6 t/ha

Varietal influence: High

Other influences: Plant population, nitrogen timing, fungicides

Stem reserves reach maximum level approximately nine days after GS59 (Figure 25). Taller crops have more structural stem material, but stem height does not reflect stem reserves.

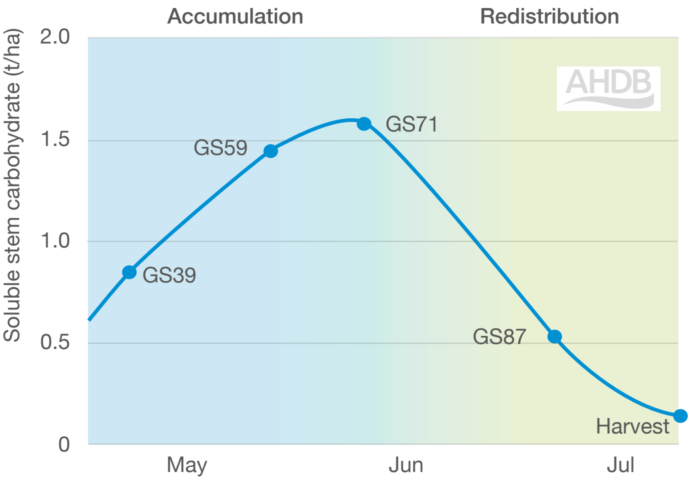


Figure 25. Accumulation and redistribution of stem carbohydrates

Table 3. Comparison of stem dry matter and soluble stem reserves in the North and the South

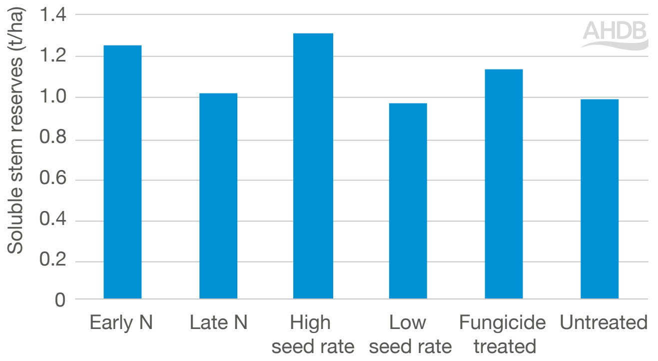
Region	Growth stages	Stem dry matter (t/ha)	Soluble stem reserve (t/ha)
North	GS39 (9 May)	3.1	0.9
	GS59 (30 May)	5.7	1.3
	GS71 (11 June)	6.8	1.7
	GS87 (14 July)	5.3	0.4
South	GS39 (3 May)	3.1	0.8
	GS59 (21 May)	5.7	1.1
	GS71 (5 June)	6.9	1.8
	GS87 (28 June)	5.1	0.3

Remobilisation of stem reserves

Reserve redistribution begins after grain filling starts. This accounts for a decrease of about 1.5 t/ha in dry stem weight between flowering and harvest.

Stem reserves contribute 20–50% of total yield. In stressed crops, stem reserves contribute a higher proportion. Reserves make a smaller contribution to yield where post-flowering canopy survival is good.

Crop management has a significant effect on the accumulation of reserves (Figure 26).



Data from a Sustainable Arable LINK project, with SRUC and ADAS as partners

Figure 26. Effect of crop management on stem reserves of spring barley at GS59

Spring barley

The amount of stem reserves accumulated by spring barley at GS59 is comparable to that of winter barley.

Reserves are greater when nitrogen is applied at crop emergence and in crops grown at high seed rate and treated with fungicide. The effects are mostly the result of increases in stem biomass per ha, rather than the concentration of sugars in the tissue.

How to measure stem reserves

After stems are fully extended, pull up at least 10 stems (taking care not to break them) and remove leaf laminae, roots and ears. Dry the whole stems rapidly (at around 100°C), weigh them and send them for analysis by an appropriate laboratory. To determine the soluble stem reserves on an area basis, you will need to know the number of tillers in an area and multiply this by the Water Soluble Carbohydrates (WSC) per stem.

Ear formation

The storage capacity of each ear is determined by grain size and grain number per ear. Grain number has more effect on yield than grain size.

Key facts

- Grain number/ear is determined between flag leaf and ear emergence
- Barley has limited potential to compensate for low ear number by increasing grains/ear

Grain number determination

B Flag leaf to ear emergence = 20 days

B Grain number/ear = 24
North = 25; South = 24
Average of main shoots and tillers at harvest

Varietal influence: High

Other influences: Nitrogen supply, plant population, sowing date

Ear development

Varietal influence: High

Other influences: Nitrogen supply, plant population, sowing date

Grains/ear

Varietal influence: High

Other influences: Plant population

As the number of plants per m² increases, the number of grains per ear starts decreasing as shown in Figure 27.

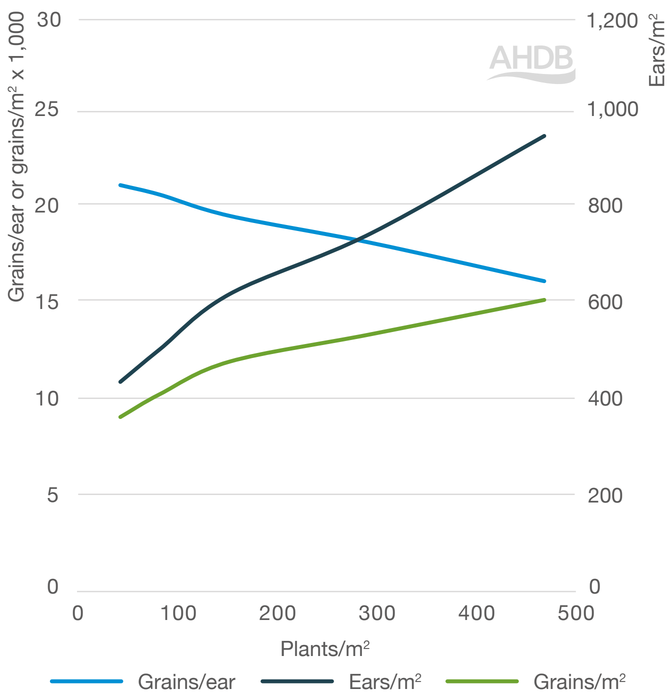


Figure 27. Impact of plant density on number of ears and grains in spring barley

The number of grains on each ear depends on the number of fertile spikelets on the rachis – the central 'stem' of the ear. In two-row barley, spikelets form in threes.

However, only the floret in the central spikelet is fertile. In six-row barley, florets in all three spikelets are fertile. Wheat spikelets contain up to nine florets (Figure 28).

With only one grain per spikelet, barley is often unable to compensate for low ear numbers by increasing grains per ear.

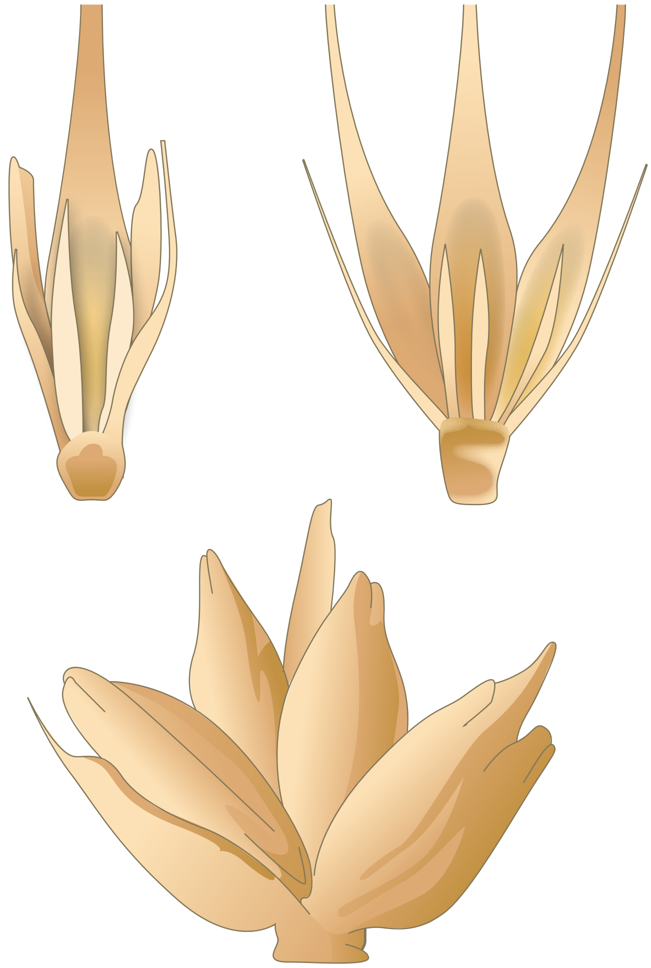


Figure 28. The number of grains on each ear depends on the number of fertile spikelets: (top left to right) two-row barley spikelet, six-row barley spikelet, (bottom) wheat spikelet

Grain number

Ⓑ Flag leaf to ear emergence = 20 days

Ⓑ Grain number/ear = 25
Average of main shoots and tillers at harvest

Ear weight

By flowering, the ear comprises florets containing grain, glumes and rachis. Grain dry weight increases slowly at first, then rapidly after GS71 (Figure 29). While grain weight increases, the weight of other parts of the ear remains almost unchanged.

Ⓑ Ear dry weight at flowering = 0.16 g/ear

Ⓑ Ear dry weight at harvest = 1.11 g/ear

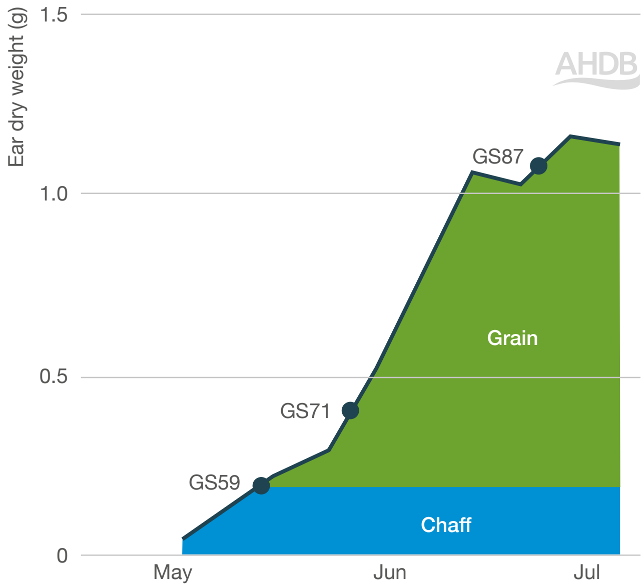


Figure 29. Dry weight accumulation of barley ears at different growth stages

Implications for management

Grains/m² and the size of individual grains determine storage capacity during grain filling. In barley, grain yield is more strongly related to grain number than grain size. Therefore, early management decisions to maximise tiller production and survival are particularly important.

How to measure grain number and ear weight

The number of grains per ear can be measured just before harvest by taking ear samples, threshing them and counting the number of grains. At least 20 representative ears should be taken and a mean of the grain numbers calculated. This data can then be combined with shoot counts to calculate grains/m².

Ear weight at flowering can be measured by taking at least 20 representative ears, drying them, weighing them, then dividing by the number of ears sampled.

Grain filling and ripening

It is important to keep the green canopy healthy for at least five weeks after ear emergence to ensure the grains are fully filled.

Grain ripening takes a further two to three weeks after grain filling is completed. During this period, dry matter content increases and water content decreases (Figure 30).

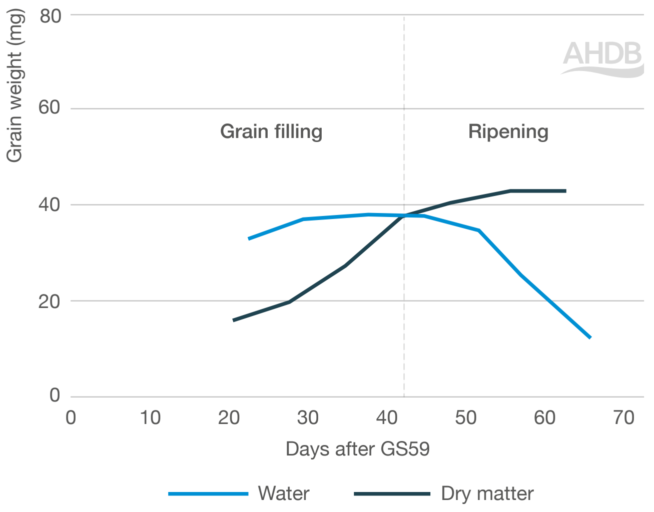


Figure 30. Grain dry weight and water content for winter barley

Final grain dry weight, appearance and specific weight are all determined during grain filling. Poor grain filling usually results in low specific weight.

Benchmark data is for six grains from the central part of the ear.

B Dry matter = 39 mg/grain

North = 41 mg
South = 38 mg

Grain filling period lasts for 40 days to 5 July.

Canopies lose most greenness in the two weeks before grain weight reaches its maximum.

B GAI = <1

Three days before maximum grain weight

After filling, seed moisture content provides the best index of ripening until grains are dry enough to harvest. Seed moisture content declines (from 70% to 45%) as dry matter accumulates in the grain, then goes down to 20% due to water loss.

Spring barley

On average, spring barley varieties produce 19–24 grains/ear – fewer than in winter barley.

Typical grain filling period is 34–41 days

Typical ear weight at GS87 is 0.8–0.9 g

Typical GAI at GS87 is 0.1–1.0

Figure 31. Winter barley crop at different developmental stages

How to measure grain filling, moisture and ripening

The grain filling period can be estimated by counting the number of days between GS65 and when the gain reaches 45% moisture content. Grain moisture can be determined by weighing grain threshed from around 20 ears, drying at 80–100°C until no further weight loss and then weighing again.

Moisture content = 100 - (grain dry weight ÷ fresh grain weight) x 100

The grain ripening period is the number of days from 45% moisture until it reaches 20% moisture.

If a grain sample is taken at the end of the grain filling period, the dried and weighed grain can then be counted and divided by the number of grains to determine the dry matter per grain.

Implications for management

To ensure grains are fully filled, use an effective fungicide strategy to maintain a healthy green canopy for at least five weeks after ear emergence.

Yield

Yield depends on the number of ears per unit area and the weight of each grain.

Key facts

- Grain yield is made up of ears/m^2, grains/ear and average grain weight
- Grain yield represents about half of the total above-ground crop dry matter produced
- Total crop dry weight indicates likely yield because the harvest index is relatively stable

Grain yield

B 8.8 t/ha at 15% moisture

Yield components

B 775 ears/m^2

B 25 grains/ear

B 46 mg/grain

Yield = Ears/m^2 x Grains/ear x Average grain weight

Most yield variation between sites and seasons reflects differences in grain number, rather than grain size (Figure 32). However, late-season drought, lodging or disease all impair photosynthesis, hence can reduce grain filling.

High yields depend on sufficient numbers of ears, so crop managers should aim to maximise growth as ears form. Some compensation for low ear numbers can occur but only crops with relatively few shoots produce more grains/ear (Figure 32).

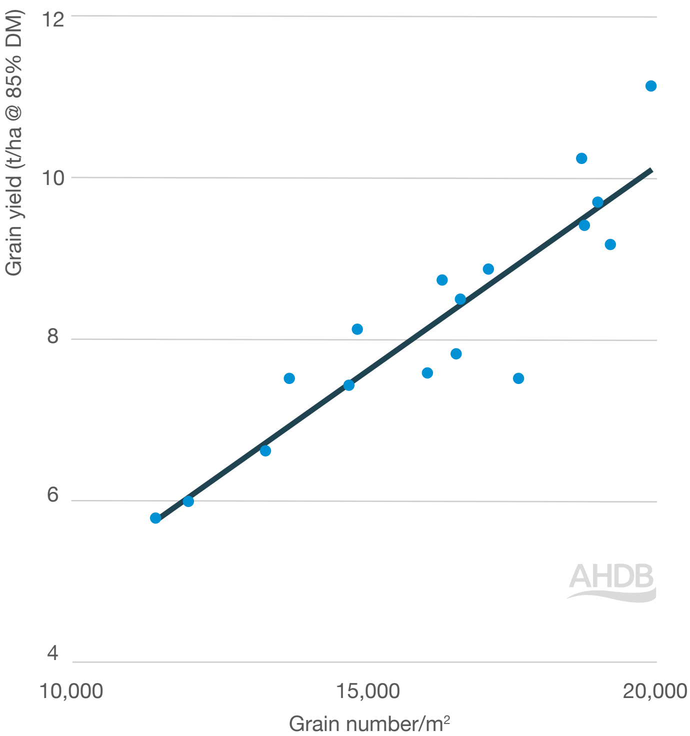


Figure 32. Contribution of grain number/m^2 to yield for winter barley

Harvest index

B Crop dry weight at harvest = 14.8 t/ha of which:

Grain = 51%
Stem and leaf material = 43%
Chaff = 6%

Varietal influence: High

Other influences: All aspects of husbandry, rainfall

The harvest index (ratio of grain weight to total above-ground crop weight) varies relatively little between site and season, unless serious lodging, late-season drought or disease significantly reduce grain filling.

Spring barley

Spring barley yields about 20% less than winter barley, although the difference is smaller in the North than in the South.

In spring barley, 30–35% of grain carbohydrate comes from the flag leaf and peduncle, 25–45% from the ear and 20–45% from the rest of the plant.

Spring barley has a harvest index of around 54%.

For current information on barley yields associated with commercial varieties, see the AHDB Recommended Lists at **ahdb.org.uk/rl**

How to measure grain yield

Grain yield can be determined in a number of ways. Yield mapping combines are now common, but it is important that these are set up appropriately and calibrated. If mapping is not available, grain can be weighed over a weighbridge. The moisture content of the grain must be known so that yields can be adjusted to 85% dry matter.

On a smaller scale, yield and harvest index (HI) can be determined from quadrat samples (as per the method in the How to measure dry matter section on page 20) taken just before harvest. To determine the HI, after weighing the whole dried sample, the grain should be threshed and weighed separately.

HI (%) = Dry weight of grain ÷ Dry weight of whole plant (grain, straw, chaff) x 100

It is important to know the moisture content of grain to determine yield at 85% dry matter and to store grain effectively (including drying strategies). Most farms have handheld moisture meters and grain intake labs also have this facility. If meters are unavailable, a grain sample can be taken, weighed, then dried and weighed again. The difference between the two values will show the seed moisture content.

Implications for management

- Manage crops early in the season to ensure high grain number/m^2 and high yield
- Maintain canopy lifespan through control of late-season disease, to maximise grain filling
- Harvest as soon as possible after the crop is ripe, to reduce harvest losses

On-farm trials

Split-field or tramline trials can be used to test the success of management strategies, including:

- Fertiliser rates, timings or products
- Varieties
- Cultivation or establishment practices
- Fungicide programmes

To draw valid conclusions, it is necessary for trials to be fair and to test only one factor at a time. To conduct fair tests:

- Pick equivalent areas of a field to compare. This could be done by comparing past yield maps
- Repeat treatments, e.g. different fertiliser rates, times or products, in more than one tramline within a field
- Try to repeat the trials in more than one field
- Excluding headlands from trial areas – harvest the headlands first, then measure the size of the treatment areas accurately. Finally, harvest the treatment areas and determine the grain weight from each treatment

Figure 33. Combine harvesting of a barley crop

Grain quality

Each market has specific quality requirements. Values published in the AHDB Recommended Lists should be used as benchmarks for specific varieties.

Key facts

- Malting markets have specific requirements including variety, germination, grain nitrogen content and size, malt extract levels and physical integrity – see ukmalt.com
- Nitrogen concentration can be manipulated for specific end-user quality specifications
- Most feed grain buyers require a minimum specific weight

Grain nitrogen concentration

Varietal influence: High

Other influences: Nitrogen supply and timing, rainfall

There are a wide range of market specifications for grain nitrogen concentration.

Table 4. Barley market specifications for the distilling/brewing industry

Market	Grain nitrogen (%)
Malt distilling	Below 1.66
Brewing total (Brewing for UK) (Brewing for export)	1.60 to 1.85 (1.60 to 1.75) (1.70 to 1.85)
Grain distilling	Above 1.85

B Grain nitrogen offtake = 132 kg/ha

B 1.76% grain nitrogen

During grain filling, nitrogen is redistributed from stems, leaves and chaff to the grain. Root systems remain active during grain filling, so high soil nitrogen availability late in the season can lead to high grain nitrogen.

Feed barley crops can take up to 35 kg nitrogen/ha from the soil after flowering. Malting crops take up less because nitrogen is applied earlier and at lower rates.

High grain nitrogen concentration can arise from a large uptake or redistribution of nitrogen late in the season or poor starch deposition. However, it can also result from drought, lodging or disease, all of which reduce yield without affecting nitrogen redistribution. Lodging risk may increase in crops grown for high nitrogen specification.

Spring barley

Grain nitrogen concentrations of malting varieties, grown in low nitrogen fertiliser regimes, tend to be lower in the North than in the South. The reason may be that greater yield dilution of grain nitrogen occurs in the North. In the North, most spring malting barley is sold for malt distilling, with the majority of grain nitrogen concentrations below 1.65%.

Most spring malting barley grown in England is destined for brewing, with the majority of grain nitrogen concentration requirements between 1.55–1.85%.

Table 5. Benchmark data for grain quality characteristics*

Market	Overall	North	South
Yield (t/ha)	8.8	9.0	8.5
Average grain weight (mg @ 85% DM)	46	48	45
Grain nitrogen (%)	1.76	1.73	1.80
Specific weight (kg/hl)	65.0	65.0	65.0

* Values for crops grown for feed.

Specific weight and screening

Varietal influence: High

Other influences: Plant population

Specific weight is a measure of individual grain density and how the grains are packed.

Specific weight is influenced by grain fill, grain size and surface characteristics. Large, well-filled grains have a high malt extract potential. Therefore, screenings need to be minimised.

Small-grained varieties are often associated with high screenings (grains that fall through a 2.5 or 2.25 mm sieve). Grains from the upper and lower parts of ears, as well as from late-formed tillers, tend to be smaller than those from the central part of the ear.

Six-row varieties, which have a high number of grains/ear and grains/m^2, tend to produce smaller grains with lower specific weights and more screenings than two-row varieties. The relatively longer grain filling period in northern Britain reduces these differences. Two-row winter barley and spring barley varieties produce similar specific weights and screenings.

Skinning

Skinning is a partial or complete loss of the outer coat (the husk). Maltsters set maximum levels for skinning.

Grain skinning is influenced by weather (e.g. intermittent wetting and drying), combine settings (e.g. drum speed) and variety.

How to measure specific weight and grain nitrogen content

Specific weight can be measured by hand using a chondrometer. Grain is, however, routinely measured at intake labs, using an NIR grain analyser, which can give readings for specific weight, moisture and nitrogen concentration. Grain can also be sent to a specialist lab for nitrogen percentage determination by methods such as Dumas or Kjeldahl.

Implications for management

- Apply all nitrogen fertiliser to winter-malting crops at or before GS31 to reduce the risk of excess grain nitrogen concentration
- Apply all nitrogen fertiliser to spring crops at or before leaf 3, unless high grain nitrogen is required
- Sow spring varieties that are vulnerable to high screenings as early as possible
- Avoid high seed rates or late sowing of spring barley to minimise screenings

Other quality criteria

Most buyers prefer large grain as this is associated with high levels of carbohydrate and reduces the risk of screenings (grains that fall through a 2.5 or 2.25 mm sieve).

Maltsters prefer varieties with a high malt extract. This increases productivity in brewing and is related to high spirit yield in distilling. Extract is a measure of the amount of sugar obtained from the malt after the mashing process.

Malt extract is influenced by variety choice, grain size and homogeneity, grain nitrogen content and enzymes. Large and even-sized grain tends to mill better and produce more extract. Lower grain nitrogen increases starch content and extract. The malt should also have sufficient enzymes to adequately convert starch to sugars.

Glossary

Assimilate The product of the crop's synthetic processes, mainly photosynthesis. Measured as dry matter

Benchmark A quantitative reference point against which a crop's performance can be compared

Canopy All green surfaces of the plant capable of photosynthesis including stems, leaves, ears and awns. Canopy is usually measured in units of GAI

Coleoptile The first shoot to emerge from the seed. The first true leaf emerges through the coleoptile

Day degrees See 'thermal time'

Development Changes in crop structure, as defined by the decimal growth stage (GS) code

Dry matter (DM) Crop constituents other than water, left after tissue has been dried. Often, 'total dry matter' refers to just the above-ground parts of the crop

Floret A single flower containing a single grain

Frost heave Lifting of the soil surface, caused by freezing of moisture in the topsoil and expansion, often leading to stretching and breaking of roots and other sub-surface structures

GAI Green Area Index. The ratio between the total area of all green tissues, one side only, and the area of ground from which they came

Growth Changes in crop size or weight

Growth phase Period during which a specific crop structure is produced

Growth stage A finite point in a crop's development

Harvest index The ratio of grain weight to above-ground crop weight

Imbibition Initial uptake of water by dry seed

Internode The section of stem between two adjacent nodes

Leaf sheath The basal portion of a leaf that encloses the stem and sheaths of younger leaves

Ligule A small structure at the junction of leaf sheath and leaf blade

Lodging Permanent displacement of a stem or stems from a vertical posture. Lodging can be considered as an event occurring within one day, although lodged stems may initially lean rather than lie horizontally

Main shoot The primary axis of the plant, on which the primary tillers are borne

Mean The average. The sum of all the values divided by the number of values

Median The middle value when all values are ranked by size. Medians may provide more robust summaries than means because they are not influenced by exceptional values

N Nitrogen

Node The point at which a leaf sheath is attached to the stem

NVZ Nitrate Vulnerable Zone. Areas determined to pose a risk of nitrates leaching into watercourses. These areas are subject to regulations that must be complied with by farmers

Partitioning The division of dry matter between organs

Peduncle The topmost node between the flag leaf node and the base of the ear (the collar)

PGR Plant growth regulator. The PGR programme used to grow the benchmark crop included chlormequat (at GS30 to 31) and Terpal (at GS37 to 39)

Photosynthesis Formation of sugars by green tissues from absorbed carbon dioxide and water, and driven by energy from sunlight

Phyllochron The time taken for each leaf to emerge, measured in thermal time

Rachis The portion of the stem within the ear (above the collar) bearing the spikelets

Ripening A loose term describing the changes that occur in grain between completion of growth and maturity. These include drying and development and loss of dormancy

Senescence Loss of greenness in photosynthetic tissues, normally the result of ageing but also by disease or drought

Shoots All the stems of a plant with the potential to bear an ear – includes main stem and all tillers

Soil stability The tendency for soil aggregates to retain their integrity when wetted and disturbed. It is measured by assessing how easily aggregates break up into fine particles

Specific weight The weight of grain (corrected for variation in moisture content) when packed into a standard container. It is expressed in kilograms per hectolitre (100 litres)

Spikelet A structure containing one or more florets. In two-row barley, there is only one floret in each spikelet

Stem reserves Soluble carbohydrate stored in the stem that can translocate and contribute to yield

Thermal time The sum of all daily temperatures (mean of maximum and minimum) above a base temperature below which the process in question stops. In the case of leaf development, this is 0ºC. Results are expressed in ‘day degrees’ (ºC days)

Tillering The production of tillers – side shoots to the main stem

Vernalisation A change in physiological state of a plant from vegetative to reproductive brought about by a period of cold

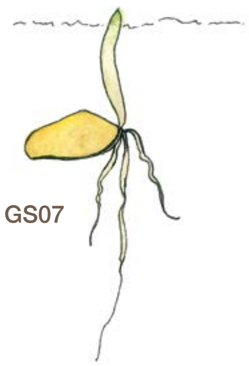
Waterlogging Filling of soil pores with water to the extent that there is insufficient oxygen for normal root function

Cereal growth stages and benchmarks

Decimal growth stages (GS) can be used to identify the most appropriate benchmark during the season. The stages can also be used to guide spray timings.

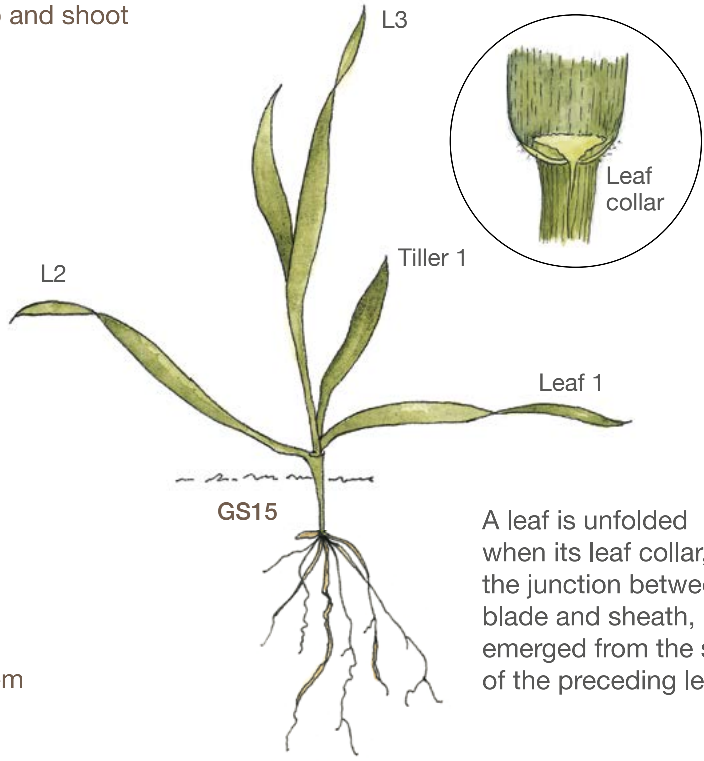
Germination

GS07 Germinating seed with root (which forms first) and shoot

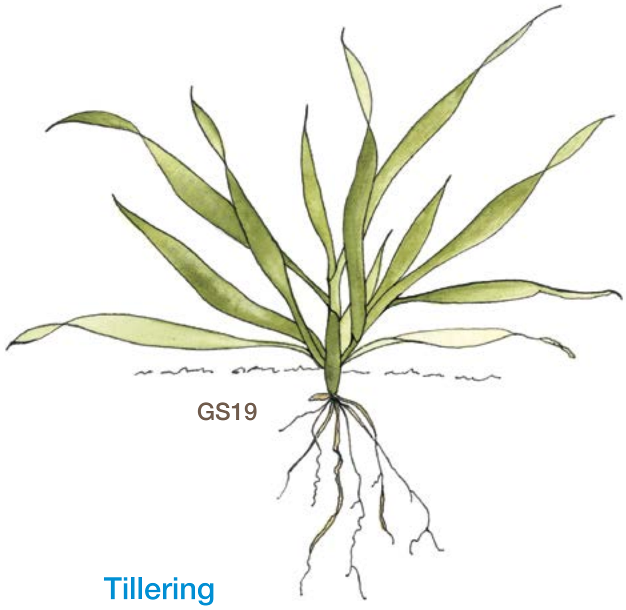


Seedling growth

GS10 First leaf through coleoptile
GS11 First leaf unfolded (ligule visible)
GS13 Three leaves unfolded on the main shoot
GS15 Five leaves unfolded
GS19 Nine or more leaves unfolded on the main stem



A leaf is unfolded when its leaf collar, at the junction between blade and sheath, has emerged from the sheath of the preceding leaf.



Tillering

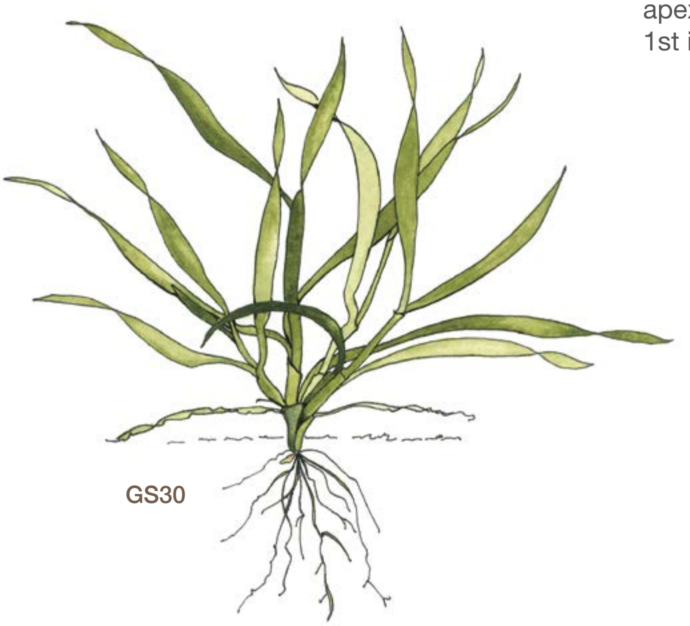
GS20 Main shoot only
GS21 Main shoot and one tiller
GS23 Main shoot and three tillers
GS25 Main shoot and five tillers
GS29 Main shoot and nine or more tillers

GS21	Overall	South	North
Main shoot and one tiller	13 November	10 November	15 November
Plants/m^2 (85% of seeds sown)	305	277	327
GAI	0.3	0.3	0.3

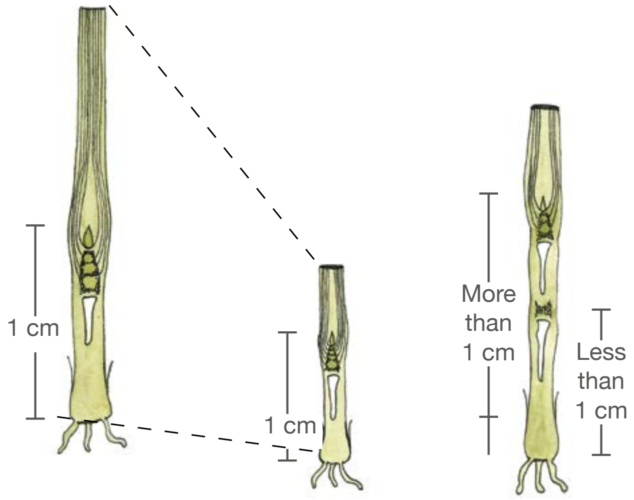
Stem elongation

GS30 Ear at 1 cm (pseudostem erect)
GS31 First node detectable
GS33 Third node detectable
GS37 Flag leaf just visible
GS39 Flag leaf blade all visible

GS30	Overall	South	North
Ear at 1 cm	2 April	31 March	5 April
GAI	1.4	1.6	1.3
Shoots/m^2 (Shoot numbers start to decrease)	1180	1080	1280


GS30

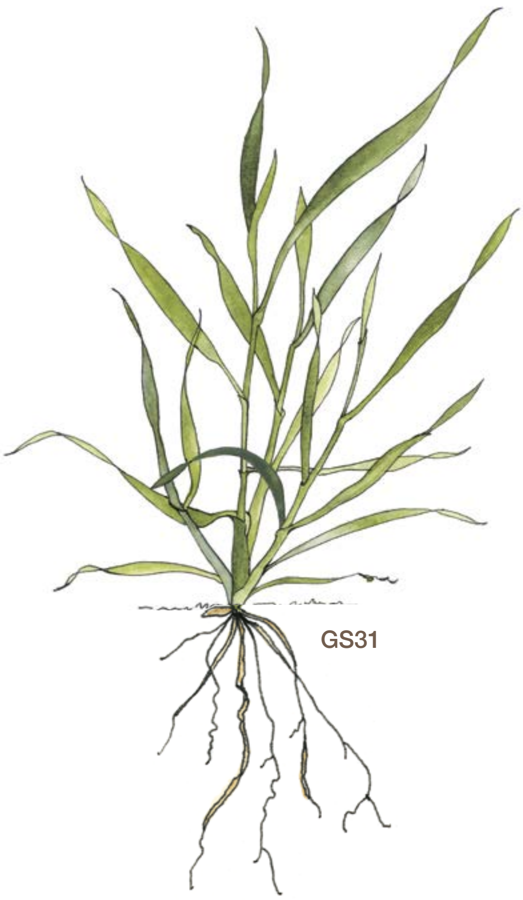
Distance between base of the plant and the top of the shoot apex on the main stem is 1 cm or more, but the length of the 1st internode is less than 1 cm.



When stem elongation begins it is necessary to split the main shoot to determine the correct crop growth stage.

For a quick, but crude assessment, fold back the leaf sheaths then count the slight 'bumps' caused by each node.

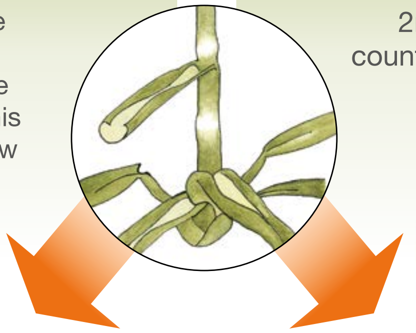
The exact stage is revealed by stripping off leaves and cutting the main stem longitudinally with a sharp knife.

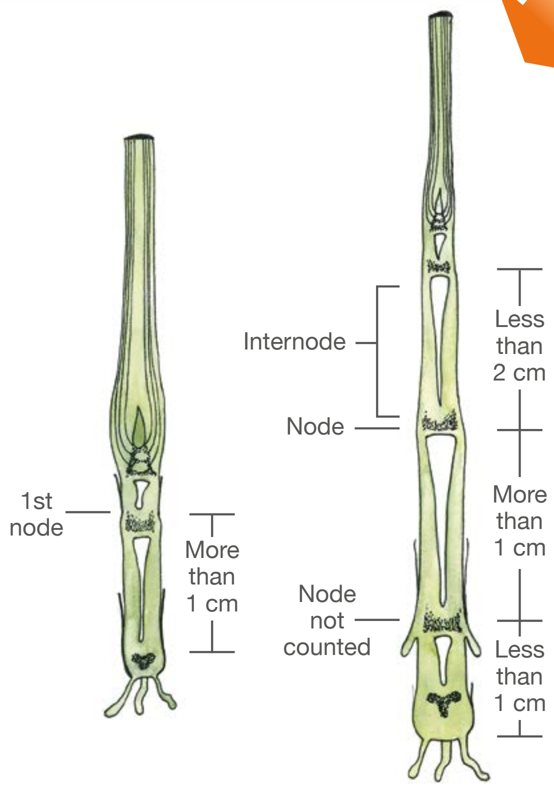

GS31

GROWTH STAGE 31

1st node detectable

An internode is 1 cm or more but the internode above is less than 2 cm. Sometimes a node may be below the ground and may bear roots. Even if this occurs, as long as the internode below it exceeds 1 cm it is still counted.

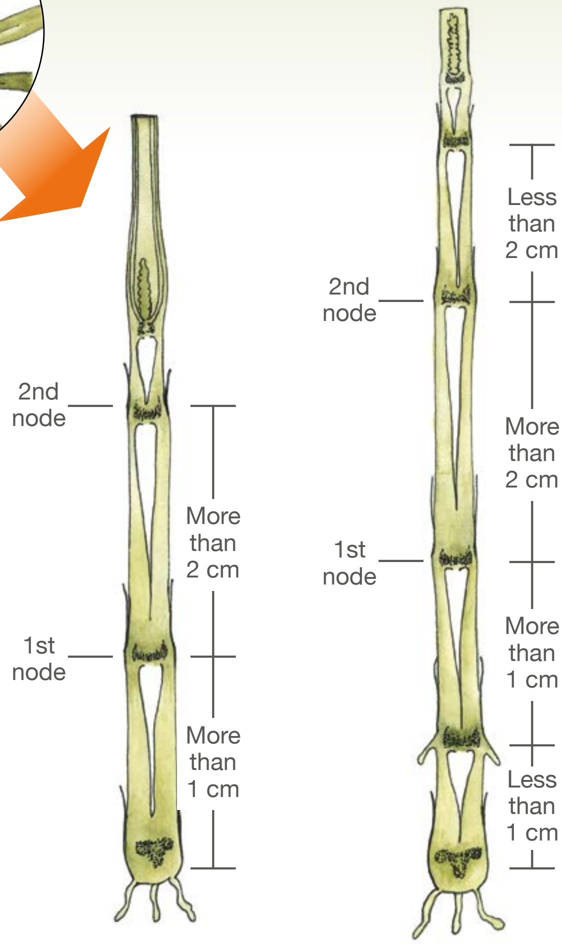




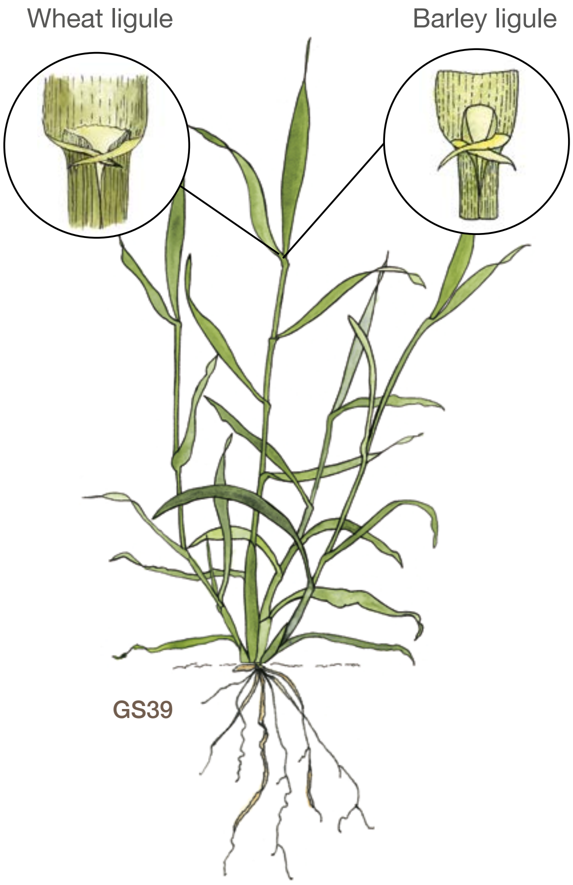
GROWTH STAGE 32

2nd node detectable

2nd and subsequent nodes counted when the internode below them exceeds 2 cm.



GS31	Overall	South	North
First node detectable	16 April	13 April	19 April
Leaf 3 emerged	15 April	15 April	15 April
Leaf 2 (Leaves emerge every 108°C days (day degrees))	25 April	24 April	27 April
GAI (Canopy increases up to 0.2 units/day until GS39)	2.4	2.6	2.3
Nitrogen uptake (kg/ha) (About 35% of final nitrogen uptake)	65	67	63
Crop height (cm)	11	12	9
Total dry weight (t/ha) (Only 16% of final dry weight)	2.4	2.6	2.1



GS39	Overall	South	North
Flag leaf (leaf 1) blade visible	6 May	3 May	9 May
Total leaf number (No further leaves emerge on main shoot)	14	15	13
GAI	5.1	5.1	5.1
Nitrogen uptake (kg/ha) (Uptake now slows)	128	122	133
Crop height (cm)	45	47	42
Total dry weight (t/ha) (About 35% of final dry weight)	5.2	5.1	5.3

Booting

GS41 Flag leaf sheath extending
GS43 Flag leaf sheath just visibly swollen
GS45 Flag leaf sheath swollen
GS47 Flag leaf sheath opening
GS49 First awns visible

Ear emergence

GS51 First spikelet of ear just visible above flag leaf ligule
GS55 Half of ear emerged above flag leaf ligule
GS59 Ear completely emerged above flag leaf ligule

GS59

GS59	Overall	South	North
Ear completely emerged (also GS61 flowering starts at the end of ear emergence)	26 May	21 May	30 May
Shoots/m²	855	835	875
GAI (Awned ears represent 10% GAI)	5.8	5.8	5.8
Nitrogen uptake (kg/ha)	163	164	162
Crop height (cm) (Little further stem extension)	87	89	86
Total dry weight (t/ha) (About 80% of final dry weight)	9.6	9.6	9.6

Flowering

GS61 Start of flowering
GS65 Flowering halfway
GS69 Flowering complete

Wheat

GS65

Barley

Milk development

GS71 Grain watery ripe
GS73 Early milk
GS75 Medium milk
GS77 Late milk

GS77

GS71	Overall	South	North
Grain watery ripe	8 June	5 June	11 June
GAI (Leaf loss lower in the canopy)	5.0	5.0	5.0
Crop height (cm) (No further extension occurs)	93	89	98
Stem dry weight (t/ha)	6.9	6.9	6.8

Dough development

GS83 Early dough
GS85 Soft dough
GS87 Hard dough (thumbnail impression held)

GS85

GS87	Overall	South	North
Hard dough	5 July	28 June	14 July
GAI	0.4	0.3	0.6
Grain filling period (days)	40	38	45
Ripening period (days) (45% to 20% moisture content)	20	21	18
Total dry weight (t/ha)	15.7	15.4	16.1

Ripening

GS91 Grain hard (difficult to divide)
GS92 Grain hard (not dented by thumbnail)
GS93 Grain loosening in daytime

GS91

Harvest	Overall	South	North
	26 July	18 July	1 August
Total nitrogen offtake (kg/ha)	181	179	183
Shoots/m^2	775	795	755
Stem weight (t/ha)	6.4	6.2	6.6
Grain weight (mg) (15% moisture content)	46	45	48
Grain specific weight (kg/Hl)	65	65	65
Grain nitrogen (%)	1.73	1.80	1.73
Total dry weight (t/ha)	14.8	14.4	15.2
Grain yield (t/ha) (15% moisture content)	8.8	8.5	9.0

Further information

Other publications from AHDB

- Wheat growth guide (ahdb.org.uk/wheatgg)
- Oilseed rape growth guide (ahdb.org.uk/osrgg)
- Recommended Lists for cereals and oilseeds (ahdb.org.uk/rl)
- The encyclopaedia of arable weeds (ahdb.org.uk/weed-encyclopaedia)
- The encyclopaedia of cereal diseases (ahdb.org.uk/disease-encyclopaedia)
- The encyclopaedia of pests and natural enemies (ahdb.org.uk/pests)
- Nutrient management guide (ahdb.org.uk/rb209)
- Grain storage guide (ahdb.org.uk/grain-storage)

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