

Barley growth guide



Managing barley growth

Crop managers need to respond to unexpected weather or growth throughout the season.

The steps in any management cycle are to:

1. Set targets
2. Assess progress
3. Adjust inputs
4. Monitor success

Measurement is vital for effective management at every stage of a crop's progress.

In addition to assessments on weeds, pests and diseases, managers must assess the crop itself. Crop assessments should be objective, targeted and, where possible, measured.

This guide presents measurements by which barley growth and development can be monitored. It also explains how measurements interrelate.

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Benchmarks

This symbol identifies a benchmark, a quantitative reference point against which a crop's performance can be compared. While benchmarks are compatible with good yields, they should not necessarily be regarded as management targets.

Page 4 gives the important growth stages and page 5 gives the benchmark values for key processes. All benchmarks are then explained in subsequent sections.

Each benchmark in this guide represents a median value derived from measurements made on the two-row winter barley variety, Pearl.

Trials were sown between 15 September and 10 October at six trial sites across the UK in each of the three harvest years 2002–2004. Full crop protection and lodging control was applied to minimise potential crop losses. Fertiliser use was for feed quality grain rather than for malting.

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

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.

Using the benchmarks

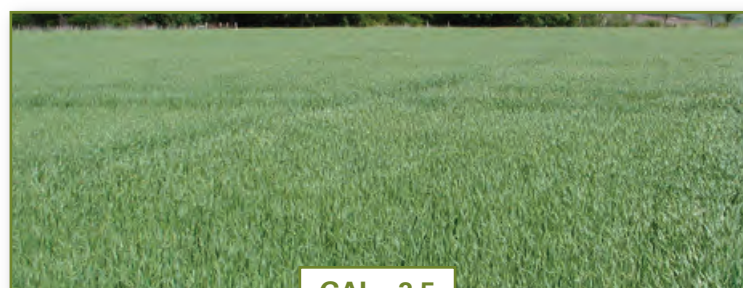
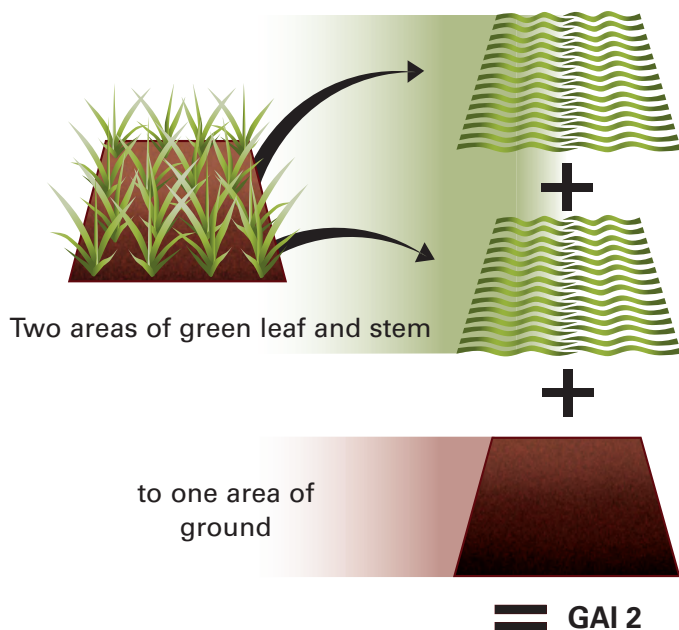
- Set targets – considering variety, sowing date, soils and weather conditions
- Assess crop progress against benchmark values
- Modify current husbandry, where possible, to meet targets
- Re-assess crop progress and final performance
- Amend future crop management in light of observations.



Green Area Index

Canopy size can be expressed as Green Area Index – the ratio of total green area (one side only) to the ground area occupied. These photographs illustrate typical GAIs.

Illustration of GAI = 2
(two areas of green leaf and stem to one area of ground)

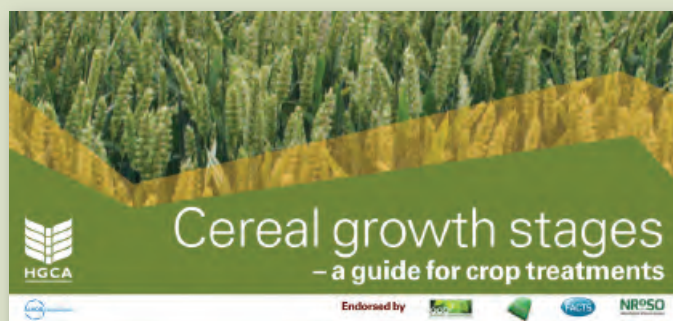


For more information

Publications and details of projects funded by AHDB Cereals & Oilseeds are all available at cereals.ahdb.org.uk/publications

AHDB Recommended Lists for cereals and oilseeds (annual)

- G66** Wheat growth guide (2015)
- G65** Oilseeds rape guide (2015)
- G64** Barley disease management guide (2015)
- G61** Managing weeds in arable rotations – a guide
- G49** Cereal growth stages – a guide for crop treatments (2009)



Locations of reference crop trial sites

Benchmarks are provided for the UK and where needed for north and south as indicated above.



Barley growth stages and benchmarks

Growth stages



Growth Stage	GS21	GS30	GS31	GS39	GS59	GS71	GS87	Harvest
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Growth Stage	Description of stage
Seedling growth	
GS10	First leaf through coleoptile
GS11	First leaf unfolded
GS13	3 leaves unfolded
GS15	5 leaves unfolded
GS19	9 or more leaves unfolded
Tillering	
GS20	Main shoot only
GS21	Main shoot and 1 tiller
GS23	Main shoot and 3 tillers
GS25	Main shoot and 5 tillers
GS29	Main shoot and 9 or more tillers
Stem elongation	
GS30	Ear at 1cm (pseudostem erect)
GS31	First node detectable
GS33	3 rd node detectable
GS35	5 th node detectable
GS37	Flag leaf just visible
GS39	Flag leaf blade all visible
Booting	
GS41	Flag leaf sheath extending
GS43	Flag leaf sheath just visibly swollen
GS45	Flag leaf sheath swollen
GS49	First awns visible

Growth Stage	Description of stage
Ear emergence	
GS51	First spikelet of ear just visible
GS55	Half of ear emerged
GS59	Ear completely emerged
Flowering	
GS61 *	Start of flowering
GS65	Flowering half-way
GS69	Flowering complete
Milk development	
GS71	Grain watery ripe
GS73	Early milk
GS75	Medium milk
GS77	Late milk
Dough development	
GS83	Early dough
GS85	Soft dough
GS87	Hard dough
Ripening	
GS91	Grain hard (difficult to divide)
GS92	Grain hard (not dented by nail)

*in some spring crops GS61 may precede GS59


Barley growth stages


The Decimal Code system for measuring barley growth used throughout this guide is based on work published in Tottman, DR, Makepeace, RJ and Broad, H (1979) An explanation of the decimal code for the growth stages of cereals, with illustrations. Annals of Applied Biology **93**, 221–234.





Benchmarks


Benchmarks are reference values, compatible with high yields but they are not management targets.

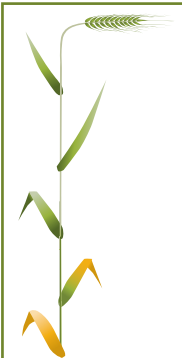
GS21	Overall	South	North
	Main shoot + 1 tiller 13 November	10 November	15 November
Plants/m ² 85% of seeds sown	305	277	327
GAI	0.3	0.3	0.3

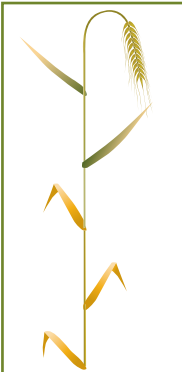
GS30	Ear at 1 cm	Overall	South	North
	Main shoot + 3 tillers	2 April	31 March	5 April
	GAI	1.4	1.6	1.3
	Shoots/m² <i>Shoot numbers start to decrease</i>	1180	1080	1280

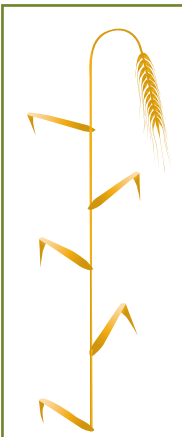
GS31		Overall	South	North
	First node detectable	16 April	13 April	18 April
	Leaf 3 emerged	15 April	15 April	15 April
	Leaf 2 emerged <i>Leaves emerge every 108°C days (day degrees)</i>	25 April	24 April	27 April
	GAI <i>Canopy increases at up to 0.2 units/day until GS39</i>	2.4	2.6	2.3
	N uptake (kg/ha) <i>About 35% of final N uptake</i>	65	67	63
	Crop height (cm)	11	12	9
	Total dry weight (t/ha) <i>Only 16% of final dry weight</i>	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 stem	14	15	13
GAI	5.1	5.1	5.1
N 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

GS59	Overall	South	North
	Ear completely emerged (also GS61 flowering starts at the end of ear emergence) 26 May	21 May	30 May
Shoots/m ²	855	835	875
GAI Awned ears represent 10% GAI	5.8	5.8	5.8
N 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

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)	7.4	7.3	7.5

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

Harvest	Overall	South	North
	26 July	18 July	1 August
Total N 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/ha)	65	65	65
Grain N (%)	1.76	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

Development and growth

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

Key facts:

- 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
- The rate at which barley passes through its life cycle may only be managed through variety choice and sowing date

Growth

Growth, 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 crop to utilise light energy and store dry matter

Growth can only be managed by altering green canopy size.

Development

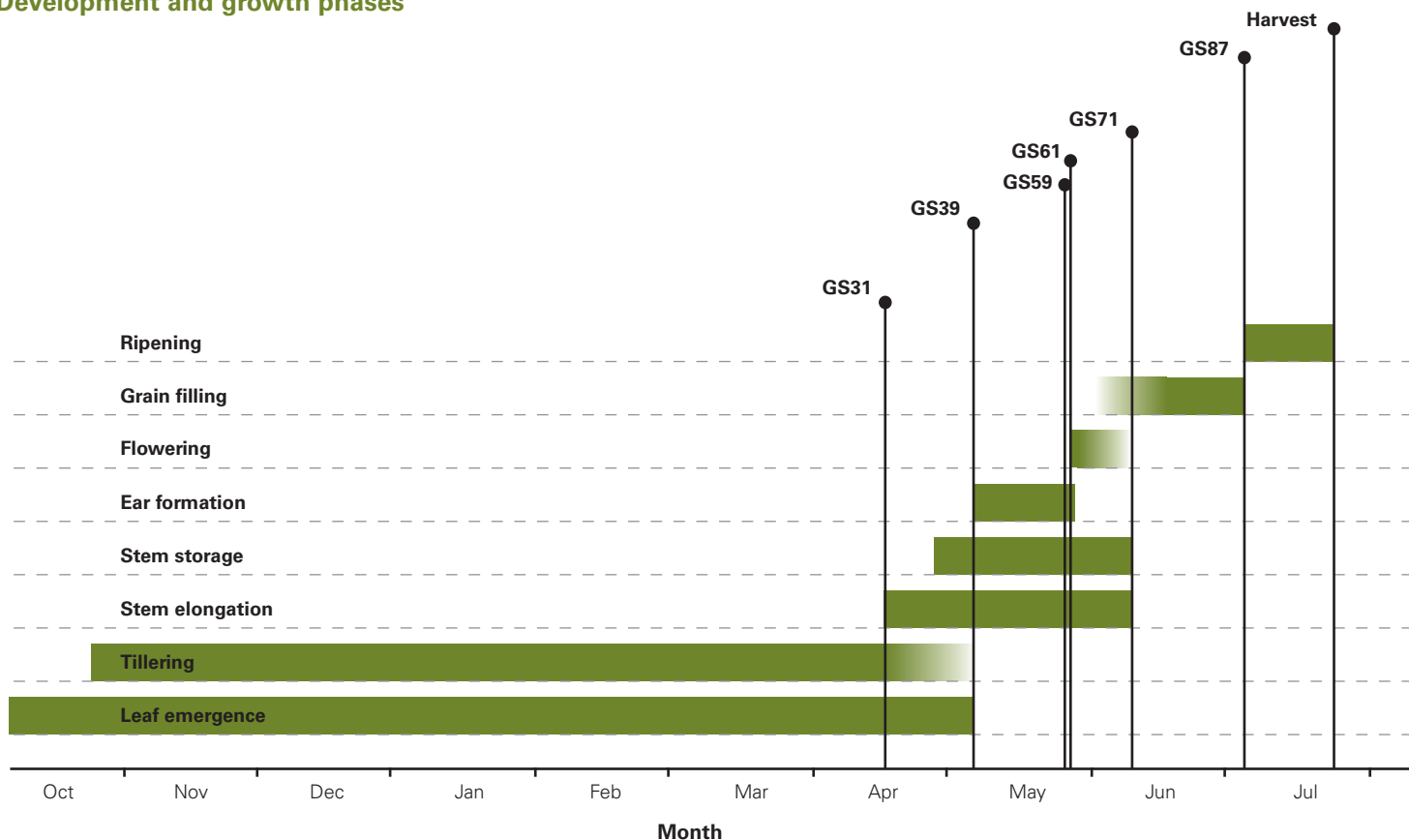
Crop development is measured by progress through 'growth stages'. Crop processes 'switch' on or off at key stages (GS21, GS31, GS39, GS59, GS71 and GS87).

Development can only be altered by variety choice and sowing date. Subsequent management decisions aim to influence growth during a developmental phase, eg 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 young plants
- **Photoperiod** – long days advance floral development

Development and growth phases





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.

In the spring, barley begins reproductive development earlier than wheat and so may be more susceptible to frost damage.

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.

Spring varieties on the current AHDB Recommended List mature within a narrower period than two-row winter barley varieties.

Maximising growth

Growth in any phase of a crop's life is maximised by bright, cool weather because:

- high light energy maximises photosynthesis
- cool temperatures slow development and increase the length of any phase

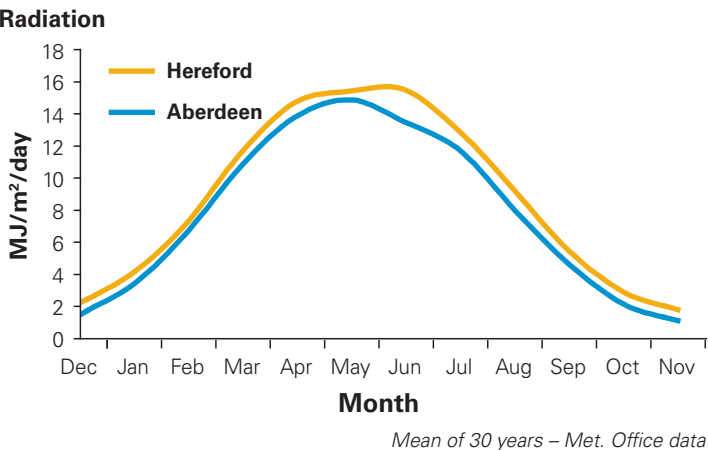
Summer light levels and temperatures are both lower in the north than in the south.

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

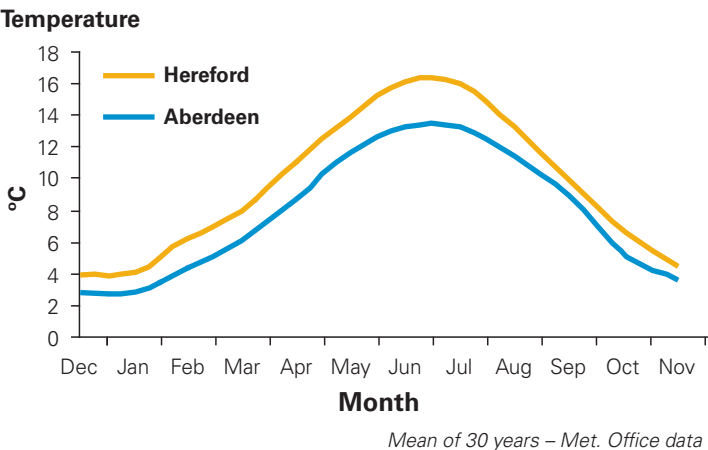
On cloudy days, light energy is less than half that intercepted on sunny days.

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

Daily incident radiation in Aberdeen in June is 96% of that in Herefordshire



In June, the average temperature in Aberdeen is 84% of that in Herefordshire



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 0°C and oxygen
- Speed of emergence is governed by soil temperature and sowing depth
- Overwinter survival can be very variable, according to site and season

Seed rates and plant populations

B Spring population = 305 plants/m²

In recent years many farmers have reduced winter wheat seed rates. This is possible because wheat can compensate by increasing ear size and number on each plant. There is less scope for barley to compensate by increasing grain number in each ear, as there is only one floret in each spikelet.

Calculating seed rate

Calculations need to work back from the target spring plant population to an autumn seed rate.

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

Germination

Seeds can only germinate if moisture is adequate; if this requirement is met, germination rate is controlled directly by soil temperature.

Initially, water penetrates the seed coat, softening the hard, dry tissues inside: the process of imbibition. Good contact between seed and soil speeds up water transfer from soil to seed, 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.

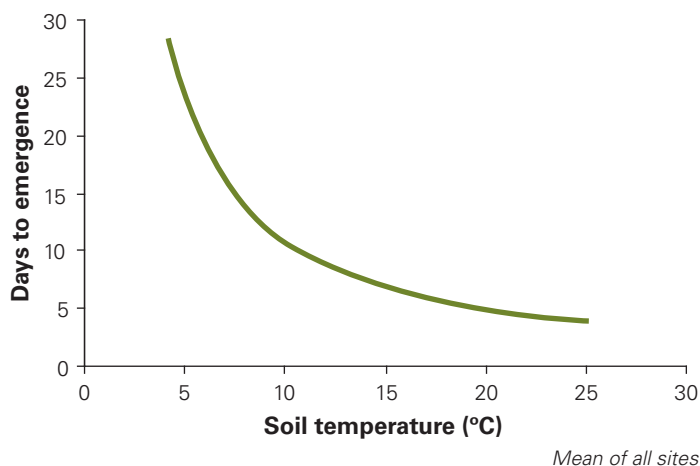
Emergence

B Thermal time to 50% emergence = 150°C days

Temperature drives emergence. Temperature affects the rate of both germination and emergence, so a measure incorporating both time and temperature – ie accumulated mean daily temperature from sowing – measured in thermal time (°C days) is used.

At the reference sites, crops reached 50% emergence in 150°C days. The thermal time was much higher where dry soil limited establishment. In autumn, as daily temperatures decline, crops take longer to emerge, but emergence accelerates as temperatures increase in spring.

Emergence in days at different soil temperatures



In the warmer south, the threshold of 150°C days is reached sooner than in the north.

Days to accumulate 150°C days		
Sowing date	North (Aberdeen)	South (Herefordshire)
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

Mean of 30 years – Met. Office data

Overwinter survival



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

Losses can occur from frost heave, waterlogging and direct frost effects, as well as pests. The risk of losses is increased by:

- Shallow, late sowing
- Low seed rates
- Manganese deficiency

Seedbed consolidation reduces the risk of frost heave.

Winter hardiness ratings of winter barley varieties are given in the AHDB Recommended List.



Spring barley

Seedbed

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 tiller well to compensate.

In a good seedbed, typical 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 potential to reduce seed rates is less.

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

Action:

- ▷ Consolidate seedbeds in dry conditions to improve seed:soil contact, water uptake and germination.
- ▷ At drilling:
 - Avoid late and shallow drilling
 - Increase seed rate when sowing after the optimal dates to offset poor establishment or tillering
 - Consider pests, eg slugs and leatherjackets, when determining seed rates.
- ▷ Prevent BYDV in winter crops if appropriate, by seed treatment or spraying against aphid vectors.
- ▷ Correct manganese deficiency, which can decrease winter hardiness in autumn.
- ▷ Select varieties with good winter hardiness for northern and exposed sites.

Leaf emergence and tillering

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

Key facts:

- Temperature drives speed of leaf appearance – rates differ between varieties and sowing dates
- Thermal time controls number of leaves initiated
- Tillering is affected by temperature, not location, within the UK
- Final shoot number is a key component of yield; ear number is correlated with yield

Number of leaves



Number of leaves = 14

North = 13

South = 15

Crops usually produce fewer leaves at northern sites than at southern sites, as less thermal time is accumulated before the crop switches to reproductive development in cooler winter weather.

Leaf emergence



Phyllochron = 108°C days

No location effect

The first leaf emerges from the coleoptile soon after drilling. Leaves then emerge continuously on main stems and tillers until the final leaf emerges.

Temperature drives leaf emergence. The phyllochron (time taken for each leaf to emerge) is measured in thermal time (°C days).

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.

Late-sown winter crops accumulate less thermal time to GS39 and produce fewer leaves. However, the phyllochron decreases in later-sown crops so the rate of leaf emergence increases.

Barley varieties exhibit a day length response that may influence rate of leaf emergence. Varieties vary in the relative influence of day length and temperature on rate of leaf emergence. However, no current varieties are day length insensitive.

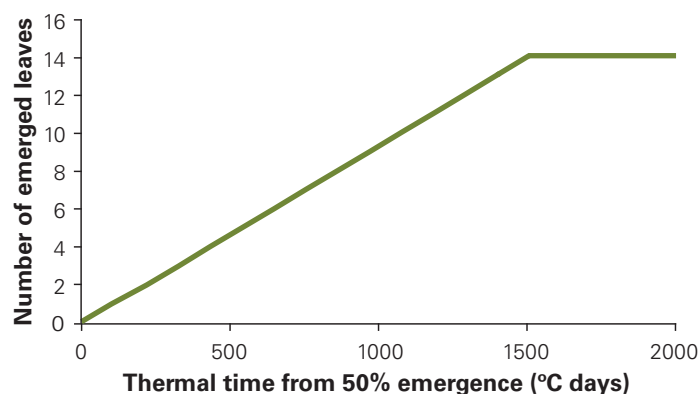
Spring barley

Spring barley generally produces fewer (8–10) leaves than winter barley. Phyllochrons are around 10% less than in the winter crop, depending on variety, as less time is available for canopy expansion.

Tiller initiation, but not appearance, stops just after stem extension ends. Spikelets are initiated after two leaves have unfolded.

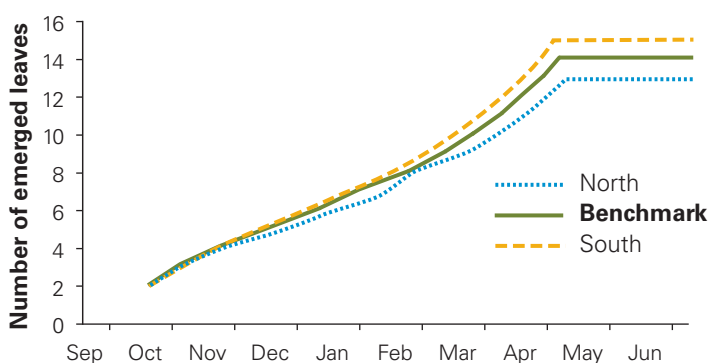
Final ear numbers are similar in spring and winter varieties; however, spring crops produce fewer tillers.

Thermal time and leaf emergence



Mean of 3 years

Date and leaf emergence



Mean of 3 years



Tillering

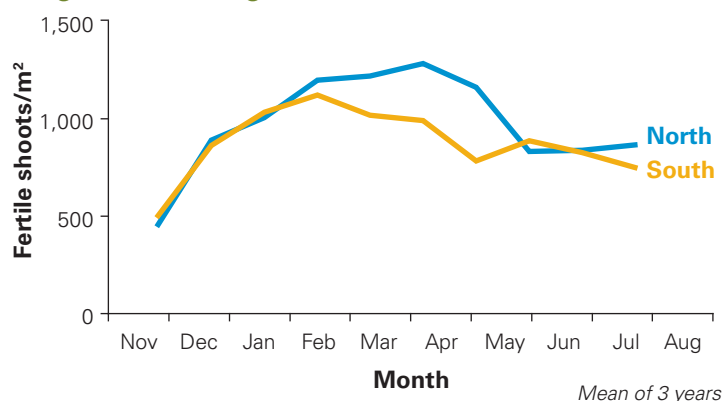


Shoot numbers by GS30 (2 April) = 1,180 shoots/m²
 North (5 April) = 1,280 shoots/m²
 South (31 March) = 1,080 shoots/m²

Tillering, the production of shoots in addition to the main stem, occurs after leaf 3 emerges and continues until stem extension in the spring. Tillering is affected by temperature, water and nutrients. It determines ears/m² – an important yield component.

Reference crops tillered equally well at northern and southern sites. The process of tiller death began earlier at southern sites but final ear numbers were similar at all locations.

Progress of tillering



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.

Tiller numbers may be reduced by late sowing, delayed emergence, poor nutrient availability and low autumn temperatures. Early sown crops tiller for longer and so compensate for low plant populations.



Final shoot number



Final shoot number = 775/m²
 3 shoots/plant

Over the season, the maximum shoot number usually exceeds final shoot number. Increasing competition for both light and nutrients results in smaller, more recently formed tillers dying to make way for the main yield-forming shoots.

The final fertile shoot number is similar throughout the UK but is reached by mid-March in the south and by mid-April further north.



Action:

- ▷ Review N timing and rate to remedy low tiller numbers.
- ▷ Ensure fungicide strategies protect the last 3–4 leaves.
- ▷ Choose an early maturing spring barley variety for late sowing.

Canopy expansion and senescence

Canopy size is determined by both leaf emergence and tiller numbers.
Managing canopy size and senescence is the key to maximum yield.

Key facts:

There are three distinct phases of canopy expansion and senescence:

- Canopy expansion occurs slowly until GS30
- Canopy expansion continues rapidly from GS30–59
- Senescence begins soon after ear emergence

Canopy refers to all the crop's green surface area (leaves, stems, ears and awns), with leaf blades forming the largest area.

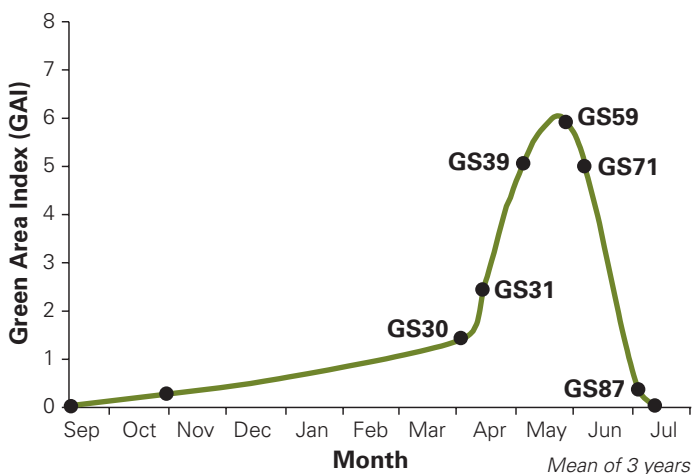
Canopy size can be expressed as green area index (GAI) – the ratio of green area (one side only) to the ground area occupied (page 3).

Early canopy expansion

B GAI = 1.4 by GS30 (2 April)

Leaves and tillers emerge through the autumn and winter. At this time the crop is small and intercepts little light. Cool temperatures and low light levels slow leaf emergence, tillering and growth during this period.

Change in GAI over the growing season



Rapid canopy expansion

B Canopy closure* (GAI 3) = 21 April
*5 days after GS31
North = 22 April
South = 20 April

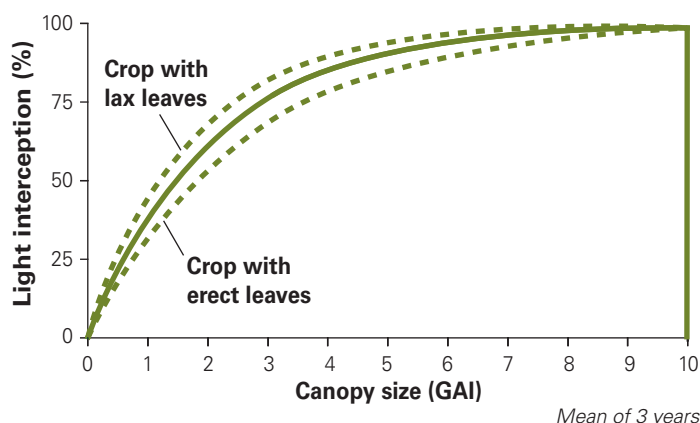
B Peak GAI at GS59 = 5.8

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, crop growth equates to an average of 1 unit of GAI every 12 days. Growth is most rapid from GS30–39, when GAI increases by one unit every week. '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. 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.

Light interception increases with canopy size



Canopy senescence



GAI = <0.5 by 5 July

North by 16 July

South by 27 June

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

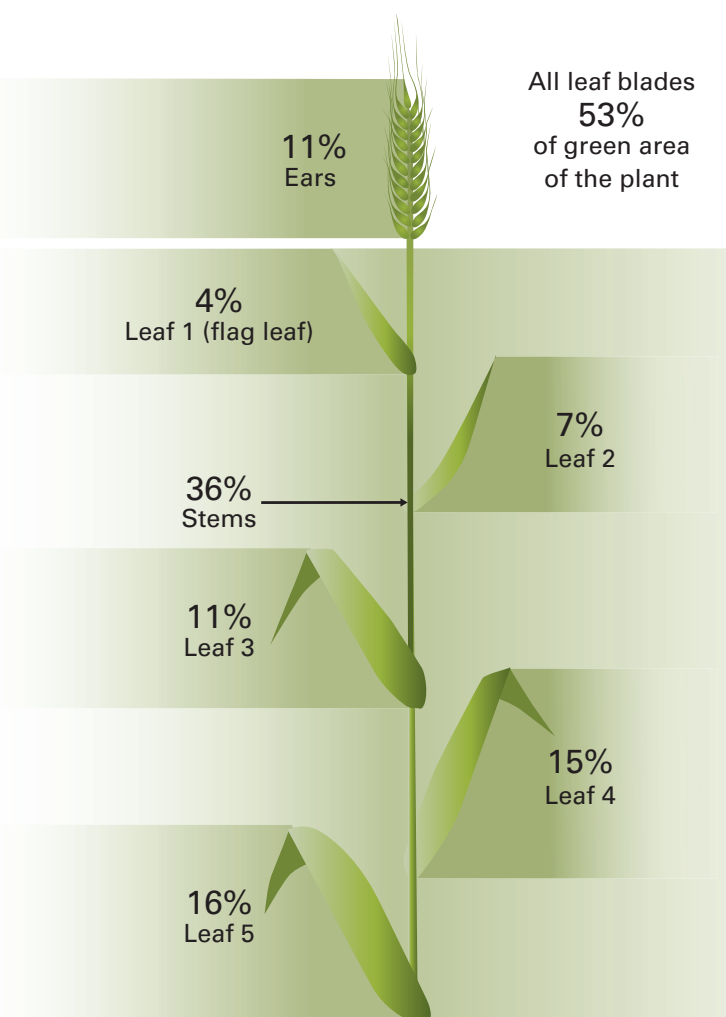
Canopy expansion tends to be slightly more rapid than that in winter barley.

Peak green area index in spring barley is 15% to 20% less than in winter barley (ie GAI= 5 at GS59).



Distribution of green area

In barley, each successive emerging leaf has less green area. The flag leaf is usually half the area of leaf 2. By contrast, in wheat the large flag leaf intercepts most of the light. Lower leaves of barley are more important for light interception after flowering than in wheat.



Action:

- ▷ Reduce spring N if canopy size is excessive to prevent excessive tillering and lodging.
- ▷ Ensure crops have adequate N at GS30 to achieve required canopy size.
- ▷ For future years, consider options to increase canopy size, if necessary:
 - sow early
 - use high seed rates
 - apply spring N early.

Nitrogen uptake

Barley is usually grown on sites with low soil N, so yield mainly depends on timing and rate of fertiliser applications.

Key facts:

- Soil N rarely supplies all the N required: N applications can be used to manage canopy size
- Over the season, N affects different aspects of canopy development

Pattern of N uptake

Canopy size is directly related to N uptake throughout the crop's life.

Overwinter to mid-March

Early sown crops are likely to experience good autumn growing conditions with increased N uptake, depending on soil N availability.

Mid-March to GS31

B Rate of N uptake = 1.2 kg/ha/day
Total uptake = 65 kg/ha by GS31

Rate of N uptake increases in mid-March as warmer conditions stimulate canopy expansion through more rapid leaf emergence and tillering.

GS31–39

B Rate of N uptake = 3.1 kg/ha/day
Total uptake = 128 kg/ha by GS39

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

GS39–59

B Rate of N uptake = 1.8 kg/ha/day
Total uptake = 163 kg/ha by GS59

N uptake slows as canopy size peaks and ears begin to form.

Nitrogen requirements

B N uptake = 28 kg/ha/GAI unit

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

Available soil N is likely to be no more than 60–80 kg/ha on medium soils and less than 60 kg/ha on light sands and shallow soils. Soil N is rarely sufficient for crop requirement. Unless adequate N is made available, shoot numbers and yield will be restricted.

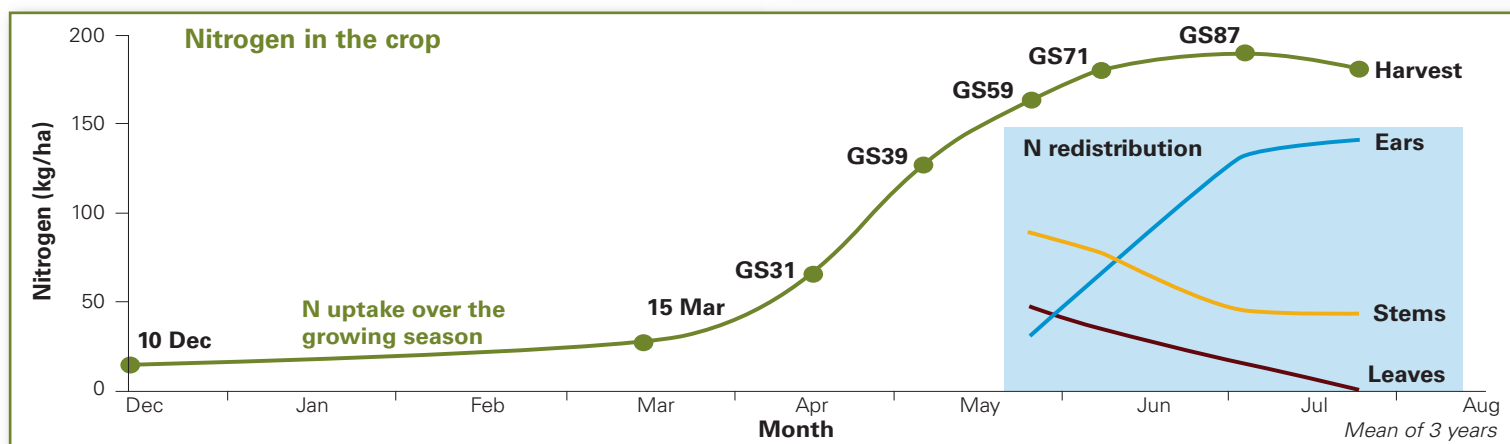
After ear emergence (end-May), relatively little nitrogen is taken up and N is redistributed within the plant. Protein in leaves and stems transfer to form grain protein in developing ears.

Spring barley

The maximum N offtake in spring barley is 25–30% less than that in winter barley, ie 130 kg N/ha at harvest.

Action:

- ▷ Time N applications to ensure N is available from mid-March to GS59.
- ▷ Apply early spring N to encourage tillering and ensure adequate ear number/m².
- ▷ Use late spring N to encourage rapid canopy expansion through tiller survival, and ensure sufficient grains/ear.
- ▷ Avoid excess N applications later in the season which impairs quality due to high grain N.



Dry matter growth

Growth 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 after the canopy has closed
- Crop dry weight gain slows mid-way through grain filling after considerable canopy senescence
- Barley growth is maximised in bright, cool weather

Growth up to canopy closure



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

Between sowing and canopy closure (about 5 days after GS31) some 18% of total dry matter is produced. Growth is slow. This period can extend up to 200 days as the canopy is incomplete.

Growth after canopy closure



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

A GAI of over 3 is maintained for eight weeks. During this period 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 mid-way through grain filling.

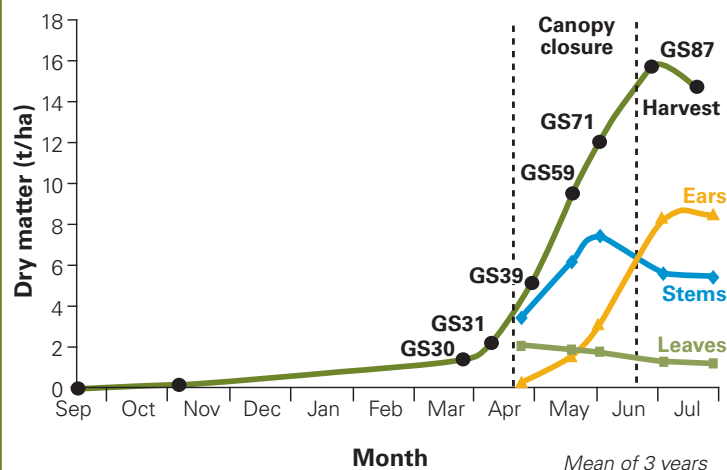
Dry matter redistribution during grain filling

Dry matter continues to accumulate in the ear until GS87 while stems and leaves lose weight through respiration and retranslocation of carbohydrate reserves and nitrogen into the developing grain.

Leaves lose dry matter, then stems lose soluble reserves after GS71 when final internodes stop extending.

Maximum crop dry weight occurs at GS87, the end of grain filling. Then dry weight falls as leaf tissue is shed before harvest.

Dry matter accumulation



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 disease pressure. Growing barley as a first cereal helps to reduce yield losses caused by these diseases.

Foliar diseases

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

Spring barley

Maximum dry weight in spring barley (12.5 t/ha at GS87) is about 80% that of winter barley.

Action:

- ▷ Adopt measures to hasten canopy closure in spring if necessary.
- ▷ Control diseases to preserve green leaf area.
- ▷ Control rabbits and slugs to protect young tillers in autumn and winter.
- ▷ Consider autumn disease control if growth is poor, or tiller survival is threatened.
- ▷ For future years, consider earlier drilling if canopy develops late.

Stem elongation

Height is influenced by variety choice and agronomic practice.

Key facts:

- Crop 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 regulators

Height and node number

B Nodes in extended stem = 4
5 internodes

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

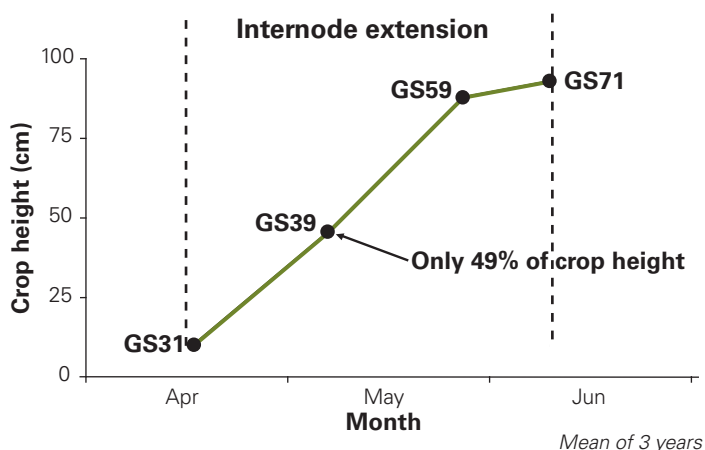
*Height measured from soil level to collar of ear
PGRs = chlormequat at GS30–31, Terpal at GS37–39

At GS39, a barley crop has only reached half of its final potential height. Agronomic conditions and crop management will influence final height.

After GS59, only small increases in crop height occur.



Crops grow taller as internodes extend



Lodging risk

Barley generally has weaker stems than wheat. The crop is more susceptible to stem lodging at the base as well as brackling/necking further up the plant.

Key risk factors include:

Varieties: vary significantly in lodging resistance, see the AHDB Recommended Lists for variety scores

Soil mineral N: 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

Late sowing: generally reduces lodging risk

High plant populations: increase lodging risk, mainly due to reduced anchorage strength

Poorly structured soils: provide weak anchorage and increase root lodging risk.

Plant growth regulators can be used between GS30 and GS45. Later treatments containing 2-chloroethyl phosphonic acid can reduce crop height by up to 15 cm. Chlormequat has proved less effective at reducing height and lodging in barley than in wheat.

Spring barley

Variety and season affect spring barley height. The use of dwarfing genes in breeding programmes has reduced the height of many varieties. Spring crops are usually 5 cm shorter than winter ones. PGRs are not usually required.

Action:

- ▷ Consider varietal lodging risk when planning cropping.
- ▷ Assess lodging risk early in the season, before GS30.
- ▷ Use PGRs when appropriate.

Stem carbohydrate storage

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

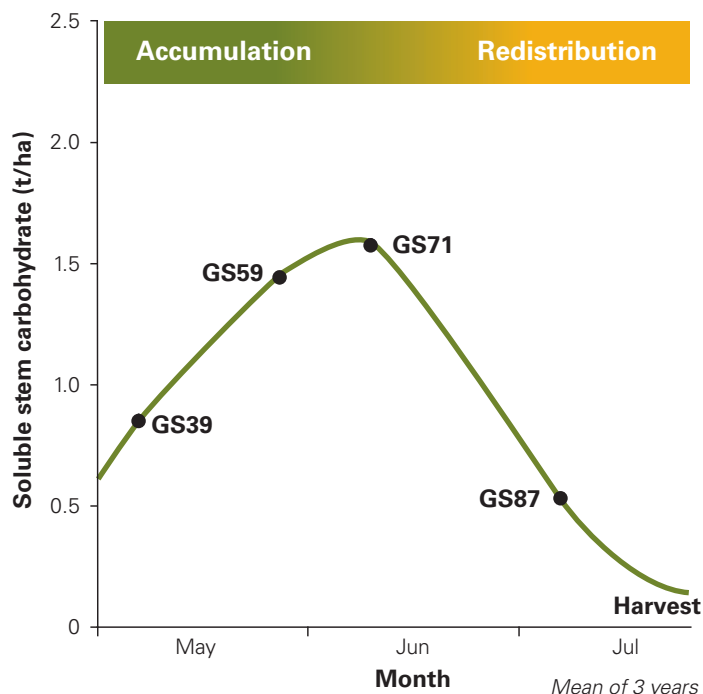


Reserves at flowering = 1.6 t/ha

Stem reserves reach a maximum nine days after GS59 – the end of ear emergence. Variety and growing conditions affect the reserves.

Taller crops have more structural stem material. Stem height does not reflect stem reserves.

Accumulation and redistribution of stem carbohydrates



Comparison of stem reserves in north and south

	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 (9 May)	3.1	0.8
GS59 (30 May)	5.7	1.1
GS71 (11 June)	6.9	1.8
GS87 (14 July)	5.1	0.3

Grain filling and yield

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

Stem reserves contribute 20% to 50% of total yield. In crops under stress, eg drought or pest attack, stem reserves contribute a higher proportion. Reserves make a smaller contribution to yield where post-flowering canopy survival is good.

Ear formation

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

Key facts:

- Potential grain number/ear is determined before flag leaf emergence during spikelet initiation
- Ear weight increases rapidly after GS71
- Grain filling determines grain size and final yield

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

The number of grains on each ear depends on the number of fertile spikelets on the rachis – the central ‘stem’ of the ear. In barley, each spikelet contains only one floret, while wheat spikelets contain two to five fertile florets.

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.

Crop management, particularly nutrition, can significantly influence grains/ear and ears/m². Together these determine the number of grains/m².

Grains/m² and the size of individual grains determine storage capacity during grain filling.

In winter barley, grain yield is more strongly related to grain number than grain size. Therefore, early management decisions to optimise tiller production and survival are particularly important.

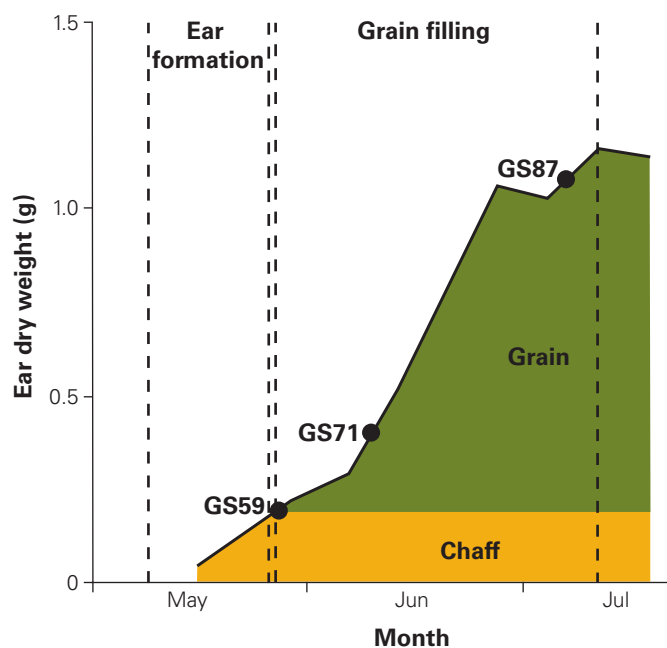
Ear weight

B Ear weight at flowering = 0.16 g/ear

B Ear weight at harvest = 1.11 g/ear

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

Ear weight increases rapidly after GS71



Mean of 3 years



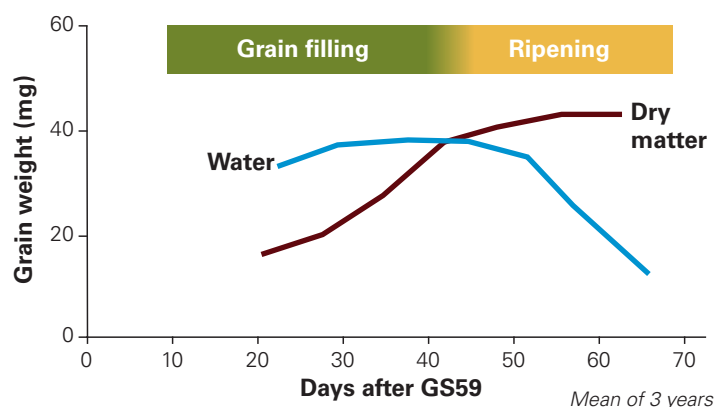
Grain filling and ripening

Grain filling and ripening

Ear and leaf photosynthesis and redistribution of stem reserves are all-important in the 6–7 week grain filling period.

Grain ripening takes a further 2–3 weeks. During this period dry matter content increases and water content decreases.

Grain weight and water content



Final grain dry weight, appearance and specific weight are all determined during grain filling. Benchmark data are for six grains from the central part of the ear.



Dry matter = 39 mg/grain

North = 41 mg

South = 38 mg

40 days to 5 July

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



GAI = <1

3 days before maximum grain weight

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



Ripening period = 20 days



Spring barley

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

New varieties and improved management have led to increases in thousand grain weight (TGW) over recent years. Values are now similar to those of two-row winter crops. Higher TGWs tend to occur in the north than in the south.

Grain yield

Marketable yield depends on grain weight and size and the number of ears per unit area.

Key facts:

- Marketable grain yield represents about half of the total above-ground crop dry matter produced
- Total crop dry weight indicates likely yield because 'harvest index' is relatively stable
- Grain yield is made up of:
 - ears/m²
 - grains/ear
 - average grain weight

Harvest index

B Crop dry weight at harvest = 14.8 t/ha
of which: Grain = 51%
Stem and leaf material = 43%
Chaff = 6%

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.

Small seasonal variations in harvest index can occur, for example, it may reduce if good growing conditions up to flowering are followed by dull weather. This limits photosynthesis during early grain-filling when potential grain size is determined.

Harvest index can vary between varieties.

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.

Yield components

B Grain yield = 8.8 t/ha (85% dry matter)
Ears/m² = 775
Grains/ear = 24
Average grain weight = 46 mg (85% dry matter)

$$\text{Final grain yield} = \text{Ears/m}^2 \times \text{Grains/ear} \times \text{Average grain weight}$$

Most yield variation between sites and seasons reflects differences in grain number rather than grain size.

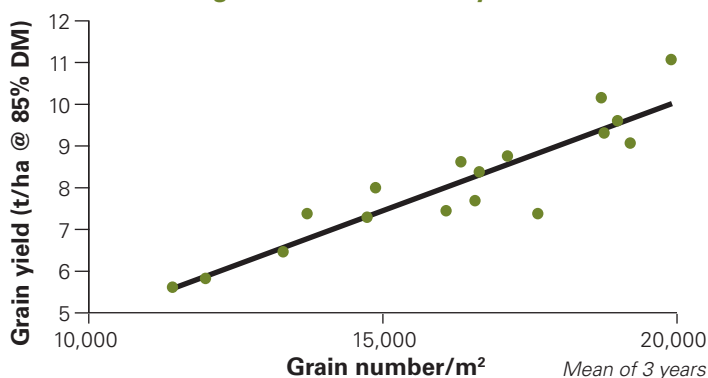
There is a strong relationship between grain number/m² (ears/m² x grains/ear) and yield, but only a weak relationship between average grain weight and yield.

High yields depend on sufficient numbers of ears, and crop managers should aim to maximise growth as ears form. Some compensation for low ear numbers can occur; crops with relatively few shoots produce more grains/ear.

Barley only has one fertile floret/spikelet, so yields do not recover as much as is possible with wheat. Fewer spikelets (and hence florets) abort in crops with few ears.

Late-season drought, lodging or disease all impair photosynthesis and hence can reduce grain filling.

Contribution of grain number/m² to yield



Action:

- ▷ Manage crops early in the season to ensure high grain number/m² and so 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.

Grain quality

Feed barley is usually purchased on a minimum specific weight basis.

Malting markets have specific requirements. Key characteristics are variety, germination, nitrogen content and grain size (www.ukmalt.com).

Key facts:

- Nitrogen content can be manipulated for specific end-user quality specifications
- Most feed grain buyers specify specific weight

Protein content

 **Grain N uptake = 132 kg/ha**
1.76% grain N

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

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

High grain N content arises from a large uptake or redistribution of N late in the season, or poor starch deposition.

High grain N can also result from drought, lodging or disease, all of which reduce yield without affecting N redistribution. In crops grown for high N specification, lodging risk may increase.

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, where most spring malting barley is sold for malt distilling, with 70% of grain nitrogen concentrations below 1.65%.

Most spring malting barley grown in England is destined for brewing, with 70% of grain nitrogen concentration requirements in the range 1.55% to 1.85%.

Benchmark data for grain quality characteristics*

	Overall	North	South
Yield (t/ha)	8.8	9.0	8.5
Average grain weight (g @ 85 % DM)	46	48	45
Grain N (%)	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 screenings

Specific weight, a measure of individual grain density and how they pack, 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 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 with a high number of grains/ear and grains/m² 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.

Action:

- ▷ Apply all N fertiliser to winter malting crops at or before GS31 to reduce the risk of excess grain N concentration.
- ▷ Apply all N fertiliser to spring crops at or before leaf 3, unless high grain N 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.

Measurements

To support husbandry decisions, comparisons with commercial crops must be made using careful in-field observations and measurements.

For quantitative assessments, at least four samples should be taken (one from each quarter of the field). In a variable crop more samples are required. Each sample point should be selected to represent the crop but should be away from headlands, gateways and atypical patches.

Development or 'Growth Stages'

The decimal (or 'Zadoks') growth stage code should be used (see page 4). Assessments are restricted to main shoots until flag leaves emerge. To determine the growth stage of the crop as a whole, quote the middle (median) stage from an odd number of plants arranged in order.

For example:

If five plants were taken and their growth stages were:

33

37

37

39

39

then the crop would be considered to be at GS37.

For more information see: G49 Cereal growth stages – a guide for crop treatments (2009)



Plant populations

Take at least four samples (more if variable) across the field. Throw down a quadrat (a square frame) and count the number of plants inside it. Divide this number by the area (m²) of the quadrat to get the number of plants/m².

Alternatively, use a ruler and count the number of plants growing along a measured length of row. Divide this by the row width (m) and length (m) to determine the number of plants per square metre, as follows:

$$\frac{\text{No. of plants counted in the row}}{\text{Row length (m) x Row width (m)}} = \text{Plants/m}^2$$

For example:

$$\frac{15 \text{ plants counted in the row} \times 10,000}{50 \text{ (cm)} \times 15 \text{ (cm)}} = 200 \text{ plants/m}^2$$

The same method can be used to work out shoot numbers/m², counting shoots instead of plants.

Crop canopy

Crop canopies are measured by their Green Area Index (GAI). This is the surface area of green material (one side only) divided by the area of ground it occupies. For example if, when all the green parts (leaves, shoots and ears) from 1 m² of a field were separated and laid out adjacent and flat, they covered 2 m², the crop would have a GAI of 2. If they covered 4 m², the crop would have a GAI of 4, and so on.

Alternatively, it is possible to assess the GAI by comparison with crops of known GAI (see right).



Dry weight

Dry weight is less easy to assess in the field than canopy size.

Crop biomass can be measured by throwing down a quadrat, removing the crop and then drying it.

One option for drying is:

1. Place harvested material in a microwave at high power for 10–15 minutes.
2. Turn 2–3 times during drying.
3. Weigh dried weight (g) accurately.
4. Divide dried weight by quadrat area (m²) to get biomass (g/m²).
5. Divide by 100 for biomass (t/ha).

Ear dry weight measurements can help predict yield after the grain has reached 45% moisture content.

To do this, dry and weigh a known number of ears at around 45% moisture content (as 1–3 above), then:

1. Divide by ear number and multiply by 0.90 to correct for chaff.
2. Multiply by fertile shoot number/m² to give estimated grain yield (g/m²).
3. Divide by 100 for yield (t/ha).

Glossary

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.

Key stages are:

- canopy closure, usually a week after GS31 when GAI = 2.4
- canopy expansion
- onset of senescence.

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

Development: Changes in crop structure, as defined by the Decimal Code (pages 4–5).

Dry matter (DM): All crop constituents, other than water, left after the tissue has been dried by a standard method to constant weight.

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.

Green Area Index (GAI): The ratio of the area of all green tissues (one side only) and the equivalent ground area occupied – a measure of canopy size.

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 – as described on pages 4–5.

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

Imbibition: Initial uptake of water by dry seed.

Internode: The hollow length of stem between two nodes.

Leaf sheath: The basal portion of a leaf which 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.

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

Peduncle: The topmost node between the flag leaf node and the base of the ear – the collar.

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 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. Also caused by disease or drought.

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

Specific weight: Or bulk density, is 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 barley, there is only one floret in each spikelet.

Stem reserves: Soluble carbohydrate stored in the stem which can translocate and contribute to yield.

Thermal time: The sum of all daily temperatures (mean of minimum and maximum) above a base temperature at which a process stops. In the case of leaf development this is 0°C. Results are expressed in day-degrees (°C days), as shown below:

Day	Mon	Tue	Wed	Thur	Fri	Sat	Sun
Temperature* (°C)	19	18	19	18	19	18	19
Thermal time (°C days)	114	48	114	48	114	48	114

Average temperature over 24 hours.

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.

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