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GRDC
GROWNOTES™

GRDC
GRAINS RESEARCH
& DEVELOPMENT
CORPORATION

BARLEY

SECTION 4

PLANT GROWTH AND PHYSIOLOGY

GERMINATION AND EMERGENCE | FACTORS AFFECTING GERMINATION AND EMERGENCE | EFFECT OF TEMPERATURE, PHOTOPERIOD AND CLIMATE ON PLANT GROWTH AND PHYSIOLOGY | PLANT GROWTH STAGES

SECTION 4

Plant growth and physiology

4.1 Germination and emergence

4.1.1 Germination

Germination begins when the seed absorbs water and ends with the appearance of the radicle. Germination has three phases:

- water absorption (imbibition)
- activation
- visible germination

Phase 1: Water absorption (GS01)*

*(*See under heading 'Plant growth stages' below for detail on Zadoks Cereal Growth Stage Key)*

Phase 1 starts when the seed begins to absorb moisture. Generally, a barley seed needs to reach a moisture content of around 35–45% of its dry weight to begin germination. Water vapour can begin the germination process as rapidly as liquid can.

Barley seeds begin to germinate at a relative humidity of 97.7%. Soil so dry that roots cannot extract water still has a relative humidity of 99%, much higher than that of a dry seed. So even in dry conditions, there can be enough moisture for the seed to initiate germination, albeit at a slower pace than in damp conditions.

Phase 2: Activation (GS03)

Once the embryo has swollen, it produces hormones that stimulate enzyme activity. The enzymes break down starch and protein stored in the seed to sugars and amino acids, providing energy to the growing embryo. If the seed dries out before the embryo starts to grow, it remains viable.

Phase 2 continues until the rupture of the seed coat, the first visible sign of germination.

Phase 3: Visible germination (GS05–GS07)

In Phase 3 the embryo starts to grow visibly. The radicle emerges, followed soon after by primary roots and the coleoptile. The enzymes produced in Phase 2 mobilise sugars and amino acids stored in the seed and enable their transfer to the growing embryo. [1]

4.1.2 Emergence (GS07)

As the first primary roots appear, the coleoptile bursts through the seed coat and begins pushing towards the surface. Emergence is when the coleoptile or the first leaf becomes visible above the soil surface.

[1] N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW/NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

Coleoptile formation

The coleoptile is well developed in the embryo, forming a thimble-shaped structure covering the seedling leaf and the shoot. Once the coleoptile emerges from the seed, it increases in length until it breaks through the soil surface.

The fully elongated coleoptile is a tubular structure ranging from 50 to 80 mm in length and about 2 mm in diameter. It is white, except for two strands of tissue that contain chlorophyll. The end of the coleoptile is bullet-shaped and is closed except for a small pore, 0.25 mm long, a short distance behind the tip.

When the coleoptile senses light, it stops growing and the first true leaf pushes through the pore at the tip. Up to this point, the plant is living on reserves within the seed.

4.2 Factors affecting germination and emergence

4.2.1 Dormancy

In a barley seed, germination begins after a very short period of dormancy. Some level of seed dormancy is necessary to help prevent ripe grain from germinating in the head before harvest. However, excessive dormancy can be a problem in malting barley, forcing maltsters to store the grain for an extended period after harvest before it can be successfully malted. Australian varieties generally have low dormancy, some such as Hamelin(ϕ) and Flagship(ϕ) being particularly low.

At least two genes influence the level of dormancy in Australian barley. One gene is expressed in the embryo of the seed and needs to be present for any level of seed dormancy to develop. This gene makes the seed sensitive to the plant hormone abscisic acid, which prevents germination at crop maturity. The second gene is expressed in the seed coat and, in combination with the embryo gene, produces a more robust and stable dormancy. [2]

4.2.2 Moisture

Soil moisture influences the speed of germination. Germination is rapid if the soil is moist. When the soil dries to near the permanent wilting point, the speed of germination slows. When the soil reaches permanent wilting point, germination will take 10 days at 7°C instead of 5 days at 7°C when there is adequate moisture.

The germination process in a seed may stop and start in response to available moisture. Seeds that have taken up water and entered Phase 2, but not reached Phase 3, remain viable if the soil dries out. When the next fall of rain comes, the seed resumes germinating, taking up water and moving quickly through Phase 2.

This ability to start and stop the germination process in response to conditions before the roots and coleoptile have emerged is an important consideration when dry-sowing. If the seedbed dries out before the coleoptile has emerged, the crop needs to be monitored to determine whether it will emerge, so that the critical decision to re-sow can be made.

Soil moisture also affects emergence. Sowing into hard-setting or crusting soils that dry out after sowing may result in poor emergence. Hard soil makes it difficult for the coleoptile to push through to the surface, particularly in varieties with short coleoptiles. In some crusting soils, gypsum and/or lime may improve soil structure and assist seedling emergence.

Stubble reduces the impact of raindrops on the soil surface and helps to prevent soil crusts from forming. Stubble retention also encourages biological activity and increases

[2] N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW/NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

the amount of organic matter, which improves the stability of the soil by binding the soil particles together. [3]

4.3 Effect of temperature, photoperiod and climate on plant growth and physiology

4.3.1 Temperature

Germination

Germination is dependent on temperature. The ideal temperature for barley germination is 12°–25°C, but germination will occur between 4°C and 37°C.

The speed of germination is driven by accumulated temperature, or degree-days. Degree-days are the sum of the average daily maximum and minimum temperatures over consecutive days compared with a base temperature. For barley, that is 0°C during vegetative growth and 3°C in the reproductive phase.

Barley requires 35 degree-days for visible germination to occur (see Table 1). For example, at an average temperature of 7°C, it takes 5 days for visible germination to occur; at 10°C, it takes 3.5 days. Other examples are presented in Table 2.

Table 2: Number of degree-days required for germination and emergence

	No. of degree-days required
Root just visible	27
Coleoptile visible	35
Emergence (40 mm)	130
Each leaf	100

Table 3: Examples of how different temperatures affect germination

Temperature	No. of days to germination
3.5°C	10
5°C	7
7°C	5
10°C	3.5

Emergence

Extension of the coleoptile is directly related to soil temperature. Soils that are too cold or too hot shorten the coleoptile length. Research shows that coleoptiles are longest when soil temperatures are 10°–15°C. This results in variation in emergence and establishment times for different sowing dates and for different regions. Barley cultivars differ in coleoptile length, but this characteristic is not closely linked to plant height or to dwarfing genes.

Establishment

High temperatures during establishment cause seedling mortality, reducing the number of plants that establish. In hot environments, the maximum temperature in the top few centimetres of soil can be 10–15°C higher than the maximum air temperature, especially with a dry, bare soil surface and high radiation intensity.

In these conditions, soil temperature can reach 40–45°C, seriously affecting seedling emergence. Brief exposure to extreme soil temperatures can also restrict root growth and tiller initiation.

[3] N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW/NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

Table 3 shows the average number of plants that established with increasing soil temperatures. Seed at 100 kg/ha was planted at a depth of 30–40 mm. The soil temperature was measured in the field at a depth of 50 mm.

Table 4: Number of plants established at various soil temperatures
The difference between 20.2°C and 33.2°C is statistically significant [4]

Mean max soil (°C)	No. of plants established per m²
20.2°C	315
33.2°C	256
42.2°C	89

4.3.2 Oxygen

Oxygen is essential to the germination process. Seeds absorb oxygen rapidly during germination, and without enough oxygen, they die. Germination is slowed when the soil oxygen concentration is <20%. During germination, water softens the seed coat to make it permeable to oxygen; dry seeds absorb almost no oxygen.

Seeds planted in waterlogged soils cannot germinate because of a lack of oxygen. It is commonly thought that, in very wet conditions, seeds burst; in fact, they run out of oxygen and die. [5]

4.3.3 Seed quality

Early seedling growth relies on stored energy reserves in the seed. Good seedling establishment is more likely if seed is undamaged, stored correctly and from a plant that had adequate nutrition. Seed grading is an effective way to separate good-quality seed of uniform size from small or damaged seeds and other impurities.

Seed size is also important—the larger the seed, the greater the endosperm and starch reserves. Therefore, although size does not alter germination, bigger seeds have faster seedling growth, a greater number of fertile tillers per plant and potentially higher grain yield.

Seed size is usually measured by weighing 1000 grains, known as the 1000-grain weight. The 1000-grain weight varies among varieties and from season to season. This indicates that sowing rates need to vary according to the 1000-grain weight for each variety and in each season in order to achieve desired plant densities.

Some seed treatments can delay emergence by slowing the rate of germination, and others, which contain triazole fungicides, can shorten the length of the coleoptile. Some treatments can also shorten the length of the first leaf and the sub-crown internode. [6]

4.3.4 Coleoptile length

Some tall varieties (e.g. Buloke(b)) have short coleoptiles, whereas some short varieties (e.g. Baudin(b)) have relatively long coleoptiles. Sowing seeds deeper than the coleoptile length will result in the coleoptile not reaching the surface, making plant emergence unlikely. Deeply sown seeds also lack early vigour, and tillering can be delayed.

In research at Condobolin, New South Wales, in 2008, plant emergence was shown to decrease with deeper sowing and was dependent on variety. When plants were sown

[4] N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW/NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

[5] N Fettell, P Bowden, T McNee, N Border (2010), Barley growth & development. PROCROP Series. Industry & Investment NSW/NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

[6] N Fettell, P Bowden, T McNee, N Border (2010), Barley growth & development. PROCROP Series. Industry & Investment NSW/NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

at 87 mm depth, emergence was 50–80% of that sown at a shallow 44 mm. For plants sown at 112 mm, emergence was 35–60% of that with sowing at 44 mm. [7]

4.3.5 Nutrition

Adequate nutrition is essential for good plant growth and development, yield and grain quality. Nutritional requirements vary depending on potential yield and soil fertility status. A soil test should be carried out before sowing to measure soil nutrients and calculate fertiliser requirements.

Historically, rates of fertiliser application to barley crops have been low. Barley was perceived to perform well on poor soils and in low-fertility situations. This is not true. In fertile soils, barley will yield comparably to wheat without necessarily producing a protein level above that acceptable for malting specifications. [8]

Nitrogen

Nitrogen (N) is essential to plant growth and is commonly applied at moderate to high levels before or at sowing. Urea-ammonium nitrate or urea are commonly used to apply N at high rates. Different forms of fertiliser N need specific management. For example, the soil needs to be moist when anhydrous ammonia is applied so it is sealed within the soil.

Nitrogen can be leached from light soil if sowing is delayed by heavy rains or continuous wet weather. Excessive N fertiliser applied close to the seed can lead to toxicity problems. Under good moisture conditions, seed can tolerate a maximum of ~25 kg N/ha without seedling mortality. This amount is based on an 18-cm row spacing and fertiliser banded with the seed. Deep banding of N, which requires seed and fertiliser to be separated by >25 mm, and pre-drilling of urea at sowing are two methods that will prevent seedlings from overdosing on fertiliser.

Markets for malting barley demand moderate protein levels and feed barley markets do not pay a premium for protein. Therefore, it is good practice to apply N fertilisers for vegetative growth early to give a higher yield potential, rather than having reserves of N at grain-filling that the plant will put into grain protein.

There is no reason to be wary of high-fertility paddocks or the use of N fertiliser to increase the yield potential of barley. After moderate additions of N, the protein percentage can remain relatively constant, whereas the yield can increase dramatically. High N availability or the use of high levels of N fertiliser can lead to an increase in grain protein but the major determinant of this is seasonal conditions during grainfill.

Nitrogen rates will vary depending on whether you are trying to meet malt specifications, use the crop for grazing, or maximise the yield of a feed variety. [9]

Phosphorus

Phosphorus (P) is essential to seed germination and early root development and for increasing seedling vigour and establishment. Large amounts are taken up during early growth. Phosphorus deficiency at this early stage of growth significantly reduces yield potential. Many of the soils in southern Australia have very low levels of available P, and in some areas it is the limiting nutrient.

Unlike N, P is relatively immobile in the soil; therefore, it needs to be placed near the seed. Regardless of soil test results, some P needs to be applied with seed at sowing.

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7 N Fettell, P Bowden, T McNee, N Border (2010), Barley growth & development. PROCROP Series. Industry & Investment NSW/NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

8 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW/NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

9 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW/NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

One method of estimating P requirement is to allow 4 kg P per tonne (t) of target yield. For example, a barley crop of 3 t/ha requires 12 kg P/ha. Delays in the uptake of P to critical levels can delay maturity, which in turn can increase grain screenings. [10]

4.4 Plant growth stages

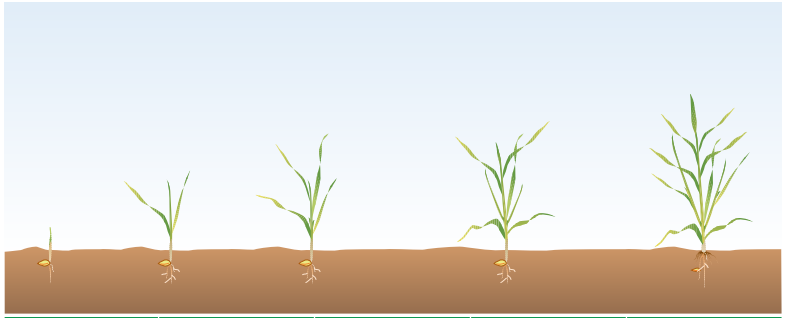
4.4.1 Plant growth stages

A growth stage key provides farmers, advisers and researchers with a common reference for describing the crop's development. Management by growth stage is critical to optimise returns from inputs such as N, plant growth regulators, fungicides and water.

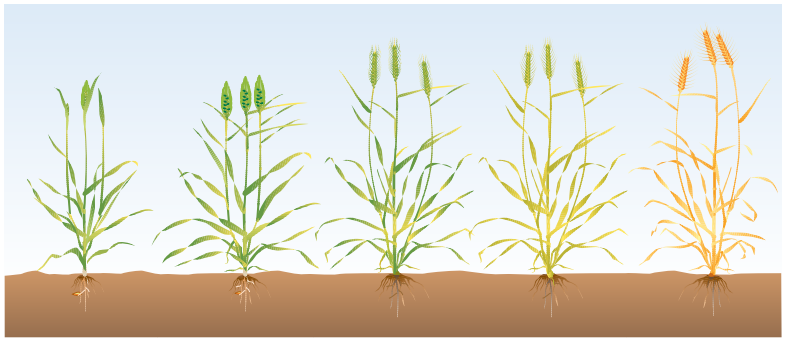
4.4.2 Zadoks Cereal Growth Stage Key

Zadoks Cereal Growth Stage Key (Figure 1) is the most commonly used key to growth stages for cereals, in which the development of the cereal plant is divided into ten distinct development phases covering 100 individual growth stages. Individual growth stages are denoted by the prefix GS (growth stage) or Z (Zadoks), for example, GS39 or Z39.

The principal Zadoks growth stages used in relation to disease control and N management are those from the start of stem elongation through to early flowering: GS30–GS61.



Zadoks Growth Stage	GS 00-09	GS10-19	GS20-29	GS30-39	GS40-49
Development phase	Germination	Seedling growth	Tillering	Stem elongation	Booting



Zadoks Growth Stage	GS 50-59	GS60-69	GS70-79	GS80-89	GS90-99
Development phase	Ear emergence	Flowering	Milk development (grain fill period)	Dough development (grain fill period)	Ripening

Figure 1: Zadoks growth stages. [11]

[10] N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW/NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

[11] N Poole (2005) Cereal growth stages guide. GRDC, http://www.grdc.com.au/uploads/documents/GRDC%20Cereal%20Growth%20Stages%20Guide1.pdf

Early stem elongation GS30–33 (pseudostem erect—third node on the main stem)

This period is important for both timing of N application and protection of key leaves. To ensure the correct identification of these growth stages, plant stems are cut longitudinally so that internal movement of the nodes (joints in the stem) and lengths of internodes (hollow cavities in the stem) can be measured.

Leaf dissection at GS32 and GS33

This is a method for determining which leaves are emerging from the main stem prior to the emergence of the flag leaf. Knowing which leaves are present is critical if fungicide use is to be optimised to protect leaves.

The Zadoks Cereal Growth Stage Key does not run chronologically from GS00 to GS99; for example, when the crop reaches three fully unfolded leaves (GS13), it begins to tiller (GS20) before it has completed four, five and six fully unfolded leaves (GS14, GS15, GS16).

It is easier to assess main stem and number of tillers than it is the number of leaves (owing to leaf senescence) during tillering. The plant growth stage is determined by main stem and number of tillers per plant; for example, GS22 is main stem plus two tillers and GS29 is main stem plus nine or more tillers.

In Australian cereal crops, plants rarely reach GS29 before the main stem starts stem elongation (GS30). Because of growth stages overlapping, it is possible to describe a plant with several growth stages at the same point in time. For example, a cereal plant at GS32 (second node on the main stem) with three tillers and seven leaves on the main stem would be at GS32, 23 and 17, yet practically, it would be regarded as GS32, because this describes the most advanced stage of development.

Note: After stem elongation (GS30), the growth stage describes the stage of the main stem; it is not an average of all the tillers. This is particularly important with timing fungicide; for example, GS39 is full flag leaf on the main stem, meaning that not all flag leaves in the crop will be fully emerged. [12]

For more information, download the GRDC guide: Cereal growth stages.

[12] N Poole (2005) Cereal growth stages. Grains Research and Development Corporation, http://www.grdc.com.au/uploads/documents/GRDC%20Cereal%20Growth%20Stages%20Guide1.pdf