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GRAINS RESEARCH
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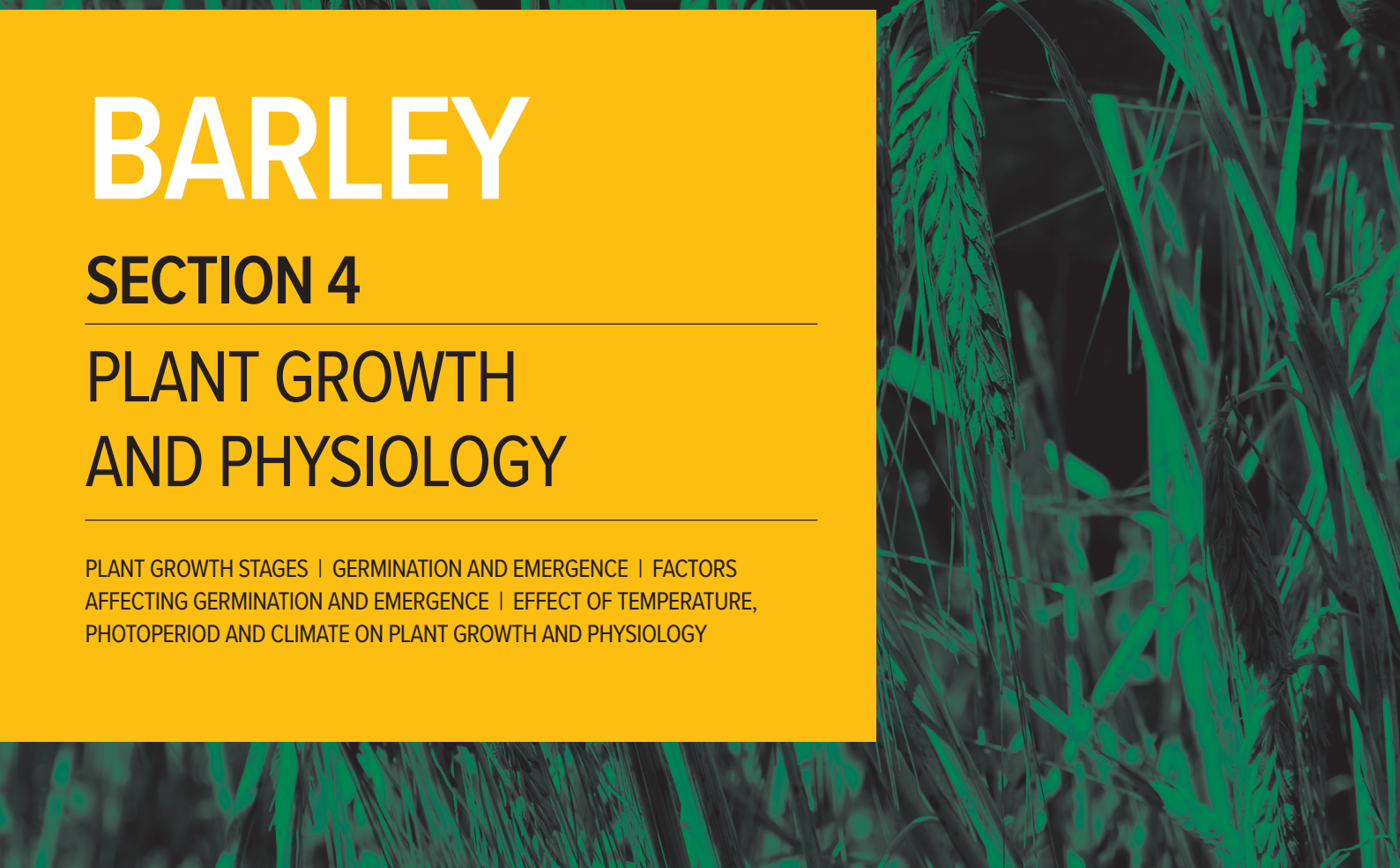
CORPORATION

BARLEY

SECTION 4

PLANT GROWTH AND PHYSIOLOGY

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



Plant growth and physiology

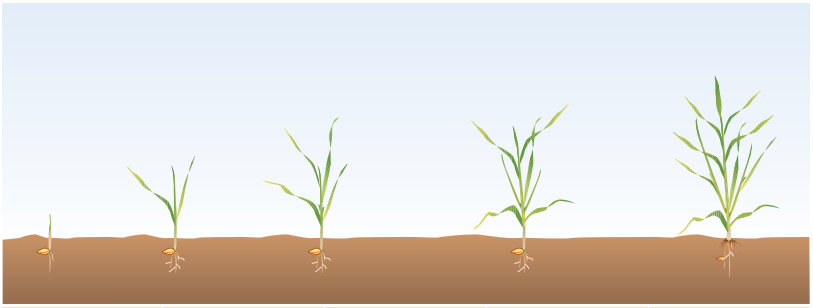
4.1.1 Plant growth stages

A growth-stage key provides farmers, advisers and researchers with a common reference for describing the crop's development.

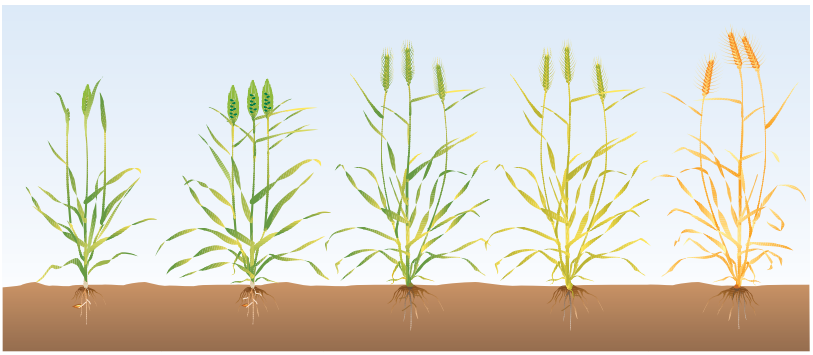
4.1.2 Zadoks Cereal Growth Stage Key

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.*

Source: GRDC

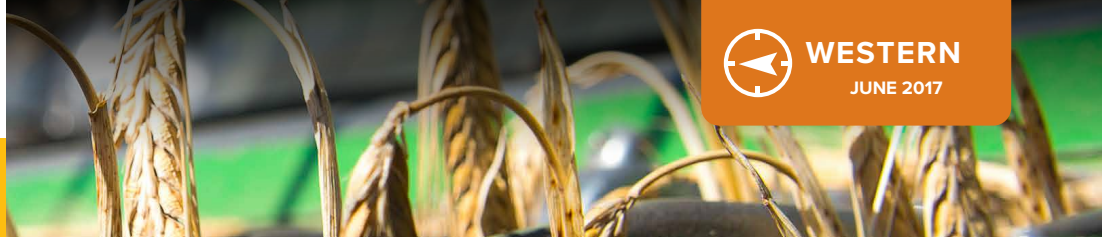
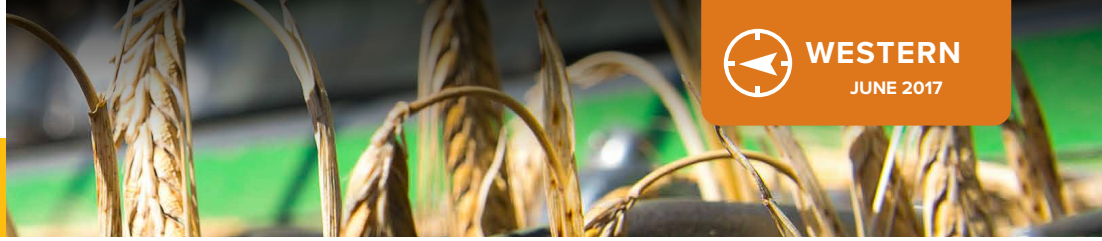


Table 1: *Zadoks decimal growth scale for cereals*

Germination	
00	Dry seed
01	Start of imbibition
03	Imbibition complete
05	Radicle emerged from seed
07	Coleoptile emerged
09	Leaf just at coleoptile tip
Seedling growth	
10	First leaf through coleoptile
11	First leaf unfolded
12	2 leaves unfolded
14	4 leaves unfolded
16	6 leaves unfolded
18	8 leaves unfolded
Tillering	
20	Main shoot only
21	Main shoot & 1 tiller
22	Main shoot & 2 tillers
24	Main shoot & 4 tillers
26	Main shoot & 6 tillers
28	Main shoot & 8 tillers
Stem elongation	
30	Stem starts to elongate (head at 1 cm)
31	1st node detectable
32	2nd node detectable
34	4th node detectable
36	6th node detectable
37	Flag leaf just visible
39	Flag leaf/collar just visible
Booting	
41	Flag leaf sheath extending
43	Boot just visibly swollen
45	Boot swollen
47	Flag leaf sheath opening
49	First awns visible
Head emergence	
50	1st spikelet of head just visible
53	1/4 of head emerged
55	1/2 of head emerged
57	3/4 of head emerged
59	Emergence of head complete
Anthesis (flowering)	
61	Beginning of anthesis
65	Anthesis 50%
69	Anthesis compete
Milk development	
71	Seed watery ripe
73	Early milk
75	Medium milk
77	Late milk
Dough development	
83	Early dough
85	Soft dough
87	Hard dough
Ripening	
91	Seed hard (difficult to divide by thumbnail)
92	Seed hard (can no longer be dented by thumbnail)
93	Seed loosening in daytime
94	Overripe, straw dead & collapsing
95	Seed dormant
96	Viable seed giving 50% germination
97	Seed not dormant
98	Seed dormancy induced



Early stem elongation GS30–33

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. [1]

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

MORE INFORMATION

http://www.nvtonline.com.au/wp-content/uploads/2013/02/Zadoks-Growth-Scale.pdf

4.1.3 Maturity

The maturity, or length of time taken for a variety to reach flowering, depends on vernalisation, photoperiod and thermal-time requirements. Recommended sowing times are decided by assessing the maturity of varieties in different environments and with different sowing times.

After grainfilling, the vascular system supplying the grain with water and nutrients is blocked and the grain stops growing and turns brown. This is physiological maturity. The mature barley grain comprises mainly starch (75–85%), protein (~9–12%) and water (~8–12%). [2]

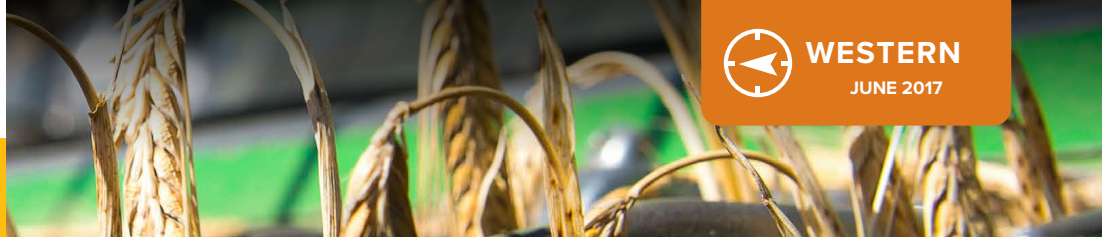
Physiological maturity occurs between 40 and 50 days after flowering. When maximum grain dry weight is achieved in the field, the loss of green colour from the glumes and peduncle is an approximate indication of physiological maturity together with a rapid decline in grain moisture occurring at this time.

At ~12% moisture, the barley is ready for harvest. The current receival standards generally require delivered grain to have no more than 12.5% moisture. Storage of grain with higher moisture content is undesirable. [3]

1 N Poole (2005) Cereal growth stages guide. GRDC Publications, https://www.researchgate.net/file.PostFileLoader.html?id=5780fa6bf7b67e860b4def31&assetKey=AS%3A381929540079624%401468070506798

2 GIWA Grain Standards in Western Australia http://www.giwa.org.au/standards

3 DAF Qld (2012) Barley planting, nutrition and harvesting. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting



4.2 Germination and emergence

4.2.1 Germination

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

- Phase 1: water absorption (imbibition)
- Phase 2: activation
- Phase 3: visible germination

Phase 1: Water absorption (GS01)

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. [4]

4.2.2 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 of the first leaf becomes visible above the soil surface.

Coleoptile formation

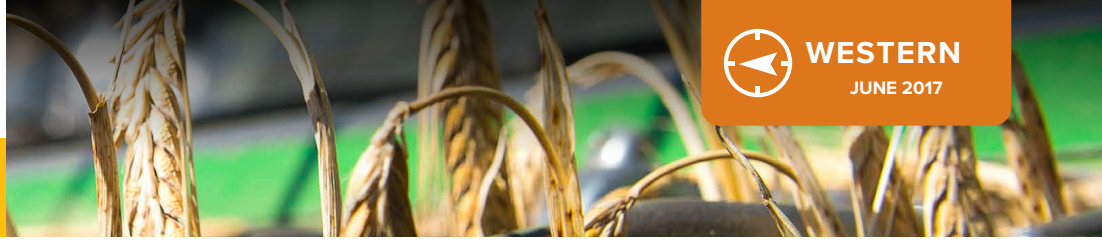
The coleoptile is well developed in the embryo, forming a thimble-shaped structure covering the seedling leaf and the shoot. Once the coleoptile emerges from the seed, it increases in length until it breaks through the soil surface.

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. [5]

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



4.3 Factors affecting germination and emergence

4.3.1 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 and Flagship 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. [6]

4.3.2 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 five 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 structure 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 can 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 the amount of organic matter, which improves the stability of the soil by binding the soil particles together. [7]

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

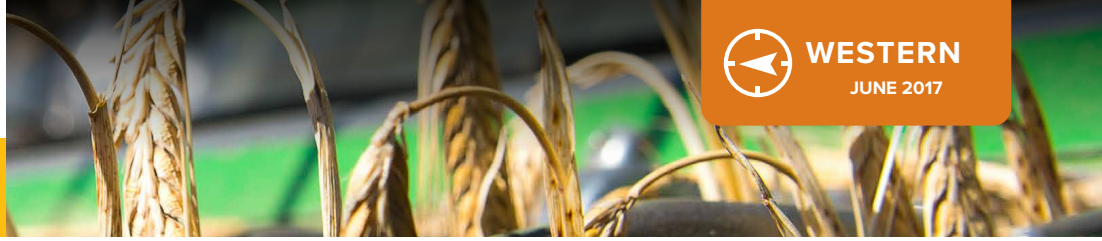
4.4.1 Temperature

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.

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

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



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 (Table 22). For example, at an average temperature of 7°C, it takes five days for visible germination to occur; at 10°C, it takes 3.5 days (Table 33).

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

Source: UNE

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

Source: UNE

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 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.

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 cm 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.

Table 44 shows the average number of plants that establish with increasing soil temperatures, with seed at 100 kg/ha planted at a depth of 30–40 mm and soil temperature measured in the field at a depth of 50 mm.

Table 4: *Number of plants established at various soil temperatures.*

Mean max soil (°C)	No. of plants established per m^2
20.2°C	315
33.2°C	256
42.2°C	89

The difference between 20.2°C and 33.2°C is statistically significant. [8]

4.4.2 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. [9]

Coleoptile length

Coleoptile length is an important characteristic as it contributes to the maximum depth that a cultivar can be sown. Cultivars with a short coleoptile may fail to emerge in situations where the first internode cannot elongate enough to bring the crown close to the soil surface and allow the first true leaf to emerge.

Cultivars with a short coleoptile impact on the capacity of growers to chase moisture and sow seed at depths greater than 50 mm. The suggested sowing depth for barley in WA is 20–30 mm.

An improvement in the tolerance to deep seeding is likely to become an important adaptive trait for barley in Australia, as climate change is expected to increase the variability of the seasonal break, moisture availability during May and June, and decrease total in-season rainfall.

Research in WA has shown that coleoptile length of cultivars can range from 38 mm (Morell) to 93 mm (Doolup). Most of the 44 spring barley cultivars in the study had a coleoptile length between 60 and 80 mm. However, five cultivars (Buloke(p), Dash, Harrington, Morrell and Tallon) had a coleoptile length shorter than 60 mm. Seven cultivars (CM72, Doolup, Finniss, Fleet(p), Hannan, Haruna Nijo and Macumba had a coleoptile length longer than 80 mm.

The development of barley cultivars with a coleoptile length above 100 mm or a capacity to successfully emerge when sown below 100 mm could be useful and is a challenge for Australian barley breeders. Only two of the 44 cultivars evaluated in the study had a coleoptile length over 90 mm and none were over 100 mm.

Coleoptiles longer than 100 mm would be useful in assisting growers to sow closer to the optimum sowing time in situations where moisture is present at depth but not at the surface. Long coleoptiles would also be beneficial for growers in their tactical management at seeding including stubble management, furrow sowing and the use of seed fungicides and herbicides incorporated by seeding.

Genetic variation exists and markers have been identified that could be exploited to develop germplasm that could give more robust options for growers as they adopt management systems to deal with seasonal variability and the drying seasons of WA. [10]

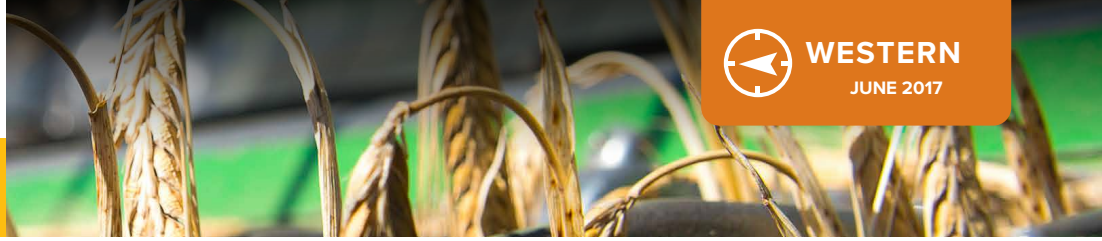
4.4.3 Nutrition

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.

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

10 B Paynter and G Clarke (2010) Coleoptile length of barley (*Hordeum vulgare L.*) cultivars. Genetic Resources and Crop Evolution. 57:395–403, https://www.researchgate.net/publication/226534038_Coleoptile_length_of_barley_Hordeum_vulgare_L_cultivars



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. [11]

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.

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 grainfilling 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 malt specifications are being targeted, the crop is being grazed, or the yield of a feed barley crop maximised. [12]

Phosphorus

Unlike N, phosphorus (P) is relatively immobile in the soil; therefore, it needs to be placed near the seed.

P is essential to seed germination, 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. WA soils were very low in P, however with large amounts of P applied since clearing many soils now have adequate P levels for wheat and barley. Soil testing is critical to assess soil P levels, however it is recommended to use some starter P with all cereal crops as not all soil P may be available to the plant.

One method of estimating P requirement is to allow 4 kg P/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. [13]

DAFWA research has shown that barley has a similar response to P as wheat.

MORE INFORMATION

R Malik and B Paynter (2015) Nitrogen rates and timing for new malting barley varieties. Agribusiness Crop Update.

11 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

12 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

13 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