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GRDC GROWNOTES™

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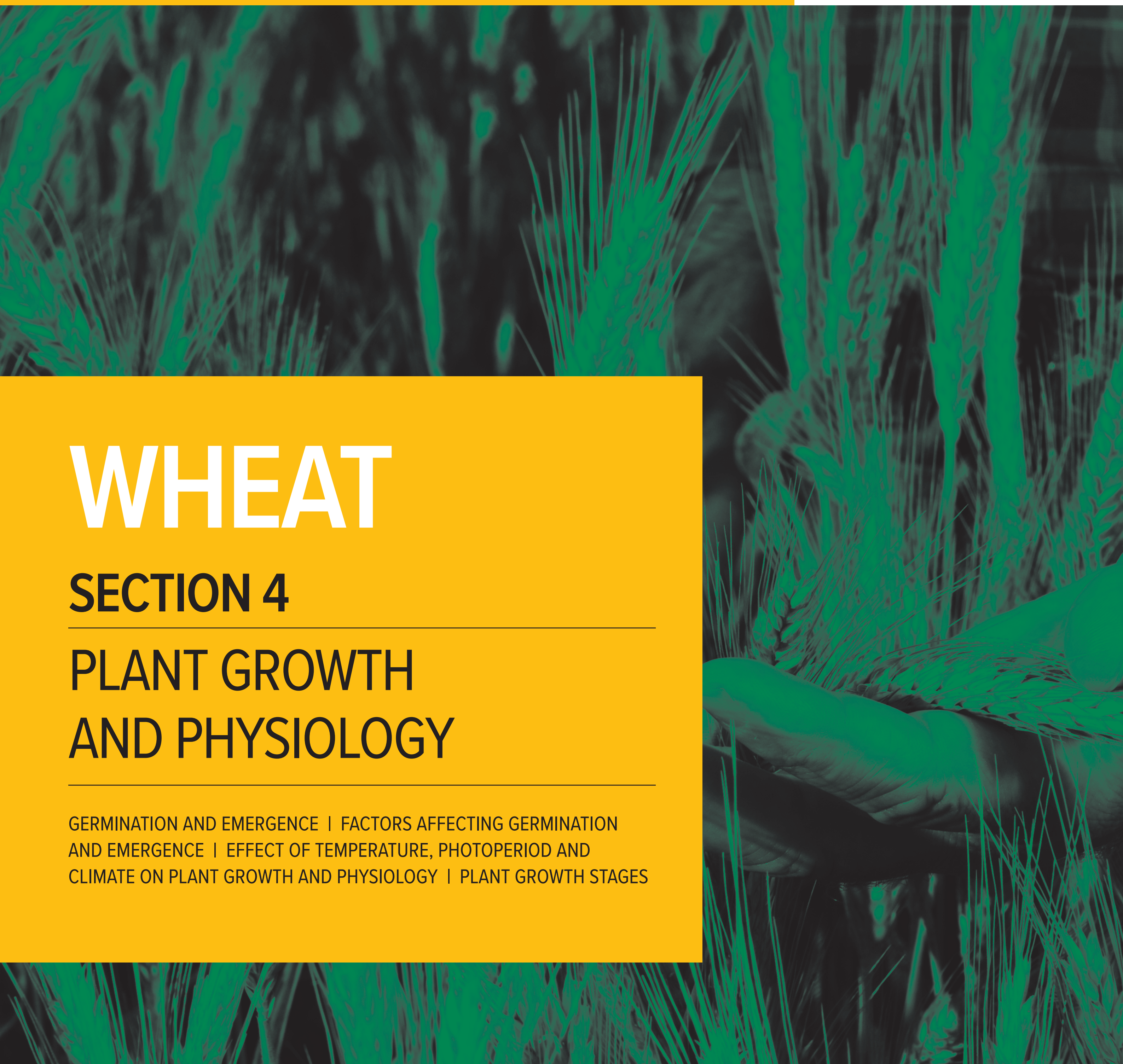

WHEAT

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

Wheat 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 1.4 Growth Stages, for detail on Zadoks Cereal Growth Stage Key)*

Phase 1 starts when the seed begins to absorb moisture. Generally, a wheat 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.

Wheat 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 absorb and begin Phase 1, but it takes longer than in moist 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. The larger the seed, the more starch and, consequently, energy it will have. 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–GS09)

In Phase 3 the embryo starts to visibly grow. The radicle emerges, followed soon after by other 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]

Storage on-farm

Seed that is dry, cool and not weather-damaged will remain viable for longer. In well-managed storage, germination can be expected to reduce by only 5% after 6 months. To achieve this, grain moisture content should be kept below 12%.

Grain temperature also has a major impact on germination. Aim for grain temperatures of ≤20°C in seed storage by using aeration cooling (with auto control). Wheat at 12%

1 NSW DPI Agronomists (2007) *Wheat growth and development.* PROCROP Series, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

moisture content stored at 30–35°C (unaerated grain temperature) will have reduced germination percentages and seedling vigour when stored over a long period. Small seed silos should be positioned in the shade or painted reflective white to assist in keeping grain cool. [2] (See *Section 13. Storage*.)

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.

Coleoptile formation

The coleoptile (Figure 1) is well developed in the embryo, forming a thimble-shaped structure covering the seedling tube 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 about 50 mm long and 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, and 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. [3] The difference between the coleoptile and the first true leaf is that the coleoptile knows which way the soil surface is. If it does not reach the surface the first leaf may emerge under the soil and grow in any direction.

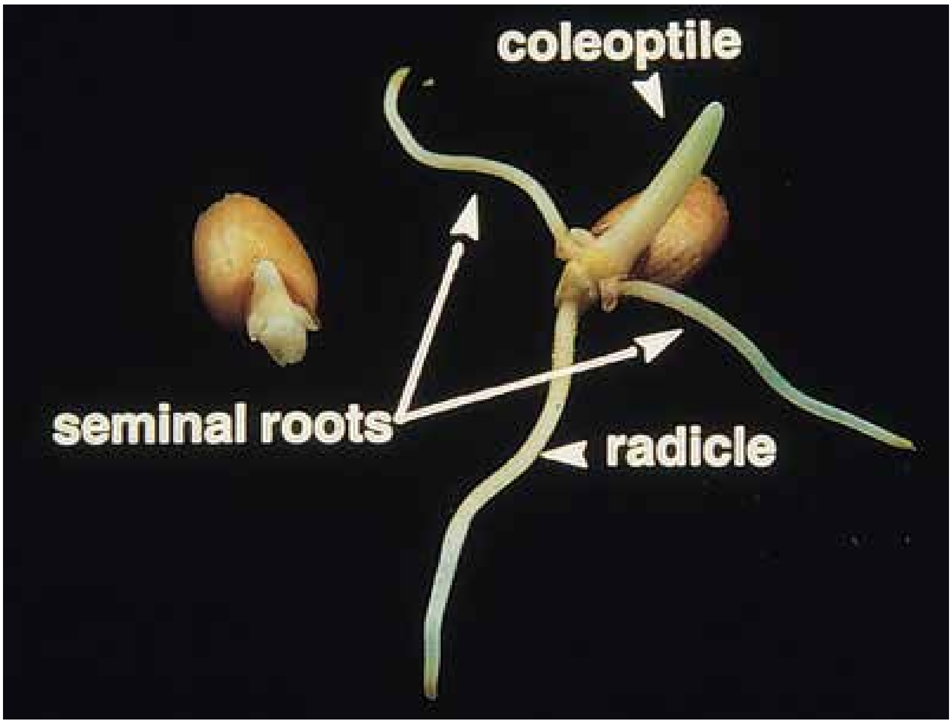

Figure 1: Germinated wheat seed. (Source: University of Minnesota)

[2] P Burrill, P Botta, C Newman, B White, C Warrick (2013) Northern and southern regions—Grain storage pest control guide. GRDC Grain Storage Fact Sheet, June 2013, http://storedgrain.com.au/northern-southern-regions-grain-storage-pest-control-guide/

[3] NSW DPI Agronomists (2007) *Wheat growth and development*. PROCROP Series, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

4.2 Factors affecting germination and emergence

4.2.1 Dormancy

In a wheat seed, germination begins after a very short period of dormancy. Australian wheats have a low level of dormancy that is easily broken down, allowing germination to begin. By contrast, European and North American red wheat varieties have a dormancy derived from their seed coat that lasts 3–7 months. This dormancy is linked to anthocyanins, the enzymes that give the seed coat the red colour.

In Australian white wheats, at least two genes influence the level of dormancy. One gene is expressed in the embryo of the seed and must be present for any level of seed dormancy to develop. This gene makes the grain sensitive to the plant hormone abscisic acid, which prevents germination at the time of 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. This level of dormancy is essential in varieties targeted for Queensland and northern New South Wales because of summer rainfall, and is highly desirable in southern Australia. [4]

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. Instead of 5 days at 7°C when there is adequate moisture, germination will take 10 days at 7°C when soil reaches the permanent wilting point.

The germination process in a seed may stop and start in response to available moisture. Therefore, seeds that have taken up water and entered Phase 2, but not reached Phase 3, remain viable if the soil dries out. This can happen when dry sowing is followed by a small fall of rain that keeps the soil moist for a few days before drying out. When the next fall of rain comes, the seed resumes germinating, taking up water and moving quickly through Phase 2, so that germination is rapid.

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 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. The 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 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. [5]

4 NSW DPI Agronomists (2007) *Wheat growth and development*. PROCROP Series, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf.

5 NSW DPI Agronomists (2007) *Wheat growth and development*. PROCROP Series, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf.

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 range for wheat germination is 12°–25°C, but germination will occur between 4° 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.

Wheat requires 35 degree-days for visible germination to occur (Table 1). For example, at an average temperature of 7°C, it takes 5 days before visible germination. At 10°C, it takes 3.5 days.

Table 1: Degree-days required for germination and emergence

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

Source: J Passioura 2005.

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 between 10° and 15°C. This is one reason why there is variation in emergence and establishment in the different wheat-growing areas.

Establishment

Plant emergence and establishment are the starting points of crop growth. 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.

Table 2 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. [6]

Table 2: Number of wheat plants established at various soil temperatures

Mean max. soil temp. (°C)	No. of plants established (plants/m²)
20.2°C	315.3
33.2°C	256.7
42.2°C	89.8

Note: The difference between 20.2°C and 33.2°C is statistically significant.

[6] NSW DPI Agronomists (2007) *Wheat growth and development*. PROCROP Series, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

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, making it permeable to oxygen. This means that 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. [7]

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, while 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. Sowing rate needs to vary according to the 1000-grain weight for each variety, in each season, in order to achieve desired plant densities. Growers or their advisers need to weigh seeds to determine applicable sowing rates to their region.

Weather-damaged seed is more likely to have reduced germination and emergence. Further reduction may be caused by stress from azole seed dressings (a group of fungicides containing the chemical called azole), deep sowing and low soil moisture. [8]

4.3.4 Coleoptile length

The length of the coleoptile is determined more by genetics than by seed size or protein. Most modern, semi-dwarf wheats have a dwarfing gene (*Rht1* or *Rht2*) that reduces plant height, increases resistance to lodging and increases the ratio of grain weight to above-ground dry matter (harvest index). However, these genes also produce short, weak coleoptiles, usually ≤70 mm long, and poorer seedling vigour. Figure 2 presents a comparison of the average coleoptile lengths in varieties with the *Rht2* dwarfing gene, the *Rht8* alternative dwarfing gene, and the non-dwarfing gene, *Rht*. [9]

7 NSW DPI Agronomists (2007) *Wheat growth and development.* PROCROP Series, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

8 NSW DPI Agronomists (2007) *Wheat growth and development.* PROCROP Series, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

9 NSW DPI Agronomists (2007) *Wheat growth and development.* PROCROP Series, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

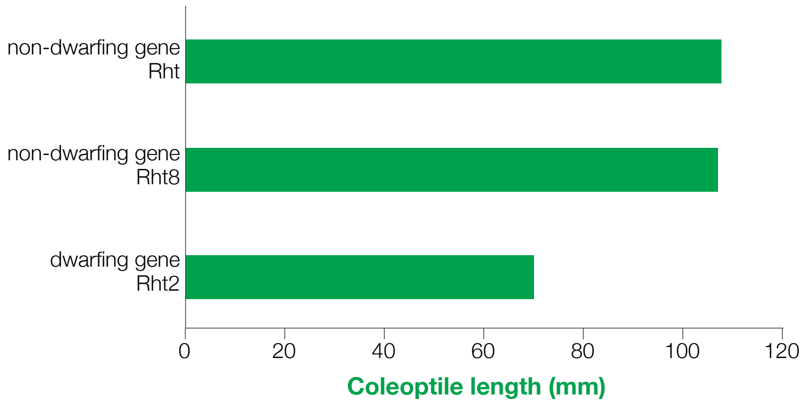

Figure 2: Comparison of coleoptile lengths.

Plant-breeding innovations such as the long-coleoptile wheat genotypes being developed by CSIRO could deliver additional yield benefits under water-limited conditions.

Long coleoptiles can emerge from deeper in the soil profile, allowing timely sowing when effective pre-crop management such as summer weed control and stubble retention have ensured soil water is available. However, without appropriate fallow management and stubble retention, the innovative long-coleoptile genotype provides little benefit. [10]

More information

NSW DPI Fact Sheet: http://www.dpi.nsw.gov.au/agriculture/broadacre/winter-crops/winter-cereals/coleoptile-length

Varieties with shorter coleoptiles are less likely to emerge if sown too deeply, because the coleoptile is not long enough to break through to the surface. Fewer seedling plants emerge, reducing tiller numbers. [11]

Semi-dwarf varieties with relatively long coleoptiles include EGA Gregory⯑, with a predicted mean coleoptile length of 5.9 cm in NSW Department of Primary Industry trials. [12]

Growers should always read the label of any wheat seed dressing fungicide to see what effect it may have on coleoptile length.

4.3.5 Nutrition

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

Nitrogen

Nitrogen (N) is essential to plant growth and is commonly applied in moderate to high levels during seedbed preparation, anhydrous ammonia or urea being commonly used.

Nitrogen can be leached from light soil if heavy rain or continuous wet weather delays sowing. Excessive N fertiliser applied close to the seed can lead to toxicity problems. (See Section 2: Pre-planting.)

Many crops are now sown with wider row spacing, and with narrow points/press-wheel setups or disc seeders. In this case, the maximum N rate needs to be lower, as the fertiliser becomes concentrated within the row.

10 GRDC (2013) Short and long-term focus needed to lift WUE. GRDC Ground Cover Issue 103, https://www.grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS103/Short-and-long-term-focus-needed-to-lift-WUE

11 NSW DPI Agronomists (2007) *Wheat growth and development.* PROCROP Series, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

12 P Matthews, D McCaffery, L Jenkins (2014) Winter crop variety sowing guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/winter-crop-variety-sowing-guide

More information

GRDC Update paper *'Nitrogen volatilisation losses—how much N is lost when applied in different formulations at different times':* http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/03/Nitrogen-volatilisation-losses-how-much-N-is-lost-when-applied-in-different-formulations-at-different-times

More information

http://farmercommunity.incitecpivotfertilisers.com.au/Latest%20News/Bede's%20fertiliser%20at%20seed

Deep banding is one method of applying N fertiliser at sowing without causing seedling losses. It requires seeding systems that can separate seed and fertiliser.

Pre-drilling N is another option and can work well in minimum-till or conventional systems. This can be especially effective where a disc seeder is used and offers ideal fertiliser placement with very little loss of soil moisture before sowing. Alternatively, N fertiliser can be broadcast and incorporated at sowing, provided uniform incorporation can be achieved.

Phosphorus

Phosphorus (P) is essential to seed germination and early root development. Large amounts are taken up during germination. Phosphorus deficiency at this early stage of growth significantly reduces yield potential. The plant's peak uptake of P is in the first 6 weeks.

Many of the soils in NSW and Queensland have very low levels of P, and in some areas, it is the limiting nutrient.

Phosphorus is relatively immobile in the soil (unlike N), so needs to be placed near the seed and cannot be topdressed. Regardless of soil test results, some P needs to be applied at sowing in close proximity to the seed.

One method of estimating P requirement is to allow 4 kg P per tonne (t) of target yield. For example, a 3 t/ha wheat crop requires 12 kg P/ha. [13]

4.4 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 regulator, fungicides and water.

4.4.1 Zadoks Cereal Growth Stage Key

This is the most commonly used key to growth stages for cereals, in which the development of the cereal plant is divided into 10 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 (Figure 3) used in relation to disease control and N management are those from the start of stem elongation through to early flowering: GS30–GS61.

[13] NSW DPI Agronomists (2007) *Wheat growth and development*. PROCROP Series, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

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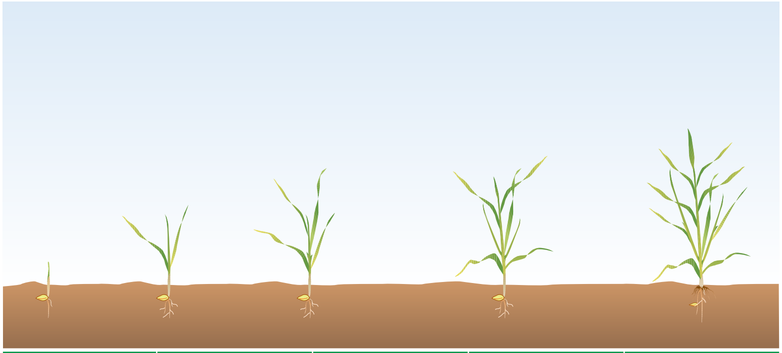
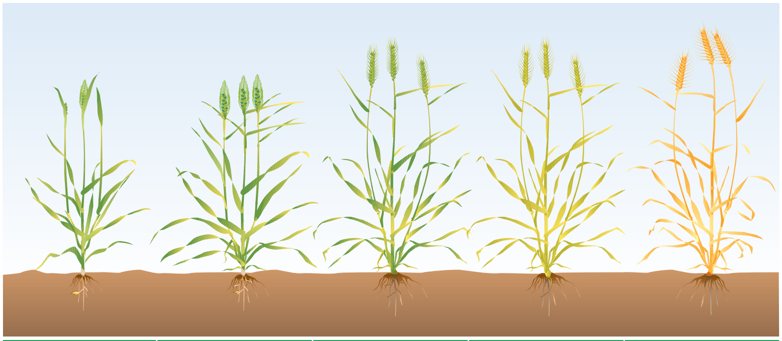


Zadoks Growth Stage	GS 00-09	GS10-19	GS20-29	GS30-39	GS40-49
Development phase	Germination	Seedling growth	Tillering	Stem elongation	Booting



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 3: Zadoks growth stages

Early stem elongation GS30–GS33 (pseudostem erect–third node on the main stem)

This period is important for both timing of N application and protection of key leaves. In order 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 (due 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 to stem elongate (GS30). Because of growth stages overlapping, it is possible to describe a

More information

GRDC 'Cereal growth stages guide': http://www.grdc.com.au/uploads/documents/GRDC%20Cereal%20Growth%20Stages%20Guide1.pdf

CSIRO VIDEO: http://www.csiro.au/Organisation-Structure/Divisions/Plant-Industry/Deep-roots.aspx

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, 17, yet practically would be regarded as GS32, since 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. [14]

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