WESTERN

JUNE 2018

GRDC GROWNOTES™

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

DURUM

SECTION 3

PLANT GROWTH (PHENOLOGY)

WHEAT DEVELOPMENT STAGES | KEY GROWTH STAGES OF WHEAT | GRAIN YIELD

MORE INFORMATION

GRDC '2005 Growth Stages of Cereals (Illustrated)': http://www.nvtonline.com.au/resource/zadoks-growth-scale-2/

NSW Department of Primary Industries 'Durum Wheat Growth and Development': http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/516185/Procrop-wheat-growth-and-development.pdf

Plant growth (phenology)

3.1 Wheat development stages

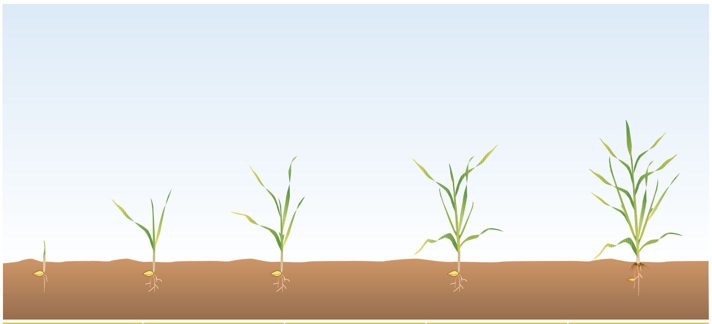
The growth and development of the wheat plant is a complex process.

During the plant's life cycle, many of the growth stages overlap and while one part of the plant may be developing another part may be dying.

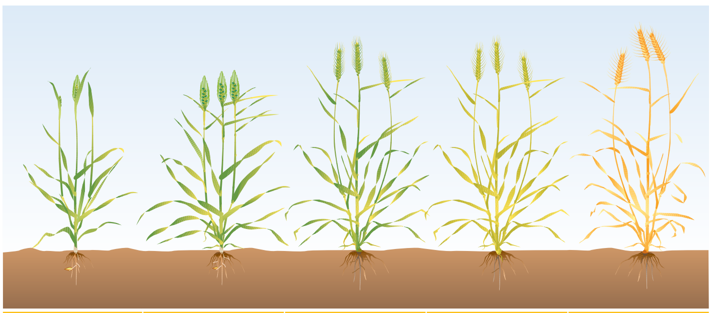
Managing durum wheat crops to the correct plant developmental stage is essential to achieve optimal returns from nitrogen (N), other nutrient, fungicide and herbicide inputs.

The most commonly used wheat development scale used in Australia to identify the correct growth stage of the crop is the Zadoks Growth Scale, as shown in Figure 1 and further outlined in Table 1.

Figure 1: *Zadoks Growth Scale for wheat.*[1]
Developmental phases of a wheat plant from germination through to maturity and the Zadoks Growth Scale associated with each phase.



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



Zadoks Growth Scale	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

1 GRDC (2005) 'Growth Stages of Cereals (Illustrated)': http://www.nvtonline.com.au/resource/zadoks-growth-scale-2/

Table 1: Zadoks' decimal growth scale for cereals.[2]

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	¼ of head emerged
55	½ of head emerged
57	¾ 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

NOTE: Each point on the Zadoks scale has two digits, the first indicating the growth stage and the second the number of plant parts or secondary stages of development. For example, GS15 means growth stage 1 with 5 leaves on the main stem. GS24 means growth stage 2 with 4 tillers. Several of the growth stages occur together, so a plant may have more than one decimal code applied at the same time. For example, a plant may be producing leaves and tillering at the same time and so could have a code of GS15, 22, meaning it has five leaves on the main stem and two tillers.

2 GRDC (2005) 'Growth Stages of Cereals (Illustrated)': http://www.nvtonline.com.au/resource/zadoks-growth-scale-2/

The Zadoks Growth Scale is based on 10 primary plant growth stages, each divided into 10 secondary growth stages that indicate the number of plant parts on the main stem or secondary stage of development. This extends the scale from 00 to 99.

The Zadoks Growth Scale does not run chronologically from GS00 to 99.

For example, when the crop reaches three fully unfolded leaves (GS13) it begins to tiller (GS20) before it has completed four, five or six fully unfolded leaves (GS14, 15 and 16).

It is easier to assess main stem and number of tillers than it is to assess 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 (e.g. GS22 is main stem plus two tillers, up to GS29 – main stem plus nine or more tillers).

In Australian cereal crops, plants rarely reach GS29 before the main stem starts to elongate (GS30).

After stem elongation (GS30), the growth stage describes the stage of the main stem and is not an average of all the tillers.

This is particularly important with fungicide timing (e.g. GS39 is full flag leaf on the main stem, meaning that not all flag leaves in the crop will be fully emerged).

Successful crop management requires an ability to identify wheat growth stages and how these are impacted by nutrition, disease, application of herbicides and fungicides and environmental stressors.[3]

The principal growth stages used in relation to disease control and N/nutrient management are those from the start of stem elongation through to early flowering (GS30-GS61).

3.2 Key growth stages of wheat

3.2.1 Germination (GS00-09)

During germination and establishment, the crop is most vulnerable to pests and management practices connected to depth of sowing, fertiliser toxicity and poor soil-seed contact.

The goal is to achieve a vigorous, highly competitive crop through uniform germination and rapid seedling emergence and establishment.

Sowing depth plays a big role in seedling establishment and vigour.

Fertiliser, herbicides (such as trifluralin) and some fungicide seed dressings can also impact on seedling vigour. Pests can lower germination and establishment rates significantly.

3.2.2 Vegetative growth (GS10-GS31)

During the vegetative growth stage, the goal is to set up the wheat crop to support maximum grain production.

Root and leaf area, along with tiller number, underpin the capacity of the crop to access soil nutrients and water and convert sunlight into biomass via photosynthesis.

Western Australian wheat varieties commonly form between eight and 14 leaves on the main stem.

3 Anderson, W and Garlinge, J (2000) The Wheat Book: Principles and Practice, Chapter 3. Western Australian Department of Agriculture, Perth, WA, http://researchlibrary.agric.wa.gov.au/bulletins/6/

However, because continual leaf death and tiller production make leaf counting difficult, it is seldom possible to determine leaf number past GS16 (the six-leaf stage).

The rate at which leaves appear is controlled by daily temperature.

Wheat crops sown in June will typically generate one leaf about every 10 days.[4]

Leaf growth in wheat occurs at temperatures between 0°C and 38°C, but is optimum at 29°C. As temperature drops below this optimum level, leaf growth slows.[5]

The optimum temperature for leaf growth is associated with faster tillering, which is why early-sown crops tend to develop biomass more quickly.

Individual leaves have a limited life span and, as leaves at the base of a stem die, new leaves form and unfold higher up the plant.

The leaf area per unit of ground area (leaf area index — or LAI) determines crop water use. The higher the LAI, the more water is used during the vegetative growth stage. Excessive early season N can result in a large LAI during early vegetative growth which, in turn, can result in insufficient soil moisture for flowering and grain fill (commonly referred to as 'haying off').

3.2.3 Root growth

There is a strong connection between the number of leaves, tillers and nodal roots on a wheat plant.

In southern Australia, root growth rates are typically about 1-1.5 centimetres per day and the wheat root system can reach at least 150 cm by flowering (and even deeper by grain maturity).[6]

The pattern of root elongation and branching means a considerable length of root can develop on each plant.

The total amount of dry matter in roots is substantial. In terms of returning organic matter to the soil, the root dry matter can equal the contribution of stubble remaining after harvest (as shown in Table 2, where there is 2.8 tonnes per hectare equivalent in root material in this example).

Table 2: Root and shoot dry matter (g/m^2) in a wheat crop grown at Merredin, Western Australia.[7]

Dry matter (g/m^2)	34 days	62 days	104 days (flowering)
Roots	22	75	280
Shoots	12	69	509
Root to shoot ratio	2:1	1:1	0.5:1
Root % total dry matter	65	52	35

Depth of soil moisture tends to determine the final rooting depth in wheat crops, but several factors can prevent roots from developing in the subsoil. These include: lack of moisture; chemical constraints, such as salinity, acidity or high aluminium (Al); and physical constraints such as soil density or compaction.

4 NSW Department of Primary Industries (2008) 'Durum Wheat Growth and Development', http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/durum-wheat-production

5 NSW Department of Primary Industries (2008) 'Durum Wheat Growth and Development', http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/durum-wheat-production

6 NSW Department of Primary Industries (2008) 'Durum Wheat Growth and Development', http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/durum-wheat-production

7 Anderson, W and Garlinge, J (2000) The Wheat Book: Principles and Practice, Chapter 3. Western Australian Department of Agriculture, Perth, WA, http://researchlibrary.agric.wa.gov.au/bulletins/6/

3.2.4 Tillering (GS20-26)

Tillers are lateral branches, or shoots, that emerge from buds in the axil of the leaves at the base of the main stem.

Primary tillers are produced from the leaves of the main stem and can form their own secondary tillers.

Not all tillers produce an ear (head). Non-productive tillers can provide nutrient and carbohydrate reserves for grain-bearing tillers.

In dryland wheat production systems, about 100 heads per square metre are required to produce 1 t/ha.[8]

Typically, only 70-75 percent of tillers will produce a head. So, for a target yield of 3 t/ha, about 400 tillers/m^2 would be needed by the end of tillering (typically around the stage of stem elongation).[9]

Tiller production is very sensitive to environmental and nutritional stresses and tiller development can slow or stop in response to poor N supply or water stress.

Tillers are produced until about the start of stem elongation, when numbers reach a maximum. Tiller numbers then decline until flowering and remain more or less constant until harvest.

Tillers cannot survive alone until they have about three leaves and have started to produce their own nodal roots. Typically only the first two to three tillers reach this stage before tillering and leaf production stops.

3.2.5 Reproductive growth (GS14-69)

Final grain yield is predominantly a function of grain number which, in turn, is set by floret production and survival.

Florets are produced on spikelets, which collectively make up the wheat ear (head). Ear or head number is set by tiller number which, in turn, is a function of wheat variety and environmental conditions — particularly N.

Floret number per spikelet rises and then falls so that by flowering, typically about two to five florets per spikelet remain. The exact reason for this floret death is uncertain, but could be the result of competition between the stem and the ear for carbohydrate reserves.

In a typical wheat crop, only 30-40 percent of florets will set grain.[10]

Water stress and high temperatures two to three weeks before flowering (GS61-69) can seriously reduce floret production and survival. Pollen formation is also highly vulnerable to water deficit and excessive temperatures.

Frost damage can occur at all stages of crop development, but is particularly damaging to floret production and survival between flag leaf emergence and 10 days after flowering.

Floret survival is highest when there is an adequate supply of water and nutrients, optimum temperature and high solar radiation.

8 NSW Department of Primary Industries (2008) 'Durum Wheat Growth and Development', http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/durum-wheat-production

9 NSW Department of Primary Industries (2008) 'Durum Wheat Growth and Development', http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/durum-wheat-production

10 NSW Department of Primary Industries (2008) 'Durum Wheat Growth and Development', http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/durum-wheat-production

3.2.6 Terminal spikelet

The terminal spikelet signals the end of the wheat head development phase.

The total number of spikelets produced per ear typically varies between 18 and 22.[11]

After the terminal spikelet is initiated, rapid head growth begins and the stem elongates.

3.2.7 Head at 1 cm (GS30)

The developing head is not visible until it is at least 1 cm above the ground. Once the terminal spikelet is formed, rapid stem growth brings the well-developed head from below ground to above ground.

Any grazing stock must be removed from the crop before 'head at 1 cm' (GS30), or stock will remove heads and cause extensive yield loss.

3.2.8 Stem elongation (GS31-GS36)

Stem growth is the result of the elongation of the internodes.

The wheat crown (base of stem) consists of eight to 14 nodes stacked closely above one another, separated by internodes less than 1 millimetre in length. The growth of the first five or six internodes pushes the head higher and elongates the stem.[12]

Lower internodes remain compressed at the base, with the number depending on sowing rate and variety.

When the internodes elongate, the individual nodes become detectable.

Stem elongation represents a period of rapid dry matter production and high N demand. About 60 percent of total crop N uptake occurs during stem elongation.[13]

3.2.9 Flag leaf extension (GS39)

The flag leaf is located just below the head and is the last leaf to develop.

The flag leaf plays an important role in producing carbohydrates for grain fill, particularly in higher rainfall areas. Protecting the flag leaf from fungal disease is an important management requirement in medium-high rainfall areas.

The emergence of the tips of the awns (awn peep) is an indicator that the flag leaf is fully extended (GS39).

3.2.10 Flowering and grain fill

Flowering (GS61-69) is a short phase, tending to last only a few minutes in an individual floret, a couple of hours in a head and about three to four days across a wheat crop.

The vast majority of florets self-pollinate, with the empty anthers appearing on the outside of the head following fertilisation.

Grain enlargement starts after floret fertilisation and continues for 10 to 14 days.[14]

Grain fill follows the period of grain enlargement and tends to last for 15 to 35 days.[15] During this stage, grain weight increases at a constant rate as carbohydrate and protein are deposited into the grain.

---

11 NSW Department of Primary Industries (2008) 'Durum Wheat Growth and Development', http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/durum-wheat-production

12 NSW Department of Primary Industries (2008) 'Durum Wheat Growth and Development', http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/durum-wheat-production

13 NSW Department of Primary Industries (2008) 'Durum Wheat Growth and Development', http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/durum-wheat-production

14 NSW Department of Primary Industries (2008) 'Durum Wheat Growth and Development', http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/durum-wheat-production

15 NSW Department of Primary Industries (2008) 'Durum Wheat Growth and Development', http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/durum-wheat-production

The grain moves from what is known as 'milk' stage through to 'dough' stage. The exact stage is determined by the amount of solids in the grain 'milk' or the stiffness of the grain 'dough'.

Once filled, the wheat grain is 70 percent carbohydrate, with 97 percent of this carbohydrate being starch. The protein content is typically between 8 and 15 percent, depending on final grain weight (which can range from 2.5-4.5 milligrams).[16]

3.3 Grain yield

The four components to wheat grain yield are:

- Number of ears (heads)/m^2
- Number of spikelets per ear
- Number of grains per spikelet
- Weight per grain.

Ear and spikelet numbers are set well before flowering. Grain numbers are set at around flowering and grain weight is set between flowering and maturity.

Grain weight is the least variable of the yield components because it is largely determined by the genetic potential of the variety.

Grain yield is, therefore, most closely related to the number of grains produced by the crop.

3.3.1 Yield compensation

Wheat yield can respond to seasonal conditions almost to maturity due to the capacity of the wheat plant to increase or decrease some — or all — of its yield components.

For example, low tiller numbers caused by stress during tiller formation can be compensated for by a larger number of spikelets per head and more grains per spikelet.

Similarly, an excessive number of ears/m^2 might result in smaller ears or lower grain weight.

3.3.2 Estimating grain yield

The yield of a wheat crop can be estimated by:

Grain yield (kg/ha) = ears/m^2 x grains/spikelet x weight/grain (g) x 10.

Ears per square metre

Count the ears in 1 m^2 of crop, or count the number of ears in a 1 m row length and multiply by 5.6 (there are 5.62 m of row in 1 m^2 for a 7-inch or 17.8 cm row spacing). For 12-inch (or 30 cm) row spacing, multiply by 3.3.

Spikelets per ear

Count the number of spikelets on an average ear – for most crops it will be between 16 and 20.

Grains per spikelet

Count the grains in spikelets at the top, middle and bottom of the ear. More and heavier grains are usually set in the central spikelets. The number should be between two and four.

16 NSW Department of Primary Industries (2008) 'Durum Wheat Growth and Development', http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/durum-wheat-production

Grain weight

Grain weight depends on growing conditions and variety, but will typically be between 0.025 and 0.045 g/grain (2.5-4.5 mg). To determine grain weight – count and weigh 1000 grains and divide by 1000 to get weight/grain.[17]

If it is not possible to weigh grain, a good average figure to use is 0.0356 g/grain (3.56 mg/grain), which is equivalent to 28 grains/g.[18]

Using the components above, the grain yield can be calculated as:

Yield = 100 (ears/m^2) x (18 spikelets x 2 grains/spikelet x 0.03 g/grain) = 100 x 1.08 = 108 g/m^2 or 1.08 t/ha

This leads to the very simple rule of thumb that 100 ears/m^2 will generate about 1 t/ha of grain.[19]

17 NSW Department of Primary Industries (2008) 'Durum Wheat Growth and Development', http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/durum-wheat-production

18 Anderson, W.K. The Wheat book: principles and practice, 2000, http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1005&context=bulletins

19 Anderson, W.K. The Wheat book: principles and practice, 2000, http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1005&context=bulletins