NORTHERN
SEPTEMBER 2018

GRDC GROWNOTES™

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

CEREAL RYE

SECTION 4

PLANT GROWTH AND PHYSIOLOGY

GERMINATION AND EMERGENCE ISSUES | ENVIRONMENTAL EFFECTS ON PLANT GROWTH AND PHYSIOLOGY | PLANT GROWTH STAGES

Plant growth and physiology

Key messages:

- Cereal rye seeds are thought to be able to remain viable and dormant in soils for around five years. [1]
- Seeds germinate from autumn to spring with a flush in autumn at temperatures of 1–5°C. [2]
- Rye needs a temperature sum of 90°C for field emergence, provided there is sufficient water. [3]
- Cereal rye is a long-day plant; that is, it requires increasing day length to induce flowering. Flowering is induced by 14 hours of daylight accompanied by temperatures of 5–10°C. [4]
- Cereal rye has a more extensive root system in the top 30 cm than both wheat and oats. This more developed root system increases soil stabilisation and allows the plant to explore more of the topsoil profile, increasing the plants tolerance to dry conditions. It also means that cereal rye potentially dries the soil profile more than wheat and oats. [5]

Key characters of cereal rye (Table 1):

- inflorescence a dense cylindrical spike and not enclosed in the leaf sheath
- spikelets, subtended by two glumes, solitary at each node of the rachis, not digitate, sessile, erect with two (rarely three) bisexual florets, breaks above the more or less persistent glumes
- two lemmas, awned, five-ribbed. [6]

Table 1: *Characteristics of rye plant.*

Plant part	Description
No. of cotyledons	One
Leaves	Emerging leaf rolled in the bud Blade: rough to touch, flat; hairless; 75–300 mm long, 10–20 mm wide Ligule: membranous rim, 1 mm long; flat on top Auricles: small Sheath: hairless; rolled and overlapping; prominent veins Collar: prominent and lighter; hairless
Stem	Erect, slender, 200–1500 mm tall; hairless or hairy below the seed head. Usually has a waxy bloom. Tillers vigorously with usually fewer than 10 stems arising from the base

1 WL Stump, P Westra (2000). The seedbank dynamics of feral rye *Secale cereale*. Weed Technology, 14(1), 7–14, https://www.jstor.org/stable/3988499?seq=1#page_scan_tab_contents

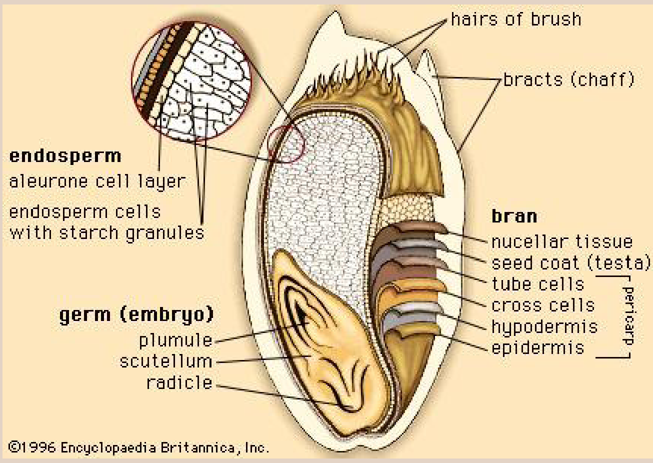
2 HerbiGuide. Rye. HerbiGuide Pty Ltd, http://www.herbiguide.com.au/Descriptions/hg_Rye.htm

3 [3] RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press, https://www.crcpress.com/Rye-Genetics-Breeding-and-Cultivation/Schlegel/p/book/9781466561434

4 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press, https://www.crcpress.com/Rye-Genetics-Breeding-and-Cultivation/Schlegel/p/book/9781466561434

5 P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide 2016. Department of Primary Industries New South Wales, https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide

6 HerbiGuide. Rye. HerbiGuide Pty Ltd, http://www.herbiguide.com.au/Descriptions/hg_Rye.htm

Plant part	Description
Flower head	Bearded, dense cylindrical spike; 70–150 mm long; erect initially and drooping with age; awned (Photo 1).  **Photo 1:** *Comparison of flower heads between A, bread wheat; B, cereal rye and C: triticale.* Source: Palomar College, CA, USA
Flowers	Spikelets: no stalk, flattened; single and overlapping in a row on opposite sides and pressed against a zigzag stem; strongly attached to the stem; two fertile florets per spikelet Florets: bisexual Glumes: two the same size and shape, awl-shaped, 7–10 mm long, one rib, keeled, flattened, rough to touch Palea: 12–15 mm long, narrow, no awns, two lobes, two keels Lemma: sticks out from the glumes, oblong to narrowly egg shaped, 12–15 mm long, stiff, five ribs, flattened; hairy or finely toothed on the keel and edges. Keel tapers to a long straight awn about 20 mm long
Seeds	Light to dark brown. Oblong to oval or wedge-shaped, 5–7 mm long, 2–3 mm wide. Almost circular in cross section. Surface grooved, wrinkled and hairless. Easily rubbed from the husks (Figure 1).  **Figure 1:** *Cross-section of cereal rye seed.* Source: Encyclopaedia Britannica
Roots	Many and fibrous

Source: HerbiGuide Pty Ltd

4.1 Germination and emergence issues

4.1.1 Dormancy

Cereal rye seeds are thought to be able to remain viable and dormant in soils for around five years.

IN FOCUS

The seedbank dynamics of volunteer rye

Buried feral rye seeds were rapidly depleted in soil in the first year due to *in situ* germination. Less than 1% of the viable seeds persisted after 45 months of burial. Although after five years a small number of seedlings still emerged, soil seedbank decline was rapid when seed production was prevented. A low level of induced dormancy was detected and may explain the small populations of feral rye that persisted. Seed and seedling population shifts were large over a five-year period and were related to environmental conditions. Tillage or chemical control of feral rye in the fallow period reduced populations compared to the untreated weedy check. Moldboard plowing provided the greatest feral rye control compared to shallow tillage and chemical fallow. Feral rye seedbank populations rebounded following a wet final year of the study. These results help explain feral rye persistence in a wheat-fallow agroecosystem by the persistence of a small portion of the seedbank and by large seed inputs into the system during environmentally favorable years. Feral rye reduced wheat yield as much as 92% and represented up to 73% contamination in harvested wheat. [7]

4.1.2 Germination

Seeds germinate from autumn to spring with a flush in autumn. [8] Minimal temperatures for germinating cereal rye have been variously given as between 1°C and 5°C. [9] Rye prefers light loams or sandy soils and will germinate even in fairly dry soil. [10]

Research has shown that rye sown at a 2.5 cm depth had twice the emergence of rye sown at ~5 cm and that shallow-seeded rye had greater winter hardiness. [11]

While investigating environmental stress factors in seed germination and seedling growth, cereal rye was found to be exceptionally resistant to a wide variety of ordinarily harmful conditions:

- Germination is anaerobic, and proceeds well in the presence of carbon monoxide, nitrous oxide and hydrogen.
- Rye grains germinate readily at constant low temperatures (5°C, for example) and some can germinate on a cycle of 16 h at −30°C and 8 h at 20°C over seven days; liquid nitrogen temperatures can also be endured by dry seeds.

---

7 WL Stump, P Westra (2000). The seedbank dynamics of feral rye *Secale cereale*. *Weed Technology* 14, 7–14, https://www.jstor.org/stable/3988499?seq=1#page_scan_tab_contents

8 HerbiGuide. Rye. HerbiGuide Pty Ltd, http://www.herbiguide.com.au/Descriptions/hg_Rye.htm

9 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press, https://www.crcpress.com/Rye-Genetics-Breeding-and-Cultivation/Schlegel/p/book/9781466561434

10 A Clark (Ed.) 2007. Managing cover crops profitably. 3rd edn. Sustainable Agriculture Network, Beltsville, MD. https://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition

11 Alberta Government (2016) Fall rye production. Alberta Agriculture and Forestry, http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex1269/$file/117_20-1.pdf

- In seawater and similar media, 100% germination can be effected in 10 days. [12]

Rye has been found to be more tolerant to saline conditions during germination than wheat and some triticale varieties. [13]

Optimum planting depth varies with planting moisture, soil type, seasonal conditions, climatic conditions and the rate at which the seedbed dries. The general rule is to plant as shallow as possible, provided the seed is placed in the moisture zone but deep enough that the drying front will not reach the seedling roots before leaf emergence, and to separate the seed from any pre-emergent herbicides used. [14]

When shallow seeding, the previous crop's residue will have a greater tendency to interfere with good seed–soil contact. Even spreading of the previous crop residue is essential for quick emergence. Make sure seed–soil contact occurs. [15]

For other germinating plants, rye residue that remains at the soil surface can modify the physical and chemical environment during seed germination and plant growth. [16]

4.1.3 Emergence

Rye needs a temperature sum of 90°C for field emergence, provided there is sufficient water (Photo 2). [17]

Photo 2: *Emergence of rye cover crop 11 days after planting.*

Source: Virginia Association for Biological Farming

Sowing depth influences the rate and percentage of emergence. Deeper seed placement slows emergence. Seedlings emerging from greater depth are also weaker, more prone to seedling diseases, and tiller poorly.

If deep sowing, it is important to avoid smaller sized seed because smaller seeds have shorter coleoptiles, which may stop growing before reaching the soil surface. The first leaf will then emerge from the coleoptile while still below the soil surface.

12 SM Siegal, LA Halpern, C Giumarro (1964) Germination and seedling growth of winter rye in deuterium oxide. *Nature* 201, 1244–1245, http://www.nature.com/nature/journal/v201/n4925/abs/2011244a0.html

13 UR Bishnoi, DK Pancholy (1980) Comparative salt tolerance in triticale, wheat and rye during germination. *Plant and Soil* 55, 491–493, https://www.jstor.org/stable/42935011

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

15 Alberta Government (2016) Fall rye production. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex1269/$file/117_20-1.pdf

16 EA Oelke, ES Oplinger, H Bahri, BR Durgan, DH Putnam, JD Doll, KA Kelling (1990) Rye. In Alternative field crops manual. University of Wisconsin and University of Minnesota, https://hort.purdue.edu/newcrop/afcm/rye.html

17 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press, https://www.crcpress.com/Rye-Genetics-Breeding-and-Cultivation/Schlegel/p/book/9781466561434

Because it is not adapted to pushing through soil (it does not know which way is up), the leaf usually buckles and crumples, failing to emerge and eventually dying. [18]

Rye has been found to be slightly less salt-tolerant during plant emergence than during subsequent stages of growth. [19]

4.2 Environmental effects on plant growth and physiology

4.2.1 Photoperiod and temperature

Cereal rye is a long-day plant; that is, it requires increasing day length to induce flowering. Flowering is induced by 14 hours of daylight accompanied by temperatures of 5–10°C. Rye shows a shorter growth period than other winter and spring cereals that also differ considerably in vernalisation period (i.e. induction of a plant's flowering process by exposure to prolonged cold). Winter types of rye require 40–60 days, whereas spring types require only 10–12 days of cold temperatures to shift into the reproductive stage. [20]

Rye has been found to achieve more rapid rates of pre-anthesis dry matter accumulation, irrespective of whether it was grown at high (20–15°C) or low (10–7°C) day–night temperatures. Tiller number and leaf area per plant were greater for rye, especially at low temperatures, than triticale and wheat. [21]

4.2.2 Salinity

Cereal rye is thought to be relatively tolerant to saline soils, similar to barley, but will be affected in highly saline soils (ECe, electrical conductivity of the soil saturated paste extract, 8–16 dS/m). [22]

Relative grain yield of two rye cultivars in a field experiment in Canada was unaffected up to a soil salinity of 11.4 dS/m. Each unit increase in salinity above 11.4 dS/m reduced yield by 10.8%. These results place rye in the salt-tolerant category. Yield reduction was attributed primarily to reduced spike weight and individual seed weight rather than spike number. Bread quality decreased slightly with increasing levels of salinity. Straw yield was more sensitive to salinity than was grain yield. Rye was found to be slightly less salt tolerant during plant emergence than during subsequent stages of growth. [23]

For more information, see Section 14: Environmental issues.

4.3 Plant growth stages

The developmental cycle of rye can be divided in 12 stages. During stage one, the growing point is not differentiated. In stage two, the primordia of stems, nodes and internodes are formed in the growing point. Rye, usually planted in autumn and moderate climate, enters winter in stage two. In stage three, the growing point differentiates into further segments, which are primordia of spikelets. During this period, nitrogen supply has a positive effect on the formation of a large number of spikelets, which leads to the subsequent formation of longer spikes with a greater number of flowers and grains. A further differentiation of growing points takes place

18 DPI NSW (2007) Wheat growth and development. PROCROP Series. Department of Primary Industries New South Wales, https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

19 LE Francois, TJ Donovan, K Lorenz, EV Maas (1989) Salinity effects on rye grain yield, quality, vegetative growth, and emergence. Agronomy Journal, 81(5), 707–712, https://dl.sciencesocieties.org/publications/aj/abstracts/81/5/AJ0810050707?access=0&view=pdf

20 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press, https://www.crcpress.com/Rye-Genetics-Breeding-and-Cultivation/Schlegel/p/book/9781466561434

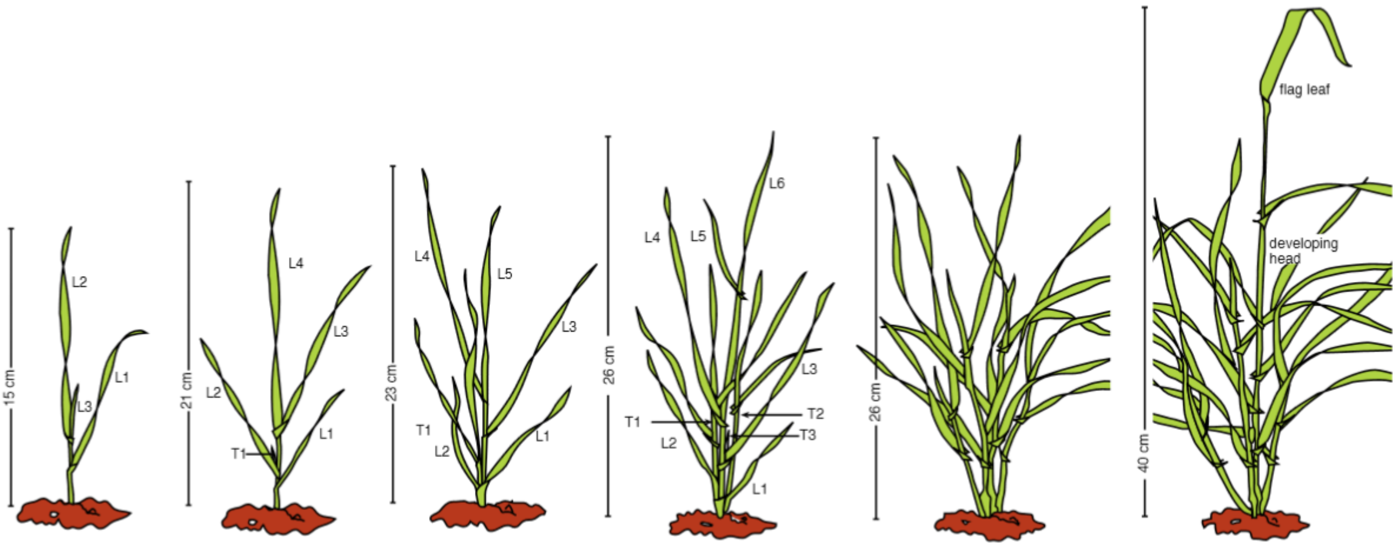
21 M Winzeler, DE McCullough, LA Hunt (1989) Leaf gas exchange and plant growth of winter rye, triticale and wheat under contrasting temperature regimes. *Crop Science* 29, 1256–1260, https://dl.sciencesocieties.org/publications/cs/abstracts/29/5/CS0290051256?access=0&view=pdf

22 C Henschke, T Herrmann (2007) Testing for soil and water salinity. PIRSA Fact Sheet No:66/00. Primary Industries and Regions South Australia, June 2007

23 LE Francois, TJ Donovan, K Lorenz, EV Maas (1989) Salinity effects on rye grain yield, quality, vegetative growth, and emergence. *Agronomy Journal* 81, 707–712, https://dl.sciencesocieties.org/publications/aj/abstracts/81/5/AJ0810050707?access=0&view=pdf

during stages three and four, in which flower primordia are formed. This process takes place in early spring. During the formation of spikelet primordia in the upper part of the spike, flowers are formed in the middle portion. The plant then enters stage five of organogenesis. Under conditions of long days and poor nitrogen supply, this process is relatively fast. Meiosis of pollen mother cells and the formation of tetrads, the embryo sac and the egg take place during stages six and seven of organogenesis. Stage seven is characterised by extensive elongation growth during which pronounced elongation of shoot internodes takes place. In stage eight, the plants ear and subsequently flower. Fertilisation and maturation of caryopses and plant then follow in the remaining four stages of development. [24]

Figure 2 presenta diagrams and descriptions of corresponding stages of rye growth.



Crop growth stage					
2-leaf stage	Start of tillering	Tillering stage	Fully tillered stage	Start of jointing	Early boot stage
Two leaves (L) have unfolded; third leaf present, yet to expand fully	First tiller (T1) appears from between a lower leaf and the main shoot. Usually 3 or 4 leaves are on the main tiller	Tillers come from the base where leaves join the stem and continue forming, usually until 5 leaves are on the main shoot. Secondary roots developing	Usually no more tillers form after the very young head starts forming in the main tiller. Tillering completed when first node detected at base of main stem	Jointing or node formation starts at the end of tillering. Small swellings (joints) form at the bottom of the main tiller. Heads continue developing and can be seen by dissecting a stem	The last leaf to form (the flag leaf) appears on top of the extended stem. The developing head can be felt as a swelling in the stem
Zadoks decimal code					
2 leaves unfolded (Z12)	4 leaves unfolded (Z14) Main shoot and 1 tiller (Z21)	5 leaves on main shoot or stem (Z15) Main shoot and 1 tiller (Z21)	6 leaves on main shoot or stem (Z16) Main shoot and three tillers (Z23)	First node formed at base of main tiller (Z31)	Z35–Z45

Figure 2: *Growth stages for cereal rye.*

Source: NSW Department of Primary Industries

24 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press, https://www.crcpress.com/Rye-Genetics-Breeding-and-Cultivation/Schlegel/p/book/9781466561434

4.3.1 Roots

Rye has four primary roots that originate from the seed and it can send out roots and tillers from the second, third and fourth node. This extensive root system within the first 30 cm of soil is more developed than in other cereals (Photo 3). This is useful when sowing over eroded or disturbed sites where depth is hard to control and it makes the plant more drought resistant. [25] This more developed root system also increases soil stabilisation and allows the plant to explore more of the topsoil profile, increasing tolerance to dry conditions (Photo 3). [26]

Figure 3: *Dense root structure of cereal rye.*

Source: Iowa Farmer Today

Despite having no taproot, its quick growing, fibrous root system can take up and hold as much as 45 kg of nitrogen, although 12–23 kg is more typical. [27]

Cereal rye roots can grow to over 1 m deep (Photo 4). This helps to recycle nutrients as well and building organic matter in the soil. [28]

25 L Martin (2015) Growing cereal rye to increase carbon and prevent wind erosion. Liebe Group, March 2015, http://www.liebegroup.org.au/wp-content/uploads/2015/03/Case-Study-Jeff-Pearse-March-2015.pdf

26 P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide 2016. NSW Department of Primary Industries, https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide

27 L Martin (2015) Growing cereal rye to increase carbon and prevent wind erosion. Liebe Group, March 2015, http://www.liebegroup.org.au/wp-content/uploads/2015/03/Case-Study-Jeff-Pearse-March-2015.pdf

28 L Betts (2012). Rye crop calendar. Farm Progress, http://farmprogress.com/story-2012-rye-cover-crop-calendar-14-94095

MORE INFORMATION

Research paper: Soil conditions and cereal root system architecture: review and considerations for linking Darwin and Weaver

Figure 4: *Deep growth of cereal rye roots.*

Source: Farm Progress

4.3.2 Plant development: photosynthesis and maturation

With the beginning of shooting, the reduction of tillers starts. This is reinforced by nutrients, especially nitrogen deficiency and/or drought. Overall, rye should not have to reduce more than 50% of the preformed tillers. The flag leaf is smaller and less important in photosynthesis. Rye has the longest stems of all cultivated small grains and these provide most of the photosynthetic area. During grain formation, stems with sheaths account for 60–80% of the total plant area. At grain-set, leaf blades provide 15–20% of the photosynthetic area, which is much lower than that for maize, wheat and oat. Stems and sheaths have lower rates of photosynthesis and export of assimilates than leaves. The most important periods of yield formation are flowering and grainfill. Successful pollination depends on sufficient spreading of husks. Cold and rainy weather at flowering hamper the opening of husks, and thus pollen distribution.

The maturation date of rye varies according to soil moisture, but vegetative growth stops once reproduction begins. In general, rye matures earlier than oat. The growth period—that is, the time from sowing to harvest—is ~295 days in rye. For rye, the photosynthetic area decreases rapidly after seedset and does not achieve a plateau near the maximum as seen with other grains. Its grain formation occurs under favourable physiological conditions for yielding.

The vegetation period lasts for ~120–150 days. [29]

4.3.3 Vegetative behaviour

Field and pot investigations of the vegetative and early reproductive growth of a winter wheat cultivar and a winter rye cultivar over three seasons showed that higher and earlier forage yields of rye are due to a combination of factors, notably more rapid rates of germination, crop emergence, leaf appearance and leaf expansion, coupled with higher leaf area ratios. Studies of net assimilation rate found no

29 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press, https://www.crcpress.com/Rye-Genetics-Breeding-and-Cultivation/Schlegel/p/book/9781466561434

evidence that the photosynthetic apparatus of rye plants is better adapted than wheat to the low temperature and light conditions of winter and early spring. However, the earlier initiation of rye stem extension was associated with significant increases in net assimilation rate, which compensated for reductions in the leaf area ratio. [30]

Rye tillers grow profusely. Individual plants can easily be split into several clones. Genotypes can differ in cloning and ability. The production of tillers can be stimulated by cutting back the plants, which helps to retard the development of spikes. Cool, moist and short-day conditions increase the tillering capacity. Continuous light prevents jointing.

Earlier than 280 degree-days after emergence, the four-leaf phase is reached and tillering starts. Once a shoot has formed six leaves and it is the vernalised enough, the formation of spikelets begins. [31]

Rye has an erect slender stem topped with a curved spike that is 7–15 cm long. The head is made up of individual spikelets, each with two florets that produce one or two kernels. The spikelets are arranged alternately along the length of the head. The leaves of the plant grow from nodes on the stem and are lance-like blades, blue-green in color. Rye can reach 1–3 m in height and it is grown either as an annual (spring rye) or as a biennial (winter rye). [32]

Rates of dry matter accumulation early in the growing season were significantly greater for rye crops than for triticale and wheat. [33]

In cereal rye, 53–58% of total grain yield has been found to be produced by lateral shoots, depending on the cultivar and the growing conditions. [34]

Winter rye generally overwinters in the tillering stage. The winter temperatures near freezing satisfy the vernalisation requirement and allow the plants to initiate reproductive development the following spring. Rye varieties are long-day plants, but they do not have an absolute requirement for a specific day length. Rye is cross-pollinated, and relies on windborne pollen. The florets remain open for some time, but if conditions are not favorable for cross-pollination, rye spikes may have several empty florets. The inflorescence is a spike with one sessile spikelet per rachis node. Spikelet initiation begins in the middle of the spike and proceeds toward the tip and base. Only the two basal florets in each spikelet produce seed. Spring rye does not require vernalisation to induce flowering. [35]

Grazing

The earliest time to start grazing is when the plants are well anchored and reaching the tillering stage (Zadoks growth stage 21–29). For most grazing cereal types under good growing conditions, this will occur 6–8 weeks from plant emergence, depending on variety.

With winter types, by deferring early grazing, more feed can be accumulated and saved for winter. For erect types, crops will usually be 20–25 cm high.

Varieties without a strong winter habit but sown in early autumn should be grazed even before tillering to retard growth and subsequent premature stem elongation and head initiation. When stem elongation occurs, immature heads are located just above the highest node (joint). If these are removed, tiller death occurs. Although the plant is usually able to produce more tillers, forage production (and grain production)

30 RKM Hay, MKA Al-Ani (1983) The physiology of forage rye (*Secale cereale*). *The Journal of Agricultural Science* 101, 63–70, https://www.cambridge.org/core/journals/journal-of-agricultural-science/article/the-physiology-of-forage-rye-secale-cereale/2E6A22C9703921F7A721CC51A2C3AB36

31 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press, https://www.crcpress.com/Rye-Genetics-Breeding-and-Cultivation/Schlegel/p/book/9781466561434

32 Plant Village. Rye *Secale cereale*. Pant Village, https://www.plantvillage.org/en/topics/rye/diseases_and_pests_description_uses_propagation

33 D McCullough, L Hunt (1993) Mature tissue and crop canopy respiratory characteristics of rye, triticale and wheat. *Annals of Botany* 72, 269–282, http://aob.oxfordjournals.org/content/72/3/269

34 K Hakala, K Pahkala (2003) Comparison of central and northern European winter rye cultivars grown at high latitudes. *The Journal of Agricultural Science* 141, 169–178, https://www.cambridge.org/core/journals/journal-of-agricultural-science/article/comparison-of-central-and-northern-european-winter-rye-cultivars-grown-at-high-latitudes/F935401E09A79882E0A9937D9BF3AEC5

35 EA Oelke, ES Oplinger, H Bahri, BR Durgan, DH Putnam, JD Doll, KA Kelling (1990) Rye. In Alternative field crops manual. University of Wisconsin and University of Minnesota, https://hort.purdue.edu/newcrop/afcm/rye.html

is severely reduced. The latest time for grazing and the severity of grazing of crops intended for grain recovery or hay production should be governed by the position of the immature head in the stem. Some growers opt to graze late and remove these heads, particularly if the crop or variety is prone to lodging. These growers choose to accept lower grain or hay yields as a trade-off for having a standing crop at harvest. [36]

4.3.4 Flowering and grain formation

Cereal rye flowers around August in southern Australia and from July to October in Western Australia. [37]

After flowering, the grain begins to form. As the grain forms and matures, it goes through a clear liquid phase prior to the commencement of starch deposition. The grain then enters the 'milky' stages, described as early, medium and late milk, followed by soft dough (Photo 3) and hard dough stages and eventually as a dry grain suitable for grain harvesting (Photo 4).

As the plant reaches maturity, sugars in the stems and leaves are translocated to the grain and converted to starch. These changes are associated with changes in colour from an all-green plant in the vegetative stages to an all-yellow plant in the fully mature plant at the hard grain stage (Photo 5). [38]

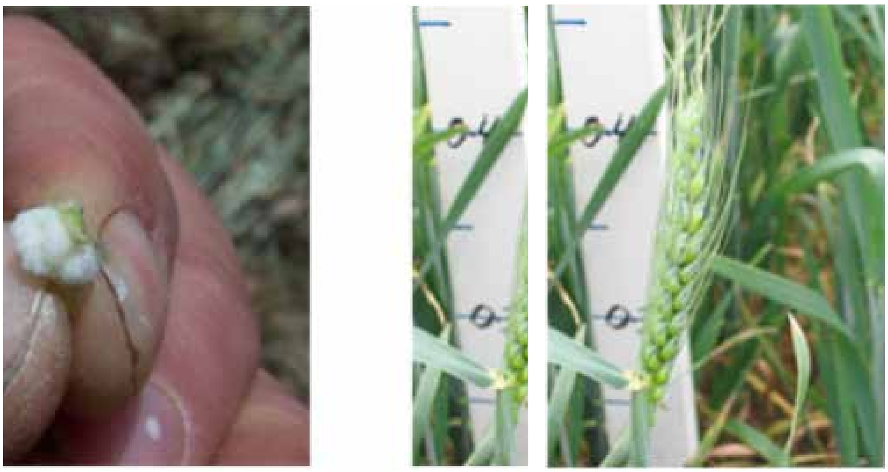


Photo 3: *Cereal grain (left) and plant (right) at the soft dough stage.*

Source: Agriculture Victoria

36 G Hennessy, D Clements (2009) Cereals for grazing. PrimeFact 270. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/288191/Cereals-for-grazing.pdf

37 HerbiGuide. Rye. HerbiGuide Pty Ltd, http://www.herbiguide.com.au/Descriptions/hg_Rye.htm

38 Agriculture Victoria (2008) When to cut forage cereals. Government of Victoria EDJTR, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/when-to-cut-forage-cereals

Photo 4: *Cereal rye grain.*

Source: Atlas of Living Australia

Photo 5: *Rye ripening.*

Source: Plant Village

Frost tolerance

Frost occurs on clear nights in early spring when the air temperature drops to ≤2°C. Damage to crops from frost may occur at any stage of development but is most damaging at and around flowering. Symptoms of frost damage can occur as sterility and stem damage. Physical damage to the plant occurs when ice forms inside the plant tissue, as expanding ice bursts membranes, resulting in mechanical damage and dehydration injury. Frost damage can reduce both grain yield and quality. After oats, cereal rye is regarded as the cereal crop least susceptible to frost damage, followed by barley, wheat and triticale. Oats are thought to be ~4°C more tolerant than wheat and barley ~2°C more tolerant, with rye therefore somewhere between 2°C and 4°C more tolerant than wheat. [39]

39 DAFWA. Frost and cropping. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/frost/frost-and-cropping

Frost tolerance varies between varieties of cereal rye. Bevy flowers about two weeks later than SA Commercial and is less prone to frost, which often affected yields of the SA Commercial variety. [40]

For more information on frost, see Section 14: Environmental issues.

40 Agriculture Victoria (2013) Growing cereal rye. Government of Victoria EDJTR, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye