WESTERN
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GRDC GROWNOTES™

GRDC™ GRAINS RESEARCH & DEVELOPMENT CORPORATION

TRITICALE

SECTION 14

ENVIRONMENTAL ISSUES

Environmental issues

Key messages

- Triticale appears to be more sensitive to frost damage than other cereals. Dry sowing for a portion of the crop is one option that has proven very successful, and can be considered for triticale as well as other cereals.
- Among the cereals, triticale has the best adaptation to waterlogged soils and those with high pH (alkaline soils).
- Triticale is also tolerant of low pH (acid) soils, grows well on sodic soils, and tolerates soils high in boron.
- Farmers appreciate the ability of triticale to tolerate periods of drought through the growing season, and at the other extreme, its tolerance of waterlogging.
- The crop is highly tolerant to soil with high concentrations of aluminium and to saline soils.

MORE INFORMATION

The abiotic stress response and adaptation of triticale

Agronomist's guide to information for managing weather and climate risk

Frost – Frequently Asked Questions booklet

Being a derivative of rye, triticale has always been assumed to be relatively resistant to abiotic stress (i.e. non-living factors such as frost or drought that adversely affect the plant). Its high productivity is most likely derived from high rates of carbon assimilation linked to stomatal physiology and, probably, low respiration rate. Triticale retains good to excellent adaptation to conditions of limited water supply and problem soils with conditions such as salinity, low pH, mineral toxicity or deficiency, and waterlogging. [1]

14.1 Frost issues for this crop

Key points:

- Frost events can have major and sudden impacts on cereal yields.
- Frost is a relatively rare occurrence but some areas are more prone to it.
- There has been an increase in frost frequency in many areas in the last 20 years.
- In the event of severe frost, monitoring needs to occur up to two weeks after the event to detect the full extent of the damage done. [2]
- Triticale has been estimated to be one of the cereals most susceptible to frost. Crop susceptibility to frost from most to least susceptible is triticale, wheat, barley, cereal rye, and oats. [3]

Frost is a complex and erratic constraint to Western Australian cropping systems, and can result in dramatic losess to a grower's business. In recent decades, the frost patterns in WA have changed, so that now:

- WA's frost window has widened, and on average frosts start three weeks earlier and finish two weeks later in the year.
- Consecutive frost events have increased by an average of up to three days at a time, and mostly occur in August and September in the frost-prone regions.
- Minimum temperatures of frosts are getting colder.

Due to the nature of frost and its damaging effects, an integrated approach to managing it is recommended. This means making complex decisions that involve strategically combining information on environmental, management, and genetic approaches to cater to your situation. Risk assessment, property mapping, crop type, variety choice, sowing time, and stubble load are key pre-seeding factors that

1 A Blum (2014) The abiotic stress response and adaptation of triticale: a review. Cereal Research Communications, 42 (3), 359–375.

2 D Grey (2014) Frost damage in crops: where to from here? GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

3 GRDC (2009) Managing the risk of frost. Factsheet. GRDC, https://grdc.com.au/resources-and-publications/all-publications/bookshop/2009/03/grdc-fs-frostrisk

growers can consider to reduce the risk of crop losses from spring frosts in high-risk areas. [4]

Frost occurs on clear nights in early spring when the air temperature drops to 2°C or less. 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, and, in the process of expanding, bursts tissue membranes, and causing mechanical damage and dehydration injury. Frost can reduce both grain yield and quality. [5]

Winter cereals are most susceptible to low temperatures during the reproductive stage as reproductive parts are not protected by the leaf sheaths and ice can nucleate directly on them. As a result, complete or serious yield losses are felt when frost occurs between the booting and grain ripening stages (Photo 1). [6] Identification of winter cereals with reproductive frost tolerance is a priority for frost research in Australia.

Photo 1: *Frosted cereal grain head.*

Source: GRDC

Once heads and grain have been frosted, small discoloured grain may be produced (Photo 2). [7] In addition to direct yield loss, frost also results in economic losses by

4 GRDC (2016) Pre-seeding planning to manage frost risk in WA. GRDC, https://grdc.com.au/Media-Centre/Hot-Topics/Preseeding-planning-to-manage-frost-risk-in-WA/Details

5 DAFWA (2016) Frost and cropping. DAFWA, https://www.agric.wa.gov.au/frost/frost-and-cropping

6 GRDC (2014) Frost publication addresses hot research topic. GRDC, https://grdc.com.au/news-and-media/news-and-media-releases/west/2014/03/frost-publication-addresses-hot-research-topic

7 S Tshewang (2011) Frost tolerance in triticale and other winter cereals at flowering. Master's thesis. University of New England, https://e-publications.une.edu.au/vital/access/manager/Repository/une:8821;jsessionid=C91FFA8964B3A49AD3A44FC3BD03EA2E?exact=sm_contributor%3A%22Birchall+C%22

causing the crop quality to drop because it has lower organic matter digestibility and lower metabolisable energy. Frost can cause reductions in grain size, decrease flour extraction, decrease dough strength and baking quality, and cause increases in flour ash and α-amylase activity.

Photo 2: *Comparison of healthy (left) and frost-damaged (right) H20 triticale grain.*

Source: Tshewang 2011

14.1.1 Industry costs

Frost is a significant problem in the wheat growing regions of WA and a direct revenue loss of more than AU$ 100 million has been recorded in the state within one season. [8] When another major frost event hit WA growers in September 2016, it was estimated that yield losses of 1.5 million tonnes were expected. [9]

The real cost of frost is a combination of the actual cost due to reduced yield and quality, and the hidden cost of management tactics used to try and minimise the damage of predicted frosts. These latter costs include:

- Delayed sowing, which is associated with lower yields.
- Sowing less profitable crops such as barley and oats
- Avoiding cropping on the valley floors, where some of the most productive parts of the landscape are.

The historical incidence of frost varies strongly across the agricultural regions of Western Australia, with the greatest occurrence being in the central, eastern, and southern regions. Northern and coastal regions, in general, have a lower risk.

Frosts can also have a large social impact, as they occur so suddenly, unlike droughts, which develop more slowly, so growers can adapt to them mentally and financially by reducing inputs as they unfold.

8 GRDC (2009) GroundCover Issue 79: Early season planning to minimise frost. https://grdc.com.au/resources-and-publications/groundcover/ground-cover-issue-79-march-april-2009/early-season-planning-to-minimise-frost-risk

9 T de Landgrafft (2016) West Australian grain crop downgraded 18 per cent thanks to frost damage. 7 November. ABC News, http://www.abc.net.au/news/2016–11-07/wa-frost-giwa-report-downgrades-tonnage/8001558

14.1.2 Triticale and frost

Triticale has been rated as susceptible to frost damage (Photo 3). One study has ranked frost resistance in desecending order of rye, bread wheat, triticale, barley, oats, and durum wheat, and another study reported that triticale is the most susceptible crop, followed by wheat, barley, rye and oats. While species difference in frost tolerance do exist, frost damage is also determined by other factors such as crop growth stage and environmental conditions.

One of the reasons a greater area is not devoted to triticale on most farms is its poor tolerance to frost at flowering. While most cereals can suffer yield loss to frost at flowering, triticale is regarded as one of the most likely to do so. [10] Growers have reported that frost susceptibility was one of their main constraints in triticale production and expansion. [11]

Photo 3: *Frost-damaged grain head of H20 triticale plant (left), and cold damage to triticale leaf (right).*

Sources: left, S. Tshewang, right, Florida Downunder

IN FOCUS

Frost tolerance in triticale and other winter cereals at flowering

A series of experiments was conducted to evaluate the relative reproductive frost tolerance in different commercial triticale genotypes, and how they compared with two other winter cereals, wheat and barley. Eight triticales (cv. Bogong⁽ᵇ, Tahara, H20, H151, H418, H426, JRCT 74 and JRCT 400), four bread wheats (cv. Kite, Ventura, Young and Wyalkatchem), one durum wheat (cv. Bellaroi) and one barley (cv. Kaputar) were tested over two years (2009 and 2010). In addition, the roles of cold hardening and potassium fertilisation in frost tolerance were also investigated using the triticale variety H426. The plants were grown in a glasshouse and treated to a single overnight natural frost at flowering (±5 days). The damage was assessed by counting the number of fertile grains at maturity.

The collated results of two years showed a difference in frost tolerance between the different triticale varieties. However, the difference was not huge and varietal responses were mainly determined by frost temperature.

10 J Lawes, R Jessop, C Bluett, M Jenkinson (1998) Frost tolerance of triticale varieties 1998. Online Farm Trials, http://www.farmtrials.com.au/trial/15345

11 J Roake, R Trethowan, R Jessop, M Fittler (2009) Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

Temperatures particularly below –3.9°C were found to be destructive (Figure 1). At –4.2°C, there was little effect on barley floret survival, while triticale and wheat were severely affected (Figure 2). [12]

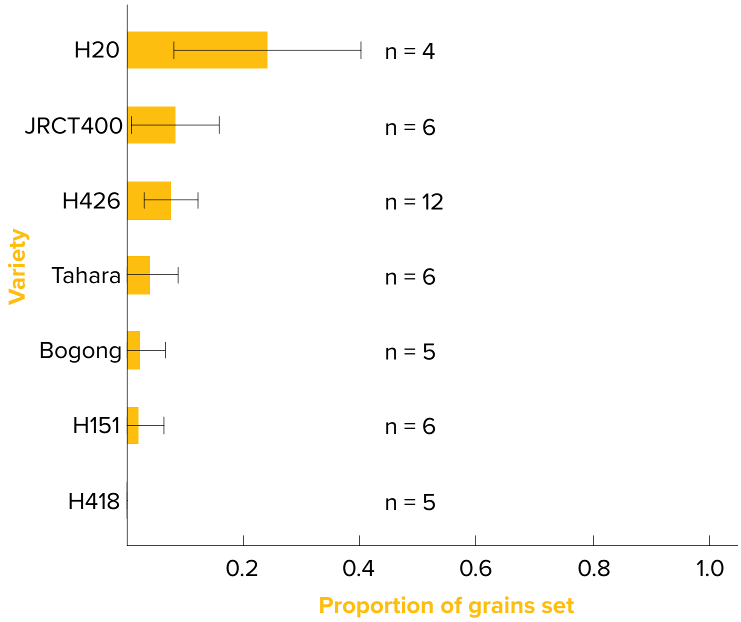


Figure 1: *Proportion of grains that set in different triticale varieties at –4.2°C (2009). Bars are the lower and upper 95% confidence interval. N = the number of heads frosted.*

Source: S Tshewang 2011

12 S Tshewang (2011) Frost tolerance in triticale and other winter cereals at flowering. Master's thesis. University of New England, https://e-publications.une.edu.au/vital/access/manager/Repository/une:8821;jsessionid=C91FFA8964B3A49AD3A44FC3BD03EA2E?exact=sm_contributor%3A%22Birchall+C%22

VIDEOS

WATCH: Plant frost mechanisms with Glenn McDonald

MORE INFORMATION

Frost and plant physiology: Q&A with Glenn McDonald

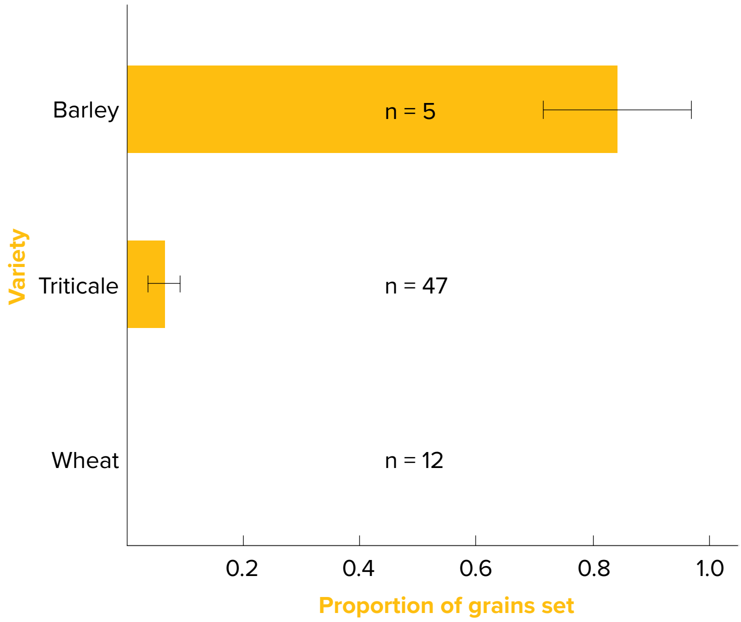


Figure 2: *Proportion of grains that set in different species at –4.2°C (2009). Bars are the lower and upper 95% confidence interval. n = number of heads frosted.*

Source: S Tshewang 2011

14.1.3 Conditions leading to frost

Clear, calm and dry nights following cold days are the precursor conditions for a radiation frost (or hoar frost). These conditions are most often met during winter and spring where high pressures follow a cold front, bringing cold air from the Southern Ocean and settled, cloudless weather (Figure 3). [13] When the loss of heat from the earth during the night decreases the temperature at ground level to zero, a frost occurs. Wind and cloud reduce the likelihood of frost by decreasing the loss of heat to the atmosphere. The extent of frost damage is determined by how quickly the temperature gets to zero, how long its stays below zero, and the how far below zero it falls.

13 D Grey (2014) Frost damage in crops: where to from here? GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

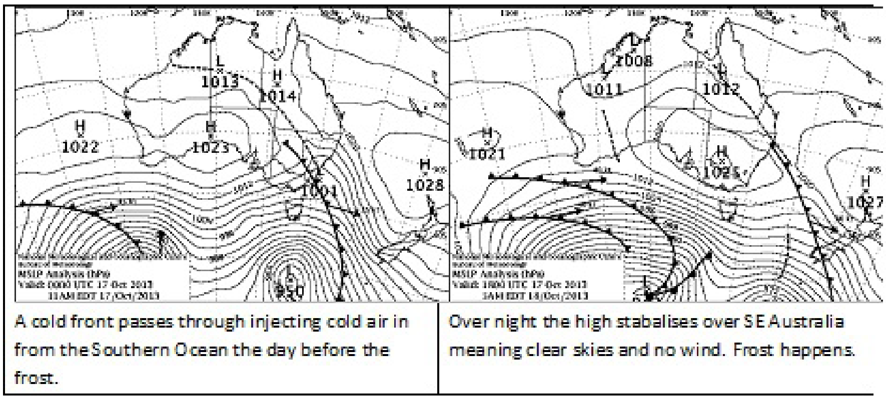


Figure 3: *A cold front passes through, injecting cold air in from the Southern Ocean the day before frost (left). Overnight the high-pressure system stabilises over south-eastern Australia, which means clear skies and no wind leading to a frost event (right).*

Source: GRDC.

Though temperatures (particularly in winter and spring) are getting warmer, frost is still a major issue, and likely to remain so. CSIRO researchers found that in some areas of Australia the number of frost events is increasing (with the greatest increase in August), and that central western NSW, the Eyre Peninsula, Esperance and the northern Victorian Mallee were the only major crop growing areas to be less affected by frost from 1961 to 2010 (Figure 4). [14] This increase is thought to be caused by the latitude of the subtropical ridge of high pressure drifting south (causing more stable pressure systems) and the existence of more El Niño conditions during this period. [15]

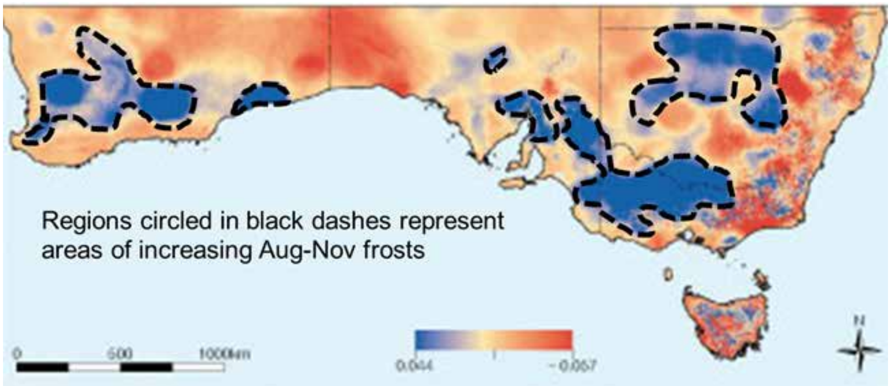


Figure 4: *Region of increasing August–November frost events.*

Source: GRDC

14.1.4 Diagnosing stem and head frost damage in cereals

Table 1 shows how to diagnose frost damage to stems and heads. Although the information given is for wheat, it applies equally to triticale. [16]

VIDEOS

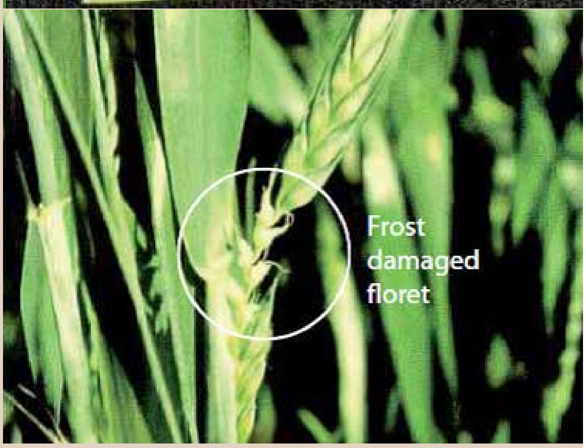
WATCH: GCTV20: Frost's emotional impact—is it greater than its economic impact?.

14 D Grey (2014) Frost damage in crops: where to from here? GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

15 D Grey (2014) Frost damage in crops: where to from here? GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

16 R Barr (2014) Frost-damage concern for south-eastern Australia. GRDC, https://grdc.com.au/Media-Centre/Media-News/South/2014/09/Frost-damage-concern-for-southeastern-Australia

Table 1: *Symptoms of frost during early growth stages.*

Crop growth stage	Inspection details	Frost symptoms in wheat	Example
Vegetative (before stem extension)	Examine leaves	Leaves are limp and appear brown and scorched	
Elongation (before and after head emergence)	Pull back leaf sheath or split stem to inspect damage	Stem has a pale green to white ring that usually appears sunken, rough to touch, and soft to squeeze Stem or nodes can also be cracked or blistered Stems can be damaged on the peduncle (stem below head) or lower in the plant If the head has emerged it is likely that the flowering parts or developing grain has sustained damage If the head is in the boot then ongoing monitoring is required to assess the level of damage	 

Crop growth stage	Inspection details	Frost symptoms in wheat	Example
Flowering and post-flowering (Flowering is the most vulnerable stage, because exposed florets cannot tolerate low temperatures and are sterilised)	Peel back the lemma (husk), inspect the condition of the florets (floral organs) in the head	Grain will not form in frosted florets Some surviving florets may not be affected Pollen sacs (or anthers, normally bright yellow) but become dry, banana-shaped and turn pale yellow or white	

Source: GRDC

What to look for in the paddock

- Symptoms may not be obvious until 5–7 days after the frost.
- Heads on affected areas have a dull appearance that becomes paler as frosted tissue dies (Photo 4). [17]
- At crop maturity, severely frosted areas remain green longer.
- Severely frosted crops have a dirty appearance at harvest, due to blackened heads and stems, and discoloured leaves.

Photo 4: *Frost damage in wheat at Black Rock in the South Australian upper north.*

Photo Jim Kuerschner

What to look for in the plant

- Before flowering:

17 R Barr (2014) Frost-damage concern for south-eastern Australia. GRDC, https://grdc.com.au/Media-Centre/Media-News/South/2014/09/Frost-damage-concern-for-southeastern-Australia

- Freezing of the emerging head by cold air or water is caught next to the flag leaf or travels down the awns into the boot. Individual florets or the whole head can be bleached and shrivelled, stopping grain formation. Surviving florets will form normally.
- Stem frost by a small amount of water that has settled in the boot and frozen around the peduncle. Symptoms include paleness or discolouration, roughness at the affected point on the peduncle, and blistering or cracking of nodes and leaf sheath. Stems may be distorted.
- Flowering head:
- The ovary in frosted flowers is 'spongy' when squeezed and turns dark in colour. In normal flowers the ovary is bright white and 'crisp' when squeezed. As the grain develops, it turns green in colour.
- Anthers are dull-coloured and are often banana-shaped. Normal anthers are green to yellow before flowering, and yellow turning white after flowering
- Grain:
- Frosted grain at the milk stage is white, turning brown, with a crimped appearance. It is usually spongy when squeezed and doesn't exude milk or dough. Healthy grain is light to dark green and plump, and exudes white milk or dough when squeezed (Photo 5).
- Frosted grain at the dough stage is shrivelled and creased along the long axis, rather as though a pair of pliers has crimped the grain (Photo 6). [18]

Photo 5: *A normal cereal head (left) compared to frost-damaged cereal showing discoloured glumes and awns.*

Source: DAFWA

18 DAFWA (2015) Diagnosing stem and head frost damage in cereals. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-stem-and-head-frost-damage-cereals

VIDEOS

WATCH: GCTV15: Frost ratings

WATCH: GCTV15: The frost ranking challenge

WATCH: GCTV12: Frost susceptibility ranked

Photo 6: *Frosted hollow grain dries back to a typically shrivelled appearance.*

Source: GRDC

14.1.5 Managing frost risk

Key points:

- The widening of the frost 'season' has been exacerbated by changes in grower practices.
- Since the risk, incidence, and severity of frost varies between and within years, as well as across landscapes, so growers need to assess their individual situation regularly.
- The occurrence of frost and damage to grain crops is determined by a combination of factors including temperature, humidity, wind, topography, crop species and variety, how the crop is managed, and soil type, texture, and colour.
- The greatest losses in grain yield and quality are observed when frosts occur between the booting and grain-ripening stages of growth.
- Frost damage is not always obvious, and crops should be inspected within five to seven days after a suspected frost.
- Methods to deal with the financial and personal impact of frost also need to be considered in the farm management plan.
- Careful planning and zoning, and choosing the right crops, are the best options to reduce frost risk. [19]

Significant frost damage has occurred several times in triticale crops in Australia in recent years. Triticale often suffers more from frost damage than wheat, hence it should generally be sown later. The risk of being frosted, particularly in low-lying paddocks, can be reduced by not planting too early; however, heat stress during grainfill may become a more important factor as the sowing date is delayed. Newer varieties with some winter habit, combined with the ability to cope with drier seasons, offer growers a significant improvement in variety choice. [20]

The variability in the incidence and severity of frost means that growers need to adopt a number of strategies as part of their farm management plan. These include pre-season, in-season, and post-frost strategies. There are two types of pre-season management tactics available for growers:

1. at the level of farm management planning; and
2. within identified frost zones of a farm.

19 GRDC (2016) Managing frost risk: northern, southern and western regions. Tips and Tactics. GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

20 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

Farm-management planning tactics

Step 1: Assess personal approach to risk

Consider your personal approach to risk in your business; every individual will have a different approach. As part of this process, identify and measure the extent of the risk, evaluate risk-management alternatives and tailor the risk advice according to your attitude to and level of comfort with risk. The risk of frost can promote conservative farming practices, which should be carefully and regularly reviewed in light of the latest research.

Step 2: Assess frost risk of property

Carefully consider the risk of your property incurring frosts due to the location. Use historical seasonal records and forecasts. Because cold air will flow into lower areas, spatial variability (topography and soil type) across the landscape should also be considered. Temperature-monitoring equipment, such as Tinytags, iButtons and weather stations, can determine temperature variability across the landscape.

Step 3: Diversify the business

A range of enterprise options should be considered as part of a farm-management plan, so as to spread financial risk in the event of frost damage. Options are subject to the location of the business and skill set of the manager, but the largest financial losses with frost have occurred where growers have a limited range of enterprises or crop types. Intensive-cropping systems, especially those focused on canola and spring wheat, are more at the mercy of frost than a diversified business, as both crops are highly susceptible to frost.

Step 4: Zone property and paddock

Paddocks or areas in paddocks that are prone to frost can be identified through experience, and the use of precision tools such as topographic, electromagnetic, and yield maps, and temperature monitors to locate susceptible zones. This can help determine the appropriate management practice to use to mitigate the incidence of frost. Be aware that frost-prone paddocks can be high-yielding areas on a farm when frosts do not occur.

Frost-zone management tactics

Step 1: Consider enterprise within a zone

The use of identified frost zones should be carefully considered, for example using them for grazing, hay or oat production, and avoiding large-scale exposure to frost of highly susceptible crops like peas or expensive crops like canola. It may be prudent to sow annual or perennial pastures on areas that frost regularly, in order to avoid the high costs of crop production.

Step 2: Review nutrient management

For high-risk paddocks, set fertiliser (nitrogen, phosphorus, potassium) and seeding rates to achieve realistic yield targets, rather than for extra high yields. By doing this, the grower should minimise their financial exposure, reduce frost damage and increase whole-paddock profitability over time. Nutrients not applied in these paddocks could be reallocated to lower-risk areas of the farm.

While high levels of nitrogen (N) increase yield potential, N also promotes the production of vegetative biomass and increases the susceptibility of the crop to frost. Using conservative N rates at seeding and avoiding late top-ups results in less crop damage.

It is best if crops are not deficient in potassium or copper, as insufficient amounts of these elements may increase susceptibility to frost events. The levels of these nutrients can be assessed from initial soil tests and with plant-tissue testing. Copper deficiency can be ameliorated with a foliar spray pre-flowering and as late as the booting stage to optimise yield, even in the absence of frost. Potassium plays a role

VIDEOS

WATCH: Frost Initiative: Do micronutrients reduce frost risk?

WATCH: MPCN: Copper and frost relationship investigated

in maintaining cell-water content in plants, and it has been shown that plants deficient in potassium are more susceptible to frost. Soils that are deficient in potassium could benefit from increasing potassium levels at the start of the growing season. However, it is unlikely that there will be a benefit of extra potassium applied to plants that are not potassium-deficient.

There is no evidence that applying other micronutrients has any impact to reduce frost damage.

Step 3: Modify the soil heat-bank

The soil heat-bank helps reduce the risk of frost (Figure 5). [21] Farmers can manipulate the way heat-banks operate, to store heat absorbed during the day and release it during the night into the crop canopy, to reduce the impact of a frost.

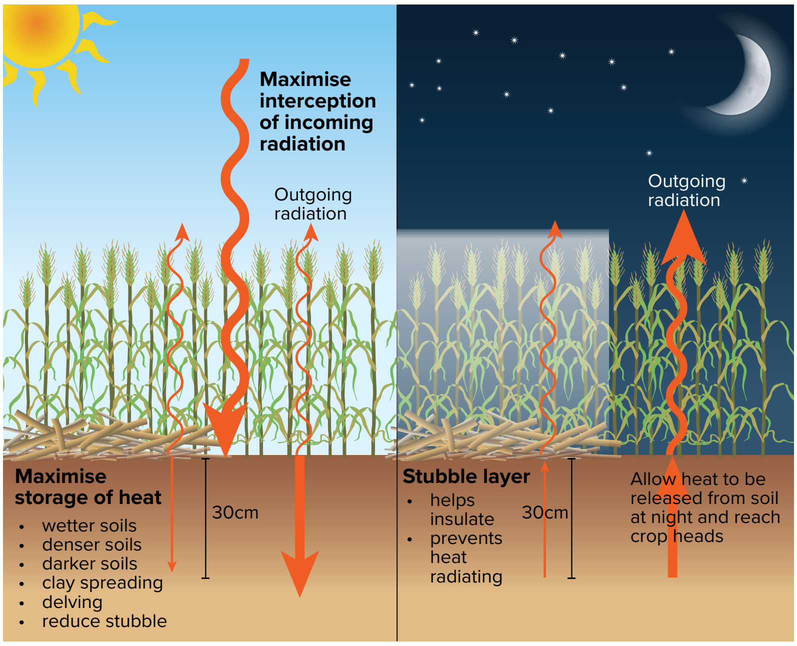


Figure 5: *The soil heat-bank captures heat during the day and radiates that heat into the crop canopy overnight, which warms flowering heads and minimises frost damage.*

Source: GRDC

Agronomic practices that may assist with storing heat in the soil heat-bank include:

- Practices that alleviate non-wetting sands, such as clay delving, mouldboard ploughing or spading, have multiple effects, and include increasing heat storage, nutrient availability and infiltration rate.
- Rolling sandy soil and loamy clay soil after seeding can reduce frost damage. It also prepares the surface for hay cutting should that be necessary.
- Reducing the amount of stubble—stubble loads above 1.5 t/ha in low-production environments (2–3 t/ha) and 3 t/ha in high-production environments (3–5 t/ha) generally increase the severity and duration of frost events, and have had a detrimental effect on yield under frost.
- Halving the normal seeding rates can reduce frost severity and damage by creating a thinner canopy and more tillers, which result in a spread of flowering time. However, weed competitiveness can be an issue.

21 GRDC (2016) Managing frost risk: northern, southern and western regions. Tips and Tactics. GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

- Cross-sowing—crops sown twice, with half the seed sown in one direction and half in the other, have a more even plant density. This means that heat is released from the soil heat-bank more slowly, to warm the crop canopy at head height in the early morning when frosts are more severe. This practice, however, increases sowing costs.

IN FOCUS

Stubble reduces frost severity

In a 2012 trial at Wickepin, WA, yields of wheat were 0.7 tonnes per hectare higher in burnt stubble high in the landscape (where there was moderate frost risk) and 0.3 t/ha higher in burnt stubble lower in the landscape where the frost risk is higher (Table 2). Wheat in the high stubble plots had almost 85% sterility, while plants beyond the stubble had 20–30% sterility, indicating that the high stubble load increased the frost damage. Temperature data showed substantially colder temperatures in plots with high stubble. This is because stubble can insulate the soil surface, which lowers the amount of heat absorbed into the soil compared with paddocks without stubble. Less heat is radiated from the soil in stubble paddocks at night, which lowers the canopy temperature and leads to greater frost severity, duration and damage. [22] Reducing the amount of stubble is likely to reduce the risk of frost damage in triticale.

Table 2: *Yield and yield component data for Nyabing. Where frost induced sterility (FIS), harvest index (HI) 100 grain weight (100GW) and screenings.*

Position	Low landscape			High landscape		
Stubble	**Additional***	**Standing**	**Removed**	**Standing**	**Removed**	**LSD0.05**
Stubble biomass in August	3.5	2.6	0.5	2.6	0.5	0.5
Average minimum canopy temperature during September–October frosts	–2.4	–2.0	–1.8	–1.1	–1.3	0.16
Hours below zero	45	33	32	22	24	
Yield (t/ha)	0.6	1.0	1.8	1.9**	2.5**	0.40
FIS (%)	87	33	35	20	13	4.0
Screenings (%) <2mm	56	9	9	13	13	5.5

*Additional stubble plot was unreplicated and was only located low in the landscape.
**Yield estimated from small plot trial harvester cuts with two replicates per plot.
Source: GRDC.

Step 4: Select appropriate crops

Crop selection is an important factor to consider for frost-prone paddocks. Crops grown for hay are harvested for biomass, so the problem of grain loss from frost does not arise. Pasture rotations are a lower-risk enterprise, and oats are the most frost-tolerant crop during the reproductive stage. Barley is more tolerant than wheat at flowering, but it is not known if barley and wheat have different frost tolerance during

22 B Biddulph in J Paterson (2014) Groundcover Supplement Issue 109: Frost - Stubble lifts frost severity. https://grdc.com.au/__data/assets/pdf_file/0028/75835/gcs109highres-pdf.pdf.pdf

MORE INFORMATION

[Yield Prophet®]

[Flower Power]

grainfill. Canola is an expensive crop to risk on frost-prone paddocks, due to high input costs.

Yield Prophet® and Flower Power are useful tools to match the flowering time of varieties to your own farm conditions.

Step 5: Manipulate flowering times

When cereals are sown in frost-risk areas, a good tactic is to ensure the flowering window of the cropping program is spread widely. This can be done by using more than one variety and manipulating sowing date and planting varieties with different phenology drivers so that crops flower over a wide period during the season. It should be noted that flowering later than the frost may result in lower yields in seasons with hot, dry finishes, as plants will be subjected to heat and moisture stress.

Staging sowing dates over a 3–6-week period is recommended. If sowing just one variety, this would provide a wide flowering window. If sowing more than one variety: sow winter wheat first; then a long-season spring wheat or a day-length-sensitive wheat; then an early-maturing wheat last. A whole-wheat program like this is planned so that flowering occurs over a two-week period, potentially exposing it to more frost risk but maximising the yield potential in the absence of frost. Even with this strategy in place, it is possible to have more than one frost event that causes damage. Flowering over a wide window will probably mean that some crop will be frosted, but the aim is to reduce extensive loss rather than prevent it altogether.

Sowing at the start of a variety's preferred window will achieve higher yields at the same cost as sowing late. Sowing time remains a major driver of yield in all crops, so the primary objective with this tactic is to achieve a balance between crops flowering after the risk of frost has passed and before the onset of heat stress. The loss of yield from sowing late to avoid frost risk is often outweighed by the gains from sowing on time to reduce heat and moisture stress in spring.

To minimise frost risk, there needs to be a mix of sowing dates, crop types, and maturity types to be able to incorporate frost-avoidance strategies into the cropping system. In years of severe frost, regardless of which strategy is adopted it may be difficult to prevent damage.

Trials have shown that blending a short-season variety with a long-season variety is an effective strategy. However, the same effect can be achieved by sowing one paddock with one variety and the other with another variety to spread risks. [23]

In regions where spring frosts are a likely problem, a delay of 7–10 days in sowing compared with main-season wheat varieties should reduce potential frost effects. The avoidance of frost-prone areas (e.g. low-lying paddocks and creeks) will also reduce possible frosting effects. [24]

In monetary values, the loss by delayed sowing in WA alone can reach about $18.4 million (Table 3). [25]

23 GRDC (2016) Managing frost risk: northern, southern and western regions. Tips and Tactics. GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

24 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

25 Hayman et al. (2007) in S Tshewang (2011) Frost tolerance in triticale and other winter cereals at flowering. Master's thesis. University of New England, https://e-publications.une.edu.au/vital/access/manager/Repository/une:8821;jsessionid=C91FFA8964B3A49AD3A44FC3BD03EA2E?exact=sm_contributor%3A%22Birchall+C%22

MORE INFORMATION

Effect of fodder cuts on grain yield of early sown wheat and triticale 2006

Table 3: *Estimated cost of delayed sowing of wheat to minimize the impact of frost.*

Site	Days delayed	Loss (kg/ha)	Loss ($/ha)	Average loss ($/ha)
Merredin	18	360	79	16
Narrogin	10	200	44	14

data from Hayman et al. 2007

Step 6: Fine-tune cultivar selection

As no wheat or barley varieties are tolerant to frost, consider using varieties that have lower susceptibility to frost during flowering, as a means of managing the frost risk of the cropping program while maximising yield potential. There is no point selecting less-susceptible varieties for the whole cropping program if there is an opportunity cost of lower yield without frost.

Preliminary ranking information for current wheat and barley varieties for susceptibility to reproductive frost is available from the National Variety Trials website. A new variety should be managed based on how known varieties of similar ranking are managed. [26]

Guidelines to reducing frost risk and assessing frost damage

Matching variety to planting opportunity

The current best strategy to maximise long-term crop yields is to aim to time crop heading, flowering, and grainfilling in the short window of opportunity after the main frost risk has passed and before day-time maximum temperatures become too high.

It is essential that varieties are sown within the correct window for the district, as outlined in variety guides.

Planting in the optimum window does not guarantee that crop loss due to frost will be averted, nor does it always prevent drastic yield reduction due to late-season heat and drought stress. However, planting a variety too early gives a much higher probability of crop loss.

With seasonal temperature variation, the days to flowering for each variety will change from season to season, as discussed above.

Current variety ratings based on floret damage may not provide a useful guide. Floret-damage ratings are yet to be correlated with more significant head and stem-damaging frosts.

Measuring crop temperature

Temperatures taken in the crop are useful in determining whether the crop may have been exposed to damaging temperatures. A historic comparison of on-farm and district minimum temperatures also allows growers to fine-tune district management recommendations to better suit their property and individual paddocks. District recommendations are based on one, or at best, a few sites, for each district, and may not correlate well with the experience of individual growers. Thus, in many instances, the recommendations likely err on the side of caution.

Stevenson screen temperatures measured at Bureau of Meteorology stations do not fully explain frost risk, either. In crops, the temperature can vary several degrees from the temperature measured in the screen. On nights of still, cold air, clear skies, and low humidity, temperatures can drop rapidly, resulting in radiant frost (Figure 6). [27] Temperatures in a crop can vary widely, due to differences in topography, micro-environments and recording methods.

26 GRDC (2016) Managing frost risk: northern, southern and western regions. Tips and Tactics. GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

27 J Christopher, B Zheng, S Chapman, A Borrell, T Frederiks, K Chenu (2016) An analysis of frost impact guidelines to reduce frost risk and assess frost damage. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/An-analysis-of-frost-impact-plus-guidelines-to-reduce-frost-risk-and-assess-frost-damage

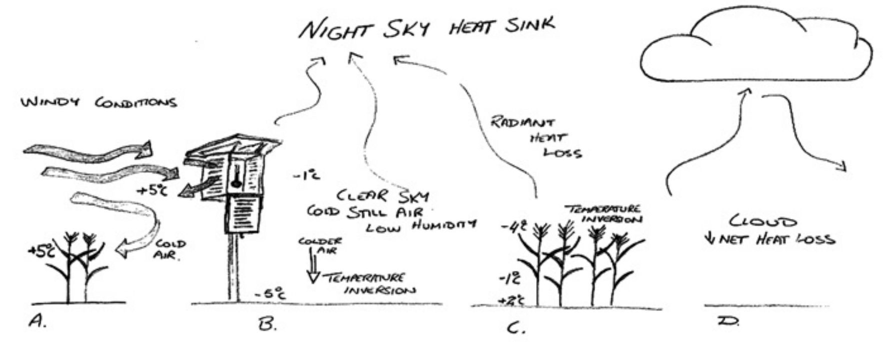


Figure 6: *If clear skies and still, cold, dry air coincide, heat can be lost rapidly to the night sky, resulting in a radiant frost. Minimum air temperatures measured at head height can be several degrees colder than reported screen temperatures. Some indicative temperatures are illustrated for (A) windy conditions, (B) clear, still conditions in an open area, (C) clear, still conditions in a cropping area, and (D) cloudy conditions.*

Source: GRDC

Measurements taken using exposed thermometers at canopy height (Photo 7) give a much more accurate indication of the likelihood of crop damage. [28]

Photo 7: *Canopy temperature being measured using a calibrated minimum–maximum thermometer. For best results, a minimum of two or three field thermometers are required to give representative temperatures for a crop. In undulating country, more thermometers should be used to record temperatures at various heights in the landscape.*

Source: GRDC)

28 J Christopher, B Zheng, S Chapman, A Borrell, T Frederiks, K Chenu (2016) An analysis of frost impact guidelines to reduce frost risk and assess frost damage. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/An-analysis-of-frost-impact-plus-guidelines-to-reduce-frost-risk-and-assess-frost-damage

14.1.6 What to do with a frosted crop

Once a frost has occurred, especially at or after flowering, the first step is to inspect the crop and collect a random sample of heads to estimate the yield loss incurred. In the event of severe frost (Photo 8), [29] monitoring needs to occur for up to two weeks after the event to detect all the damage.

Photo 8: *Crops in severely frosted areas such as this mature later and are often stained or discoloured.*

Source: DAFWA

After the level of frost damage has been estimated, the next step is to consider options for the frost-damaged crop. The grower must weigh up the advantages and disadvantages of each option (Table 4). [30] A few of these options are discussed below.

29 DAFWA (2015) Diagnosing head and stem frost damage in cereals. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-stem-and-head-frost-damage-cereals

30 GRDC (2014) Frost damage concern for south-eastern Australia. GRDC, https://grdc.com.au/news-and-media/news-and-media-releases/south/2014/09/frost-damage-concern-for-southeastern-australia

Table 4: *Management options for frost damaged crop, each with advantages and disadvantages.*

Options	Advantages	Disadvantages
Harvest	Salvage remaining grain More time for stubble to break down before sowing Machinery available	Cost may be greater than return Need to control weeds Threshing problems Removal of organic matter
Hay, silage	Stubble removed Additional weed control	Costs $35–$50/t to make hay Quality may be poor Nutrient removal
Chain, rake	Retains some stubble (reduces erosion risk) Allows better stubble handling	Costs $5/ha to rake Time taken
Graze	Feed value	Insufficient stock to use feed Remaining grain may cause acidosis Stubble may be difficult to sow into
Spray	Stops weeds seeding Preserves feed quality for grazing Gives time for final decisions Retains feed Retains organic matter	With a thick crop, difficulty getting chemicals onto all of the weeds May not be as effective as burning Boom height limitation Costs $5/ha, plus the cost of herbicide Some grain still in crop
Plough	Recycles nutrients and retains organic matter Stops weed seed set Green manure effect	Requires offset disc to cut straw Soil moisture needed for breakdown and incorporation of stubble
Swath	Stops weed seedset Windrow can be baled Regrowth can be grazed Weed regrowth can be sprayed	Relocation of nutrients to windrow Low market value for straw Poor weed control under swath Costs $20/ha to swathe Costs $5/ha per herbicide to spray
Burn	Recycles some nutrients Controls surface weed seeds Permits re-cropping with disease control Can be done after rain	Potential soil and nutrient losses Fire hazard Loss of organic matter

Source: GRDC

Option 1: Take through to harvest

If the frost is prior to or around growth stage GS 31 to GS 32, most cereals can produce new tillers to compensate for damage, provided spring rainfall is adequate, so it may be worth keeping the crop and harvesting it. Tillers already formed but lower in the canopy may become important. Naturally, tiller response depends on the location and severity of the damage. Compensatory tillers will mature later, but where

VIDEOS

WATCH: GCTV3: Frost R&D

WATCH: GCTV16: National Frost Initiative

MORE INFORMATION

Managing frost risk: Case studies of growers in Western Australia

GRDC factsheet, Managing frost risk

DAFWA, Frost risk: manage wheat variety and sowing time

soil-moisture reserves are high, or it is early in the season, they may contribute to grain yield.

A later frost is more concerning, especially for crops such as triticale, wheat and barley, as there is less time for compensatory growth. The grain yield needed to recover the costs of harvesting should be determined using gross margins.

Option 2: Cut and bale

Cutting and baling is an option when late frosts occur during flowering and through grainfill. Assess crops for hay quality within a few days of a frost and be prepared to cut a larger area than you had intended to before the start of the season.

Producing hay can also be a good management strategy to reduce stubble, the weed seedbank, and disease loads for the coming season. This may allow more rotational options in the following season to aid financial recovery from frost, for example to go back to cereal on cereal in paddocks cut early for hay. However, as hay making can be an expensive exercise, growers should have a clear path to market or a use for the hay on the farm before committing to this option.

Option 3: Grazing, manuring and crop-topping

Grazing is an option after a late frost, when there is little or no chance of plants recovering, or when hay is not an option. Spraytopping for weed-seed control may also be incorporated into this option, especially if the paddock will be sown to crop the next year. Ploughing in the green crop is an option to return organic matter and nutrients to the soil, manage crop residues and weeds, and improve soil fertility and structure. The economics need to be considered carefully. [31]

Depending on the degree of damage incurred, the grain may still be very valuable as stock feed. Severely frosted grain may have a metabolisable energy (ME) of approximately 1MJ/kg lower than unfrosted grain. Provided allowance is made for this decrease in energy value, the grain is still valuable in a feed ration. [32]

Useful tools

- AgExcellence Alliance has an annotated list of several weather and farming apps.
- Plant-development apps, e.g. MyCrop, DAFWA's Flower Power
- Temperature monitors
- Yield Prophet®

National Frost Initiative

The objective of the GRDC's National Frost initiative is to provide the Australian grains industry with targeted research, development, and extension solutions to manage the impact of frost and maximise seasonal profit. It funds multidisciplinary projects in the following areas:

- Genetics—developing more frost-tolerant wheat and barley germplasm, and ranking current wheat and barley varieties for susceptibility to frost.
- Management—developing best-practice crop canopy, stubble, nutrition, and agronomic management strategies to minimise the effects of frost, and searching for innovative products that may minimise the impact of frost.
- Environment—predicting the occurrence, severity, and impact of frost events on crop yields and at the farm scale to enable better risk management. [33]

31 GRDC (2016) Managing frost risk: northern, southern and western regions. Tips and Tactics. GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

32 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

33 GRDC (2016) Managing frost risk: northern, southern and western regions. Tips and Tactics. GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

14.2 Waterlogging and flooding issues for triticale

Key points:

- Waterlogging occurs when roots cannot respire due to excess water in the soil profile.
- Though cereals can be more prone to waterlogging than other crop types, triticale has been found to be more tolerant of waterlogged conditions than wheat. [34]
- Water does not have to appear on the surface for waterlogging to be a potential problem.
- Improving drainage from the inundated paddock can decrease the time that crop roots are subjected to anaerobic conditions.
- While raised beds are an expensive management strategy, they are also the most effective at improving drainage.
- Waterlogging increases the release from soils of nitrous oxide (N2O), a particularly damaging greenhouse gas.

Waterlogging occurs whenever the soil is so wet that there is insufficient oxygen in the pore spaces for plant roots to be able to respire adequately (Photo 9). [35] Other gases detrimental to root growth, such as carbon dioxide and ethylene, also accumulate in the root zone and affect the plants.

Plants differ in their demand for oxygen, so there is no universal level of soil oxygen that can be used to identify what constitutes waterlogged conditions. In addition, a plant's demand for oxygen in the root zone will vary with its stage of growth. [36]

Photo 9: *Waterlogged cereal paddock near Kendenup, WA.*

Source: DAFWA

Many wetland plants are specially adapted to cope with life in waterlogged soils: they have a combination of a high volume of aerenchyma (soft plant tissue containing air spaces) and a barrier to prevent radial oxygen loss (ROL) from roots. The lack of a barrier to ROL in dryland cereals presumably contributes to their sensitivity to soil waterlogging. [37]

Among the cereals, triticale has been reported to be more tolerant of waterlogged conditions than wheat. [38] Some farmers have noted that triticale also outperforms barley in areas prone to waterlogging. [39] At one farm, the variety Rufus was

34 CJ Thomson, TD Colmer, ELJ Watkin, H Greenway (1992) Tolerance of wheat (Triticum aestivum cvs Gamenya and Kite) and triticale (Triticosecale cv. Muir) to waterlogging. New Phytologist, 120 (3), 335–344.

35 DAFWA (2015) Management to reduce impact of waterlogging in crops. DAFWA, https://www.agric.wa.gov.au/waterlogging/management-reduce-impact-waterlogging-crops

36 D Bakker (2017) Waterlogging. Factsheet. Soilquality.org, http://soilquality.org.au/factsheets/waterlogging

37 AI Malik, AKMR Islam, TD Colmer. Physiology of waterlogging tolerance in wheat, hordeum marinum and their amphiploid

38 CJ Thomson, TD Colmer, ELJ Watkin, H Greenway (1992) Tolerance of wheat (Triticum aestivum cvs Gamenya and Kite) and triticale (Triticosecale cv. Muir) to waterlogging. New Phytologist, 120(3), 335–344.

39 GRDC (2006) Triticale. Ground Cover. No. 59. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-59/Triticale

completely under water for 4–5 days and still yielded 1.34 t/ha. It also carried no rust, and the straw was baled for sale to dairy producers. [40]

Researchers in WA explored the responses of two genotypes of wheat (Triticum aestivum cvs Gamenya and Kite) and one genotype of triticale (Triticosecale cv. Muir) in stagnant solution culture and in waterlogged soil, using plants that were 23 to 36 days old. The stagnant nutrient solutions decreased shoot fresh weight of Gamenya by 21% compared with aerated plants, while the shoot fresh weight of Muir was unaffected. Reductions in nodal root fresh weight under stagnant conditions were also less for Muir than Gamenya. [41]

Australian researchers have found that seed size is related to waterlogging tolerance. On average, larger seed results in greater plant growth for triticale cultivars, and seed mass is positively related to the plant biomass and adventitious nodal root mass under waterlogged conditions. [42]

14.2.1 Where does waterlogging occur?

Waterlogging occurs:

- Where water accumulates or drains poorly in areas such as valleys, at the change of slope, or below rocks.
- In duplex soils, particularly sandy duplexes with less than 30 cm of sand over clay.
- With deeper sown crops.
- In crops with a low nitrogen status.
- In very warm conditions when oxygen is more rapidly depleted in the soil. [43]

Waterlogging greatly increases crop damage from salinity. Germination and early growth can be much worse in marginally saline areas after they have been waterlogged.

Identifying problem areas

The best way to identify problem areas is to dig holes about 40 cm deep in winter and see if water flows into them (Photo 10). [44] If it does, the soil is waterlogged. Digging holes for fence posts often reveals waterlogging.
Some farmers put slotted PVC pipe into augered holes. They can then monitor the water levels in their paddocks.
Symptoms in the crop of waterlogging include:

- Yellowing of crops and pastures.
- Presence of weeds such as toad rush, cotula, dock and Yorkshire fog grass. [45]

40 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

41 CJ Thomson, TD Colmer, ELJ Watkin, H Greenway (1992) Tolerance of wheat (Triticum aestivum cvs Gamenya and Kite) and triticale (Triticosecale cv. Muir) to waterlogging. New Phytologist, 120 (3), 335–344.

42 DK Singh, V Singh (2003) Seed size and adventitious (nodal) roots as factors influencing the tolerance of wheat to waterlogging. Crop and Pasture Science, 54 (10), 969–977.

43 DAFWA (2015) Diagnosing waterlogging in cereals. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-cereals

44 B Cotching, D Bakker (2017) Waterlogging, Tasmania. Factsheet. Soilquality.org, http://soilquality.org.au/factsheets/waterlogging-tas

45 D Bakker (2017) Waterlogging. Factsheet. Soilquality.org, http://soilquality.org.au/factsheets/waterlogging

Photo 10: *Water fills a hole while digging in waterlogged soil.*

Source: Soilquality.org

14.2.2 Symptoms and causes

Waterlogging occurs when the soil profile or the root zone of a plant becomes saturated. In rain-fed situations, this happens when more rain falls than the soil can absorb or the atmosphere can evaporate. The lack of oxygen in the root zone of plants causes their root tissues to decompose. Usually this occurs from the tips of roots, and causes the roots to appear as if they have been pruned. The consequence is that the plant's growth and development is stalled. If the anaerobic circumstances continue for a considerable time (e.g days to weeks), the plant will eventually die.

Most often, however, waterlogging does not last this long. Once a waterlogging event has passed, plants recommence respiring. As long as soil conditions are moist, the older roots close to the surface allow the plant to survive. However, further waterlogging-induced root pruning and/or dry conditions may weaken the plant to the extent that it may not recover, and may eventually die.

Many farmers do not realise that a site is waterlogged until water appears on the soil surface. However, by this stage, plant roots may already be damaged and yield potential severely affected.

What to look for in the paddock

- Poor germination or pale plants in areas where water collects, particularly on shallow duplex soils (Photo 11). [46]
- Wet soil and/or water-loving weeds are present.
- Early plant senescence in waterlogging-prone areas.

46 DAFWA (2015) Diagnosing waterlogging in cereals. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-cereals

Photo 11: *Pale plants in waterlogged area.*

Source: DAFWA

What to look for in the plant

- Waterlogged seed will be swollen and may have burst.
- Seedlings may die before emergence, or be pale and weak if they do emerge.
- Waterlogged plants appear to be nitrogen-deficient, with pale plants, poor tillering, and older leaf death.
- If waterlogging persists, roots (particularly root tips) cease growing, become brown, and then die (Photo 12).
- Seminal roots may be damaged. As these roots are important for accessing deep subsoil moisture, waterlogging damage may leave the plants more sensitive to spring drought.

Plants are particularly vulnerable from seeding to tillering, with seminal roots being more affected than later forming nodal roots.

Photo 12: *Waterlogged roots, particularly seminal roots and tips, become brown and then die.*

Source: DAFWA

14.2.3 How waterlogging can be monitored

Waterlogging can be monitored by:

- Regularly checking water levels using bores or observation pits (but keep in mind that water tables can vary greatly over short distances).
- Observe plants for symptoms, and the paddock for clues, and verify by digging a hole in the paddock and watching for the appearance of water in it—plants can become waterlogged if there is a water table within 30 cm of the surface. There may be no indication of waterlogging at the surface. [47]

14.2.4 Other impacts of waterlogging and flood events

Heat from stagnant water

Stagnant water, particularly if it is shallow, can heat up in hot, sunny weather and kill plants in a few hours. Remove excess water as soon as possible after flooding to give plants the best chance of survival.

Chemical and biological contaminants

Floodwater may carry contaminants, particularly from off-farm run-off. You should discard all produce, particularly leafy crops, exposed to off-farm run-off.

Make sure you take food-safety precautions and test soils before replanting, even if crops look healthy. Contaminants will reduce over time, with follow-up rain and sunny weather.

47 DAFWA (2015) Diagnosing waterlogging in cereals. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-cereals

VIDEOS

WATCH: GCTV3: Big wet—managing strategies after flooding

Iron chlorosis or nitrogen deficiency

Floods and high rainfall can leach essential nutrients from the soil, which can affect plant health. Nutrients such as iron and nitrogen can be replaced through the use of fertiliser.

Soils with high clay content

Soils with a high clay content can become compacted and form a surface crust after heavy rainfall or flooding. Floodwater may also deposit a fine clay layer on top of the soil, and this will prevent oxygen penetrating into the soil (aeration). This layer should be broken up and incorporated into the soil profile as soon as possible.

Pests and diseases

Many diseases are more active in wet, humid conditions, and pests can also cause problems then, too. Remove dying or dead plants that may become an entry point for disease organisms or insect pests. Apply suitable disease control measures as soon as possible and monitor for pests. [48]

14.2.5 Managing waterlogging

Key points:

- Sow waterlogging-tolerant crops such as oats and faba beans.
- Sow as early as possible with a higher cereal seeding rate.
- Drainage may be appropriate on sandy duplex soils on sloping sites.
- Raised beds are more effective on relatively flat areas and on heavier-textured soils, but areas need to be large enough to justify the machinery costs. [49]

Drainage

Drainage is usually the best way of reducing waterlogging. Good drainage is essential for maintaining crop health. Wet weather provides a good opportunity to improve the drainage of your crop land, as it allows you to identify and address any problem areas. There are several things you can do to improve crop drainage, immediately and in the longer term.

Drain waterlogged soils as quickly as possible, and cultivate between rows to aerate the soil.

Other management options to reduce the impact of waterlogging include the choice of crop, seeding, and fertiliser, and weed control.

Drainage problems after flooding

After significant rain or flooding, inspect the crops as soon as it is safe to do so, and mark areas (e.g. with coloured pegs) that are affected by poor drainage. If possible, take immediate steps to improve the drainage of these areas so that the water can get away (e.g. by digging drains).

Irrigation after waterlogging

To avoid the recurrence of waterlogging, time irrigation by applying small amounts often until the crop's root system has recovered.

Ways to improve drainage

In the longer term, look for ways to improve the drainage of the affected areas. Options might include:

- re-shaping the layout of the paddock
- improving surface drainage

48 Queensland Government (2016) Managing risks to waterlogged crops. Queensland Government, https://www.business.qld.gov.au/industry/agriculture/crop-growing/disaster-recovery-for-crop-farming/saving-crops-floods/managing-risks-waterlogged-crops

49 DAFWA (2015) Diagnosing waterlogging in cereals. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-cereals

- installing subsurface drainage

If the drainage can't be improved, consider using the area for some other purpose (e.g. as a silt trap). [50]

Choice of crop species

Some species of grains crop are more tolerant of waterlogging than others. Grain legumes and canola are generally more susceptible to waterlogging than cereals and faba beans.

Seeding crops early and using long-season varieties help to avoid crop damage from waterlogging. Crop damage is particularly severe if plants are waterlogged between germination and emergence. Plant first those paddocks that are susceptible to waterlogging. However, if waterlogging delays emergence and reduces cereal plant density to fewer than 50 plants/m2, re-sow the crop.

Seeding rates

Increase sowing rates in areas susceptible to waterlogging to give some insurance against uneven germination, and to reduce the dependence of cereal crops on tillering to produce grain. Waterlogging depresses tillering. High sowing rates will also increase the competitiveness of the crop against weeds, which will take advantage of stressed crops.

Nitrogen fertiliser

Crops tolerate waterlogging better if the soils has a good nitrogen status before waterlogging occurs. Applying nitrogen at the end of a waterlogged period can be an advantage if nitrogen was applied at or shortly after seeding, because it avoids loss by leaching or denitrification. However, nitrogen cannot usually be applied from vehicles when soils are wet, so consider aerial applications.

If waterlogging is moderate (7–30 days), then nitrogen application after waterlogging events when the crop is actively growing is recommended where basal nitrogen applications were 0–50 kg N/ha. However, if waterlogging is severe (greater than 30 days), the benefits of nitrogen application after waterlogging are questionable. But this recommendation requires verification in the paddock at a range of basal nitrogen applications using a selection of varieties.

MORE INFORMATION

Should waterlogged crop be top-dressed with N fertiliser?

Weeds

Weed density affects a crop's ability to recover from waterlogging. After the water has drained, they will compete with the crop for water and the small amount of remaining nitrogen. This is why the waterlogged parts of a paddock are often weedy, and require special attention if the yield potential is to be achieved. [51]

14.3 Other environmental issues

Triticale will grow on similar soils to wheat and barley, but is also adapted to soils that are too acid for the other cereals. It is relatively tolerant of boron, and is tolerant of high aluminium levels. On alkaline soils where other cereals are affected by manganese, zinc or copper deficiency, triticale is less affected. [52]

50 Queensland Government (2016) Improving drainage of crop land. Queensland Government, https://www.business.qld.gov.au/industry/agriculture/crop-growing/disaster-recovery-for-crop-farming/saving-crops-floods/improving-drainage-crop-land

51 DAFWA (2015) Management to reduce the impact of waterlogging in crops. DAFWA, https://www.agric.wa.gov.au/waterlogging/management-reduce-impact-waterlogging-crops

52 Birchip Cropping Group (2004) Triticale agronomy 2004. Online Farm Trials, http://www.farmtrials.com.au/trial/13801

14.3.1 Drought and heat stress

Long-term historical records indicate that our climate is becoming progressively warmer and dryer. This trend is expected to continue due to increased levels of greenhouse gases in the atmosphere, with dry seasons likely to become more frequent over southern Western Australia. [53]

Drought is one of the major environmental factors that reduce grain production in rain-fed and semi-arid regions of Australia (Photo 13). The direct effects of heat stress are estimated to cost grain growers nationally about $1.1 billion. Due to the effects of climate change, both heat stress and frost are likely to play an increasing role in the future and will require growers to take steps to manage the risks. [54]

Photo 13: *Drought conditions in 2015 left a dry landscape prone to dust storms.*

Photo: Brad Collis, Source: GRDC.

Triticale has been variably rated for its resilience in drought, with one study ranking cereal in terms of highest-yielding in drought conditions as, in descending order, barley, complete triticale, durum wheat, bread wheat, substituted triticale, and oats. [55] Triticale is well adapted to conditions of limited water supply.

Overseas data indicates that in dry conditions triticale's biomass production falls, but that the biomass of wheat normally falls much further, so triticale's relative advantage is likely to become more pronounced during droughts. In a study in a Mediterranean climate, researchers found that the yield of wheat dropped significantly (by 25%, 54%, and 87%) under drought stress, while the yield of triticale showed only a slight and insignificant decrease (by 8%), compared to an irrigated control. It is suggested that the greater drought resistance of triticale can be attributed to the earliness of its heading, and to the greater capacity of its roots to extract water from the soil. [56]

In another study, in 1988–89 in Mexico, 24 early triticale lines were tested under drought stress (mean yield of 1,720 kg/ha) and with no stress (mean yield of 7,180 kg/ha), and compared with the best standard wheat cultivar available. Under drought conditions, triticale had a yield advantage over wheat. [57]

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53 DAFWA (2016) Drought. DAFWA, https://www.agric.wa.gov.au/climate-land-water/climate-weather/drought

54 R Barr (2016) Diversity the key to balancing frost heat risks. GRDC, https://grdc.com.au/Media-Centre/Media-News/South/2016/01/Diversity-the-key-to-balancing-frost-heat-risks

55 C López-Castañeda, RA Richards (1994) Variation in temperate cereals in rainfed environments II. Phasic development and growth. Field Crops Research, 37 (1), 63–75.

56 F Giunta, R Motzo, M Deidda (1993) Effect of drought on yield and yield components of durum wheat and triticale in a Mediterranean environment. Field Crops Research, 33 (4), 399–409.

57 A Blum (2014) The abiotic stress response and adaptation of triticale: a review. Cereal Research Communications, 42 (3), 359–375.

In 2009, laboratory experiments indicated that the varieties Tickit and Credit were able to accumulate more carbohydrates (sugars) in their stems, and to translocate them to the grain compared with varieties such as Everest and Kosciusko. The better translocation capacity may be related to improved drought tolerance. More detailed field assessment of water relations in triticale compared with wheat is needed, especially with the likelihood of drier conditions associated the current projections on climate change. [58]

Heat-stress affects crop and cereal production in all regions of the Australian wheatbelt. It can have significant effects on grain yield and productivity, with potential losses equal to, and potentially greater than, other abiotic stressors such as drought and frost. Controlled-environment studies have established that a 3–5% reduction in the grain yield of wheat can occur for every 1°C increase in average temperature above 15°C. Field data suggest that yield losses can be in the order of 190 kg/ha for every 1°C rise in average temperature, in some situations having a more severe effect on yield loss than water availability.

Plants are more sensitive to elevated temperatures during the reproductive stages of growth, with physiological responses including premature leaf senescence, reduced photosynthetic rate, reduced seedset, reduced duration of grainfill, and reduced grain size, all of which lead, ultimately, to reduced grain yield. Elevated temperatures are a normal, largely unavoidable occurrence during the reproductive phase of Australian crops in September and October. [59]

In some cereals, heat stress can be identified by the withering and splitting of leaf tips (Photo 14). The tips can also turn brown to grey in colour. In this situation, some or all grains fail to develop in a panicle. [60]

Photo 14: *Withered and split tips in heat-stressed cereal.*

Source: DAFWA

Managing drought and heat stress

Key points:

- Heat stress is a key yield limiting factor in crop production.
- Heat stress has been shown to adversely affect yield as early as GS 45.
- Post-flowering heat stress is most common in southern Australia.

58 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

59 P Telfer, J Edwards, H Kuchel, J Reinheimer, D Bennett (2013) Heat stress tolerance of wheat. GRDC Update Paper. GRDC, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Heat-stress-tolerance-of-wheat

60 DAFWA (2016) Diagnosing heat stress in oats. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-heat-stress-oats

- Delayed sowing increases the chance of the crop being exposed to heat stress, particularly at the vulnerable pre-flowering growth stages.

Because drought can be unpredictable and can last for extended periods of unknown length, it is difficult to prepare for it. See the links below for some tips on managing drought.

The results of recent research in southern Australia suggest that variety selection and early sowing are still the most effective means to reduce the risk of a crop being damaged by excessive heat. A later-sown crop has a greater likelihood of being exposed to the heat stress at more sensitive growth stages, particularly pre-flowering, and will have greater consequences on grain yield. [61]

In drought, it is important to not ignore the signs and to have a plan, act early, review and then plan again, and revise the plan with each action as you play out your strategy.

Step One: Check the most limiting farm resources:

- funds available;
- surface/subsoil moisture for crop leaf and root growth;
- need to service machinery – breakdowns cost time, money and frustration.

Step Two: Set action strategies, considering:

- breakeven position of each strategy chosen;
- windows of opportunity to adopt management practices that will be profitable during drought;
- available resources and the implications for ground cover, chemical residues, etc., of carrying out each strategy;
- when situations are changing, conditional and timely fall-back options.

Step Three: Monitor and review performance, position and outlook by:

- using your established network to stay informed about key factors that affect your drought strategies;
- being proactive about the decisions made;
- being prepared for change;
- remembering that the impact falls very heavily not only on the decision makers but on the whole farm family. [62]

Soil management following drought

The principal aim after rain should be to establish either pasture or crop as a groundcover on your bare paddocks as quickly as possible. This is especially important on the red soils, but is also important for the clays. After drought, many soils will be in a different condition to what is considered to be their 'normal' condition. Some will be bare and powdery on the surface, some will be further eroded by wind or water, and some will have higher levels of nitrogen (N) and phosphorus (P) than expected. Loss of effective ground cover (due to grazing or cultivation) leaves the soil highly prone to erosion by wind and water. Research by the former Department of Land and Water Conservation's Soil Services showed that erosion due to drought-breaking rain can make up 90% of the total soil loss in a 20–30 year cycle. Following a drought, available N and P levels in the soil are generally higher than in a normal season. However, most of the N and P is in the topsoil, so if erosion strips the topsoil much of this benefit is lost. [63]

MORE INFORMATION

Make sure the impact of herbicide residues following drought is considered.

Winter cropping following drought

Soil management following drought

NSW DPI, Drought Hub

Drought planning

61 P Telfer, J Edwards, D Bennett, H Kuchel (2013) Managing heat stress in wheat. Mallee Sustainable Farming, http://www.msfp.org.au/wp-content/uploads/Managing-heat-stress-in-wheat.pdf

62 Meaker G, McCormick L, Blackwood I. (2007). Primefacts: Drought planning. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/96236/drought-planning.pdf

63 Jenkins A. (2007). Primefacts: Soil management following drought. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0012/104007/soil-management-following-drought.pdf

14.3.2 Aluminium toxicity

At soil pH levels of below 5, aluminium (Al) and manganese (Mn) become available in soil solution, and can damage root growth and reduce yields. Screening work in flow-culture systems and field observations has indicated that triticale has a range of tolerances to aluminium. For example, Tahara is highly Al-tolerant, while Empat, an older grazing-and-grain type, had much poorer Al-tolerance. [64]

Triticale grows productively on acidic soils where the high availability of aluminium ions reduces the economic yield of many other crops. [65]

Many triticale cultivars are able to grow better than wheat in soils with high aluminium toxicity. [66]

Many of the new varieties have now been screened in flow culture for Al tolerance (Table 5). [67] In the screening system, small plants are given an aluminium stress in solution and afterwards examined for root regrowth. The presence of regrowth and its length indicate relative tolerance, with greater length of regrowth being a measure of greater Al tolerance. As expected, the wheat variety (Janz) had poor Al tolerance, rye showed a good tolerance, and the triticales showed a range of tolerances, with Canobolas⦇D⦈ being the most Al-tolerant variety. [68]

Table 5: *Aluminium tolerance of newer triticales.*

Variety	Re-growth length (mm)
Wheat	2.4
Rye	40.6
Tobruk⦇D⦈	21.0
JCRT 74	29.5
JCRT 75	30.8
Breakwell⦇D⦈	36.5
Tahara	35.1
AT528	27.6
H20	27.6
H55	39.6
H116	29.5
Bogong⦇D⦈	29.5
H128	35.4
H157	29.5
H249	32.8
Canobolas⦇D⦈	46.1
H426	48.7

Source: Jessop and Fittler 2009)

Many of the yellow earths in the Western Australian wheatbelt have naturally acidic subsoils that can reduce the yield of wheat grown on them. In WA, the major problem

64 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

65 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, http://www.fao.org/docrep/009/y5553e/y5553e00.htm

66 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, http://www.fao.org/docrep/009/y5553e/y5553e00.htm

67 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

68 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

when soils acidify is aluminium toxicity in the subsurface soil. Low pH in topsoils primarily affects nutrient availability, and decreases nodulation of legumes and nitrogen fixation in pastures. These problems are minimised if the topsoil pHCa is maintained above 5.5.

In most wheatbelt soils, aluminium will reach toxic levels when subsurface pHCa falls below 4.8. Generally, there is sufficient organic matter in topsoil that aluminium can remain bound and does not become toxic to plant roots, even though it is extractable in a laboratory analysis. [69]

69 DAFWA (2016) Effects of Soil acidity. DAFWA, https://www.agric.wa.gov.au/soil-acidity/effects-soil-acidity