NORTHERN
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GRDC GROWNOTES™

GRDC™ GRAINS RESEARCH & DEVELOPMENT CORPORATION

TRITICALE

SECTION 14

ENVIRONMENTAL ISSUES

FROST ISSUES FOR TRITICALE | DROUGHT AND HEAT STRESS | WATERLOGGING AND FLOODING ISSUES FOR TRITICALE

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. There is limited research into triticale's ability to tolerate heat stress, but it is likely to have similar responses as wheat and rye.
- The crop is highly tolerant to soil with high concentrations of aluminium and to saline soils.

Due to the effects of climate change, both heat stress and frost are likely to play an increasing role in farming in the future, and growers will need to take steps to manage the risks and decrease their impact on crops. [1] A survey conducted in 2015 revealed that grain growers and advisers rate grain filling heat as a greater risk than frost. [2]

Despite these results, triticale, being a derivative of rye, is still assumed to be relatively resistant to abiotic stress. 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 which involve salinity, low pH, defined mineral toxicities and deficiencies and waterlogging. [3]

MORE INFORMATION

The abiotic stress response and adaptation of triticale

Agronomist's guide to information for managing weather and climate

14.1 Frost issues for triticale

Key points:

- Frost events can have major and sudden impacts on cereal yields.
- Frost doesn't cause extensive damage every year, but some areas are more prone to it and can feel frequent damage.
- There has been an increase in frost frequency in many areas in the last 20 years.
- Minor agronomic tweaks might be necessary in some frost prone areas.
- 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. [4]
- Triticale has been estimated as 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. [5]
- It is estimated that frost costs the Australian grains industry about $360 million annually in direct and indirect yield losses. [6]

1 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

2 D Grey, J Nuttal, K Barlow (2015) South east Australian grain growers and advisors rate grain filling heat as a greater risk than frost. 17th Australian Agronomy Conference, 20–24 September, http://agronomyaustraliaproceedings.org/images/sampledata/2015_Conference/pdf/agronomy2015final00094.pdf

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

4 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

5 GRDC (2009) Managing the risk of frost. Factsheet. GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

6 N Lee (2015) Frost ratings new tool to manage costly issue. GRDC, https://grdc.com.au/Media-Centre/Media-News/National/2015/02/Frost-ratings-new-tool-to-manage-costly-issue

Spring radiation frost is of significant importance in Australia, as it causes large yield and revenue losses to the national economy: it is estimated to cost about $360 million a year in unfulfilled or lost yield potential. [7] 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). [8] 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). [9] In addition to direct yield loss, frost also results in economic losses by 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.

7 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

8 N Lee (2014) Frost publication addresses hot research topic. GRDC, https://grdc.com.au/Media-Centre/Media-News/West/2014/03/Frost-publication-addresses-hot-research-topic

9 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

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

Source: Tshewang 2011

Counterintuitively, crops grown in warmer climates, such as Australia's northern cropping region, are at greater risk of frost injury because they develop faster, which increases the risk of heading and grain filling coinciding with the frost season: while July and August are theoretically the optimum flowering months for Northern Region crops, they are also the region's highest frost-risk months. Long-term climate data show that there are typically multiple severe frosts in July and August, so growers need to delay crop sowing to ensure crops flower after this period. However, delaying flowering costs growers considerable yield benefits. Even under the best management, crop losses due to frost are estimated to average about 10% in the Northern Region. That figure is even higher in the northern part of the Northern grain region as potential yield is also reduced due to late sowing. Variety guides and decision-support tools can help growers match the best time for planting different varieties to optimise yields with an acceptable frost risk. There is little useful difference in frost resistance between current cultivars, so choosing the variety with the optimum flowering date for a particular sowing opportunity is more important.

Recommendations for northern farmers are to:

- use several cultivars and planting dates to spread the frost risk;
- determine the correct sowing window for the district for each cultivar;
- consider early sown cultivars with a longer growing season when favourable seasonal conditions are expected; and
- take into account the topography of the farm. Lower areas will be more prone to damage–sow these areas last;
- consider shorter-season cultivars when below-average rain for the season is forecast. [10]

14.1.1 Frost risk in Queensland: a grower's experience

Severe frosts are common on Brian Gibson's property at Dulacca, in Queensland. The property can lose half of its yield to frost, and grain quality can drop from prime hard to feed grade overnight. Over the past decade or more, a trend towards warmer weather from May to June has meant that cereal crops have been induced

10 J Paterson (2014) Frost curbs early sowing in north. In Frost. Ground Cover Supplement. Issue 109, March–April 2014. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS109

to head sooner, exposing them to the risk of frost in August. Mr Gibson said that thermometers placed at head height monitored minimum temperatures, and gave him a good indication of where the frost line was. One of his strategies is to plant above this line on the elevated country, which is usually 2–3°C warmer than lower areas, and to select slower-growing varieties with a longer coleoptile length, as these flower after the frost risk has passed. [11]

14.1.2 Triticale and frost

Triticale has been rated as susceptible to frost damage (Photo 3). One 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 why a greater area is not devoted to triticale on most farms is the poor tolerance to frost at flowering: in one study, growers said that frost susceptibility was one of the main constraints of triticale production and expansion. [12]

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

Sources: left, S Tshewang 2011; 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⟨D, 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.

11 J Paterson (2014) Frost curbs early sowing in north. In Frost. Ground Cover Supplement. Issue 109, March–April 2014. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS109

12 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

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. 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). [13]

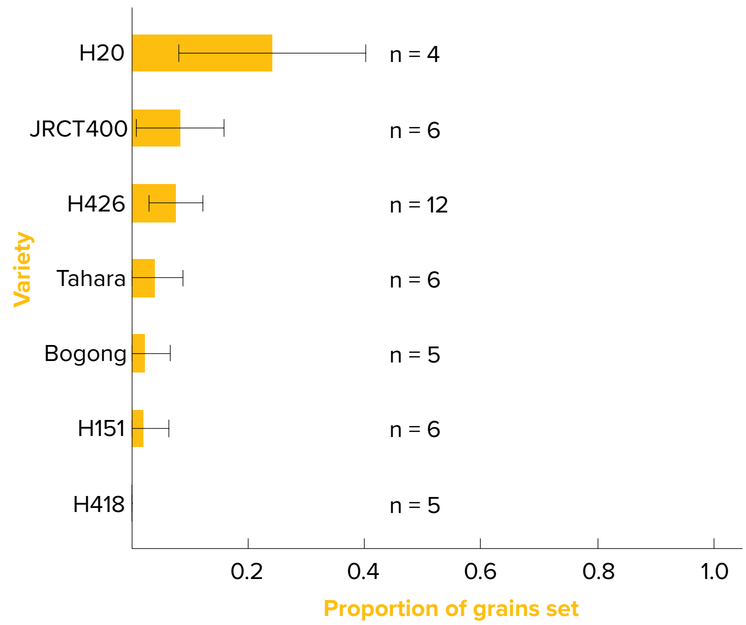


Figure 1: *Proportion of grains that set in different triticale varieties at –4.2°C (2009). Bars are the lower and upper 95% confidence interval. N = the number of heads frosted.*

Source: S Tshewang 2011

13 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—explained.

MORE INFORMATION

Frost and plant physiology: Q&A with Glenn McDonald

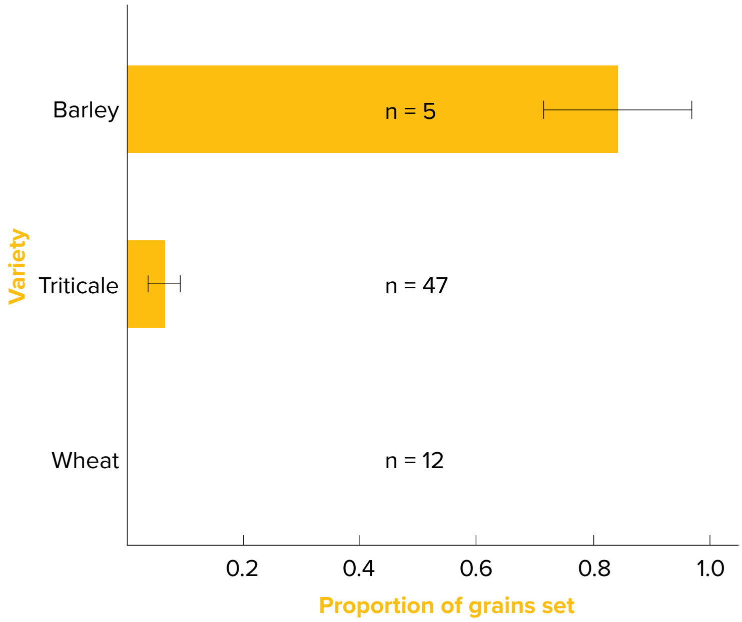


Figure 2: *Proportion of grains that set in different species at –4.2°C (2009). Bars are the lower and upper 95% confidence interval. N = number of heads frosted.*

Source: S Tshewang 2011

14.1.3 Conditions that lead 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). [14] 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.

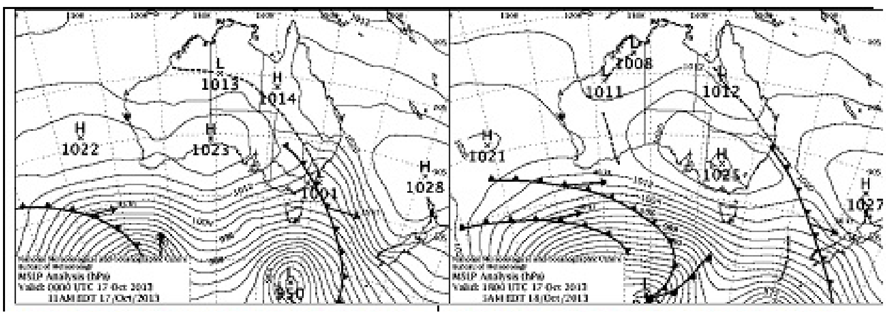


Figure 3: *A cold front passes through, injecting cold air in from the Southern Ocean the day before a frost (left). Overnight, the high-pressure system stabilises over south-east Australia, meaning clear skies and no wind leading to a frost event (right).*

Source: GRDC

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

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). [15] 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. [16]

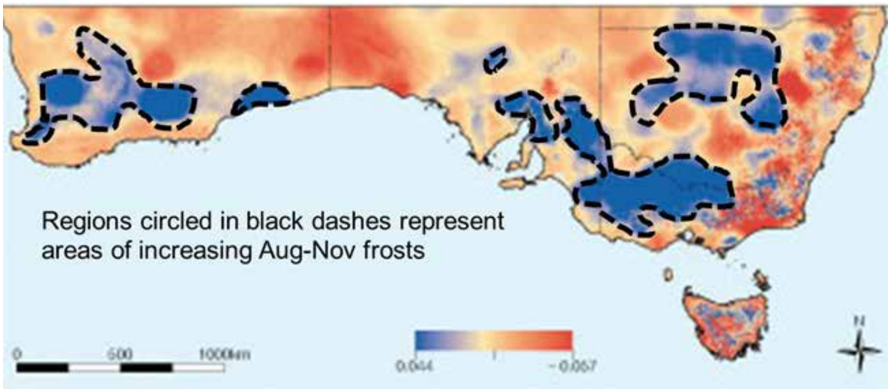


Figure 4: *Region of increasing August–November frost events.*

Source: GRDC

VIDEOS

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

14.1.4 Diagnosing stem and head frost damage in cereals

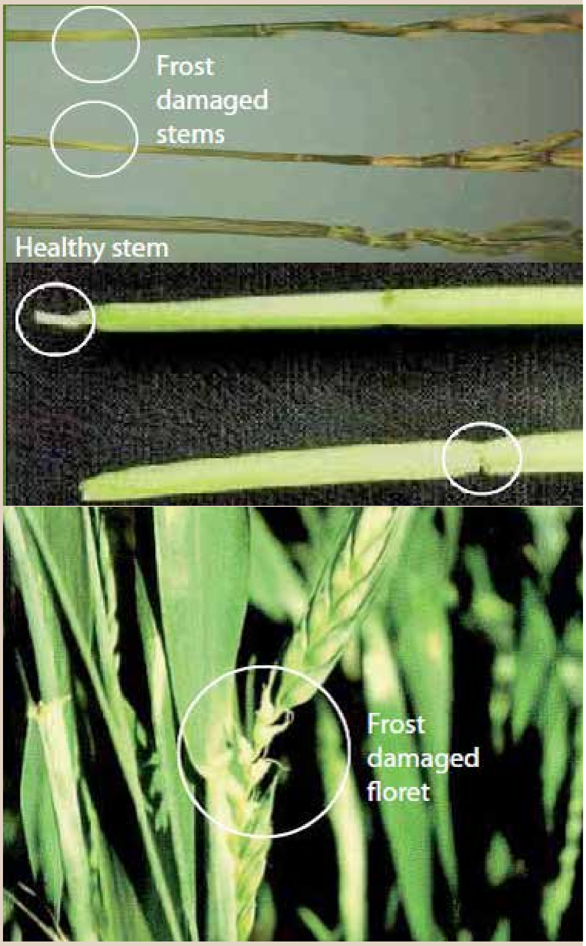
Table 1 shows how to diagnose frost damage to stems and heads. Although the information given is for wheat, it applies equally to triticale. [17]

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 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

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

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). [18]
- 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.
- sample plants in the lowest parts of the paddock first, as this is where the damage will be the worst.

Photo 4: *Frost damage in cereal.*

Photo: Jim Kuerschner

18 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

What to look for in the plant

- Before flowering:
- 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 feels spongy when squeezed and turns dark in colour. In normal flowers the ovary is bright white and feels crisp when squeezed. As the grain develops it turns green.
- Anthers are dull-coloured and are often banana-shaped. Normal anthers are green to yellow before flowering, or 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 like a pair of pliers has crimped the grain (Photo 6). [19]

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

Source: DAFWA

19 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, 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; soil type, texture and colour; crop species and variety; and how the crop is managed.
- 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 5–7 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. [20]

Significant frost damage has occurred several times in triticale crops in recent years in the eastern cropping regions. Because triticale suffers more from frost damage than wheat, it should generally be sown later. Although the risk of frosting, particularly in low-lying paddocks, can be reduced by not planting too early, heat stress during grainfill will, potentially, become more of a factor the longer the sowing date is delayed.

Newer varieties, which have more tolerance to the cold, combined with the ability to cope with drier seasons, give growers a significant improvement in variety choice. In regions where spring frosts are a likely problem, a delay 7–10 days in sowing compared with main-season wheat varieties should reduce exposure to frosts. The avoidance of frost-prone areas (e.g. low lying paddocks and creek areas) will also reduce possible frosting. [21]

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.

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20 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

21 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

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.

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 past 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 top 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.

VIDEOS

WATCH: [Frost Initiative: Do micronutrients reduce frost risk?]

WATCH: MPCN: [Copper and frost relationship investigated]

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 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). [22] 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.

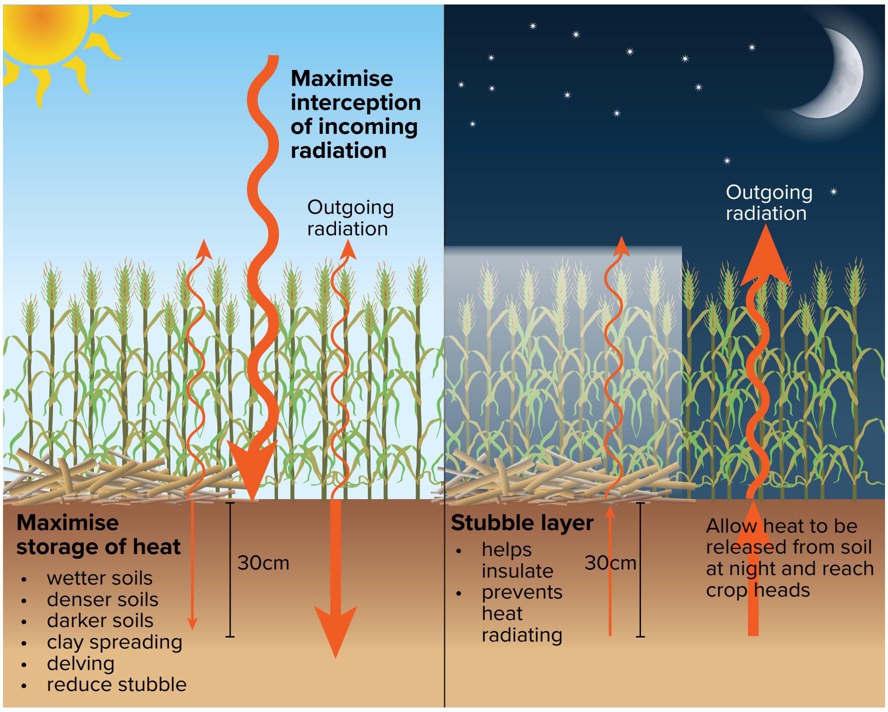

Figure 5: *The soil heat-bank captures heat during the day and radiates that heat into the crop canopy overnight, to warm flowering heads and minimise frost damage.*

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

22 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

detrimental effect on yield under frost. However, reducing stubble can also be detrimental through increasing evaporation losses, decreased mineralisation etc.

- 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.

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. 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. [23]Reducing the amount of stubble is likely to reduce the risk of frost damage in triticale. .

23 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

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

Position Stubble	Additional*	Low landscape	Removed	High landscape		LSD 0.05
		Standing		Standing	Removed	
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 (%) <2 mm	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.

MORE INFORMATION

Yield Prophet®

Flower Power

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 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 grazing cereal first; then a long-season cereal or a day-length-sensitive cereal; then an early-maturing cereal last. A whole farm planting 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.

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.

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.

MORE INFORMATION

Managing the costs of frosts

Groundcover supplement: Frost.

Step 6: Fine-tune cultivar selection

As few cereal varieties are tolerant of frost, consider using varieties that have lower susceptibility to frost during flowering as a means of managing frost risk to 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 on 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 currently managed.

14.1.6 New insight into frost events and management

Key points:

- Growers need to consider carefully whether earlier sowing is justified in seasons where warmer temperatures are predicted.
- Warmer temperatures may reduce the frequency of frosts, but also increase the rate of crop development so that crops arrive at the susceptible, post-heading stages earlier.
- Situation analysis of the national impact of frost indicates substantial losses in all regions, averaging approximately 10% using current best practice.
- There can be even greater losses in yield when crops are sown late.
- Continued research into reducing frost risk remains a high priority, despite temperatures increasing overall.
- Variety guides and decision-support software are useful for matching cultivars to sowing opportunities.
- Current variety ratings based on floret damage may not provide a useful guide to frost damage of heads and stems.
- Crops become most susceptible to frost once awns emerge.
- If crop temperature at canopy height drops below –3.5C after awn emergence, crops should be assessed for damage.
- Consider multiple sowing dates and or crops of different phenology to spread risk.

The first nationwide assessment of the comparative impact of frost in different Australian cropping regions provides important insights into how to manage frost risk in our cropping environments.

Climate data from 1957 to 2013 were used to assess the frequency and severity of frost for each region of the Australian cropping belt. [24] Night-time minimum temperatures have been observed to increase over much of the Australian cropping region during that period. However, when researchers analysed the climate data they learned that frost risk and frost impact did not reduce over the whole cropping area during that time. The effect has been that warmer temperatures have accelerated plant development, causing crops to reach the frost-susceptible, heading stages more rapidly. So, counterintuitively, planting earlier or even at the conventional date during warmer seasons may sometimes increase frost risk.

The researchers used historical climate data from a grid database and for 60 locations that represent each of the four major cropping regions of Australia to determine the frequency and severity of frost (Figure 6 top panel). They used the crop-simulation model Agricultural Production Systems sIMulator program (APSIM) to estimate yields (Figure 6 bottom panel). Expert knowledge combined with data from frost trials was used to estimate crop losses. The computer simulation allowed them to predict crop losses for all Australian cropping regions, using damage information from a limited number of frost trial sites. It also allowed them to simulate potential yields using sowing dates optimised for yield in the hypothetical absence of frost risk, something that had not been achieved in experiments before.

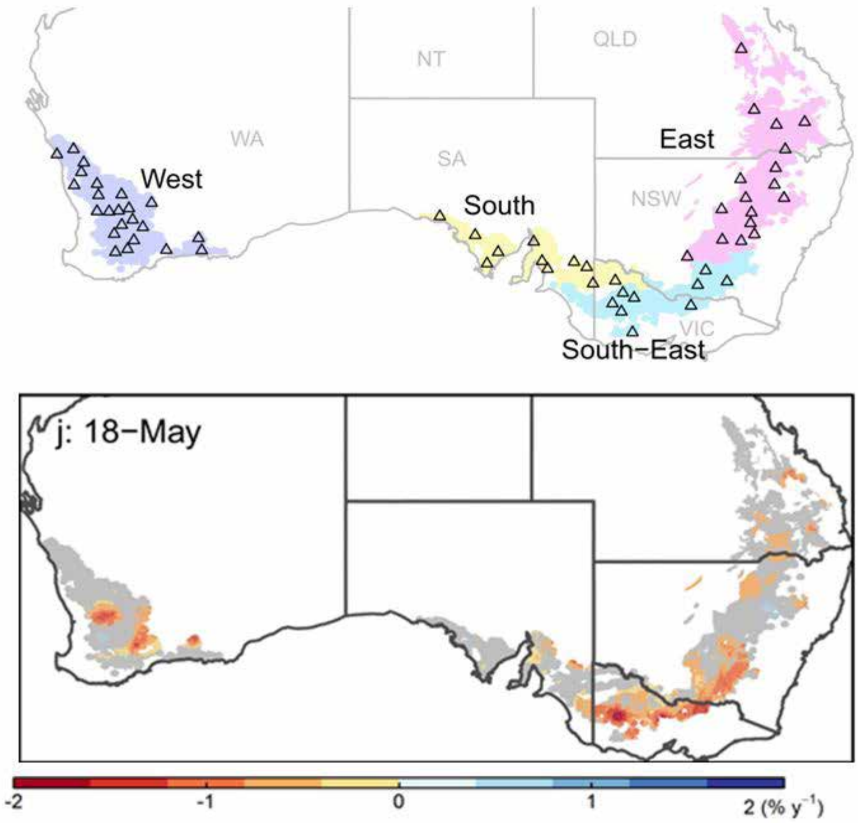

Figure 6: *Maps showing sites and regions for which climate data were analysed for the frequency and severity of frosts (top panel) and annual percentage change in yield loss due to frost from 1957 to 2013 (bottom panel). In the lower map, negative values (yellow to red) represent areas where yield loss became worse over recent decades. Estimations in the lower panel were for the cultivar Janz, sown 18 May and are based on a ~5 km × 5 km grid of climatic data. (Gridded climate data may not reflect local climatic conditions of particular paddocks within each grid, as frost events are highly spatially variable.)*

Source: GRDC

24 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

The study revealed that estimated yield losses due to direct frost damage averaged close to 10% nationally for all crop maturity types, following current sowing guidelines (Figure 7). To estimate the loss of yield potential due to late sowing, which is necessary in many areas to manage frost risk, a theoretical optimal sowing date (as early as the 1 May) was used. When lost yield potential from delayed sowing (indirect cost of frost) was added to direct damage, estimated yield losses approximately doubled to 20% nationally (see Figure 7 'direct + indirect' impact). In the eastern grains region (Queensland to central NSW), losses were even greater, with estimated yield losses due to direct damage and delayed sowing (indirect losses) of 34%, 38% and 23% for early-, mid- and late-flowering cultivars, respectively (Figure 7).

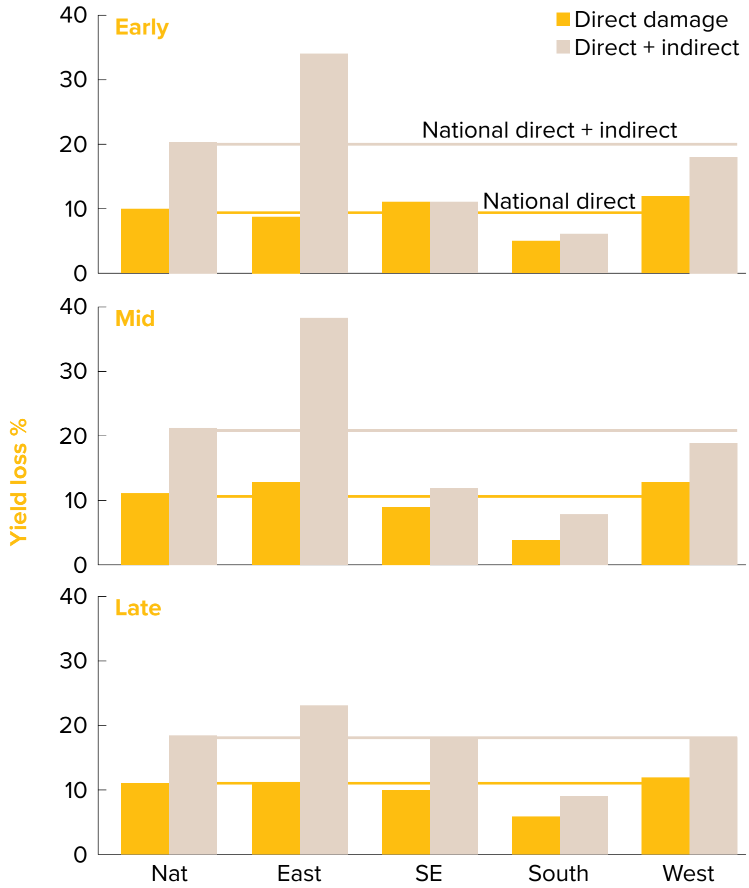

Figure 7: *Estimated wheat yield losses (%) due to frost damage for crops sown at the current best sowing date (direct frost damage), and crop losses due to both direct damage and delayed sowing currently necessitated to manage frost risks (direct + indirect) for early-, mid- and late-flowering crops.*

Source: GRDC

In some areas in each region, simulated frost impact has significantly increased between 1957 and 2013 (Figure 6, bottom panel, yellow, orange and tan areas). The estimated date of last frost has come later in some areas, but earlier in others. However, even in areas where it has come significantly earlier, higher temperatures have also increased the rate of development to frost-susceptible heading stages. The modelling suggests that crop heading dates have been brought forward more rapidly than the date of last frost, leading to an overall modelled increase in frost impact in many areas.

Over time, these trends may have implications for growers making planting decisions. They indicate that sowing early to increase yield potential may not always be the best course of action in warmer seasons, even when a lower frequency of frost events is anticipated. By increasing the rate of crop development, warmer temperatures cause the crop to develop more rapidly to the frost-susceptible, heading stages, which may actually increase frost risk.

These results indicate that continued research to reduce frost risk remains a high priority, despite increasing temperatures due to climate change. Counterintuitively, percentage yield losses are greatest in the Northern Region with the greatest yield losses actually due to delayed sowing rather than frost per se.

14.1.7 Guidelines to reduce frost risk and assess 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 period 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 8). Temperatures in a crop can vary widely, due to differences in topography, micro-environments and recording methods.

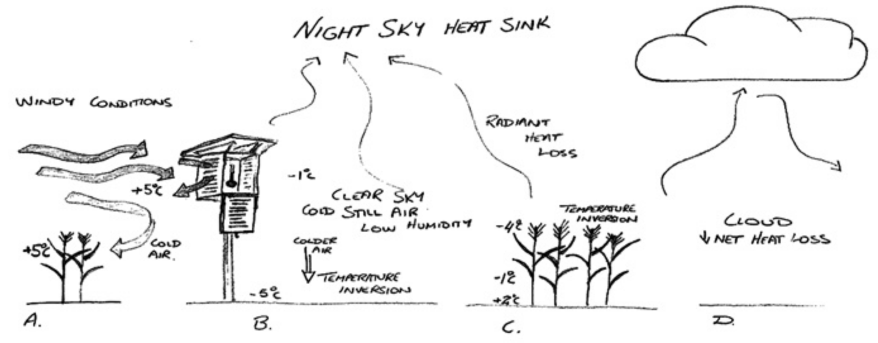

Figure 8: *If clear skies and still, cold, dry air coincide, heat can be lost rapidly to the night sky, resulting in a radiant frost. Minimum air temperatures measured at head height can be several degrees colder than reported 'screen' temperatures. Some indicative temperatures are illustrated for (A) windy conditions, (B) clear, still conditions in an open area, (C) clear, still conditions in a crop, 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. [25]

Photo 7: *Canopy temperature 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

14.1.8 What to do with a frosted crop

Once a frost has occurred, especially at or after flowering, the first step is to inspect the affected crop and collect a random sample of heads to estimate the yield loss incurred.

25 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

In the event of severe frost (Photo 8), [26] monitoring needs to occur for up to two weeks after the event to ensure all the damage is detected. After the level of frost damage is estimated, the next step is to consider options for the crop (Table 2). [27]

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

Source: DAFWA

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

A later frost is more concerning, 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 grain fill. 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, weed seedbank

26 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

27 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

and disease loads for the coming season. This may allow more rotational options in the following season to recover financially 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. Brown manuring can also be considered in this toolbox. It involves spraying out the crop with a non-selective herbicide such as Glyphosate, hence negating the detrimental effects of ploughing country. The economics need to be considered carefully. [28]

Depending on the degree of damage, the grain may still make valuable stockfeed (Table 3). Severely frosted grain can have metabolisable energy (ME) of approximately 1 MJ/kg lower than unfrosted grain. Provided allowance is made for this, the grain is useful in a feed ration. [29]

Table 3: *Management options for frost-damaged crops, 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 (which reduces erosion risk) Allows better stubble handling	Raking costs $5/ha Time taken
Graze	Feed value	Inadequate 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 cost of herbicide Some grain still in crop

28 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

29 Jessop RS, Fittler M. (2009). Triticale production manual—an aid to improved triticale production and utilisation. http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

Options	Advantages	Disadvantages
Plough	Recycles nutrients and retains organic matter Stops weed seedset Green manure effect	Requires offset disc to cut straw Soil moisture needed for breakdown and incorporation of stubble
Swathe	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 swathe 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 Organic matter loss

Source: GRDC

Useful tools

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

14.1.9 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 these 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. [30]

14.2 Drought and heat stress

Key points:

- Heat and drought stress is a key yield-limiting factor in crop production. Heat stress has been shown to adversely affect yield as early as growth stage 45.
- Post-flowering heat stress is most common in the northern region.
- Delayed sowing increases the chance of the crop being exposed to heat stress, particularly at the vulnerable pre-flowering growth stages.

Drought is one of the major environmental factors that reduces grain production in the rain-fed and semi-arid regions of Australia (Photo 9). The direct effects of heat stress are estimated to cost grain growers about $1.1 billion nation-wide. Due to the

30 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

MORE INFORMATION

GRDC factsheet, Managing frost risk

VIDEOS

WATCH: GCTV3: Frost R&D

WATCH: GCTV16: National Frost Initiative

effects of climate change, both heat stress and frost are likely to increase in the future, and will require growers to take steps to manage the risks. [31]

Photo 9: *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 under drought conditions as, in descending order: barley, triticale, durum wheat, bread wheat and oats. [32] Triticale is well adapted to conditions where water is limited.

Overseas data indicate that under 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.

These data are backed up by a study in a Mediterranean climate, in which researchers found that yields of wheat dropped significantly (by 25%, 54% and 87%) under drought stress, while those for triticale showed only a slight, and statistically insignificant, amount (by 8%) in comparison to the 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. [33]

In another study, in 1988–89 in Mexico, 24 early triticale lines were tested in under drought stress (mean yield of 1,720 kg/ha–1) and normal conditions (mean yield of 7,180 kg/ha–1) and compared with the best standard wheat cultivar available. Under drought conditions, triticale had a yield advantage over wheat. [34]

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 used commonly in New South Wales, such as Everest and Kosciusko. The better translocation capacity may be related to improved drought tolerance. More detailed field assessment of water relations

31 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

32 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.

33 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.

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

in triticale compared with wheat is needed, especially with the likelihood of drier conditions associated the current projections on climate change. [35]

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. Even without temperature increases as a result of climate change, elevated temperatures are a normal, largely unavoidable occurrence during the reproductive phase of Australian crops in September and October. [36]

In some cereals, heat stress can be identified by the withering and splitting of leaf tips (Photo 10). The tips can also turn brown to grey in colour. In this situation, some or all grains fail to develop in a panicle. [37]

Photo 10: *Withered and split tips in heat stressed cereal.*

Source: DAFWA

Heat stress is a key yield-limiting factor in crop production. The results of recent trials 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 will have an increased likelihood of being exposed to the heat stress at more sensitive growth stages, particularly pre-flowering, and will have greater consequences to the potential grain yield. [38]

35 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

36 P Telfer, J Edwards, H Kuchel, J Reinheimer, D Bennett (2013) Heat stress tolerance of wheat. GRDC Update Paper. 7 February 2013. GRDC, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Heat-stress-tolerance-of-wheat

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

38 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

14.2.1 Managing heat and drought stress

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.

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. [39]

MORE INFORMATION

Make sure to consider the impacts of herbicide residues following drought.

Winter cropping following drought

Soil management following drought

DPI NSW Drought Hub

Drought planning

Managing drought

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. [40]

14.3 Waterlogging and flooding issues for triticale

Key points:

- Waterlogging occurs when roots cannot respire due to excess water in the soil profile.

39 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

40 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

- 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. [41]
- Water does not have to appear on the surface for waterlogging to be a problem.
- Improving drainage from the inundated paddock can decrease the period at which the 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 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 11). [42] 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. [43]

Photo 11: *The 2016 July wet had a big impact on producers in Murrumburrah.*

Photo: Harden Murrumburrah Express

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. [44]

Among the cereals, triticale has been reported to be more tolerant of waterlogged conditions than wheat. [45] Some farmers have noted that triticale also outperforms

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. See also KV Cooper, RS Jessop, NL Darvey. In 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

42 Harden Murrumburrah Express (2016) Farmers feel the wet with crops under water. 19 August. Harden Murrumburrah Express, http://www.hardenexpress.com.au/story/4106306/crops-still-water-logged/

43 Soilquality.org. Waterlogging. Soilquality.org., http://soilquality.org.au/factsheets/waterlogging

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

45 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.

barley in areas prone to waterlogging. [46] At one farm, the variety Rufus was 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. [47]

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) to waterlogging. They put plants that were 23 to 36 days old in a stagnant solution and in waterlogged soil. The stagnant nutrient solutions decreased shoot fresh weight of Gamenya by 21% compared with aerated plants, while shoot fresh weight of Muir was unaffected. Reductions in nodal root fresh weight under stagnant conditions were also less for Muir than Gamenya. [48]

Australian researchers have found that seed size is related to waterlogging tolerance. On average, larger seeds resulted in greater plant growth for triticale cultivars, and larger seeds lead to increased plant biomass and adventitious nodal root mass under waterlogged conditions. [49]

14.3.1 Where waterlogging occurs

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 sand over clay.
- With deeper-sown crops.
- In crops with low levels of nitrogen.
- In very warm conditions when oxygen is more rapidly depleted in the soil. [50]

Waterlogging greatly increases crop damage from salinity. Germination and early growth can be much worse on 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 12). If it does, the soil is waterlogged. Some farmers put slotted PVC pipe into augured holes. They can then monitor the water levels in their paddocks. Digging holes for fence posts often reveals waterlogging.

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. [51]

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

51 Soilquality.org. Waterlogging. Soilquality.org, http://soilquality.org.au/factsheets/waterlogging

Photo 12: *In areas prone to waterlogging, water will fill a hole dug in the soil.*

Source: Soilquality.org

14.3.2 Symptoms and causes

Waterlogging occurs when the soil profile or the root zone of a plant becomes so saturated with water that there is no longer enough oxygen in the soil (which becomes anaerobic). In rain-fed situations, this happens when more rain falls than the soil can absorb or the atmosphere can evaporate. The lack of oxygen causes plants' 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 13). [52]
- Wet soil and/or water-loving weeds are present.
- Early plant senescence.

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

Photo 13: *Pale plants in waterlogged areas.*

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 14).
- Plants that may be more sensitive to spring drought (Photo 14) because the seminal roots, which are important for accessing deep subsoil moisture, have been damaged.

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

Photo 14: *Waterlogged roots, particularly seminal roots and tips, become brown and then die.*

Source: DAFWA

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.
- 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 on the surface that the soil is waterlogged. Also observe plant symptoms and paddock clues. [53]

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, that have been exposed to 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 rainfall and sunny weather.

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

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. The clay layer dries into a crust, which prevents oxygen penetration 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. Apply suitable disease control measures as soon as possible and monitor for pests. [54]

14.3.3 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. [55]

Draining

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. 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: choice of crop, seeding, 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
- installing subsurface drainage

VIDEOS

WATCH: GCTV3: Big Wet—Managing strategies after flooding

WATCH: Over the Fence: Raised beds boost yields at Winchelsea

MORE INFORMATION

Cropping on raised beds in southern NSW

54 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

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

If the drainage can't be improved, consider using the area for some other purpose (e.g. as a silt trap). [56]

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, especially triticale, 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/m^2, 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 soil has a good nitrogen status before waterlogging occurs. Applying nitrogen at the end of a waterlogging 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), then the benefits of nitrogen application after waterlogging are questionable. But this recommendation requires verification in the field at a range of basal nitrogen applications using a selection of varieties.

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. The waterlogged parts of a paddock are often weedy, and require special attention if the yield potential is to be achieved. [57]

MORE INFORMATION

Should waterlogged crop be top-dresses with N fertiliser?

VIDEOS

WATCH: The 2012 N story and planning for 2013

56 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

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