SOUTHERN
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GRDC GROWNOTES™

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

DURUM

SECTION 14

ENVIRONMENTAL ISSUES

FROST ISSUES FOR DURUM | WATERLOGGING/FLOODING ISSUES FOR DURUM | OTHER CLIMATIC AND ABIOTIC ISSUES

Environmental issues

Key messages

- Durum is thought to be more susceptible to frost than bread wheat. [1]
- There has been an increase in frost frequency in many areas in the last 20 years.
- Waterlogging is one of the limiting factors influencing durum wheat production. [2]
- Heat stress can reduce durum yield. [3]
- High saline and sodic soils can negatively influence durum growth. [4]
- Both very hot and very cold temperatures around flowering can be particularly damaging to durum.

14.1 Frost issues for durum

Key points

- Frost is estimated to cost south-east Australia at least $100 million a year in unfulfilled or lost yield potential. [5]
- The relative resistance to freezing of cereals is (from most resistant): Rye > Bread wheat > Triticale > Barley > Oats and Durum wheat. [6]
- Cereal crops are most susceptible to frost injury during and after flowering, and may also be susceptible at booting. Losses in grain yield and quality from frost primarily occurs between stem elongation and late grainfilling. [7]
- Frost events can have major and sudden impacts on cereal yields (Photo 1).
- Frost is a relatively rare occurrence but some areas are more prone to it.
- 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 all the damage. [8]

1 Tony Craddock. (2016). Personal Communication.

2 Pampana, S., Masoni, A., & Arduini, I. (2016). Grain yield of durum wheat as affected by waterlogging at tillering. *Cereal Research Communications*, *44*(4), 706-716.

3 Modhej, A., Naderi, A., Emam, Y., Aynehband, A., & Normohamadi, G. (2012). Effects of post-anthesis heat stress and nitrogen levels on grain yield in wheat (T. durum and T. aestivum) genotypes. *International Journal of Plant Production*, *2*(3), 257-268.

4 Rajper, I., Wright, D., & Sial, N. B. (2003). Effect of soil salinity and sodicity on the growth and yield of durum wheat (Triticum turgidum L.) genotypes. *Pakistan Journal of Agriculture: Agricultural Engineering Veterinary Sciences (Pakistan).*

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

6 FAO. Chapter 4 – Frost damage: Physiological and critical temperatures. http://www.fao.org/docrep/008/y7223e/y7223e0a.htm

7 M Rebbeck, G Knell (2007) Managing frost risk: a guide for southern Australian grains. Grains Research and Development Corporation and South Australian Research and Development Institute, June 2007, https://grdc.com.au/Resources/Bookshop/2007/06/Managing-Frost-Risk-a-guide-for-southern-Australian-grains

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

Photo 1: *Frost damaged wheat.*

Source: Rachel Bowman

Crop losses due to frost are estimated to average more than $33 million a year in South Australia (SA) and Victoria. Spring radiant frost damage to cereals post head emergence causes significant yield losses in Australia. Frost in cereals can be more devastating than drought as it has a sudden impact. Typically during the winter-spring growing season, day time temperatures are ideal for growth but night time temperatures can fall to potentially damaging levels. Wheat can be affected when the canopy air temperature reaches -1°C at flowering, with damage increasing as the temperature falls further. On nights when still, cold air, clear skies and low humidity combine, temperatures drop rapidly, resulting in radiant frost. Freezing of crops is a physical process moderated by factors such as plant development stage and temperature. The crop canopy temperatures experienced and recorded can vary widely due to differences in topography, micro-environment and recording method. [9]

Table 1 outlines the atmospheric conditions on the afternoon and evening prior to a frost event.

Table 1: *Atmospheric conditions leading up to a frost event.*

Measurement	3 pm–6 pm	6 pm–9 pm	Frost
Temperature at screen height	16 → 18°C	12 → 6°C	<2°C
Cloud cover	Very low	Low	Nil
Wind speed	<3 m/s	<1 m/s	0 m/s
Barometric pressure	1008–1009	1008–1009	1004–1008

Source: Primary Industries and Regions South Australia

MORE INFORMATION

Frost and plant physiology: Q&A with Glenn Macdonald

VIDEOS

WATCH: Plant frost mechanisms—explained

9 T Frederiks, C Birchall, J Christopher, A Borrell (2011) Frost resistance in cereals after head-emergence. GRDC update papers. Grains Research and Development Corporation, April 2011,

14.1.1 Varietal susceptibility

Durum is more susceptible to frost damage than bread wheat (Figure 1).

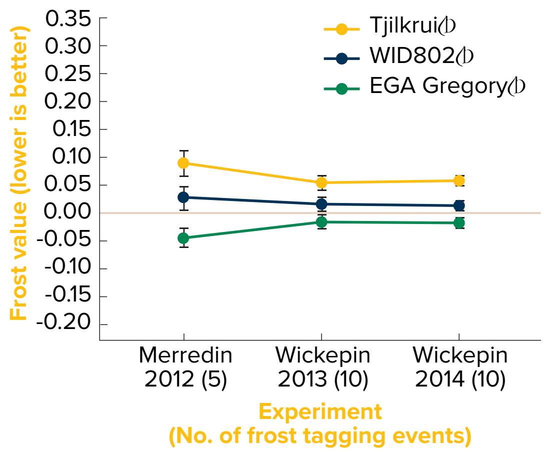


Figure 1: *Frost Value performances of two durum lines and one bread wheat line as part of experiments in the National Frost Initiative. Note that the dashed line presents an average variety for that trial and that lower values are better for frost tolerance.*

Source: NVT online, National Frost Initiative.

Recent 'time of sowing' trials in New South Wales saw a decrease in durum yield due to a -3.3°C frost event, which induced sterility. This event coincided with full head emergence and/or early anthesis for DBA Lillaroi (GS59 – GS61). Both Caparoi⊕ (~GS53 - GS55) and DBA Aurora⊕ (~GS55 - GS57) which were less advanced during this frost event also experienced yield losses of ~ 18% (1.00t/ha) and ~26% (1.37t/ha) respectively when sown on April 23. Results from this experiment indicate that DBA Lillaroi appears able to maintain grain stability (plumpness-reduced screenings) over a wide sowing window, with improved grain size relative to Caparoi⊕. DBA Lillaroi, however, was more exposed to frost risk on the earlier sowing time, reinforcing the need to match maturity type to sowing time. Sowing date and variety selection is considered a balancing act between frost risk and early onset moisture/evaporative stress. [10]

High frost risk areas in southern Australia include the Eyre Peninsula, Murray-Mallee, the Mid-North of SA and the Wimmera-Mallee region of Victoria. Crop production losses can be close to 100% in the worst affected areas. Despite an increase in annual maximum temperatures since 1960, there has not been a corresponding decrease in the number of frost events throughout southern Australia. This is probably due to the atmospheric conditions leading up to a frost having a significant impact on minimum temperatures, particularly the lack of cloud cover and no wind. In below average rainfall seasons there is often an increase in the incidence and severity of frost, due to reduced cloud cover and lower soil moisture reducing the humidity of the air mass in the crop canopy. [11]

Clear, calm and dry nights following cold days are the precursor conditions for 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 but settled, cloudless weather (Figure 2). When the loss of heat from the earth during the night decreases the temperature at ground level to zero, a frost

10 Graham R, McMullen G, Simpfendorfer S, Morphett S and Graham N. (2016). GRDC Update Papers: Durum agronomy a northern perspective. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Durum-agronomy-a-northern-perspective

11 PIRSA (2003). Impact of dry sow, frost, crop type and variety. http://pir.sa.gov.au/__data/assets/word_doc/0005/241583/Impact_of_dry_sow,_frost,_crop_type_and_variety.doc

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 takes to get to zero, the length of time its stays below zero and the how far below zero it gets.

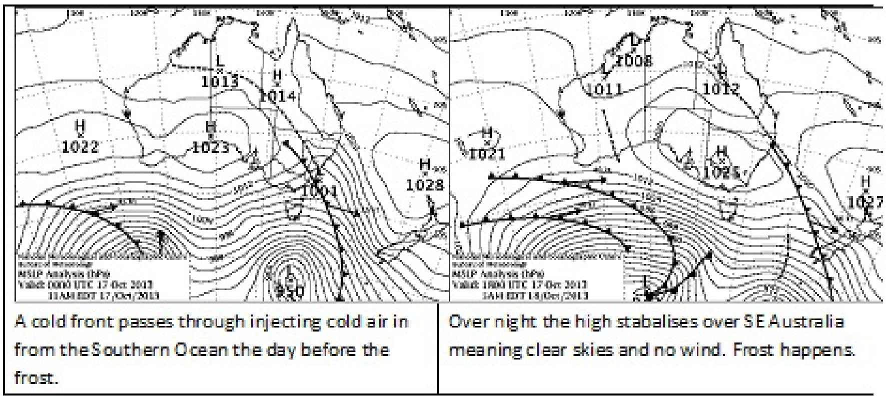


Figure 2: *A cold front passes through injecting cold air from the Southern Ocean the day before frost (left). Overnight the high pressure system stabilises over SE Australia meaning clear skies and no wind leading to a frost event (right).*

Source: GRDC

Though temperatures (particularly those in winter and spring) are getting warmer, frost is still a major issue. CSIRO researchers have found that there are areas of Australia where the number of frost events are increasing (greatest in August) with Central West New South Wales, Eyre Peninsula, Esperance and Northern Victoria (Mallee) the only major crop growing areas to be less affected by frost in the period 1961–2010 (Figure 3). This increase is thought to be caused by the latitude of the Sub Tropical Ridge of high pressure drifting south (causing more stable pressure systems) and more El Niño conditions during this period. [12]

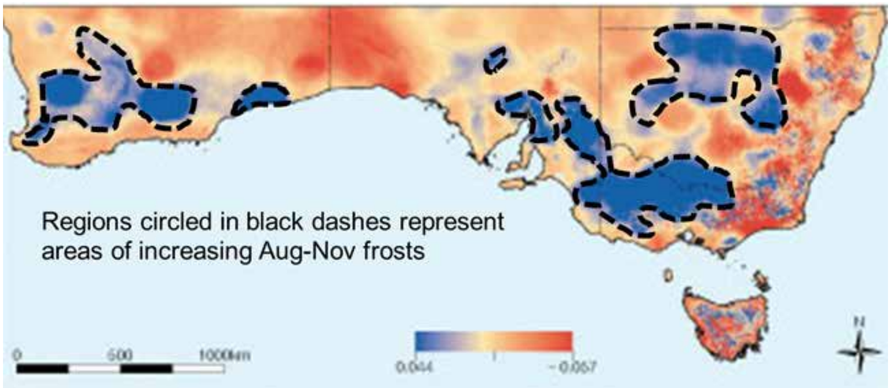


Figure 3: *Region of increasing August-November frost events.*

Source: Steven Crimp in GRDC

VIDEOS

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

14.1.2 New insight in frost events and management

Take home messages

- Growers need to consider carefully whether earlier sowing is justified in seasons where warmer temperatures are predicted.
- Warmer temperatures may reduce the frequency of frost events but also increase the rate of crop development, bringing crops to the susceptible, post-heading stages earlier.

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

- Situation analysis of national frost impact indicates substantial losses in all regions averaging approximately 10% using current best practice.
- There can be even greater losses in yield potential due to late sowing.
- These results indicate that continued research into reducing frost risk remains a high priority despite increasing temperatures.
- 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 head and stem frost damage.
- 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 Australian cropping environments.

Climate data from 1957–2013 has been used to assess the frequency and severity of frost for each region of the Australian cropping belt. Night time minimum temperatures have been observed to increase over much of the Australian cropping region during that period. However, analysis showed that frost risk and frost impact did not reduce over the whole cropping area during that time. Warmer temperatures accelerate plant development causing crops to develop to the frost-susceptible, heading stages more rapidly. So, counter intuitively, planting earlier or even at the conventional date during warmer seasons may sometimes increase frost risk.

Historic climate data from a grid database and for 60 locations representing each of the four major cropping regions of Australia was used to determine the frequency and severity of frost (Figure 4, top). Crop simulation modelling using the Agricultural Production Systems slMulator program (APSIM) was used to estimate crop yields. Expert knowledge combined with data from frost trials was used to estimate crop losses. Computer simulation allowed prediction of crop losses for all Australian cropping regions using damage information from a limited number of frost trial sites. It also allowed simulation of potential yields using sowing dates optimised for yield in the hypothetical absence of frost risk, something that has not been achieved experimentally.

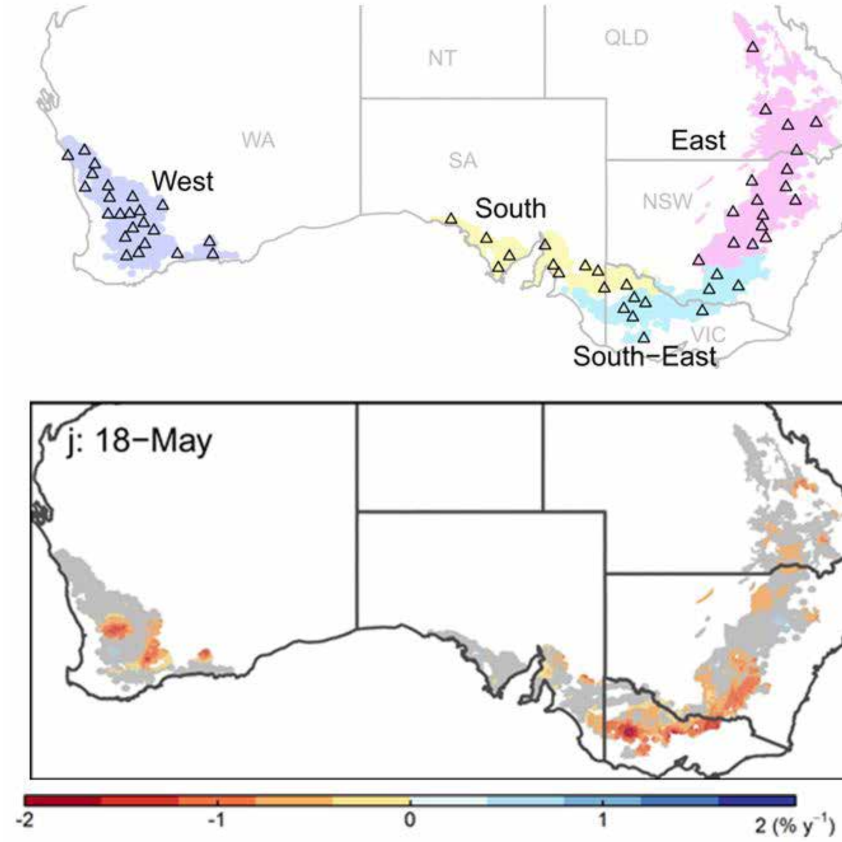


Figure 4: *Maps showing sites and regions for which climate data were analysed for the frequency and severity of frosts (top panel) and annual % change in yield loss due to frost from 1957 to 2013; negative values (yellow to red) represent areas where yield loss became worse over recent decades (bottom panel). Estimations in the lower panel were for the cultivar Janz sown 18 May and are based on a ~ 5 x 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

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 5). 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 1 May) was used. When lost yield potential from delayed sowing (indirect cost of frost) is added to direct damage, estimated yield losses approximately double from 10% to 20% nationally ("direct + indirect" impact in Figure 5). 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 5).

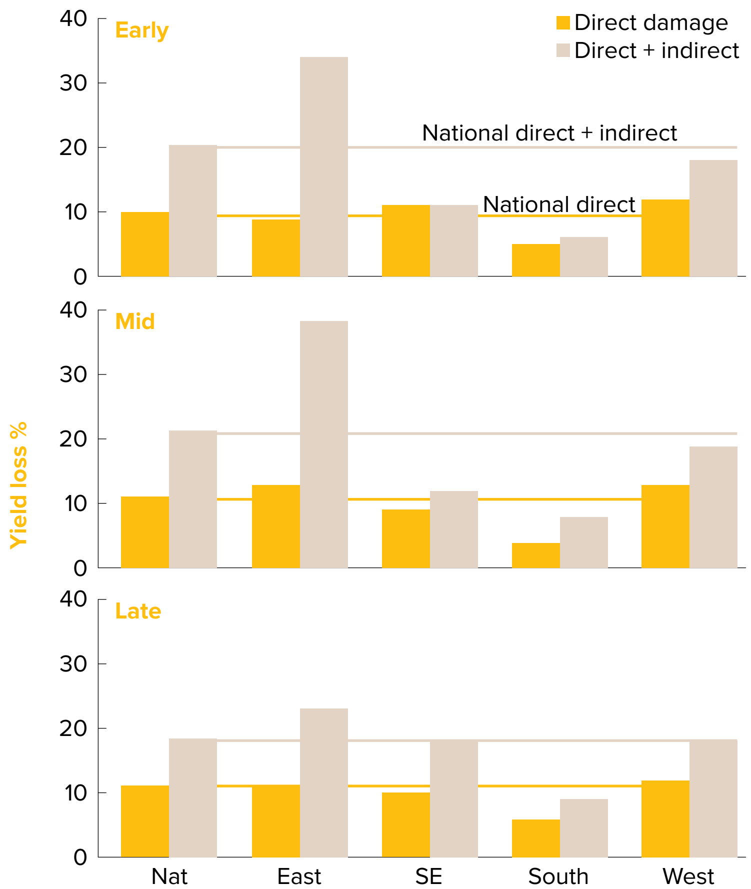


Figure 5: *Estimated wheat yield losses (%) due to frost damage for crops sown at the current best sowing date ("direct" frost damage); and crop losses due to both direct damage and delayed sowing currently necessitated to manage frost risks (direct + indirect) for early, mid and late flowering crops.*

Source: GRDC

In some areas in each region, simulated frost impact has significantly increased between 1957 and 2013 (yellow, orange and tan areas, Figure 4, bottom panel). Estimated date of last frost has come later in some areas but earlier in others. However, even in areas where the date of the last frost has come significantly earlier, increased 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.

These trends over time 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.

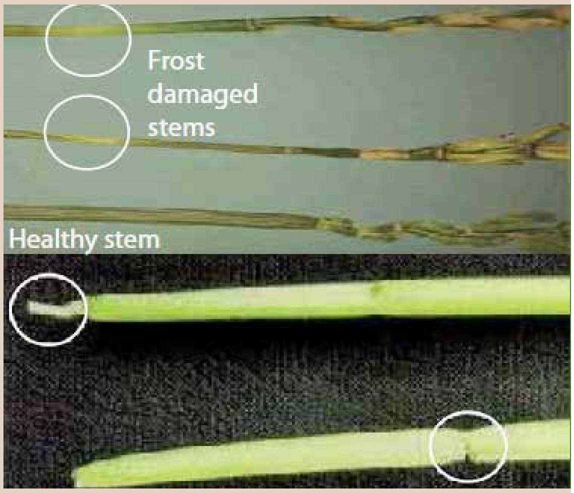
These results indicate that continued research to reduce frost risk remains a high priority despite increasing temperatures due to climate change. Counter intuitively, percentage yield losses are greatest in the Northern Grain region, with the greatest yield losses actually due to delayed sowing rather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

Results from this Frost Situation Analysis will provide valuable insights allowing GRDC to better direct research resources. They also provide valuable insights for managing frost risk now.

14.1.3 Diagnosing stem and head frost damage in cereals

Table 2: *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.	

<table>
<tr><th>Crop growth stage</th><th>Inspection Details</th><th>Frost symptoms in wheat</th><th>Example</th></tr>
<tr><td>Elongation (before and after head emergence)</td><td>Pull back leaf sheath or split stem to inspect damage.</td><td>The stem has a pale green to white ring that usually appears sunken, rough to touch and soft to squeeze. The 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 had emerged at the time of the frost then it is likely that the flowering parts or developing grain has also sustained damage. If the head is in the boot then ongoing monitoring is required to assess the level of damage.</td><td>


</td></tr>
<tr><td>Flowering and post-flowering</td><td>Peel back the lemma (husk), inspect the condition of the florets (floral organs) in the head.</td><td>Flowering is the most vulnerable stage, because exposed florets cannot tolerate low temperatures and are sterilised. Grain will not form in frosted florets, but some surviving florets may not be affected. Pollen sacs (anthers) are normally bright yellow but become dry, banana-shaped and turn pale yellow or white.</td><td></td></tr>
</table>

Source: GRDC

What to look for

Paddock

- Symptoms may not be obvious until five to seven days after the frost.
- Heads on affected areas have a dull appearance that becomes paler as frosted tissue dies (Photo 2).
- At crop maturity severely frosted areas remain green longer.
- Severely frosted crops crop have a dirty appearance at harvest due to blackened heads and stems, and discoloured leaves.

Photo 2: *Frost damage in wheat at Black Rock in the South Australian Upper North.*

Photo Jim Kuerschner. Source: GRDC

Plant

Before flowering:

- Freezing of the emerging head by cold air or water is caught next to the flag leaf or travelling down the awns into the boot. Individual florets or the whole head can be bleached and shriveled, stopping grain formation. Surviving florets will form normally.
- Stem frost results a small amount of water that has settled in the boot and frozen around the peduncle. Symptoms include paleness or discolouration and 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.
- Anthers are dull coloured and are often banana shaped. In normal flowers the ovary is bright white and "crisp" when squeezed. As the grain develops it turns green in colour. 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/dough. Healthy grain is light to dark green and plump, and exudes white milk/dough when squeezed (Photo 3).

- 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 4). [13]

Photo 3: *A normal cereal head (left) compared to frost damaged cereal showing discoloured glumes and awns.*

Source: DAFWA

Photo 4: *Frosted hollow grain dries back to the typical shrivelled frosted grain.*

Source: GRDC

14.1.4 Resistance or tolerance to frost

Frost events in spring cause major economic losses to the wheat industry across Australia through direct yield losses, quality downgrading and indirect losses through delayed seeding to reduce to reduce frost risk. To date, management practices available to growers are largely limited to diversifying flowering dates and minimising inputs in particularly frost prone paddocks.

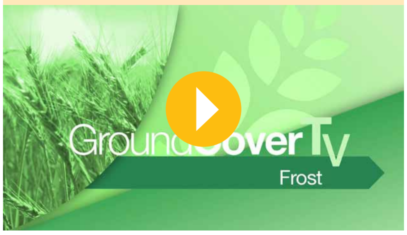
13 DAFWA (2015) Diagnosing stem and head frost damage in cereals. https://www.agric.wa.gov.au/mycrop/diagnosing-stem-and-head-frost-damage-cereals

VIDEOS

WATCH: GCTV15: Frost Ratings.

WATCH: GCTV15: The frost ranking challenge.

WATCH: GCTV12: Frost susceptibility ranked.



Growers can lower frost risk in paddocks that frequently experience frost by growing either more frost-tolerant crops or growing pastures. [14]

Historically, breeding for frost tolerance has been constrained because a robust and reliable method for accurately measuring frost damage has not been available to breeders. Over the past decade researchers have developed and refined field-based screening methods to reliably measure frost tolerance in barley. These methods have been used successfully to identify barley lines with superior frost tolerance. We are now in a position to apply this knowledge and methods to improve frost tolerance in Australian wheat varieties.

The GRDC project UA00114 is investigating frost tolerance in southern Australia. Initially the frost tolerance observed within two particular synthetic derived lines will be confirmed, particularly in the context of conventional seeding dates. This will be followed by genetic analysis within populations specifically developed for investigating frost tolerance. A smaller component of the project will examine specific lines developed from the incorporation of the winter hardiness genes from the Canadian variety 'Norstar' into Australian germplasm with spring growth habit for frost tolerance at flowering. Successful achievement of these aims is expected to result in adoption of the germplasm and associated molecular markers by breeding organisations to support the development of wheat varieties with improved frost tolerance. Frost screening will utlilise the successful approaches employed in barley projects and the previous GRDC wheat project UA00073. Field screening will be based at Loxton in the South Australian Mallee which reliably experiences significant frost events in late winter and spring. Up to nine seeding dates will be used to maximise the probability of test lines flowering when a frost event occurs. [15]

MORE INFORMATION

NVT Frost Rankings

14.1.5 Managing frost risk

Key points

- In some areas the risk of frost has increased due to widening of the frost event window and changes in grower practices.
- 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.
- Frosts generally occur when nights are clear and calm and follow cold days. These conditions occur most often during winter and spring.
- The occurrence of frost and subsequent frost 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.
- 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 event.
- Methods to deal with the financial and personal impact of frost also need to be considered in a farm management plan.
- Careful planning, zoning and choosing the right crops are the best options to reduce frost risk. [16]

To assist with early assessment of frost damage, accurate maximum–minimum field thermometers measuring temperatures at crop head height are useful. Minimum air temperatures measured at crop head height can be several degrees colder than temperatures measured in the Stevenson screen, as reported by the Bureau of Meteorology. For best results, at least two or three field thermometers are required

14 DAFWA (2016) Frost and cropping. Department of Agriculture and Food Western Australia, August 2016, https://www.agric.wa.gov.au/frost/frost-and-cropping

15 GRDC (2013) UA00114: Frost tolerance in wheat. Grains Research and Development Corporation, http://projects.grdc.com.au/projects.php?action=view_project&project_id=1904

16 GRDC (2016) Tips and tactics; Managing frost risk, http://www.grdc.com.au/ManagingFrostRisk

to give representative temperatures throughout a crop. In undulating country, more thermometers should be used at various heights in the landscape. [17]

Table 3 outlines a number of agronomic practices to reduce frost risk.

Table 3: *Agronomic practices to reduce frost risk, ranked in order of importance.*

Soil heat bank manipulation	Average increase in temperature at canopy height	Reduction in frost damage
Clay delving or clay spreading on sandy surfaced soils	1°C	Up to 80%
Rolling sandy and loamy clay soil after seeding	0.5°C	Up to 18%
Removing stubble (this had a negligible effect on yield and frost risk; in 2014 cereal stubbles increased frost risk on dark soils)	0.5°C	Minimal
Manipulation of the crop canopy		
Blending long and short season wheat varieties of the same quality classification Sowing later maturing varieties towards the middle or end of a sowing program	0°C	Later maturing variety: 12%
Cross sowing with half the seed sown in each direction, to give a more even plant density so that soil heat is released more slowly	0.6°C	13%
Increasing row spacing and lowering seeding rates	0°C	0
Frost minimising strategies		
Applying adequate seed and fertiliser inputs for target yield, rather than high inputs.		
Delaying sowing on frost prone paddocks can reduce frost risk, however it also increases the risk of end of season drought.		
Growing lower risk crops such as oats (approx. 4°C more tolerant) and long season barley (approx. 2°C more tolerant) can reduce losses from frost compared to wheat.		
Frost avoidance strategy		
Growing hay or permanent pasture on highly frost prone areas.		

Source: Primary Industries and Regions South Australia

Guidelines for 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 grain filling in the short window of opportunity after the main frost risk period has passed and before daytime 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 can lead to a very high probability of crop loss.

17 T Frederiks, C Birchall, J Christopher, A Borrell (2011) Frost resistance in cereals after head-emergence. GRDC update papers. Grains Research and Development Corporation, April 2011,

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

In-crop temperature measurements are useful to determine whether a 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 particular 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. In crops, the temperature can vary several degrees from the temperature measured in the screen. On nights when still cold air, clear skies, and low humidity conditions combine, temperatures can drop rapidly, resulting in radiant frost (Figure 6). The crop temperatures experienced and recorded can vary widely due to differences in topography, micro-environment and recording method.

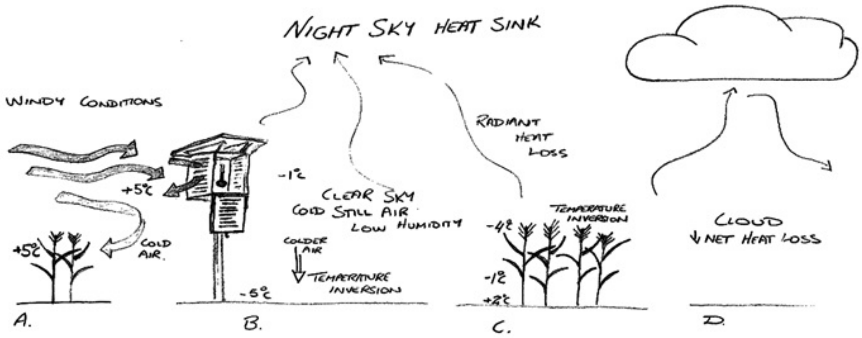


Figure 6: *If clear skies and still, cold, low humidity air coincide, heat can be lost rapidly to the night sky resulting in a radiant frost. Minimum air temperatures measured at head height can be several degrees colder than reported "screen" temperatures. Some indicative temperatures are illustrated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

Measurements taken using exposed thermometers at canopy height (Photo 5) give a much more accurate indication of the likelihood of crop damage. [18]

18 J Christopher, G Zheng, S Chapman, A Borrell, T Frederiks, K Chenu (2016) GRDC Update Papers: An analysis of frost impact plus guidelines to reduce frost risk and assess frost damage, 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

Photo 5: *Canopy temperature measured using a calibrated minimum/maximum thermometer. For best results, a minimum of two or three field thermometers are require 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

14.1.6 Sowing dates to avoid frost

To lower the risk of frost damage, winter cereals are planted 'late' so that heading and grain development occur when warmer temperatures prevail. Unfortunately, this delay increases the likelihood of drought and high temperatures during anthesis and grainfilling, dramatically reducing yield potential. Yield declines of as much as 16% for each week that flowering is delayed past the optimum time have been reported. Optimum flowering time and yields are achieved, in the long term, when a compromise between the effects of frost and drought is reached. [19]

Durum wheats are generally similar in maturity to the quickest bread wheat varieties. This is an important consideration when managing frost risk and can limit opportunities to exploit early planting opportunities. Extended flowering could reduce the risk of pollination failure caused by frost or extended moist weather.

Delaying sowing after the optimum sowing date is not economical in the long term, even in high frost risk areas. The yield loss from moisture and temperature stress during spring will be far greater than the damage caused by frost. The most severe and damaging frosts are those associated with dry conditions in mid to late spring (black frosts), which can be devastating even to crops that have completed flowering. Crops sown at the optimum time will generally be less affected by these late frosts, as they will be past the critical flowering stage. [20]

Table 5 is a simple spreadsheet model calculating the chance of minimum temperature for each sowing date, using long term records (in this case, sourced from the Bureau of Meteorology site at Keith, SA). The calculated long term yield loss is simply the chance of a frost event occurring multiplied by the damage estimate from that event. For example, the first column 61.2% x 0% loss + 18.4% x 10% loss +

19 T Frederiks, C Birchall, J Christopher, A Borrell (2011) Frost resistance in cereals after head-emergence. GRDC update papers. Grains Research and Development Corporation, April 2011,

20 PIRSA (2003). Impact of dry sow, frost, crop type and variety. http://pir.sa.gov.au/__data/assets/word_doc/0005/241583/Impact_of_dry_sow,_frost,_crop_type_and_variety.doc

14.3% x 20% loss + 4.1% x 25% loss + 2% x 80% loss equates to a long term average loss of 7.6%. [21]

Table 4: *Investigating the effect of sowing date on frost risk and wheat yields for Keith, SA.*

Sowing date	15 May	1 June	15 June	30 June
Yield penalty	0%	12%	22%	33%
Yield (t/ha)	2.7	2.4	2.1	1.8
Days to flower	117	114	111	106
Flowering date	9 Sept	23 Sept	4 Oct	14 Oct
Chance of minimum temperature (meteorological station) and estimated damage in the field				
>2°C (assume no loss)	61.2%	61.2%	73.5%	73.5%
2 to 1°C (assume 10% loss)	18.4%	20.4%	10.2%	14.3%
1 to 0°C (assume 20% loss)	14.3%	12.2%	10.2%	8.2%
0 to -1°C (assume 25% loss)	4.1%	4.1%	4.1%	2.0%
-1 to -2°C (assume 80% loss)	2.0%	2.0%	2.0%	2.0%
-2 to -3°C (assume 90% loss)	0.0%	0.0%	0.0%	0.0%
-3 to -4°C (assume 100% loss)	0.0%	0.0%	0.0%	0.0%
Calculated long term average yield loss from frost	7.3%	7.1%	5.7%	5.2%

Source: Grains Research and Development Corporation and South Australian Research and Development Institute

For more information see Section 2: Pre-planting and Section 3: Planting.

14.1.7 What to do with a frosted crop

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

In the event of severe frost (Photo 6) monitoring needs to occur for up to two weeks after the event to detect all the damage. After the level of frost damage is estimated, the next step is to consider options for the frost damaged crop.

21 M Rebbeck, G Knell (2007) Managing frost risk: a guide for southern Australian grains. Grains Research and Development Corporation and South Australian Research and Development Institute, June 2007, https://grdc.com.au/Resources/Bookshop/2007/06/Managing-Frost-Risk-a-guide-for-southern-Australian-grains

Photo 6: *Severely frosted areas mature later and are often stained/discoloured.*

Source: DAFWA

Option 1: Take through to harvest

If the frost is prior to or around (growth stage) GS31 to GS32, most cereals can produce new tillers to compensate for damaged plants, provided spring rainfall is adequate. Tillers already formed but lower in the canopy may become important and new tillers can grow after frost damage, depending on the location and severity of the damage. These compensatory tillers will have delayed maturity, but where soil moisture reserves are high, or it is early in the season, they may be able to contribute to grain yield.

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

Option 2: Cut and bale

This 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 event and be prepared to cut a larger area than originally intended pre-season. Producing hay can also be a good management strategy to reduce stubble, weed seed bank 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 with cereal on cereal in paddocks cut early for hay. Hay can be an expensive exercise. Growers should have a clear path to market or a use for the hay on farm before committing. In high frost risk areas, durum growers may consider planting a variety like Saintly which has small awns and more suitable for hay should frosted crop need to be cut for hay.

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, especially if the paddock will be sown to crop the next year. Ploughing in the green crop is to return organic matter and nutrients to the soil, manage crop residues, weeds and improve soil fertility and structure. The economics need to be considered carefully. [22]

22 GRDC (2016) Tips and tactics; Managing frost risk, http://www.grdc.com.au/ManagingFrostRisk

Table 5: *Management options for frost damaged crop, each with advantages and disadvantages.*

Options	Potential Advantages	Potential Disadvantages
Harvest	Salvage remaining grain More time for stubble to break down before sowing Machinery available	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 raking 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	Difficulty getting chemicals onto all of the weeds with a thick crop May not be as effective as burning Boom height limitation Expense $5/ha plus cost of herbicide Some grain still in crop
Plough (Cultivate)	Recycles nutrients and retains organic matter. Stop weed seed set Green manure effect	Requires offset disc to cut straw Soil moisture needed for breakdown and incorporation of stubble
Swath	Stops weed seed set 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 Expense—swathing ($20/ha) Spraying ($5/ha per herbicide)
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

- Weather apps: see AgExcellence Alliance for a review.
- Plant development apps (e.g. MyCrop, DAFWA FlowerPower)
- Temperature monitors

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.

The initiative is addressing frost management through a multidisciplinary approach incorporating projects in the following programs:

MORE INFORMATION

Managing frost risk—a guide for southern Australian growers.

Ranking cereals for frost susceptibility using frost values—southern region.

GRDC Managing frost risk Factsheet.

VIDEOS

WATCH: GCTV3: Frost R&D.

WATCH: GCTV16: National Frost Initiative.

1. Genetics: developing more frost-tolerant wheat and barley germplasm and ranking current wheat and barley varieties for susceptibility to frost.
2. Management: developing best practise 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.
3. Environment: predicting the occurrence, severity and impact of frost events on crop yields and frost events at the farm scale to enable better risk management. [23]

14.2 Waterlogging/flooding issues for durum

Key points:

- Waterlogging occurs when roots cannot respire due to excess water in the soil profile.
- 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 period in which the crop roots are subjected to anaerobic conditions.
- While raised beds are the most intensive management strategy, they are also the most effective at improving drainage.
- Waterlogged soils release increased amounts of nitrous oxide, a particularly damaging greenhouse gas.

Waterlogging occurs when the soil profile or the root zone of a plant becomes saturated (Photo 7). In rain-fed situations, this happens when more rain falls than the soil can absorb or the atmosphere can evaporate. Waterlogging occurs whenever the soil is so wet that there is insufficient oxygen in the pore space for plant roots to be able to adequately respire. 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. There is no universal level of soil oxygen that can identify waterlogged conditions for all plants. In addition, a plant's demand for oxygen in its root zone will vary with its stage of growth. [24]

Photo 7: *The 2016 July wet impacted producers in Murrumburrah.*

Source: Harden Express

23 GRDC (2016) Tips and tactics; Managing frost risk, http://www.grdc.com.au/ManagingFrostRisk

24 D Bakker. Water-logging. Soil Quality Pty Ltd, http://soilquality.org.au/factsheets/waterlogging

Flooding and long periods of waterlogging can also cause the depletion of important nutrients (e.g. nitrogen) required for growth. Soil testing after flooding is recommended.

Waterlogging is one of the limiting factors influencing durum wheat production. One study investigated the impact of seven waterlogging durations of 4, 8, 12, 16, 20, 40, and 60 days (d), imposed at 3-leaf and 4-leaf growth stages, on grain yield, grain yield components, straw and root dry weight and nitrogen concentration of grain, straw, and roots of two varieties of durum wheat. Grain yield of both varieties showed a significant reduction only when waterlogging was prolonged to more than 20 days, and 40-d and 60-d waterlogging reduced grain yield by 19% and 30%. Waterlogging depressed grain yield preventing many culms from producing spikes. It slowed down spikelet formation, consequently reducing the number of spikelets per spike, and reduced floret formation per spikelet, thus reducing the number of kernels per spike. [25]

14.2.1 Effects on plant growth

Low levels of oxygen in the root zone trigger the adverse effects of waterlogging on plant growth. Waterlogging of the seedbed mostly affects germinating seeds and young seedlings. Established plants are most affected when they are growing rapidly. Therefore, if a soil becomes waterlogged in July, final yields may not be greatly reduced; soils are cold, the demand for oxygen is low and plant growth is slow at this time of year. Prolonged waterlogging during the warmer spring period could be more detrimental, however the probability of this occurring is much lower than in July.

When plants are growing actively, root tips begin to die within a few days of waterlogging. The shallow root systems that then develop limit the uptake of nutrients (particularly nitrogen) and water, particularly when the soil profile starts to dry in spring. As a result plants may ripen early and grains may not fill properly.

Nitrogen is lost from waterlogged soils by leaching and denitrification. Denitrification leads to the gaseous loss of nitrous oxide into the atmosphere, which is a major greenhouse gas. These losses, together with the lowered ability of plants to absorb nutrients from waterlogged soil, cause the older leaves to yellow. Waterlogging also directly reduces nitrogen fixation by the nodules of legume crops and pastures. [26]

Where does waterlogging occur?

- Water accumulating in poorly drained areas such as valleys, at the change of slope or below rocks.
- Duplex soils, particularly sandy duplexes with less than 30 cm sand over clay.
- Deeper sown crops.
- Waterlogging greatly increases crop damage from salinity. Germination and early growth can be much worse on marginally saline areas after waterlogging events.
- Low nitrogen status crops.
- In very warm conditions when oxygen is more rapidly depleted in the soil. [27]

25 Pampana, S., Masoni, A., & Arduini, I. (2016). Grain yield of durum wheat as affected by waterlogging at tillering. *Cereal Research Communications*, *44*(4), 706-716.

26 D Bakker. Water-logging. Soil Quality Pty Ltd, http://soilquality.org.au/factsheets/waterlogging

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

IN FOCUS

Crop production in the high rainfall zones of southern Australia—potential, constraints and opportunities

Annual cropping has been expanding in the high rainfall zone of southern Australia. The higher rainfall and longer growing season compared with the traditional wheat belt contribute to a much higher yield potential for major crops. Potential yields range from 5 to 8 t/ha for wheat and 3 to 5 t/ha for canola, although current crop yields are only about 50% of those potentials. The large yield gap between current and potential yields suggests that there is an opportunity to lift current yields. Both genetic constraints and subsoil constraints such as waterlogging, soil acidity, sodicity, and high soil strength contribute to the low yields. Waterlogging is a widespread hidden constraint to crop production in the region. Controlling waterlogging using a combination of raised beds and surface or subsurface drains is the first step to raise the productivity of the land. Increasing root growth into the subsoil remains a key to accessing more water and nutrients for high yield through early planting, deep ripping, liming and use of primer crops to ameliorate the subsoil. In order to realise the high yield potential, it is essential to achieve higher optimum dry matter at anthesis and high ear number through agronomic management, including early sowing with appropriate cultivars, a high seeding rate and application of adequate nitrogen along with other nutrients. Current cultivars of spring wheat may not fully utilise the available growing season and may have genetic limitations in sink capacity that constrain potential yield. Breeding or identification of long-season milling wheat cultivars that can fully utilise the longer growing season and with the ability to tolerate waterlogging and subsoil acidity, and with disease resistance, will give additional benefits. It is concluded that improving crop production in the high rainfall zone of southern Australia will require attention to overcoming soil constraints, particularly waterlogging, and the development of longer-season cultivars. [28]

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 8). 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. [29]

28 H Zhang, NC Turner, ML Poole, N Simpson (2006) Crop production in the high rainfall zones of southern Australia—potential, constraints and opportunities. *Animal Production Science*, *46*(8), 1035-1049.

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

Photo 8: *Water fills a hole dug in waterlogged soil.*

Source: Soilquality.org

14.2.2 Symptoms and causes

Lack of oxygen in the root zone of plants causes their root tissues to decompose. Usually this occurs from the tips of roots, causing 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 the plant eventually dies.

Most often, waterlogged conditions do not last long enough for the plant to die. 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 will be very poorly productive 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.

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.

What to look for

Paddock

- Poor germination or pale plants, in water collecting areas, particularly on shallow duplex soils (Photo 9).
- Wet soil and/or water-loving weeds present.
- Early plant senescence in waterlogging prone areas.

Photo 9: *Pale plants in waterlogged areas.*

Source: DAFWA

Plant

- Plants are particularly vulnerable from seeding to tillering, with seminal roots being more affected than later forming nodal roots.
- Waterlogged seed will be swollen and may have burst.
- Seedlings may die before emergence or be pale and weak.
- 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 10).
- Seminal roots are important for accessing deep subsoil moisture. If damaged by waterlogging the plants may be more sensitive to spring drought.

Photo 10: *Waterlogged roots (particularly seminal roots and tips) become brown and then die.*

Source: DAFWA

How can waterlogging be monitored?

- Water levels can be monitored with bores or observation pits, but water tables can vary greatly over short distances.
- Plants can be waterlogged if there is a water table within 30 cm of the surface and no indication of waterlogging at the surface. Observe plant symptoms and paddock clues and verify by digging a hole. [30]

Other impacts of waterlogging and flood events

Heat from stagnant water

Stagnant water, particularly if 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 exposed to off-farm run-off, particularly leafy crops.

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.

30 DAFWA (2015) Diagnosing waterlogging in cereals, 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

High clay content means soils can become compacted and form a surface crust after heavy rainfall and flooding. Floodwater also deposits a fine clay layer or crust on top of the soil, 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. 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. [31]

Flooding and disease

The environment influences disease incidence, frequency and duration through moisture, temperature and wind. For disease to occur, the pathogen must have virulence to the particular variety, inoculum must be available and easily transported, and favourable conditions are needed for infection and disease development. Rainfall and flooding can transport of inoculum (crown rot, nematodes, leaf spots through movement of infected stubble and soil) and can weather-damage seed. [32]

Soil erosion due to flooding

Maintenance of productive soil base by minimising soil erosion is vital to long term crop production. Flood events will often cause damaging soil erosion. A number of approaches can be used to prevent soil erosion during flooding. Contours running down a hill generally spread the flow of water and reduce flow rates. Wheel tracks can be used like raised beds to assist drainage. These wheel tracks need to be maintained and managed for effectiveness. Wide tyres for spraying and tracks for harvesters and tractors are options to reduce compaction. [33]

VIDEOS

WATCH: GCTV3: Big Wet—Managing strategies after flooding.

Weed emergence following floods

Floodwater affects soil, stubble, weed seed and plant movement. Growers might expect to see new weed incursions and removal of topsoil caused by flooding. There is also the potential for the introduction and movement of herbicide-resistant weeds. The removal of topsoil could lead to the exposure of previously buried weed seed. It is hard to predict where weed seeds will settle, but a concentration is likely where water and trash have settled. [34] Growers should monitor for weed outbreaks following floods and take necessary weed management action.

14.2.3 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.

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

32 DAFQ (2013) Winter cereals pathology. Department of Agriculture and Fisheries Queensland, January 2013, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/prepare-for-winter-crops-following-floods/winter-cereals-pathology

33 DAFQ (2013) Soil erosion and waterlogging due to flooding. Department of Agriculture and Fisheries Queensland, January 2013, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/prepare-for-winter-crops-following-floods/soil-erosion-and-waterlogging-due-to-flooding

34 DAFQ (2011) Weed management following floods. Department of Agriculture and Fisheries Queensland, May 2011, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/prepare-for-winter-crops-following-floods/weed-management-following-floods

VIDEOS

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

- Raised beds are more effective on relatively flat areas and on heavier textured soils, but areas need to be large enough to justify machinery costs. [35] (For more information on raised beds see Cropping on raised beds in southern NSW).

Drainage is usually the best way of reducing waterlogging. Other management options to reduce the impact of waterlogging include: choice of crop, seeding, fertiliser and weed control.

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

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.

Drainage problems after flooding

After significant rain or flooding, inspect the crops when 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 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 field
- improving surface drainage
- installing subsurface drainage.

If the drainage can't be improved, consider using the area for some other purpose (e.g. for a silt trap). [36]

Choice of crop species, variety and seeding date

Some species of grains crop are more tolerant than others. Some 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 paddocks that are susceptible to waterlogging first. 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 take advantage of stressed crops.

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

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

MORE INFORMATION

Should waterlogged crop be top-dressed with N fertiliser?

VIDEOS

WATCH: The 2012 N story and planning for 2013.

Nitrogen fertiliser

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

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

Weed density affect a crop's ability to recover from waterlogging. Weeds compete for water and the small amount of remaining N, hence the waterlogged parts of a paddock are often weedy and require special attention if the yield potential is to be reached. [37]

14.3 Other climatic and abiotic issues

Water availability and heat stress are major limiting factors to wheat yield and grain quality. [38] Table 7 details the effects of various rainfall and temperature variables at both flowering and grainfill on crop yield in south eastern Australia.

Table 6: *The effect of various climatic variables on grain yield across over 600 field experiments in southern Australia, 2005–2010. The average grain yield across all trials was 2,530 kg/ha.*

Growth stage	Climatic variable	Unit	Effect (kg/ha)
Flowering	Rainfall	mm	+22
	Average daily minimum temperature	°C	-161
	Average daily maximum temperature	°C	-371
	Days >30°C	number	-379
	Average temperature	°C	-490
	Days >35°C	number	-837
Grainfilling	Rainfall	mm	+23
	Average daily minimum temperature	°C	-125
	Days >30°C	number	-130
	Days >35°C	number	-179
	Average daily maximum temperature	°C	-225
	Average temperature	°C	-224

Source: Grains Research and Development Corporation

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

38 M Sissons, B Ovenden, D Adorada, A Milgate (2014) Durum wheat quality in high-input irrigation systems in south-eastern Australia. Crop and Pasture Science, 65(5), 411–422, http://dx.doi.org/10.1071/CP13431

14.3.1 Heat stress

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 stress such as drought and frost. Controlled environment studies have established that a 3–5% reduction in grain yield of wheat can occur for every 1°C increase in average temperature above 15°C during reproductive growth. 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. [39]

In one study, heat stress was found to reduce grain yield and 1000-grain weight in durum by 33% and 42%, respectively. [40]

The reproductive stages of growth have greater sensitivity to elevated temperatures, with physiological responses including premature leaf senescence, reduced photosynthetic rate, reduced seed set, reduced duration of grainfill and reduced grain size, all ultimately leading to reduced grain yield. Such elevated temperatures are a normal, largely unavoidable occurrence during the reproductive phase of Australian crops in September and October. [41]

In some cereals heat stress can be identified by the withering and splitting of leaf tips (Photo 11). Tips of the leaves can also turn brown to grey in colour. Some or all grains fail to develop in a panicle. [42]

Photo 11: *Withered and split tips in heat stressed cereal.*

Source: DAFWA

MORE INFORMATION

Assessing and managing heat stress in cereals

14.3.2 Sodicity and salinity

Sodicity (exchangeable sodium >6%) occurs on over 80% of cropping land in Victoria and over 60% of cropping lands in Australia. Sodic soils have poor soil structure and porosity which limits available water and reduces plant growth by up to 50%. Similarly,

39 AS Dias, J Semedo, JC Ramalho, FC Lidon (2011). Bread and durum wheat under heat stress: a comparative study on the photosynthetic performance. Journal of Agronomy and Crop Science, 197(1), 50–56, http://onlinelibrary.wiley.com/doi/10.1111/j.1439-037X.2010.00442.x/abstract

40 Modhej, A., Naderi, A., Emam, Y., Aynehband, A., & Normohamadi, G. (2012). Effects of post-anthesis heat stress and nitrogen levels on grain yield in wheat (T. durum and T. aestivum) genotypes. *International Journal of Plant Production*, *2*(3), 257-268.

41 P Telfer, J Edwards, H Kuchel, J Reinheimer, D Bennett (2013) Heat stress tolerance of wheat. GRDC update papers. Grains Research and Development Corporation, February 2013, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Heat-stress-tolerance-of-wheat

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

soil salinity occurs extensively in Victoria and the cropping regions of SA. Like sodic soil, saline soils also have excessive amounts of sodium however saline soil also contain other salts, namely calcium and magnesium as well as chloride, sulphate and carbonates. Since both salinity and sodicity is related to a soil's sodium content, soil is classified along a spectrum from saline to sodic.

Salinity that affects crop growth is associated with water tables and susceptibility to waterlogging in south-east SA, whilst most cropped soils in Victoria and SA have the potential to experience transient salinity associated with excess rainfall occurring in sodic soils. The economic effect of salinity in agriculture is considerable, being estimated at $1.5 billion annually for the whole of Australia. An exception is in the higher rainfall environment of southern Victoria where salinity is not considered a major factor effecting productivity of grain crops. [43]

In one study, durum wheat was grown in artificially created saline and sodic soils. Although salinity resulted in the largest decreases in seedling emergence and survival, sodicity especially at high level caused 22% and 86% decreases in plant height and grain yield respectively. The decreases in grain yield at high salinity and high sodicity were mainly due to decreases in the number of grains per plant and mean grain mass and were associated with 29% increased concentration of Na+ and 94% lower K+/Na+ ratio over control in flag leaf sap. These effects were greater at high sodicity, where the external Na+ concentration was higher than at high salinity. [44]

Symptoms of salinity

Paddock

- Moist bare patches where seed has failed to germinate or seedlings have died (Photo 12).
- Patches of stunted and apparently water stressed or prematurely dead plants in areas subject to salinity.
- Most crop weeds will also be affected with the exception of salt tolerant species.
- Salt crystals may occur on dry soil surface.

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43 CropPro. Physical and chemical soil constraints of wheat crops in southern Australia. CropPro Diagnostic Agronomy,

44 Rajper, I., Wright, D., & Sial, N. B. (2003). Effect of soil salinity and sodicity on the growth and yield of durum wheat (Triticum turgidum L.) genotypes. *Pakistan Journal of Agriculture: Agricultural Engineering Veterinary Sciences (Pakistan).*

Photo 12: *Bare saline area with surviving plants dying prematurely.*

Source: DAFWA

Plant

- Plants have a harsh droughted appearance, and may be smaller with smaller dull leaves (Photo 13).
- Old leaves develop dull yellow tips and die back from the tips and edge.
- Heads are smaller with small grain.
- Plants die prematurely.
- Root growth is reduced, and may be brown and poorly branched or die if the plant is also waterlogged.

Photo 13: *Surviving plants appear to be limp and water stressed.*

Source: DAFWA

Management strategies

- Naturally saline soils cannot be ameliorated but managed according to season and their capability.
- Engineering solutions such as drainage may be possible for secondary salinity but must be assessed on a site-by-site basis.
- Barley is the most salt tolerant cereal, but it has poor waterlogging tolerance. [45]

There are no simple solutions for managing salinity and there is no 'quick fix'. Salinity inducing processes are complex, whether on a farm or in an urban environment.

General information is available on the management of salinity for urban, dryland and irrigation land uses. However, the expertise of technical specialists will help ensure that salinity management actions are appropriate for the specific location and set of conditions.

Managing groundwater levels

Salinity management aims to maintain groundwater levels at least 2 m below the soil surface, mainly by maximising plant water use to reduce groundwater recharge. Useful techniques include:

- Monitoring groundwater levels.
- Growing species tolerant of salt and waterlogging in low lying, non-production areas.
- Growing perennial pastures as these can use twice as much water as annual pastures.
- Avoiding long fallows when the profile is >75% of field capacity.

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

- Appropriate crop selection and crop rotations.
- Efficient irrigation management.

Troubleshooting

Recognising and acting on salinity problems early is the best solution, as soil salinity can be a more difficult and expensive issue to correct when well advanced.

Dryland salinity outbreaks can be managed by excluding grazing on saline areas and sowing saline tolerant species.

Irrigation salinity can be managed by improving irrigation management, specifically application efficiency.

Specific management of salt-affected areas could include hill/bed shapes that minimise salt accumulation around seedlings, and pumping and recycling of groundwater (this requires advice from a hydrology consultant). [46]

MORE INFORMATION

Preventing and managing salinity

Managing saline soils.

46 Soilquality.org. Salinity—NSW, http://soilquality.org.au/factsheets/salinity-nsw