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GRDC GROWNOTES™

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

BARLEY

SECTION 14

ENVIRONMENTAL ISSUES

FROST | SOIL MOISTURE ISSUES FOR BARLEY

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SECTION 14

Environmental issues

FAQ

14.1 Frost

Frost damage to cereals is a significant annual production constraint for the Australian grains industry and can result in considerable yield losses. These losses are direct losses from crops damaged by frost and indirect from growers missing opportunities. Because of the variability in the incidence and severity of frost, a number of management strategies should be utilised in a farm management plan.

Key points:

- In some Australian production areas, the risk of frost has increased because of widening of the frost-event window and changes in grower practices.
- The risk of frost varies between and within years as well as across landscapes, so growers need to assess their situation regularly.
- 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 crop management.
- Frost damage is not always obvious and crops should be inspected 5–7 days after a suspected frost event.
- Although frost damage can occur at all stages of crop development, greatest losses in grain yield and quality are observed when frosts occur between the booting and grain-ripening stages of growth. [1]

A comprehensive frost management strategy needs to be part of annual farm planning and it should include pre-season, in-crop, and post-frost-event management tactics.

Methods to deal with the financial and personal impact of frost also need to be considered in a farm management plan. [2]

14.1.1 What causes frost?

In the Australian grainbelt, frosts occur when nights are clear and calm and follow cold days. In elevated regions, frosts are often experienced after mild or even warm conditions. These conditions occur most often during winter and spring with the passage of high-pressure systems following a cold front. The clear, calm conditions encourage loss of heat from the earth and the crop itself, during the night, decreasing the temperature at ground level and within the crop canopy to below 0°C. Overnight temperatures at ground level (where heat is being lost) can be up to 5°C lower than those measured in a Stevenson screen. Differences of 10°C have been recorded.

Often frost will be more damaging when there is little soil moisture, because soil moisture adds to the heat storage capacity of the soil.

[1] GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

[2] GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

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 reach 0°C, the length of time it stays below 0°C and how far below 0°C it falls. [3]

14.1.2 Measuring temperature

Plant surfaces cool more quickly than the air surrounding them, so measuring air temperature is not entirely accurate in determining plant temperature. Temperature increases above the canopy of a crop, and if the canopy is reasonably developed, it increases below the canopy.

Measuring temperature at Stevenson screen height (1.2 m) will not be the same as at the canopy height, and the more remote the measurement is from the actual crop site, the less accurate it will be. Temperature measured above bare ground may not be a reliable indicator of the temperature of air surrounding susceptible plant parts, and certainly not a good indicator of the temperature of the plant parts themselves.

Temperatures recorded at a local Bureau of Meteorology (BOM) site at Stevenson screen height (standard) may not correlate well with those experienced at crop height in a particular location, and the correlation may change depending on the time of the year.

A rule-of-thumb is that the canopy temperature is ~1.5–2.5°C lower than Stevenson screen temperature at 1.2 m at the same point in the landscape.

The most precise method of determining paddock and crop height temperature is to use accurate loggers placed at the canopy height in crop. [4]

14.1.3 The changing nature of frost in Australia

The length of the frost season has increased across much of the Australian grainbelt by 10–55 days between 1960 and 2011, and in some parts of eastern Australia, the number of frost events has increased.

CSIRO analysis of climate data over this period suggests that the increasing frost incidence is due to the southerly displacement and intensification of high-pressure systems (subtropical ridges) and due to heightened dry atmospheric conditions associated with more frequent El Niño conditions during this period.

The southern shifting high-pressure systems bring air masses from further south than in the past. This air is very cold and contributes to frost conditions.

In the eastern Australian grainbelt, the window of frost occurrence has broadened, so frosts are occurring both earlier and much later in the season (Figure 1). In the Western Australian grainbelt, there are fewer earlier frosts and a shift to frosts later into the season.

The frost window has lengthened by 3 weeks in the Victorian grainbelt and by 2 weeks in the New South Wales grainbelt. The frost window in Western Australia and Queensland has statistically remained the same. The eastern South Australian sites are similar to Victoria, and sites in the west of South Australia are more like Western Australia. Northern Victoria seems to be the epicentre of the change in frost occurrence (Figure 2), with some locations experiencing a broadening of the frost season by 53 days.

3 GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

4 GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

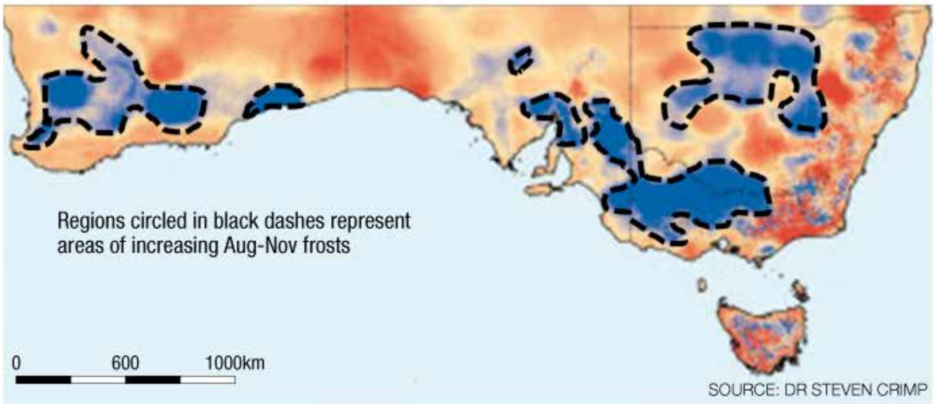

Figure 1: Regions of increasing August–November frosts.(Source: Steven Crimp, CSIRO)

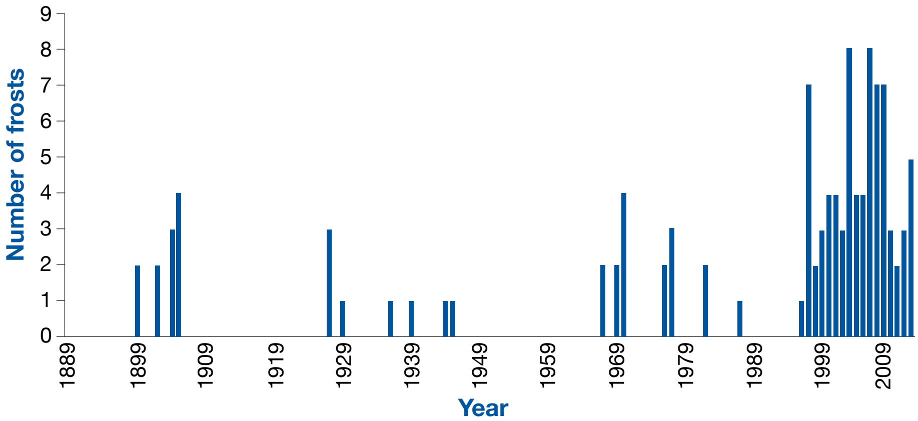

Figure 2: Historical number of frosts in the flowering window 20 September–30 October for Yitpi⁽ᴰ⁾, Longerenong, Victoria.

14.1.4 How does frost affect crops?

The ways in which frost can affect crops are complex. It has several effects on plants including cold, desiccation and freezing.

Although ice melts at 0°C, the freezing temperature of water is not 0°C. Pure water may not readily freeze until –40°C. Water and plant tissue supercool at temperatures below 0°C, to –10°C in cereals, and will only freeze or form ice crystals around small ice nucleators—the process of ice nucleation.

These ice nucleators can be particles such as dust and bacteria. Ice formation is therefore often at several degrees below 0°C and will vary depending on the concentration of plant tissue solutes and the presence of ice nucleators on plant tissues. Generally, the colder and longer the duration of subzero temperatures, the higher the probability that ice nucleation and freezing will occur.

The timing and severity of a frost may affect a crop in three ways: cold or chilling, desiccation, and finally freezing (Figure 3). It is a step-wise response (i.e. desiccation will not occur without prior cold damage, freezing damage will only occur after cold and desiccation damage). The freezing damage will be random throughout a crop canopy and tissues, owing to the random nature of the ice nucleation and formation.

1. Cold or chilling damage occurs when plants are exposed to temperatures <10°C, down to –2°C (Figure 3). If the changes in temperature are sudden, the plant is not able to increase the fluidity of membranes (largely made of fats) at the lower temperature and this compromises cellular and plant energy balance. If this occurs at critical stages in reproductive development, it can cause a few or all of the florets to abort during pollen development. The damage is not related to the formation of ice within plant tissue, although it may appear to be.

2. Desiccation from ice formation occurs at temperatures from 0°C to –2°C. When plants are exposed to freezing temperature during a white frost, the dew initially freezes on the outside of the plant, but then the ice nucleation can move within the leaf through cracks in the leaf cuticle and stomata. The water inside the leaf then starts to freeze. Initially, the water around the cells freezes but it then draws water out from inside the cells and dehydrates the cells. The cells may not necessarily freeze or have ice form inside them. This process will not necessarily kill the cells provided the dehydration and desiccation do not proceed too far. When the ice thaws, these cells can rehydrate and recover.
3. Freezing damage is the final stage of frost damage and occurs when there is rapid ice nucleation and formation of ice crystals, which punch through cell walls and membranes, physically rupturing cell walls and membranes within the cells. Freezing damage is generally not reversible, but can be limited to specific tissues within the plants by stem nodes, individual florets, individual tillers, etc.

Cereal crops are most susceptible to frost damage during and after flowering, and are susceptible at the earlier stages of booting (growth stages GS45–71; Figure 4.). Losses in grain yield and quality from frost primarily occur between stem elongation and late grain-filling.

Frost damage may be sporadic across a crop within a paddock. Not all plants will show obvious symptoms and symptoms may not be obvious until 5–7 days after the frost event has occurred. [5]

14.1.5 Effect of wet or dry canopy

A canopy that is wet from a light shower of rain is more prone to frost damage than a dry canopy. Because ice formation requires an ice nucleator such as bacteria or dust, and rainwater contains these, when rainwater falls on a crop canopy the concentration of these nucleators is often higher. This means that a slightly wet canopy from light showers will have a warmer freezing point than a dry canopy and will not supercool to as low a temperature before freezing damage occurs. [6]

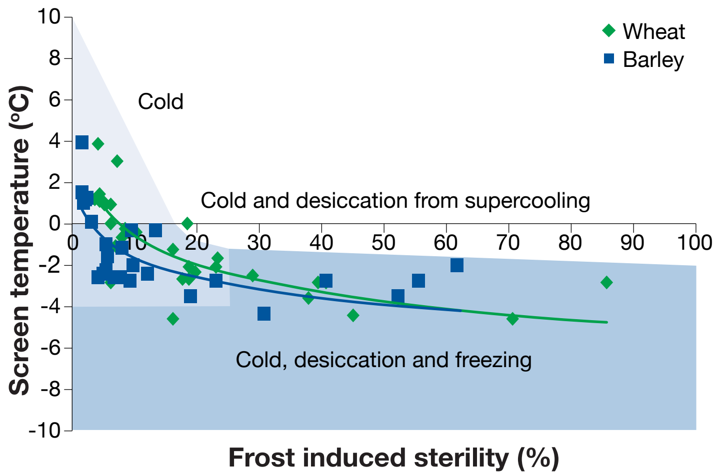

Figure 3: Average frost-induced sterility in flowering heads of wheat and barley versus minimum Stevenson screen temperature from frosts at trials from WA, SA and NSW frost nurseries 2010–14.

[5] GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

[6] GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

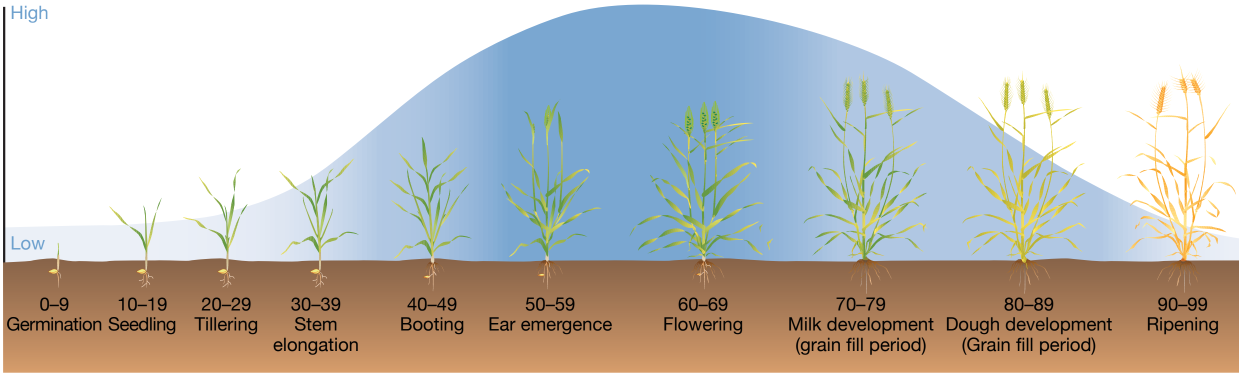

Figure 4: Susceptibility of cereals to frost during the development cycle, with Zadoks growth stages depicted.

14.1.6 Risk management for frost

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 management tactics, in-season tactics, and strategies following the incidence of frost. [7]

Pre-season management tactics

Two types of pre-season management tactics are available for growers: the first at the level of farm-management planning, and the second within identified frost zones of a farm.

Farm-management planning:

- Step 1. Assess personal approach to risk. Consider your personal approach to risk in your business—every individual will have a different approach. Growers should identify and measure the extent of the risk, evaluate risk-management alternatives, and tailor the risk advice according to their risk attitude. The risk of frost can often drive conservative farming practices, which should be carefully reviewed regularly in light of up-to-date research.
- Step 2. Assess frost risk of property. Carefully consider the risk of your property incurring frosts, based on the location, historic seasonal records and forecasts. Spatial variability across the landscape should also be considered; cold air will flow into lower regions. Temperature-monitoring equipment, such as Tinytag® data loggers and iButtons and weather stations, are commercially available for on-farm determination of temperature variability across a landscape.
- Step 3. Diversify the business. A range of enterprise options should be considered as part of a farm-management plan to spread financial risk in the event of frost damage. This will depend on the location of the business and the skillset of the manager; however, the largest financial losses with frost have occurred where growers have a limited range of enterprises or crop types.
- Step 4. Zone the property and/or paddock. Paddocks or areas in paddocks that are prone to frost can be identified through experience. Precision tools such as topographic, electromagnetic and yield maps, and temperature monitors can be used to locate susceptible zones. This can help to determine the appropriate management practice 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. Once the farm has been zoned for potential frost incidence, the following tactics can be considered. [8]

7 GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

8 GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

Frost zone management:

- Step 1. Consider enterprise within a zone. The use of an identified frost zone should be carefully considered; for example, consider grazing, hay or oat production and avoiding large-scale exposure to frost of highly susceptible crops (e.g. field peas) or expensive crops (e.g. canola). It may be prudent to sow annual or perennial pastures on regularly frosted areas to avoid the high costs of crop production.
- Step 2. Review nutrient management. Targeting fertiliser (nitrogen (N), phosphorus (P), potassium (K)) and seed rates on high-risk paddocks to achieve realistic yield targets should minimise financial exposure, reduce frost damage and increase whole paddock profitability over time. These nutrients could be reallocated to lower risk areas of the farm. Although high rates of N increase yield potential, they also promote vegetative biomass production and increase the susceptibility of the crop to frost. Conservative rates of N at seeding and avoiding late top-ups appear to result in less crop damage. Crop deficiency of K or copper (Cu) may increase susceptibility to frost events. This 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, which can influence tolerance to frost. Plants deficient in K are more susceptible to frost. Soils deficient in K could benefit from increasing K levels at the start of the growing season. There is no evidence that applying other micronutrients has any impact in reducing frost damage.
- Step 3. Modify the soil heat bank. The soil heat bank is important for reducing the risk of frost (Figure 5). Farming practices that manipulate the storage and release of heat from the soil heat bank into the crop canopy at night can reduce the impact of a frost event. [9] Agronomic practices that may assist with storing heat in the soil heat bank include:
    1. Practices that alleviate non-wetting sands, such as clay delving, mould-board ploughing or spading. These practices have multiple effects, including increasing heat storage, nutrient availability and infiltration rate.
    2. Rolling the soil surface. Rolling sandy soil and loamy clay soil after seeding has reduced frost damage and prepares the surface for hay cutting should it be necessary.
    3. Reducing the amount of stubble. Stubble loads >1.5 t/ha in low-production environments (2–3 t/ha) and 3 t/ha in high-production environments (3–5 t/ha) generally increase the severity and duration of frost events and have had a detrimental effect on yield under frost.
    4. Lowering seeding rates. Seeding rates at half of normal agronomic practice can reduce frost severity and damage by creating a thinner canopy and more tillers, resulting in a spread of flowering time. However, weed competitiveness can be an issue.
    5. Cross-sowing. Crops sown twice with half the seed sown in each direction have a more even plant density, and this has been shown to release heat from the soil heat bank more slowly to warm the crop canopy at head height in early morning when frosts are more severe. However, this practice, increases sowing costs.

[9] GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

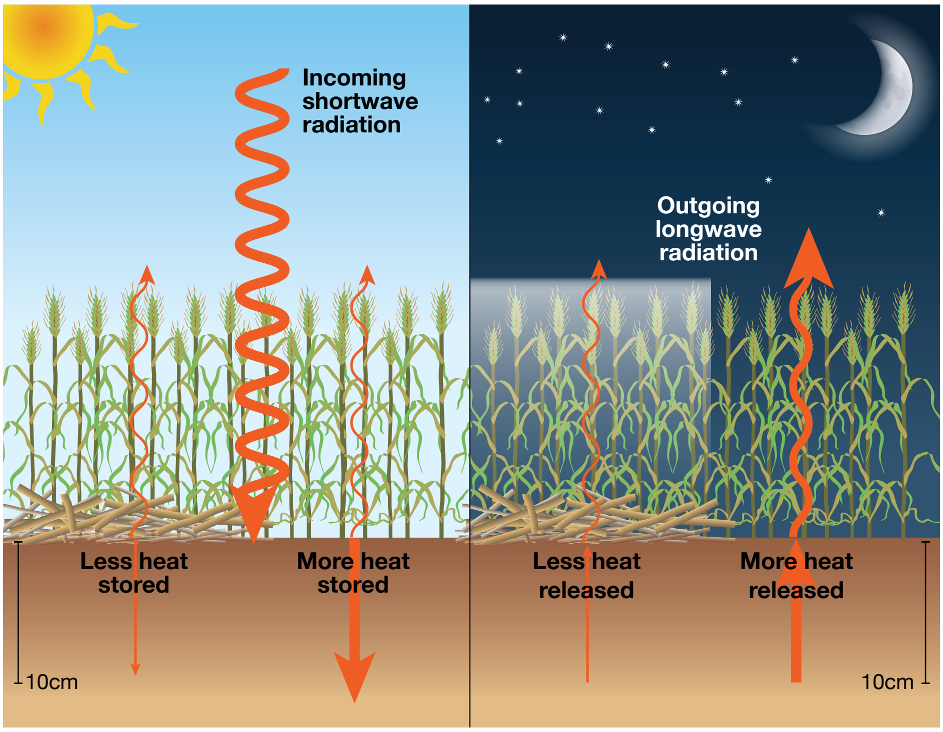

Figure 5: Soil heat bank, illustrating the role it plays in capturing heat during the day and radiating heat into the crop canopy overnight to warm flowering heads and minimise frost damage.

- Step 4. Select appropriate crops. Crop selection is an important factor to consider for frost-prone paddocks. Hay harvests biomass; therefore, reproductive frost damage does not reduce yield and in some cases can improve quality. 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; however, barley may have less frost tolerance during grainfill. Canola is an expensive crop to risk on frost-prone paddocks because of high input costs. Flower Power (from Department of Agriculture and Food WA) and Yield Prophet are useful tools to match the flowering time of varieties to your farm's prevailing conditions.
- Step 5. Manipulate flowering time of the cropping program and specific crops. When sowing in frost-risk areas, ensure that the flowering window of the cropping program is spread widely. Consider the following:
  i. Use more than one variety, and varieties with different phenology drivers, and manipulate sowing date so that crops flower over a wide window throughout the season. Flowering later than the frost window will invariably result in low yields due to heat and moisture stress.
  ii. Stage sowing dates over 3–6 weeks. If sowing just one variety, this would provide a wide flowering window. If the whole program is set to flower over a 2-week period, it is exposed to risk of greater frost damage but the yield potential is maximised in the absence of frost. Even with this strategy in place it is possible to have a number of frost events that cause damage. Flowering over a wide window will probably mean that some crop will be frosted but the aim is to reduce extensive loss.
  iii. To minimise frost risk, a mix is needed of sowing dates, crop types and maturity types to incorporate different frost-avoidance strategies into the cropping system. In years of severe frost, regardless of the strategy adopted, it may be difficult to prevent damage.
  iv. Trials have shown that blending a short-season variety with a long-season variety is an effective strategy. However, the same risk-spreading effect can be achieved by sowing one paddock with one variety and another paddock with the other.

v. Sowing at the start of a variety's preferred window will achieve higher yields than sowing late, for the same cost. Sowing time therefore remains a major driver of yield in all crops, with the primary objective of achieving flowering after the risk of frost has passed but before the onset of heat stress. Any advantage of sowing late to avoid frost risk is often outweighed by the gains from sowing on time to reduce heat and moisture stress in spring.

- Step 6. Fine-tune cultivar selection. No wheat or barley varieties are tolerant to frost. Therefore, consider using varieties that have lower susceptibility to frost during flowering. This will manage frost risk of the cropping program while maximising yield potential. However, do not select less susceptible varieties for the whole cropping program if there is an opportunity cost of lower yield without frost. Ranking information for current wheat and barley varieties for susceptibility to reproductive frost will soon be available from the National Variety Trials website (Figure 6). This information can be used to fine-tune frost risk management of new varieties after they have been selected. A new variety should be managed based on current management of known varieties of similar ranking.
  - » Example: Figure 7 shows the ranking of adapted wheat varieties for the low–medium rainfall cropping areas of the Southern Region. A grower may be considering how to incorporate La Trobe⊕ and Scope CL⊕ into their cropping program to complement Hindmarsh. From a frost-risk-management perspective, La Trobe⊕ has a slightly higher sterility under frosts than, and the same sowing/flowering time response as, Hindmarsh⊕; hence, it may need to be sown in less frost-prone parts of the landscape. Scope CL⊕ has slightly lower sterility under frost, but is also slightly later maturing than Hindmarsh⊕, so may be planted 5–7 days earlier with a slightly lower frost risk than Hindmarsh.

Figure 6: Frost research is being funded by the GRDC under the National Frost Initiative, and barley variety rankings will soon be available. ((Photo: Emma Leonard)

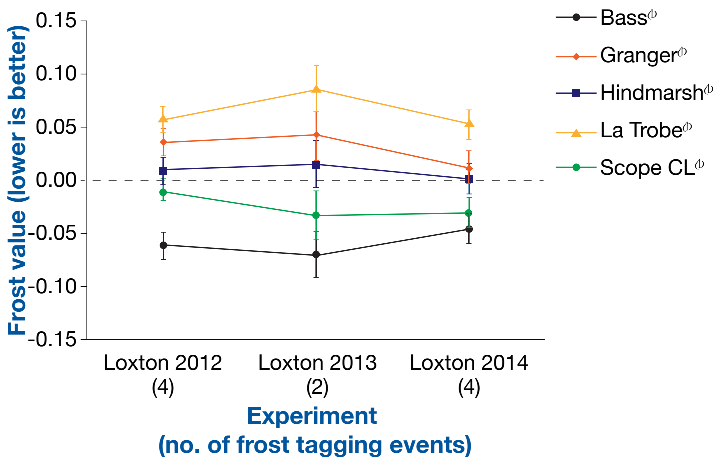

Figure 7: Frost value (FV) of sterility under flowering frost for five barley varieties tested at Loxton South Australia. FVs are presented along with prediction standard error bars. The number of frost events is indicated in parentheses for each site/year. Lower FVs are better.

Management tactics within season

The progress of the season should be monitored by regularly assessing weather forecasts and crop development in relation to frost incidence. Decisions may need to be made to use available in-crop management tactics to mitigate frost damage during the season.

Grazing

Trials in the south of Western Australis and in South Australia have shown that grazing of wheat crops in winter to delay flowering can reduce grain yield losses from spring frosts by extending the flowering date. These crops can also provide extra fodder for livestock.

This management tactic can be used not only to manipulate a crop's flowering time after seeding but also to reduce the amount of crop biomass, which will reduce frost incidence, and to compact the soil, which increases the soil heat-bank capacity.

The key message is to graze early (at the 4- or 5-leaf stage or even earlier) and intensively for a short period. Grazing for 14 days delays flowering by about 7 days. Grazing after first node (GS31) will significantly delay flowering and reduce crop yield. High stock numbers are often required.

Extra nutrients

Conservative input strategies should be adopted for frost-prone areas, and minimal or no additional nutrients should be applied during the season. Copper is the only exception, tissue test for copper during tillering and apply foliar copper at booting if tissue samples are identified as marginal. [10]

Manage N to frost risk; avoid late N top-ups in zones and paddocks identified during pre-season planning as being at higher frost risk.

Post-frost-event management tactics

Once a frost event (especially at or after flowering) has occurred, obtain an estimate of the yield loss suffered. This can be done by inspecting the affected crop and randomly collecting a sample of heads to estimate the yield loss incurred.

Then consider options for the frost-damaged crop. Tillers already formed but lower in the canopy may become important and new tillers can grow after frost damage has been incurred, depending on the location and severity of the damage. These

10 GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

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.

Option 1. Take through to harvest
If the frost occurs prior to or around GS31–32, most cereals can produce new tillers to compensate for damaged plants, provided spring rainfall is adequate. A later frost is of more concern, especially for crops such as wheat and barley, because there is no time for compensatory growth. The required grain yield to recover the costs of harvesting should be determined by using gross margins.

Option 2. Cut and bale
This is an option when late frosts occur during flowering and through grainfill. Assess crops for hay quality within a few days of the frost event and be prepared to cut a larger than intended area for hay, because grain yield may be reduced. Hay cutting can also be a good management strategy to reduce stubble, weed seedbank and disease loads for the coming season. This may allow more rotational options in the following season to recover financially from the frost (e.g. to go back with cereal on cereal in paddocks cut early for hay). Hay cutting can be an expensive exercise, and growers should have a clear path to market or a use for the hay on-farm before committing costs to this practice.

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. [11]

14.1.7 Harvesting and marketing frosted grain

The effect of frost on yield and quality of grain depends on the stage of crop development; generally, as development progresses through grain-filling, the grains become drier and less frost-susceptible.

- If affected during flowering, the grain is aborted and yield is reduced, but rarely are there any negative impacts on quality of remaining grain.
- If affected during the watery stage, grain does not develop any solids and frosted grains do not appear in the sample. Unfrosted grains can compensate and are often larger with high test weight.
- Where there is frost at the milk stage of development, grains may continue to develop, but will be light and shrivelled. Grain usually has a low hectolitre weight and high screenings, but this can usually be minimised by adjusting header settings.
- At late dough stage, frost can result in wrinkly or scalloped grains. Again, there may be low hectolitre weight and higher screenings and further cleaning may be required.

In frost-damaged crops, adjust header settings to maximise the quality of the grain harvested.

Frosted grain is in the category 'Frost Damaged', for which there is a maximum limit of 5% for Malt grades and 10% for Feed grades.

Higher classification of frost-affected grain may be achieved by cleaning grain, but the capacity and economics need to be carefully considered. [12]

[11] GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

[12] GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

14.1.8 Retaining seed from frosted crops

Grain that forms when a flowering frost has occurred is often plump and makes good-quality seed; however, where frost occurs during grainfill, the germination and establishment of these damaged grains is compromised.

Even after grading, frosted grain can have 20–50% lower crop establishment than unfrosted grain in the following season. As a result, growers need to retain more seed than usual, sow into an optimum seedbed and increase seeding rate to compensate for lower crop germination and lower vigour of frosted grain.

Growers are advised to:

- Retain and grade seed only from the less frost-damaged areas.
- Test germination prior to sowing and adjust seeding rates accordingly to ensure uniform crop establishment.
- Plan not to retain frost-affected seed for more than 1 year. [13]

14.1.9 Recovering from frost

Dealing with the financial and personal impact of frost damage:

- Act early if frost damage has had a serious financial impact.
- Prepare a future business plan and, where necessary, seek advice on tactics from consultants and rural counsellors.
- Communicate and discuss the likely impact of the frost with your bank and prepare a recovery plan with the bank and other finance providers.
- Assess the physical, financial and social situation factually so that decisions are based on the best information.
- Develop alternative strategies for dealing with frosted crops in future programs, and for how finances may need to be adjusted.
- Prepare a draft budget and physical plans for next year and provide this information to business partners and financiers.
- Develop a written plan of your proposed action and review it as information and circumstances change.
- Assess the personal impact, remain conscious of the fact the frost can be an emotional rollercoaster and trigger feelings of depression, grief and loss. Maintain contact with family, friends and colleagues and seek professional advice if necessary. Also, be aware of impact on your neighbours and community.
- Remember to assess your own situation and avoid getting caught up in negativity.
- Frost can be easily forgotten from one year to the next. Do not let early rains distract you from the plans to spread or reduce risk. [14]

14.1.10 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:

- Genetics: developing more frost-tolerant wheat and barley germplasm and ranking current wheat and barley varieties for susceptibility to frost.

13 GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

14 GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

- 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.
- 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. [15]

Useful tools

Weather apps: CliMate, Meteye, DAFWA weather stations app. AgExcellence Alliance has an app listing on their website http://agex.org.au/farming-applications/

Plant development apps: MyCrop, Flower Power

Temperature monitors: HOBO Data Loggers

14.1.11 Frost identification—what to look for and how to look for it

Key points for crop frost-damage assessment:

- Inspect crops regularly between booting and grain-filling, and when canopy temperatures fall below 1°C in your paddock.
- Examine the crop in the more susceptible low parts of the landscape or at the base of a slope first, and if damaged, continue the examination in other parts of the paddock.
- Walk through the crop and examine a whole plant every 20 or 30 paces; alternatively, drive a vehicle up the boom-spray tracks, stopping regularly to walk into the crop to inspect plants.
- Peel back the leaves and look for stem damage.
- If the head has not emerged from the boot, check to see if the head is damaged. You will need to dissect the plant carefully, with a sharp knife, from the top down to find the head of the plant.
- If the crop is flowering check the flower parts in spikelets flowering at the time.
- If the crop has flowered, open the florets to check whether the grain is developing (see Figure 8b for photo of a healthy head).
- Tag a few heads with plastic insulation tape and note the stage of grainfill. Return a few days later to determine whether grain development and grain filling are continuing. Normal grain should be extending at ~1 mm every 2 days until the full length is achieved. [16]

Assessing the damage

After a known frost event, or when the crop canopy temperature has been near or below 0°C, the crop needs to be monitored over the following week so that management decisions can be made. The pollen and anthers are most susceptible to cold, desiccation and freezing damage both before and after head emergence.

During this time, visual symptoms of frost bleaching may not be apparent; therefore, it is essential to check individual florets for signs of damage. Inspection after 2 days may show anther damage, and after 4 days should reveal whether grain development has been affected. Note that crops will often be affected unevenly and not all plants will show obvious symptoms.

Carefully remove the leaf sheath from around the stem and check above the nodes below the head for symptoms on the peduncle or stem of the plant. To inspect heads, peel back the glumes to inspect the reproductive structures or developing grain inside.

More information

GRDC Ground Cover: Extreme weather events on the rise

GRDC Ground Cover: Issue 114—Climate forecasting

GRDC Update Papers: Agronomist's guide to information for managing weather and climate risk

GRDC Fact Sheets: Farm Business Management: Making effective business decisions

GRDC Fact Sheets: Farm business management: Simple and effective business planning

GRDC: Cereal growth stages

NVT: Zadoks growth scale

GRDC Video: Frost Initiative playlist

GRDC Ground Cover: Issue 109—Frost

GRDC Back Pocket Guide: Cereals—frost identification

GRDC: Managing frost risk—a guide for southern Australian grains

DAFWA: Frost and cropping

AWB: Wheat Quality Fact Sheet

15 GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

16 GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

Inspect spikelets halfway up representative heads because this is the most developed part, then above and below the centre. A hand lens may be of benefit, and digital microscopes are very useful. Check multiple areas of the paddock.

A determination of yield loss can be crudely made by roughly calculating the percentage of affected florets and multiplying by the expected yield. For example, a barley crop with an estimated yield of 2.5 t/ha is frosted and a sample of 20 heads is taken from the crop; of the 20 heads, 12 are completely filled and 8 half-filled with grain. This would represent a yield loss of: 8/20 x 50% x 2500= 500 kg/ha. [17]

Juvenile frost damage

Frost damage frequently occurs to crops in the juvenile stage in parts of Australia; however, there is usually little or no yield loss because of ample time for the plant to compensate with new leaves or tillers.

The worst damage occurs when the growing point of the plant is above ground level and there is dense mulch on the soil surface, usually associated with the retention of large amounts of stubble. The growing point is embedded in the stubble or at the junction of the stubble and soil surface. Although stubble insulates anything it covers, the low density and light colour of stubble can produce very low temperatures on and within the stubble itself.

Leaves can often be damaged by frost, showing white, often twisted bleaching of emerging leaves and yellowing of emerged leaves. Usually leaf damage is inconsequential, but occasionally, severe photosynthetic impairment can occur to flag leaves resulting in smaller grain and lower yield. [18]

Stem-elongation frost damage

At the very early stage of development, the head is protected to a degree by the leaf sheaths surrounding it. However, during stem elongation (GS30–39), the developing head and stems can still be frozen by very severe frosts (Figures 8 and 9.)

Carefully dissect through the leaf sheaths with a sharp knife to find the approximate position of the head and then un-wind the remaining tissue to expose the small head. At this stage of development, the frosted heads/tillers will not emerge (Figure 8a) and the crop will re-tiller.

Frost damage to the stem may be evident as blistering and bleaching of the stem internodes (Figure 8a). Sometimes this is associated with damage to the head, but not always, as in Figure 10, where the stem is damaged but not the developing head.

Experience in the 2014 season indicates that crops can re-tiller and achieve reasonable yield levels, provided temperatures are favourable and either soil moisture is good or spring rainfall is adequate. [19]

[17] GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

[18] GRDC National Frost Initiative (2016) and associated partners, GRDC Tips and Tactics. http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

[19] GRDC National Frost Initiative (2016) and associated partners, GRDC Tips and Tactics. http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

Figure 8: (a) Damage to developing wheat heads from frost at stem elongation: one healthy head (left) and five frosted heads (FS, frosted stem). (b) Close up of a healthy wheat head. Frost occurred at ~GS32, and photos were taken at ~GS37, 2–3 weeks later. (Photos: (a) Karl Moore and (b) Ben Biddulph, DAFWA)

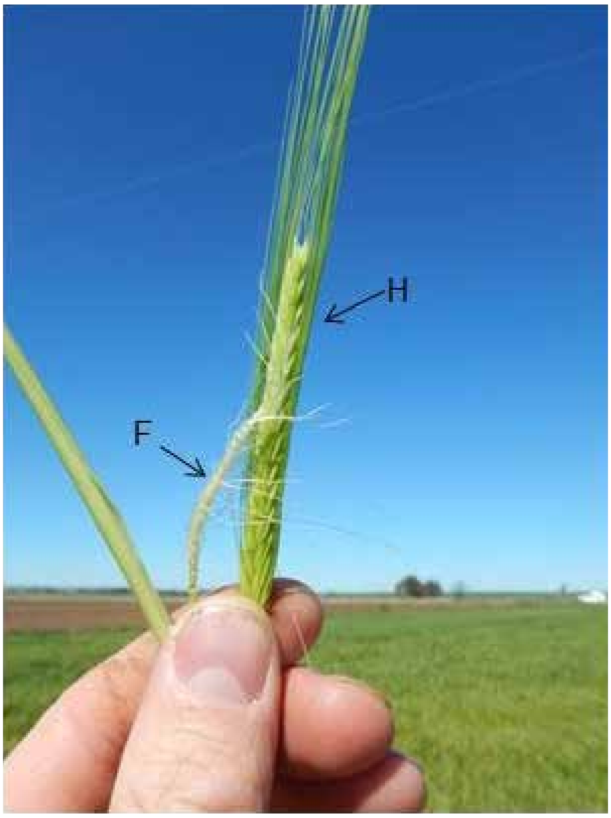

Figure 9: Damage to the developing barley head from frost at stem elongation ~GS35; frosted head (F) and healthy head (H). Photos were taken at 2–3 weeks after the frost at ~GS49. (Photo: Ben Biddulph, DAFWA)

Figure 10: Damage to the stem internodes, but viable head. (Photo: Ben Biddulph, DAFWA)

Head damage: cold damage to developing head prior to head emergence

Prior to head emergence at GS51, the head is protected to a degree by the leaf sheaths surrounding it.

If chilling or frost occurs during the sensitive stages of pollen meiosis (GS39–45) and early pollen development (GS45–65), the head or particular florets can stop development and abort.

The damage at this stage is quite distinctive and heads emerge with a pale, undeveloped colour from white (GS39; Figure 11, left panel) to light green (GS51; Figure

11, right panel), depending on the stage of pollen development at which the florets were aborted (the later in development the greener). In most cases, this is not from freezing damage but from the damaging effects of cold and desiccation associated with the frost event causing a generalised stress response and pollen abortion.

Figure 11: Cold- and desiccation-induced sterility and floret abortion from frost at booting during: left, pollen meiosis (flag leaf emergence ~GS39); centre, pollen development (booting ~GS45); right, pollen maturation (~GS49, ear peep). Photos taken at flowering after head emergence, 2–3 weeks after the frost events. (Photos: Sarah Jackson)

Head damage at flowering: cold and desiccation damage during flowering

Cold and desiccation damage to wheat heads after partial or complete head emergence (GS51 onwards) can occur when canopy temperature drops to ≤0°C.

Damage may not be visible for several days unless the heads are closely inspected and the reproductive parts inside the florets are inspected for damage as in Figures 12 and 13. A digital microscope is useful for aiding identification. [20]

During normal head development, immature anthers are light green, turning yellow on maturity just prior to flowering (Figure 13a) and prior to extruding from the floret. Healthy anthers turn from yellow prior to pollen release (Figure 13a) to white after they have released the yellow pollen (Figure 13b, c)

After a frost event, the anther may remain light green to yellow for 1–2 days before turning white and shrivelled (as in Figure 13*d*). Often anthers have a water-soaked appearance (similar to frozen lettuce leaves). The tell-tale sign of frost damage is white anthers and ovules that are not swollen or developing (Figure 13b, d).

The stigma, style and ovary (or the female reproductive parts) may also be affected. The stigma in a healthy plant will be feathery, sticky and greenish white before pollination (Figure 13a). A fertilised stigma has a light coating of yellow pollen cells and curls up (Figure 13b, c), whereas a frost-affected, unfertilised stigma will become off-white to brown and shrivelled in appearance (Figure 13d).

[20] GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

Figure 12: A head frosted at flowering (GS65) (left) compared with an unfrosted head at 2–3 days after the frost event, when at GS70.2. (Photo: Pia Scanlon, DAFWA)

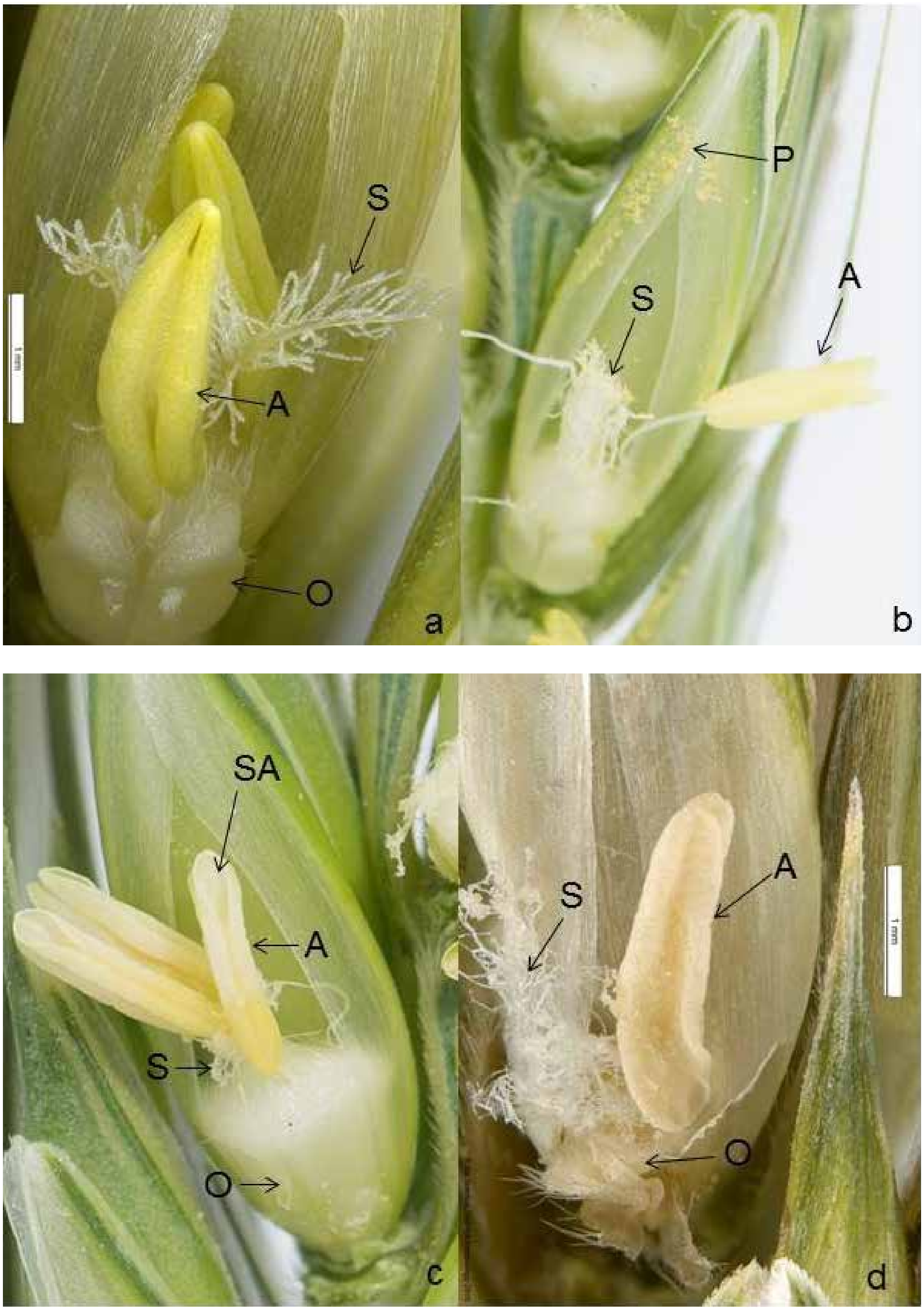

Figure 13: (a) Healthy floret about to flower: anthers (A), stigmas (S) and ovaries (O) of wheat within a floret. (b) Freshly fertilised floret: pollen (P). (c) Fertilised and swollen ovule: split anthers (SA). (d) Frosted floret. Photo of frosted floret taken at GS70.2 of heads frosted just prior to flowering (GS61). (Photos: Pia Scanlon, DAFWA)

This damage at flowering is mainly from the cold and the desiccating effects of the ice formation during a frost event. With more severe frost events when freezing damage occurs, the symptoms on the internal reproductive structures are similar, but there can be more obvious blighting of the heads (Figure 14).

Head damage at flowering: freezing damage to head and reproductive structures

If the head is partially emerged from the flag leaf during a frost, part or all of the head may be frozen and exhibit a blighted or bleached appearance several days after the frost (Figure 14).

Blighting usually affects only a small proportion of the heads as in Figure 14, but is also often associated with frost damage to the reproductive structures inside, which requires closer inspection (as in Figure 13, above).

After about 1 week, cold, desiccation and freezing head damage becomes more obvious, and may not require dissection. Because of the low fertilisation of the grain, whole heads begin to lose their green appearance, turning yellow as a result of resource reallocation to the development of new tillers, and in severe cases the heads that have been frozen turn white.

The florets do not fill with grain, so the heads will feel soft, papery and spongy when squeezed, due to physical damage from the ice formation. Heads are lighter in weight than normal, with the lack of grain development and grain filling. [21]

Figure 14: Desiccation and freezing damage, often called frost blighting, of three wheat heads compared with a healthy head (right). Frost event was at ~GS55 and the photo was taken 7 days later at GS61. (Photo: Pia Scanlon, DAFWA)

Head damage after flowering: freezing damage during grain development and grain-filling

After flowering, the head is less susceptible to cold and desiccation damage but still susceptible to freezing damage. However, flowering is not synchronous, so although the centre of a head may have completed flowering the spikelets towards the top and bottom may still be flowering.

When frosted during water and milk development (GD in Figure 15; GS70.2–79), the developing grains may be frozen and do not continue to develop. It turns a white to grey colour and becomes shrivelled and dry instead of plump and full of clear, sugar-filled solution. These grains are not normally retained in a header sample and they often shatter easily at maturity.

[21] GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

When frosted during dough development and grain-filling (GF in Figure 15; GS80–89), the grains often do not abort but become scalloped and continue to develop. Often they initially develop a dark green, water-soaked appearance that is visible through the outside of the grain. Squeezing these grains at the early dough stage (GS81), the contents will be grey and liquid instead of white, slippery and viscous.

Frosts often follow the cycle of weather patterns; therefore, crops are often frosted at several successive stages of development and will exhibit a combination of different symptoms as seen in Figure 15 where the same head has damage from frost at flowering (GS61), grain development (GS70.8) and early grain filling (GS81). These symptoms also change over time depending on the time since the frost damage occurred (Figure 16).

Wheat that has been frosted at the grain-filling stages is a little more resilient to the effects of frost, often showing grains with shrunken sides, slightly wrinkled and will have a reduced grain weight. These grains may be present in a header sample and will be counted as frost-affected grains (Figure 17).

It is not recommended to keep frost-affected grain for sowing the following year; germination may be reduced. [22]

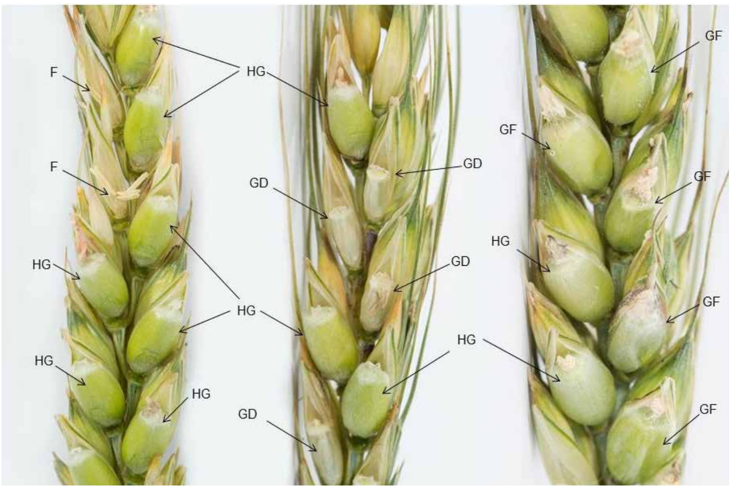

Figure 15: Wheat head that has been frosted at flowering (GS65; F) and at grain development (GS70.8; GD), and partially frosted during grain filling (GS81; GF). Frost-affected grains starting to shrivel (GD) to form a pinched or scalloped appearance (GF) compared with healthy grains (HG). Frosts occurred at ~GS65, GS70.8 and GS81, and the photo was taken at ~GS83. (Photo: Pia Scanlon, DAFWA)

22 GRDC National Frost Initiative (2016) and associated partners, GRDC Tips and Tactics. http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

Figure 16: Head partially frosted at flowering (GS65; left); frosted at flowering and grain development (GS65 and GS70.8; centre); and at flowering, grain development and grain filling (GS65, GS70.8 and GS81; right). Photo was taken of heads of the same variety from a time-of-sowing trial indicating cumulative damage and the change in symptoms with time after frost events. (Photo: Pia Scanlon, DAFWA)

Figure 17: Grains collected at maturity that are (a, b) unfrosted; or frosted (c) at GS70.5–71; (d) GS73–75; (e) GS75–79; (f) GS81–83; (g) GS83–87.

Stem damage after flowering: freezing damage to the peduncle after head emergence during grain development and grain-filling

At and after ear peep (GS51) the peduncle is susceptible to freezing damage. Two types of peduncle damage are frequently found after flowering. Type 1 damage occurs above the first node, and Type 2 is damage at, or above, the attachment of the flag leaf.

Type 2 damage is normally most severe after a slight rainfall event at ~GS51–55 when the rain causes a small amount of water to collect inside the leaf sheath surrounding the most undeveloped section of the peduncle (Figure 18).

Initially, 1–3 days after the frost event, the head and peduncle are easily pulled from the standing crop and the damaged stem has a dark green water saturated appearance (Figure 18, upper panel). This is common for Type 1 and Type 2 damage. Sometimes a slightly less severe symptom of Type 1 will be blistering.

At 3–7 days after the frost event, the head and peduncle cannot be pulled from the standing crop with Type 2 damage, and in sandy soils the whole plant will pull out. This depends on the severity of the frost. Often the stems can be pulled out because there is complete tissue death above the node. It is due to lignification and scaring of the frosted section of the peduncle (Figure 18, lower panel close up). This section is often light green and the surface of the peduncle is rough in this area. The head and peduncle can be easily pulled out with Type 1 damage, and distinct narrowing of the peduncle just above the node will be obvious.

Around 5–10 days after the frost event, the stem (or peduncle) when frosted will have a light green or white ring around it with Type 2 damage (Figure 18, lower panel; and Figure 19) and will feel rough and hard.

If the stem frost is not very severe and the reproductive tissues have not been destroyed by the same frost event, sugar and water will continue to be taken up by the developing head. The plants may recover and achieve a 20–40% reduced yield.

Recovery and compensation is greatest with ample soil water and mild temperatures. Severe Type 1 peduncle frosts can result in 100% yield loss. Viability of the tissue can be tested by taking a sample of heads together with their stalks, cutting cleanly with a knife low on the plant and placing the samples in a blue food dye solution overnight. If the tissue is viable, the heads will turn blue and grainfill may proceed normally.

More severely affected stems can become distorted and sugar and water flow may be restricted to the head, reducing grainfill and resulting in high screenings.

Frost damage can also weaken the stem, causing lodging after strong winds, making harvest difficult. Blistering and/or cracking of the nodes and leaf sheath may also occur in severe events. [23]

[23] GRDC National Frost Initiative (2016) and associated partners, GRDC Tips and Tactics. http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

A 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

Figure 18: Upper panel: stem frost damage at the bottom/growing point of the peduncle taken the morning after a frost event. Lower panel: photo taken 3 weeks after the frost, when at GS61. The crop canopy was at ~GS55 with stem-frost-affected peduncles occurring in tillers between ear peep (GS51) and partial head emergence (GS55). (Photos: upper panel, Ben Biddulph; lower panel, Pia Scanlon, DAFWA).

Figure 19: Peduncle stem damage showing light-green region (S) and bleached heads with infertile florets (B).

14.2 Soil moisture issues for barley

Availability of soil moisture has major interactions with the rate of transpiration and therefore photosynthetic production.

14.2.1 Moisture stress

Moisture stress slows photosynthesis and leaf area expansion, reducing dry matter production. It also limits root growth, which reduces nutrient uptake. This is important in areas with low rainfall. The period of crop growth is restricted at the start of the season by lack of rainfall and at the end of the season by water deficits and high temperatures. There is therefore little scope in these areas to lengthen the period of crop growth to increase dry matter production and yields. [24]

14.2.2 Waterlogging

Barley is very susceptible to waterlogging. It is less tolerant than wheat or oats. Barley should not be grown on soils where waterlogging is likely to occur for periods of >2 weeks, or on irrigation layouts with poor drainage.

Waterlogging occurs when rainfall exceeds the infiltration rate, water-holding capacity, and internal drainage rate of the soil profile. Waterlogging fills the air spaces of the soil with water, reducing the oxygen concentration. This limits root function and survival, resulting in decreased crop growth, or plant death. Availability of nitrogen and other nutrients may also be reduced. The lack of nutrients slows the rate of leaf growth and accelerates leaf death. Tiller initiation is also slowed, reducing the growth and survival of tillers. These conditions contribute to yield reductions. The amount of reduction depends on the stage of plant development when the waterlogging occurs, the duration of the waterlogging, and the soil quality. [25]

24 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series, Industry & Investment NSW/NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

25 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series, Industry & Investment NSW/NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf