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GRDC GROWNOTES™

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

WHEAT

SECTION 14

ENVIRONMENTAL ISSUES

FROST | WATERLOGGING – FLOODING ISSUES | HEAT STRESS

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 due to direct losses from crops damaged by frost and growers missing opportunities. Due to the variability in the incidence and severity of frost a number of management strategies should be utilised in a farm management plan.

Key points:

- The frost season in Australia has lengthened with earlier season starts and later finishes.
- 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, 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. [1]

Key points

A comprehensive frost management strategy needs to be part of annual farm planning, it should include

- pre-season,
- in-crop and
- post frost event management tactics
- In some Australian production areas the risk of frost has increased due to 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 individual 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 how the crop is managed.
- 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.
- Frost damage is not always obvious and crops should be inspected within five to seven days after a suspected frost event.

[1] 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;

- 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 grains belt, 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 zero. 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, as soil moisture adds to the heat storage capacity of the soil.

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 it stays below zero and the how far below zero it gets. [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 also increases below the canopy.

Measuring temperature at Stevenson Screen height (1.2m) will not be the same as at the canopy height and the more remote the measurement is taken 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.

Temperature recorded at a local BOM site at Stevenson Screen height (standard) may or 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 general rule of thumb is that the canopy temperature is approximately 1.5 to 2.5°C lower than Stevenson Screen temperature at 1.2m at the same point in the landscape.

The most accurate 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 between 10 and 55 days between 1960 and 2011 and in some parts of eastern Australia the number of frost events have increased.

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

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

[2] 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;

[3] 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;

[4] 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;

In the eastern Australian grainbelt the window of frost occurrence has broadened, so frosts are occurring both earlier and much later in the season. 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 three weeks in the Victorian grainbelt and by two weeks in the NSW grainbelt. The frost window in Western Australia and Queensland has, statistically, remained the same length, while eastern SA sites are similar to Victoria and sites in the west of SA are more like WA. Northern Victoria seems to be the epicentre of the change in frost occurrence, with some locations experiencing a broadening of the frost season by 53 days. [5]

14.1.4 How does frost affect crops?

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

While ice melts at 0°C, the freezing temperature of water is not 0°C, pure water does not readily freeze until -40°C. Water and plant tissue supercools at temperatures below 0°C, up 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 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 sub zero 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; from cold or chilling, to desiccation and then finally freezing (Figure 1). It is a step wise response, i.e. desiccation will not occur without first getting cold damage, freezing damage will only occur after first experiencing cold and desiccation damage: Then finally the freezing damage will be random throughout a crop canopy and tissues due to the random nature of the ice nucleation and formation.

1. Cold or chilling damage - occurs when plants are exposed to temperatures less than 10°C down to -2°C (Fig. 1). 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 this 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 to - 2°C (Fig. 1). 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 also then draws out the water from inside the cells and dehydrates the cells. The cells themselves may not necessarily freeze or have ice form inside them. This process won't necessarily kill the cells as long as the dehydration and desiccation doesn't go too far. When the ice thaws these cells can re-hydrate 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 (Fig. 1). The ice crystals physically rupture cell walls and membranes within the cells causing physical damage to 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 also susceptible at the earlier stages of booting (from Zadok Stage 45-71 Fig 2.). Losses

[5] 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;

in grain yield and quality from frost primarily occur between stem elongation and late grain filling.

Pulses and canola are particularly susceptible during pod filling and losses may reflect pod wall thickness and the location of pods above or below the canopy.

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. [6]

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. As 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 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. [7]

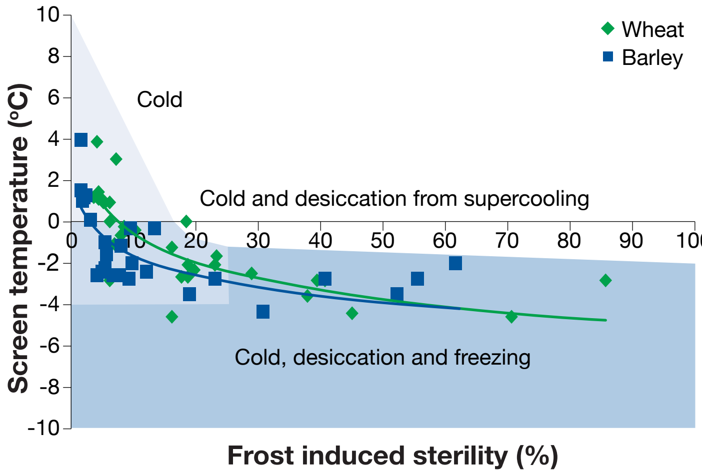

Figure 1: Average frost induced sterility in flowering heads of wheat and barley versus minimum Stevenson's screen temperature from frosts at trials from WA, SA and NSW frost nurseries 2010-2014.

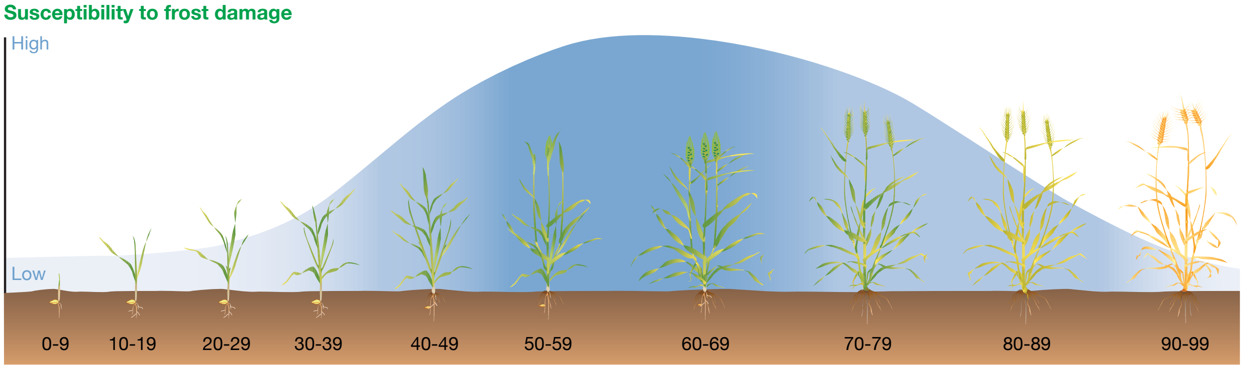

Figure 2: Susceptibility of wheat to frost during the development cycle

[6] 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;

[7] 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;

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 proactive, pre-season management tactics, in-season tactics, and strategies following the incidence of frost. [8]

14.1.7 Pre-season management tactics

There are two types of pre-season management tactics 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 tactics:

STEP 1 Assess personal approach to risk

Consider your personal approach to risk in your business, every individual will have a different approach. As part of this process 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 due to the location and using historic seasonal records and forecasts. Spatial variability across the landscape should also be considered as cold air will flow into any lower regions. Temperature monitoring equipment, such as Tiny Tags, 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 is subject to the location of the business and skill set of the manager but the largest financial losses with frost have occurred where growers have a limited range of enterprises or crop types. Intensive cropping systems especially focused only on canola and spring wheat are often at the mercy of frost more than a diversified business; both crops are highly susceptible to frost damage.

STEP 4 Zone property/paddock

Paddocks or areas in paddocks that are prone to frost can be identified through past experience, the use of precision tools such as topographic, electromagnetic and yield maps and temperature monitors to locate susceptible zones. This can help determine the appropriate management practice to use to mitigate the incidence of frost.

Be aware that frost prone paddocks can be high yielding areas on a farm when frosts do not occur. Once the farm has been zoned for potential frost incidence the following tactics can be considered. [9]

Frost zone management tactics:

STEP 1 Consider enterprise within a zone

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

8 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;

9 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;

STEP 2 Review nutrient management

Targeting fertiliser (N, P, K) on high risk paddocks and seed rates 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.

While high nitrogen rates increase yield potential it will also promote vegetative biomass production and increase the susceptibility of the crop to frost. Using conservative nitrogen rates at seeding and avoiding late top-ups appears to result in less crop damage.

It is best if crops are not deficient in potassium or copper, as this 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 potentially influence tolerance to frost. It has been shown that plants deficient in potassium are more susceptible to frost. Soils that are deficient in potassium could benefit from increasing potassium levels at the start of the growing season. However it is unlikely that there will be a benefit of extra potassium applied to plants that are not potassium deficient.

Frost tolerance can't be bought by applying extra potassium or copper to a crop that is not deficient. There is no evidence that applying other micronutrients has any impact to reduce frost damage.

STEP 3 Modify soil heat bank

Techniques that manipulate the storage and release of heat from the soil heat bank into the crop canopy at night are important to consider to reduce the impact of a frost event (Figure 3). [10]

[10] 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;

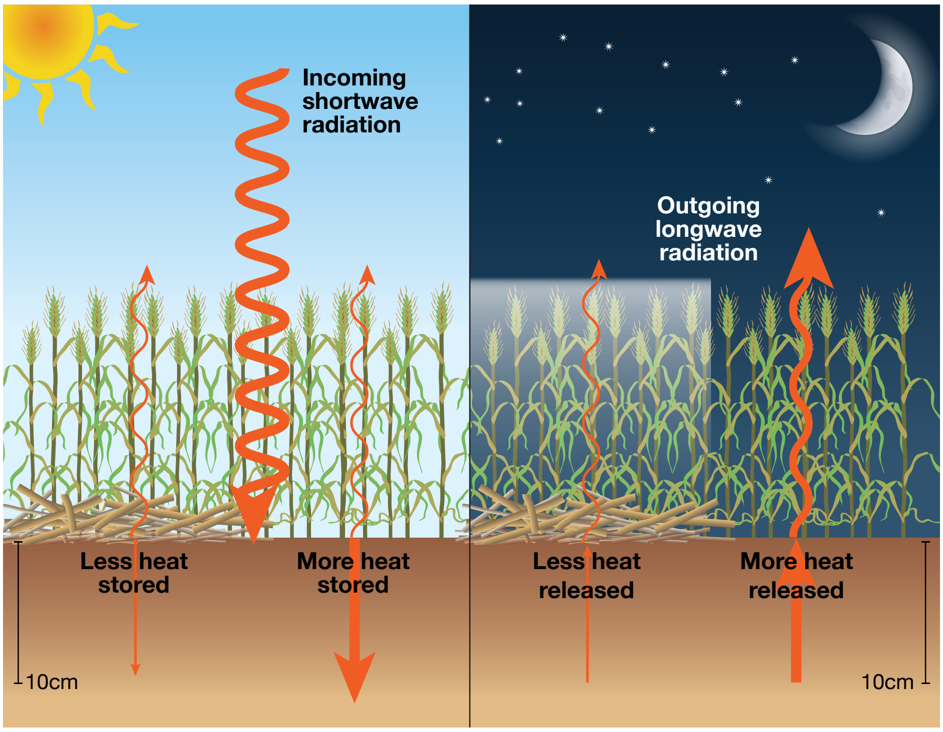

Figure 3: Soil heat bank illustrating the role in which it captures heat during the day and radiates heat into the crop canopy overnight to warm flowering heads and minimise frost damage

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

- Practices that alleviate non wetting sands such as clay delving, mould board ploughing or spading - have multiple effects; these include increasing heat storage, nutrient availability and infiltration rate.
- Rolling the soil surface - rolling sandy soil and loamy clay soil after seeding has reduced frost damage and also prepares the surface for hay cutting should it be necessary.
- Reducing the amount of stubble - stubble loads above 1.5 t/ha in low production environments (2–3 t/ha) and 3 t/ha in high production environments (3–5 t/ha) generally increase the severity and duration of frost events and have had a detrimental effect on yield under frost.
- Lower 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. Weed competitiveness can be an issue.
- Cross sowing crops sown twice with half the seed sown in each direction gives a more even plant density and 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. This practice, however, increases sowing costs.

STEP 4 Select appropriate crops

Crop selection is an important factor to consider for frost-prone paddocks. Hay harvests biomass and hence 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, but it is not known if barley and wheat have different frost tolerance during grain fill. Canola is an expensive crop to risk on frost-prone paddocks due to high input costs.

Flower Power (DAFWA) and Yield Profit are useful tools to match the flowering time of varieties to your farms prevailing conditions.

STEP 5 Manipulate flowering time of cropping program and specific crops

When wheat is planted in frost risk areas, a good tactic is to ensure the flowering window of the cropping program is spread widely by using more than one variety and manipulating sowing date and varieties with different phenology drivers so crops flower over a wide window throughout the season. It should be noted that flowering later than the frost window will invariably result in low yields due to heat and moisture stress.

It is recommended to stage sowing dates over a 3-6 week period. If sowing just one variety, this would provide a wide flowering window. If winter wheat is sown first, then a long season spring wheat or daylength sensitive wheat, then the early maturing wheats last, the whole wheat program is set to flower over a 2 week period, potentially exposing it to more frost risk but maximising the yield potential in the absence of frost. Even with this strategy in place it is possible to have 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.

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

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

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

STEP 6 Fine tune cultivar selection

No wheat or barley varieties are tolerant to frost. Consider using wheat and barley varieties that have lower susceptibility to frost during flowering to manage frost risk of the cropping program while maximising yield potential. There is no point selecting less susceptible varieties for the whole cropping program if there is an opportunity cost of lower yield without frost.

Preliminary ranking information for current wheat and barley varieties for susceptibility to reproductive frost is available from the National Variety Trial website (www.nvtonline.com.au). Use this information to fine tune frost risk of new varieties after they have been selected. A new variety should be managed based on how known varieties of similar ranking are currently managed.

Figure 4 shows an example of the ranking of adapted wheat varieties for the Western Region. A grower in the WA Upper Great Southern may be considering how to incorporate Corack and Scout into their cropping program to replace Wyalkatchem and Yitpi. From a frost risk management point of view, Corack can be treated in the same way as Wyalkatchem or Mace. Given its similar sowing/flowering time response to Mace it can essentially be treated the same in terms of sowing/flowering time and position in the landscape. Scout on the other hand although similar in frost performance to Yitpi flowers around 5-7 days earlier so may need to be sown slightly later than Yitpi to manage frost risk comparably to Yitpi.

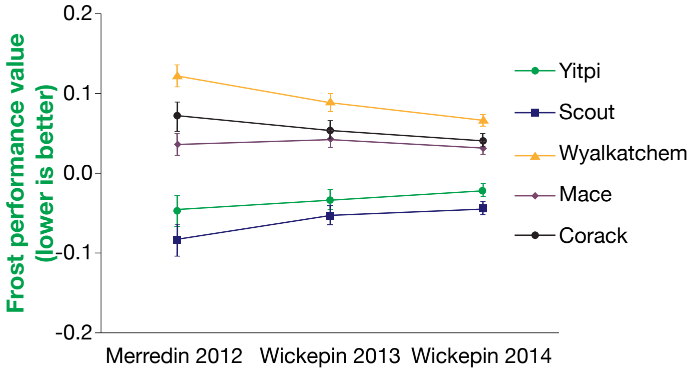

Figure 4: Rankings of regionally adapted wheat varieties for frost susceptibility in the Western Region.

Figure 5 shows an example of the ranking of adapted wheat varieties for the low to medium rainfall cropping areas of the Southern Region. Mace is a widely grown and adapted high yielding variety for most of the area. Emu Rock, Yitpi and Scout are all slightly better than Mace in their ability to yield when there are flowering frosts. Emu Rock has similar maturity to Mace while Scout is slightly later. Yitpi has some daylength sensitivity so can be sown earlier without causing earlier maturity. There could be some advantage in adopting an area of Emu Rock, Scout or Yitpi to reduce the overall farm susceptibility compared to growing all Mace.

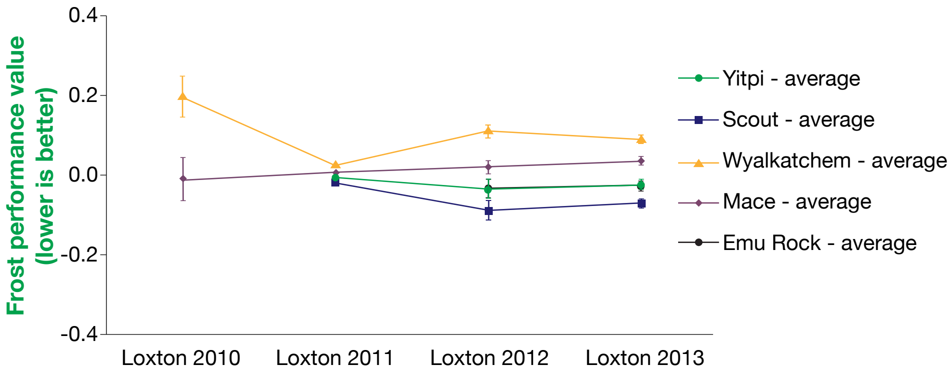

Figure 5: Frost Value graph for five wheat varieties tested at Loxton South Australia. Each FV for each variety is presented along with prediction standard error bars. The number of tagging events is indicated in brackets for each site/year. Lower FVs are better.

14.1.8 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 southern WA and SA have shown grazing wheat crops in winter to delay flowering can reduce grain yield losses from spring frosts by extending the flowering date. Additionally these crops can provide extra fodder for livestock.

This management tactic can be used as a tool to not only 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 crop four-five leaf stage or even earlier) and graze hard for a short period. Fourteen days grazing delays flowering by about seven days. Grazing after first node (Z31) will significantly delay flowering and crop yield. High stock numbers are often required.

Extra nutrients

Conservative input strategies should be adopted for frost prone area and minimal or no additional nutrients should be applied during the season. Manage nitrogen to frost risk. Avoid late nitrogen top-ups in zones and paddocks which have been identified during pre-season planning as having higher frost risk.

Copper is the only exception, tissue test for copper during tillering and apply foliar copper at booting if tissue samples are identified as marginal. [11]

14.1.9 Post frost event - management tactics

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

After the level of frost damage is estimated the next step is to 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 compensatory tillers will have delayed maturity, but where soil moisture reserves are high, or its early in the season they may be able to contribute to grain yield.

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. A later frost is more concerning, especially for crops such as wheat and barley, as there is no 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 than intended area for hay as grain yield may be reduced. 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 costs to this practice.

OPTION 3 Graze

Grazing is an option after a late frost, when there is little or no chance of plant recovery, or when hay is not an option because of farm set-up or limited marketing opportunities. Spray-topping for weed seed control may also be incorporated, especially if the paddock will be sown to crop the next year.

OPTION 4 Green or brown manure

Ploughing in the green crop or spraying out any remaining crop and weeds will return organic matter and nutrients to the soil, manage crop residues and improve soil fertility and structure. The economics need to be considered carefully.

OPTION 5 Crop topping

Accept the yield loss but ensure annual weeds are controlled for future years. Crop topping of frosted areas may still be a worthwhile practice even if harvest has been abandoned. [12]

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11 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;

12 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;

14.1.10 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 they become less frost susceptible. If affected during -

flowering: the grain is aborted and yield is reduced but there is rarely any negative impacts on quality of remaining grain.

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.

milk stage of development: grains may continue to develop, but will be light and shrivelled. They usually have a low hectolitre weight and high screenings, but this can usually be minimised by adjusting header settings.

late dough stage: can result in wrinkly/scalloped grains. Again, these may have a 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 included in the category 'Dry Green, Sappy and Frost Distorted', for which there is a maximum limit of 1% in total. Grain containing over 1% but less than 10% Frosted Grain is classified as Australian General Purpose (AGP). Any grain exceeding this level will be classified as feed and is only suitable for stock feed.

Higher classification of frost affected grain may be achieved by cleaning grain but the capacity and economics of doing this needs to be carefully considered. [13]

14.1.11 Retaining seed from frosted crops

Grain that forms when a flowering frost occurs is often plump and makes good quality seed however where frost occurs during grain fill variable effects can impact the germination and establishment of this damaged grains.

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

Growers are advised to:

1. Retain and grade seed only from less frost damaged areas. Also retain slightly more seed than normal, depending on extent of damage (screenings/ frost distorted grain counts) as seeding rate may need to be increased.
2. Test germination prior to sowing and adjust seeding rates accordingly to ensure uniform crop establishment
3. Do not plan to retain frost affected seed for more than a year. [14]

14.1.12 Recovering from frost

Dealing with the financial 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.
- Access the physical, financial and people situation factually so that decisions are based on the best information.

[13] 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;

[14] 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;

- Develop alternate strategies for dealing with frosted crops in future programs and 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 don't get caught up in negativity and 'pub talk'.
- Frost can be easily forgotten from one year to the next. Don't let early rain distract the plans to spread or reduce risk. [15]

14.1.13 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;

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. [16]

Useful tools

Weather apps: see AgExcellence Alliance for a review http://agex.org.au/

Plant development apps (eg MyCrop, DAFWA FlowerPower)

Temperature monitors for example see http://www.hobodataloggers.com.au/outpost-frost-alarm-system-3?utm_source=HOBO+Data+Logging+E-News+June+2015&utm_campaign=Data+Logging+E-News+June+2015&utm_medium=email

14.1.14 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 first and, if damaged, continue the examination in other parts of the paddock. Often the most susceptible parts are the lowest points or at the base of a slope.
- Walk through the crop and examine a whole plant every 20 or 30 paces or 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.

15 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;

16 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;

- If the head has not emerged from the boot, check to see if the head is damaged. You will need to carefully dissect the plant from the top down to find the head of the plant (with a sharp knife).
- 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 the grain is developing. See photos below for what is healthy.
- Tag a few heads with plastic insulation tape and note the stage of grain fill. Return a few days later to determine if grain development and grain filling is continuing. Normal grain should be extending at approximately 1mm every 2 days until the full length is achieved. [17]

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 to allow for management decisions to be made. The pollen and anthers are the 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 any signs of damage. An inspection after 2 days may show anther damage and after 4 days should reveal whether grain development has been affected. It is important to 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. Inspect spikelets half way up representative heads as this is the most developed part and then above and below the centre. A hand lens may be of benefit and digital microscopes are of great value. 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 wheat crop with an estimated yield of 2.5 t/ha is frosted and a sample of 20 wheat heads is taken from the crop. Out 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= 500kg/ha yield loss. [18]

Juvenile frost damage

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

The worst damage is when the growing point of the plant is above ground level and results from 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. While 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. [19]

17 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;

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;

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 (Z30-39) the developing head and stems can still be frozen by very severe frosts (Figure 6.)

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 6a) and the crop will re-tiller.

Frost damage to the stem may be evident as blistering and bleaching of the stem internodes (Figure 6a). Sometimes this can be associated with damage to the head, but not always as in Figure 3, where the stem is damaged but not the developing head.

Experience in the 2014 season indicates crops can re-tiller and achieve reasonable yield levels, providing temperatures are favourable and either soil moisture is good or spring rainfall is adequate. [20]

Figure 6: Damage to developing wheat heads from frost at stem elongation (a) one healthy head (left) and five frosted heads (FS, frosted stem). (b) Close up of a healthy wheat head. Frost occurred at ~Z32, and photos were taken at ~Z37, 2–3 weeks later. (Photos: (a) Karl Moore and (b) Ben Biddulph, DAFWA)

[20] 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;

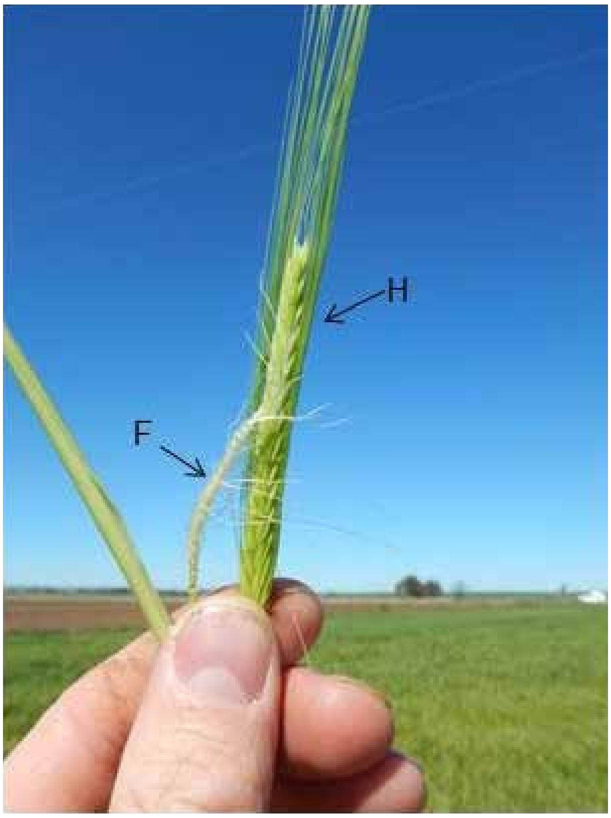

Figure 7: Damage to the developing barley head from frost at stem elongation ~Z35 , frosted head left (F) and healthy head right (H). Photos were taken at 2-3 weeks after the frost at ~Z49. (Photo: Ben Biddulph, DAFWA)

Figure 8: Damage to the stem internodes, but viable head. (Photo: Ben Biddulph, DAFWA)

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

- At the very early stage of development, prior to head emergence at Z51 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 (Z39-45) and early pollen development (Z45-65), the head or particular florets can stop development altogether and abort.
- The damage at this stage is quite distinct and heads emerge with a pale undeveloped colour from white (Z39; Figure 9a) to light green (Z51; Figure 9c)

depending on the stage of pollen development when 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 9: 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). Photo taken at flowering after head emergence, 2–3 weeks after the frost events. (Photo: 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 (Z51 onwards) can occur when canopy temperature drops to 0°C or below.

Damage may not be visually obvious for several days unless the heads are closely inspected and the reproductive parts inside the florets are inspected for damage as in Figures 10 and 11. A digital microscope is useful for aiding identification. [21]

Figure 10: 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)

[21] 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;

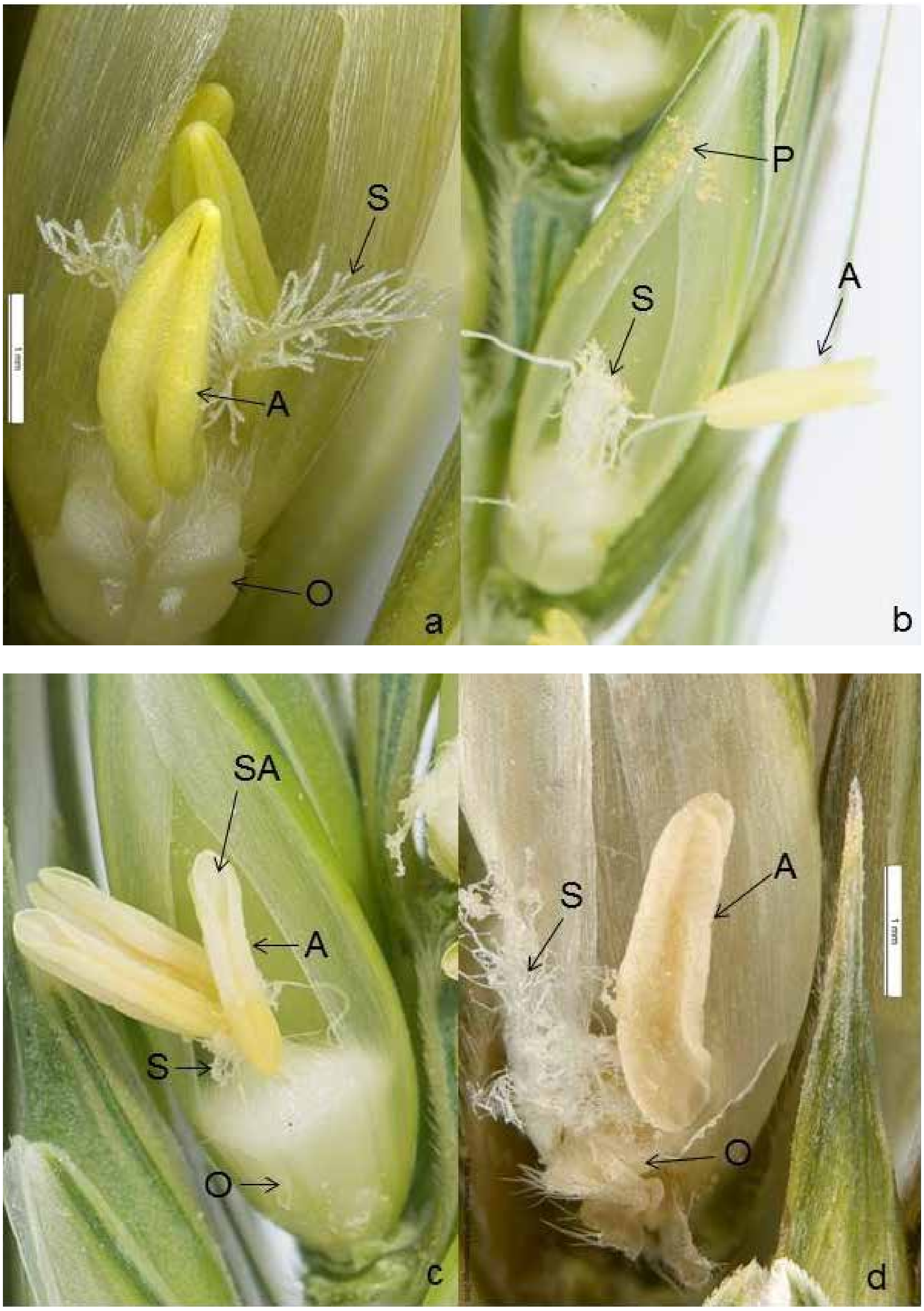

Figure 11: (a) Healthy floret about to flower: anthers (A), stigmas (S) and ovaries (O) of wheat within a floret. (b) Freshly fertilised floret: pollen (P). (c) Fertilised and swollen ovule: split anthers (SA). (d) Frosted floret. Photo of frosted floret taken at GS70.2 of heads frosted just prior to flowering (GS61). (Photo: Pia Scanlon, DAFWA)

During normal head development, immature anthers are light green, turning yellow on maturity just prior to flowering (Figure 11a) and prior to extruding from the floret.

Healthy anthers turn from yellow prior to pollen release (Figure 11a) to white after they have released the yellow pollen (Figure 11b and c)

After a frost event, the anther may remain light green to yellow for 1 to 2 days before turning white and shrivelled as in Figure 11d. Often anthers have a water soaked appearance (similar to frozen lettuce leaves)

The real tell-tale sign of frost damage is white anthers and ovules which are not swollen or developing (Figure 11b and 11d).

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 11a. A fertilised stigma has a light coating of yellow pollen cells and curls up (Figure 11b and c). While a frost affected, un-fertilised stigma will become off-white to brown and shrivelled in appearance (Figure 11d).

This damage at flowering is mainly from the cold and 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 12).

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/ bleached appearance several days after the frost (Figure 12).

Blighting usually affects only a small proportion of the heads as in Figure 7, but is also often associated frost damage to the reproductive structures inside which requires closer inspection as in Figure 12.

After about a week, cold, desiccation and freezing head damage starts to become more obvious, and may not require dissection as in Figure 12. As a result of the low fertilisation of the grain the whole heads beginning 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 which have been frozen turn white.

As the florets do not fill with grain, 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 as there is no grain development and grain filling. [22]

Figure 12: 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)

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;

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. Remember though that flowering is not synchronous so while 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 Z70.2- Z79), the developing grains may be frozen and do not continue to develop. It turns a white to grey colour and becomes shrivelled and dry (Figure 9) instead of plump and full of clear sugar filled solution (Figure 14).These grains are not normally retained in a header sample and often shatter easily at maturity.

When frosted during dough development and grain filling (Figure 8; GF Z80-89) the grains often don't abort, but become scalloped (Figure 13) and continue to develop. Often they initially develop a dark green, water soaked appearance that is visible through the outside of the grain. By squeezing these grains at the early dough stage (Z81), the contents will be grey and liquid instead of white, slippery and viscous.

As frosts often follow the cycle of weather patterns, crops are often frosted at several successive stages of development and will exhibit a combination of different symptoms as seen in Figure 8 where the same head has damage from frost at flowering (Z61), grain development (Z70.8) and early grain filling (Z81). These symptoms also change in appearance over time depending on the time since the frost damage occurred Figure 9.

The effect of frost damage over an entire crop is often the cumulative effect of several frosts that the crop has incurred during its' development over a 3-4 week window.

Wheat that has been frosted at the grain filling stages are a little more resilient to the effects of frost, often showing 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.

It is not recommended to keep frost affected grain for the following year, as germination may be reduced.

It is not recommended to keep frost affected grain for the following year, as germination may be reduced. [23]

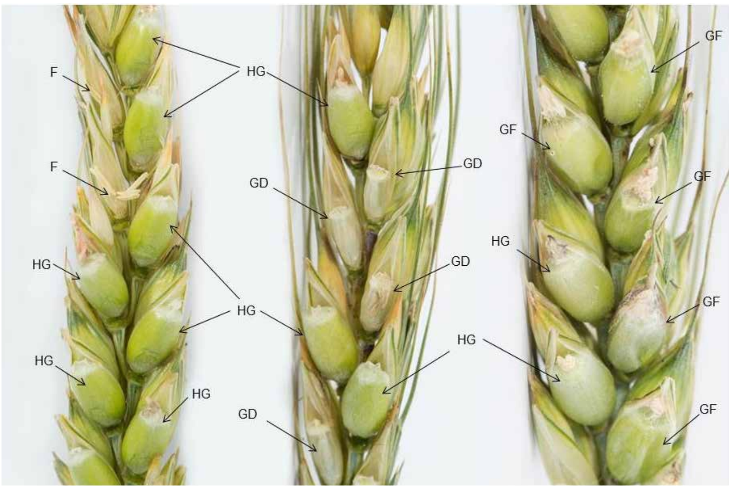

Figure 13: Wheat head that has been frosted at flowering (GS65; F) and at grain development (GS70.8; GD), and partially frosted during grain filling (GS81; GF). Frost-affected grains starting to shrivel (GD) to form a pinched or scalloped appearance (GF) compared with healthy grains (HG). Frosts occurred at ~GS65, GS70.8 and GS81, and the photo was taken at ~GS83. (Photo: Pia Scanlon, DAFWA)

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;

Figure 14: 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 15: Grains collected at maturity that are (a, b) unfrosted; (c) frosted 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 (Z51) the peduncle is susceptible to freezing damage.

There are two types of peduncle damage 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 ~Z51–55 where the rain allows a small amount of water to collect inside the leaf sheath surrounding the most undeveloped section of the peduncle. (Figure 16).

Figure 16: 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 17: Peduncle stem damage showing light-green region (S) and bleached heads with infertile florets (B).

Initially, 1–3d 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 11a). This is common for Type 1 and Type 2 damage. Sometimes a slightly less severe symptom of Type 1 will be blistering.

3–7d after the frost event the head and peduncle can't be pulled from the standing crop for Type 2 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 a result of lignification and "scaring" of the frosted section of the peduncle (Figure 11b close up). This section is often light green in colour and the surface of the peduncle is rough in this area. The head and peduncle can be easily pulled out for Type 1 and distinct narrowing of the peduncle just above the node will be obvious.

Around 5–10d after the frost event the stem (or peduncle) when frosted will have a light green or white ring around the stem for Type 2 (Figure 11b and 12) 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 then the plants may recover and achieve a 20–40% reduced yield, as sugar and water will continue to be taken up by the developing head. Recovery and compensation is greatest when there is ample soil water and mild temperatures. Severe Type 1 peduncle frosts can result in 100% yield loss. It is possible to test the viability of the tissue by taking a sample of wheat heads together with their stalks, cut cleanly with a knife low on the plant and placing them in a blue food dye solution overnight. If the tissue is viable the heads will turn blue and grain fill may proceed normally.

In more severely affected stems, they can become distorted and sugar and water flow may be restricted to the head, reducing grain fill 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. [24]

[24] 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;

The frost window

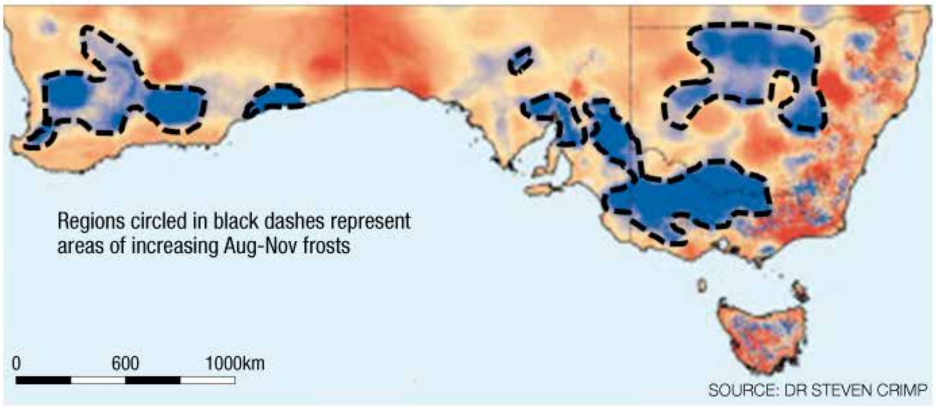

Figure 18: Regions of increasing August–November frosts.

The frost window has lengthened by 3 weeks in the Victorian grainbelt and by 2 weeks in the New South Wales grainbelt (Figure 18). Statistically, Western Australia has remained the same. Sites in eastern South Australia 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. Analysis of long-term temperature data for Longerenong in the Victorian Wimmera indicates that the incidence of moderate (2°C) and extreme (0°C) frosts during the wheat flowering window has increased in the past 15 years (Figure 19). [25]

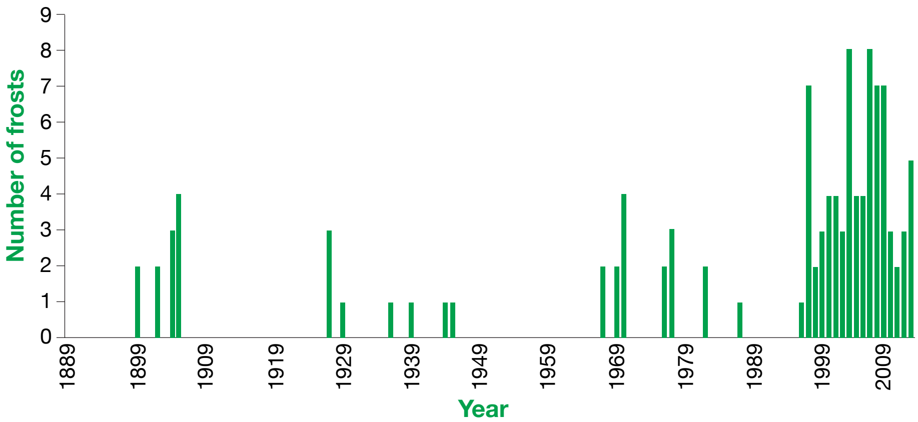

Figure 19: Historic number of frosts in the flowering window 20 September–30 October for Yitpi, Longerenong, Victoria.

14.1.15 National Frost Initiative

The objective of the Grain Research and Development'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.

Useful tools

Weather apps: see AgExcellence Alliance, CliMate, Meteye, DAFWA weather stations app.

Plant development apps: MyCrop, DAFWA FlowerPower

Temperature monitors: HOBO Data Loggers

25 GRDC (2014) Frost risk on the rise despite warmer climate. Ground Cover 109, GRDC 3 March 2014, http://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS109/Frost-risk-on-the-rise-despite-warmer-climate

- 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. [26]

14.2 Waterlogging–flooding issues

14.2.1 Winter cereal pathology

Three drivers influence the incidence of plant disease:

- the host
- the environment
- the pathogen

Aspects of host management that might promote disease are the growing of susceptible crop varieties, and widespread and sequential sowings of hosts susceptible to specific pathogens.

The environment influences disease incidence through moisture (both the frequency and duration of events), 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. [27]

Legacy of floods and rain

The legacy of the floods and rain includes transport of inoculum (crown rot, nematodes, leaf spots through movement of infected stubble and soil), development of sexual stages (leaf spots, head blights), survival of volunteers (unharvested material and self-sown plants in double-crop situations), and weather-damaged seed. Cereal diseases that need living plants over-season on volunteer (self-sown) crops; this particularly applies to rusts and mildews. Diseases such as yellow spot, net blotches and head blights survive on stubble. Crown rot and nematodes over-season in soil.

Problems are recognised by inspection of plants. Leaf and stem rusts produce visible pustules on leaves. Stripe rust survives as dormant mycelium, with spores not being produced until temperatures favour disease development. Presence of leaf spots is recognised by fruiting bodies (pseudothecia) on straw and lesions on volunteers. Head blights produce fruiting bodies (perithecia) on straw, whereas crown rot survives mainly as mycelium in straw. Soilborne nematodes are detected through soil tests.[28]

26 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;

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

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

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

Management options

Management options for disease control include elimination of volunteers, if possible producing a 4-week period that is totally host-free, crop rotation with non-hosts, growing resistant varieties, reduction of stubble, and fungicides.

Fungicides are far more effective as protectants than as eradicants, so are best applied prior to, or very soon after, infection. Systemic fungicides work within the sprayed leaf, providing 3–5 weeks of protection. Leaves produced after this spraying are not protected. Spray to protect the upper three or four leaves, which are the most important because they contribute to grainfill. In general, rusts are easier to control than leaf spots. Remember that fungicides can only protect the existing yield potential.

The application of fungicides is an economic decision, and in many cases, a higher application rate can give a better economic return through greater yield and higher grain quality. Timing and rate of application are more important than product selection. Stripe rust ratings in variety guides are for adult plant response to the pathogen, and may not accurately reflect seedling response. [29]

Strategies

The incidence and severity of disease will depend on the environment, but with known, plentiful inoculum present, even in a season with average weather, disease risks will be significant.

Strategies include:

- using the best available seed
- identifying your risks
- formulating management strategies based on perceived risk
- monitoring crops regularly
- timely intervention with fungicides [30]

14.2.2 Nutritional and structural impact of flooding on soil

A temporary loss of soil structure prevents clay particles from aggregating and forming channels for water infiltration, so despite flooding, some soil moisture profiles might not be as full as expected. This reduction in infiltration is also affected by which crop was grown most recently, with persistent roots forming channels in the soil, aiding water entry. Cultivation prior to, or during, planting of the next crop, will help to break up surface crusting.

Flooding also affects nutrient levels. Flooding and long periods of waterlogging have resulted in the depletion of nutrients. Nitrogen levels are very low in many soils tested. Soil testing has shown that N has been lost throughout the entire soil profile in many cases. It appears to have been denitrified and lost from the system. Very little has been leached through the profile and deposited at depth. [31]

Soil testing

Ideally, soil testing should be performed at the same place each time, and on the dominant soil type of the paddock. In most years, this information, combined with yield and protein levels, will guide N requirements, but after a flood year, requirements are

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

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

31 DAF Qld (2013) Nutritional and structural impact of flooding on soil. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/prepare-for-winter-crops-following-floods/nutritional-and-structural-impact-of-flooding-on-soil

very different. Placement of N fertiliser is important, with application on alternate rows close to planting time being a good option. [32]

14.2.3 Soil erosion and waterlogging due to flooding—preventing future damage

Several approaches can be used to prevent post-flooding damage. 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.

14.2.4 Weed management following floods

Floodwater affects soil, stubble/trash, weed seed and plant movement. Differences may have been seen between conventional and minimum tillage farming systems due to differences in groundcover, soil type and, ultimately, intensity of floodwater. Because of flooding, growers might expect to see new weed incursions and removal of topsoil.

New weeds could be species not previously seen on a property, or new species in specific fields from other fields or non-cultivated areas. There is also the potential for the introduction and movement of herbicide-resistant weeds. The removal of topsoil could lead to exposure of previously buried seed and, hence, the resurrection of buried problems. It is hard to predict where weed seeds will settle, but a concentration is likely where water and trash has settled. [33]

Potential problem weeds

Species of weeds in which herbicide resistance has been identified in the northern agricultural region include wild oats, sowthistle, fleabane, barnyard grass and liverseed grass. The problem is not currently widespread. [34]

Implications for the coming season

Integrated weed management principles still apply. These principles include diligent monitoring, targeting small weeds with robust rates of herbicide, rotating herbicides with different modes of action, and preventing seedset and seedbank replenishment. This approach will prevent herbicide resistance from becoming a problem.

For cropping, aim for a clean start with effective knockdown control (e.g. using a double-knock strategy). Use residual herbicides to minimise in-crop weed emergences. To control weeds in-crop, grow a competitive crop and use correct application and timing of in-crop herbicides. Stop seedset on survivors after harvest.

In fallows, weed seedlings should be effectively controlled with robust herbicide rates and/or a double-knock strategy. An early application of a residual herbicide will minimise subsequent flushes. Be diligent in control of survivors of herbicide applications.

In non-crop areas, seed may have been captured around fencelines and sheds, and these may become sources of ongoing infections. Monitor these areas and stop seedset. [35]

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32 DAF Qld (2013) Nutritional and structural impact of flooding on soil. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/prepare-for-winter-crops-following-floods/nutritional-and-structural-impact-of-flooding-on-soil

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14.3 Heat stress

Heat is a key abiotic stress. The effects of heat on grain yield are as important as effects of drought and frost. Varieties that are better adapted also generally perform better in heat-stress conditions.

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. Field data suggest that yield losses can be ~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.

The reproductive stages of growth have greater sensitivity to elevated temperatures, with physiological responses including premature leaf senescence, reduced photosynthetic rate, reduced seedset, 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. [36]

More information

Research paper: Cultivar and environmental effects on quality characters in wheat. II. Protein

Research paper: The impact of temperature variability on wheat yields

Research paper: Effects of zinc on photosynthesis and yield of wheat under heat stress

GRDC Fact Sheets: Time of sowing

Research paper: Association between wheat yield and temperature in south-eastern Australia

Research paper: Heat waves and wheat growth under a future climate

Research paper: Simulating the impact of extreme heat and frost events

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