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GRAINS RESEARCH & DEVELOPMENT CORPORATION

CEREAL RYE

SECTION 14

ENVIRONMENTAL ISSUES

FROST ISSUES FOR CEREAL RYE | WATERLOGGING/FLOODING ISSUES FOR CEREAL RYE | OTHER ENVIRONMENTAL ISSUES FOR CEREAL RYE

Environmental issues

Key messages

- Rye can withstand sandblasting and is more tolerant of drought and frost than other cereals. [1]
- Rye is more sensitive to hot weather than oats and barley. [2]
- Rye is the most productive of the cereal grain crops under conditions of low temperature, low fertility and drought.
- Rye can tolerate acid soils better than wheat, barley or canola. [3] Cereal Rye is thought to be relatively tolerant on saline soils, similar to barley, but will be affected in highly saline soils (8–16 ECe (dS/m)). [4]

14.1 Frost issues for Cereal Rye

Key points

- Rye will make even better growth than oats under cold conditions. [5]
- Frost is estimated to cost south-east Australia at least $100 million a year in unfulfilled or lost yield potential. [6]
- Frost events can have major and sudden impacts on cereal yields (Photo 1).
- Frost is a relatively rare occurrence but some areas are more prone to it.
- There has been an increase in frost frequency in many areas in the last 20 years.
- Minor agronomic tweaks might be necessary in some frost prone areas
- In the event of severe frost, monitoring needs to occur up to two weeks after the event to detect all the damage. [7]
- Cereal rye is one of the least susceptible cereals to frost and is renowned for its cold tolerance. Crop susceptibility to frost from most to least susceptible is triticale > wheat > barley > cereal rye > oats. [8]
- Flowering about two weeks later than SA Commercial, Bevy is less prone to frost, which often affects yields of the SA Commercial variety. [9]

1 L Martin (2015) Growing cereal rye to increase carbon and prevent wind erosion. Liebe Group, http://www.liebegroup.org.au/wp-content/uploads/2015/03/Case-Study-Jeff-Pearse-March-2015.pdf

2 A Clark (Ed.) (2007) Managing Cover Crops Profitably, 3rd ed. Sustainable Agriculture Network, Beltsville, MD, http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition

3 Alberta Government (2016) Fall Rye Production, http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex1269/$file/117_20-1.pdf

4 PIR.SA. Testing for soil and water salinity. Factsheet No:66/00.

5 RL Reid (Ed.) (2013) The manual of Australian agriculture. Elsevier.

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

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

8 GRDC (2009) Frost risk Factsheet, https://grdc.com.au/uploads/documents/GRDC_FS_Frost.pdf

9 Agriculture Victoria (2013) Growing cereal rye, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

MORE INFORMATION

Frost and plant physiology: Q&A with Glenn Macdonald

VIDEOS

WATCH: Plant frost mechanisms—explained

Photo 1: *Cereal heads showing frost damage.*

Source: DAFWA

Rye is the most frost tolerant cereal species. During winters it can survive intense frost temperatures. Winter hardiness is a complex feature, which includes cold resistance and resistance to damping. Frost tolerance may be increased by land treatment, e.g. melioration, high quality of tillage and timely sowing. Cold resistant rye plants have some typical morphological and biological features. They have narrow and short rosette leaves with a microcellular structure, spreading bushes, a thicker outer epidermis wall, a short mesocytyl and therefore a deeper tillering node. Frost-resistant plants grow more slowly in autumn and have a relatively higher concentration of dry matter in their cell sap. They expend this dry matter in their growth processes and respiration in a more economical way.

Cold tolerance and antifreeze activity are induced by cold temperatures in rye. Antifreeze proteins are found in a wide range of overwintering plants where they inhibit the growth and recrystillisation of ice that forms in intercellular spaces. In rye, antifreeze proteins accumulate in response to cold, short day length, dehydration and ethylene. [10]

Clear, calm and dry nights following cold days are the precursor conditions for radiation frost (or hoar frost). These conditions are most often met during winter and spring where high pressures follow a cold front, bringing cold air from the Southern Ocean but settled, cloudless weather (Figure 1). When the loss of heat from the earth during the night decreases the temperature at ground level to zero, a frost occurs. Wind and cloud reduce the likelihood of frost by decreasing the loss of heat to the atmosphere. The extent of frost damage is determined by how quickly the

10 H Domanska (1960) The influence of the autumn and spring drought on the development of winter rye and barley. Rocz Nauk Rolniczych Ser A: 229–241, http://eurekamag.com/research/014/254/014254711.php

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

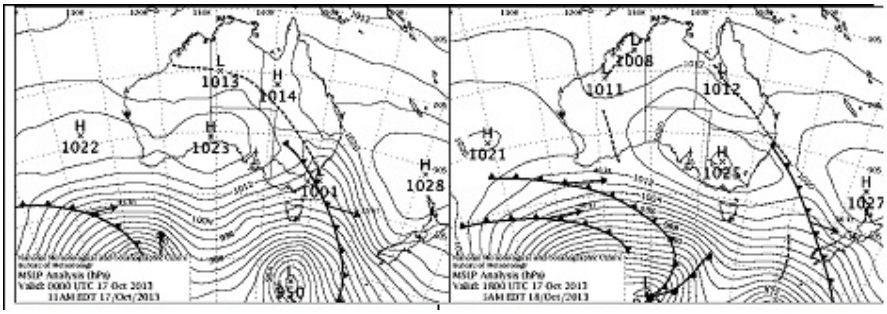

Figure 1: *A cold front passes through injecting cold air from the Southern Ocean the day before frost (left). Overnight the high pressure system stabilises over SE Australia meaning clear skies and no wind leading to a frost event (right).*

Source: GRDC

Though temperatures (particularly those in winter and spring) are getting warmer, frost is still a major issue. CSIRO researchers have found that there are areas of Australia where the number of frost events are increasing (greatest in August) with Central West New South Wales, Eyre Peninsula, Esperance and Northern Victoria (Mallee) the only major crop growing areas to be less affected by frost in the period 1961–2010 (Figure 2). This increase in frost events in much of Vic and parts of SA is thought to be caused by the latitude of the Sub Tropical Ridge of high pressure drifting south (causing more stable pressure systems) and more El Niño conditions during this period. [11]

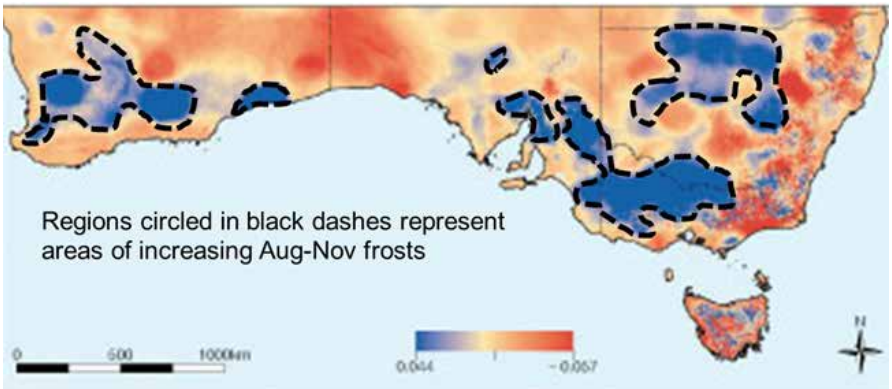

Figure 2: *Region of increasing August-November frost events.*

Source: Steven Crimp in GRDC

14.1.1 Diagnosing stem and head frost damage in cereals

Use Table 1 to help diagnose frost symptoms in your paddocks.

VIDEOS

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

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

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

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

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

Source: GRDC

What to look for

Paddock

- Symptoms may not be obvious until 5–7 days after the frost.
- Heads on affected areas have a dull appearance that becomes paler as frosted tissue dies (Photo 2).
- At crop maturity severely frosted areas remain green longer.
- Severely frosted crops crop have a dirty appearance at harvest due to blackened heads and stems, and discoloured leaves.

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

Photo Jim Kuerschner. Source: GRDC

Plant

- *Before flowering:*
- Freezing of the emerging head by cold air or water is caught next to the flag leaf or travelling down the awns into the boot. Individual florets or the whole head can be bleached and shriveled, stopping grain formation. Surviving florets will form normally.
- Stem frost by a small amount of water that has settled in the boot and frozen around the peduncle. Symptoms include paleness or discolouration and roughness at the affected point on the peduncle, and blistering or cracking of nodes and leaf sheath. Stems may be distorted.
- *Flowering head:*
- The ovary in frosted flowers is "spongy" when squeezed and turns dark in colour.
- Anthers are dull coloured and are often banana shaped. In normal flowers the ovary is bright white and "crisp" when squeezed. As the grain develops it turns green in colour. Anthers are green to yellow before flowering or yellow turning white after flowering
- *Grain:*
- Frosted grain at the milk stage is white, turning brown, with a crimped appearance. It is usually spongy when squeezed and doesn't exude milk/dough. Healthy grain is light to dark green and plump, and exudes white milk/dough when squeezed (Photo 3).
- Frosted grain at the dough stage is shrivelled and creased along the long axis, rather like a pair of pliers has crimped the grain (Photo 4). [12]

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

Source: DAFWA

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

VIDEOS

WATCH: GCTV15: Frost Ratings.

WATCH: GCTV15: The frost ranking challenge.

WATCH: GCTV12: Frost susceptibility ranked.

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

Source: GRDC

IN FOCUS

New insight in frost events and management

Take home messages:

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

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

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

Historic climate data from a grid database and for 60 locations representing each of the four major cropping regions of Australia was

used to determine the frequency and severity of frost (Figure 3, top). Crop simulation modelling using the Agricultural Production Systems sIMulator program (APSIM) was used to estimate crop yields. Expert knowledge combined with data from frost trials was used to estimate crop losses. Computer simulation allowed prediction of crop losses for all Australian cropping regions using damage information from a limited number of frost trial sites. It also allowed simulation of potential yields using sowing dates optimised for yield in the hypothetical absence of frost risk, something that has not been achieved experimentally.

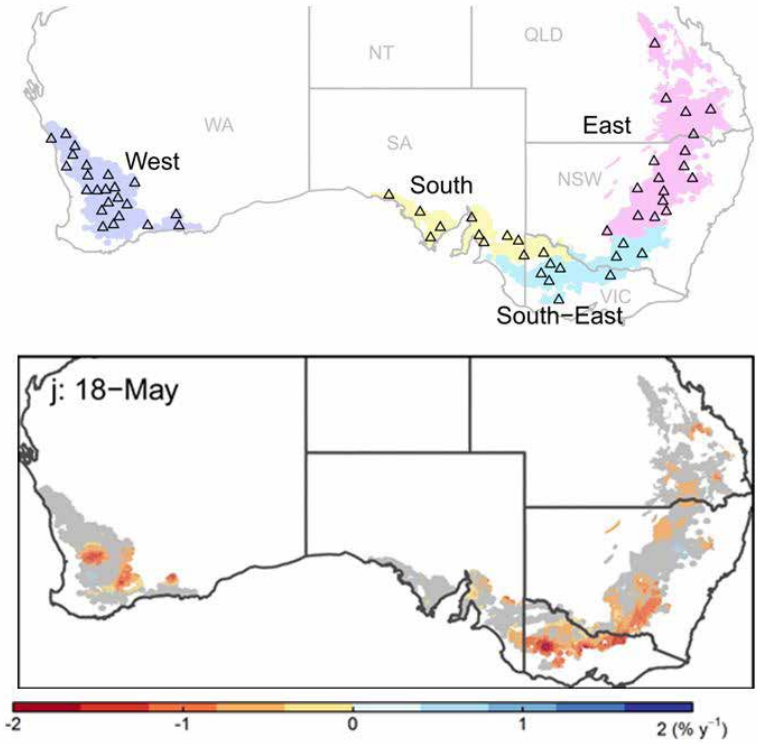

Figure 3: *Maps showing sites and regions for which climate data were analysed for the frequency and severity of frosts (top panel) and annual % change in yield loss due to frost from 1957 to 2013; negative values (yellow to red) represent areas where yield loss became worse over recent decades (bottom panel). Estimations in the lower panel were for the cultivar Janz sown 18 May and are based on a ~ 5 x 5 km grid of climatic data. (Gridded climate data may not reflect local climatic conditions of particular paddocks within each grid as frost events are highly spatially variable.)*

Source: GRDC

The researchers estimated that yield losses due to direct frost damage averaged close to 10% nationally for all crop maturity types, when current sowing guidelines were followed.

In many areas, growers must sow late to minimise frost damage. The researchers estimated the loss of yield potential for late-sown crops using a theoretical optimal sowing date (as early as 1 May). When lost yield potential from delayed sowing (indirect cost of frost) is added to direct damage (current best-sowing date), estimated yield losses doubled from 10% to 20% nationally (Figure 4, 'direct + indirect' impact). In the eastern grains region, losses were even greater, with estimated yield losses due to direct and indirect damage of 34% for early-flowering cultivars, 38% for mid-flowering and 23% for late-flowering cultivars (Figure 4).

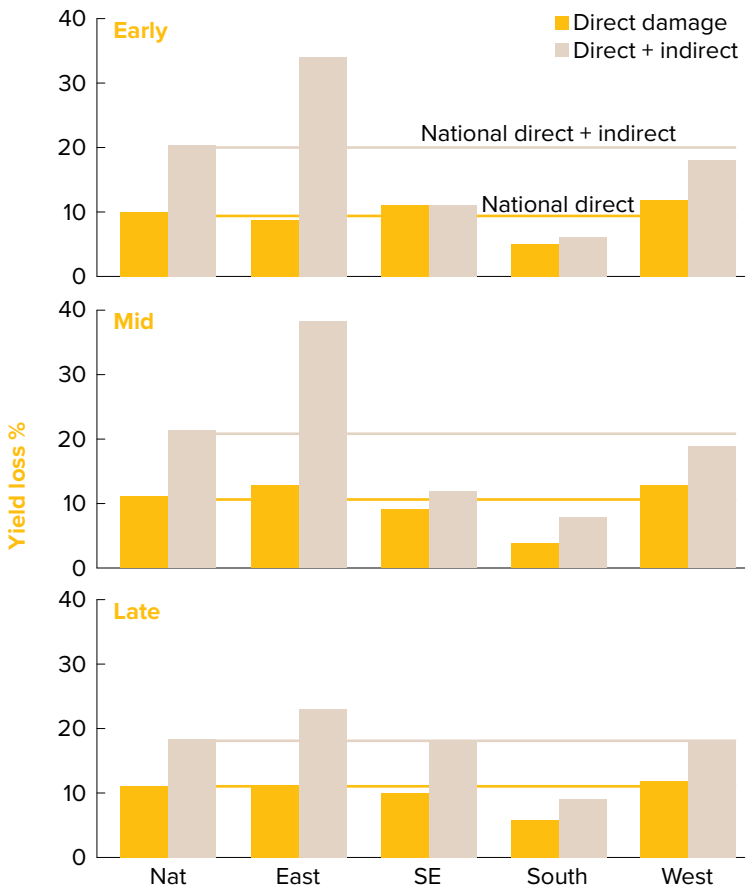

Figure 4: *Estimated wheat yield losses (%) due to frost damage for crops sown at the current best sowing date ("direct" frost damage); and crop losses due to both direct damage and delayed sowing currently necessitated to manage frost risks (direct + indirect) for early, mid and late flowering crops.*

Source: GRDC

In some areas in each region, simulated frost impact has significantly increased between 1957 and 2013 (yellow, orange and tan areas, Figure 3, bottom panel). The estimated date of last frost has changed to later in some areas and earlier in others. However, even in areas where it now comes significantly earlier, higher temperatures have also increased the rate of development to the heading stage, when the crop is more susceptible to frost. The modelling suggests that crop-heading dates have been brought forward more rapidly than the date of last frost, leading to an overall increase (in the model) in frost impact in many areas. This may actually increase the risk of frost.

Counterintuitively, yield losses were greatest in the northern grains region, with the greatest yield losses actually due to delayed sowing rather than frost per se.

These trends may force growers to change planting decisions. Sowing early to increase yield potential may now not always be the best course of action in warmer seasons, even when a lower frequency of frost events is anticipated.

These results indicate that continued research to reduce frost risk remains a high priority, despite increasing temperatures due to climate change.

Guidelines for reducing frost risk and assessing frost damage

Matching variety to planting opportunity

The current best strategy for maximising long-term crop yields is to aim for crop heading, flowering and grainfilling to be completed in the short window of opportunity between the end of the main frost risk and before day-time maximum temperatures become too high. Of course, planting in this window does not guarantee that crop loss due to frost will be averted; nor does it always prevent drastic yield reduction due to late-season heat and drought stress. However, planting a variety too early can leave growers with a very high probability of crop loss.

Seasonal temperature variations mean that the days to flowering for each variety will change from season to season. It is essential that varieties are sown within the correct window for the district as outlined in variety guides.

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

Measuring crop temperature accurately

In-crop temperature measurements are useful to determine whether a crop may have been exposed to damaging temperatures. A historic comparison of on-farm and district minimum temperatures also allows growers to fine-tune management recommendations for their district to better suit their particular property, and even individual paddocks. District recommendations are based on one, or at best a few, sites, in each district and may not reflect the conditions of individual properties, so in many instances, the recommendations likely err on the side of caution.

Stevenson screen temperatures measured at Bureau of Meteorology stations do not fully explain frost risk, either. In crops, the temperature can vary by several degrees from that measured in the screen. On nights when still, cold air, clear skies, and low humidity combine, temperatures can drop rapidly, resulting in radiant frost (Figure 5). The crop temperatures recorded can vary widely due to differences in topography, micro-environment and recording method.

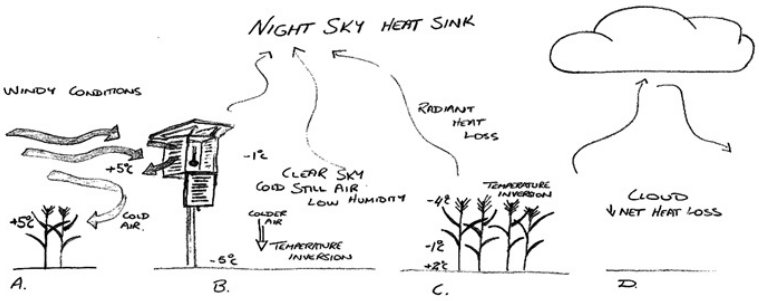

Figure 5: *If clear skies and still, cold, low humidity air coincide, heat can be lost rapidly to the night sky resulting in a radiant frost. Minimum air temperatures measured at head height can be several degrees colder than reported "screen" temperatures. Some indicative temperatures are illustrated for (A) windy conditions, (B) clear still conditions in an open area, (C) clear still conditions in a cropping area, and (D) cloudy conditions.*

Measurements taken using exposed thermometers at canopy height (Photo 5) give a much more accurate indication of the likelihood of crop damage. [13]

Photo 5: *Canopy temperature measured using a calibrated minimum/maximum thermometer. For best results, a minimum of two or three field thermometers are require to give representative temperatures for a crop. In undulating country, more thermometers should be used to record temperatures at various heights in the landscape.*

Source: GRDC

14.1.2 Managing frost risk

Key points

- In some areas the risk of frost has increased due to widening of the frost event window and changes in grower practices.
- The risk, incidence and severity of frost varies between and within years as well as across landscapes, so growers need to assess their individual situation regularly.
- Frosts generally occur when nights are clear and calm and follow cold days. These conditions occur most often during winter and spring.
- The occurrence of frost and subsequent frost damage to grain crops is determined by a combination of factors including: temperature, humidity, wind, topography, soil type, texture and colour, crop species and variety, and how the crop is managed.
- Greatest losses in grain yield and quality are observed when frosts occur between the booting and grain ripening stages of growth.
- Frost damage is not always obvious and crops should be inspected within five to seven days after a suspected frost event.
- Methods to deal with the financial and personal impact of frost also need to be considered in a farm management plan.
- Careful planning, zoning and choosing the right crops are the best options to reduce frost risk. [14]

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

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

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

There are two types of pre-season management tactics available for growers:

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

Farm management planning tactics

Step 1: Assess personal approach to risk

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

Step 2: Assess frost risk of property

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

Step 3: Diversify the business

A range of enterprise options should be considered as part of a farm management plan to spread financial risk in the event of frost damage. This is subject to the location of the business and skillset 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 more at the mercy of frost than a diversified business as 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.

Frost zone management tactics

Step 1: Consider enterprise within a zone

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

Step 2: Review nutrient management

Targeting fertiliser (nitrogen, phosphorus, potassium) 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 (N) increases yield potential, it will also promote vegetative biomass production and increase the susceptibility of the crop to frost. Using

VIDEOS

WATCH: Frost Initiative: Do micronutrients reduce frost risk?

WATCH: MPCN: Copper and frost relationship investigated.

conservative N rates at seeding and avoiding late top-ups results in less crop damage.

It is best if crops are not deficient in potassium or copper, as 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 (K) 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 K are more susceptible to frost. Soils that are deficient in K could benefit from increasing K levels at the start of the growing season. However, it is unlikely that there will be a benefit of extra K applied to plants that are not K-deficient.

Frost tolerance cannot be bought by applying extra P or copper (Cu) 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

The soil heat bank is important for reducing the risk of frost (Figure 6). Heat is released from the soil heat-bank more slowly to warm the crop canopy at head height in early morning when frosts are more severe. It is managed by using farming practices that manipulate the storage and release of heat from the soil heat-bank into the crop canopy at night.

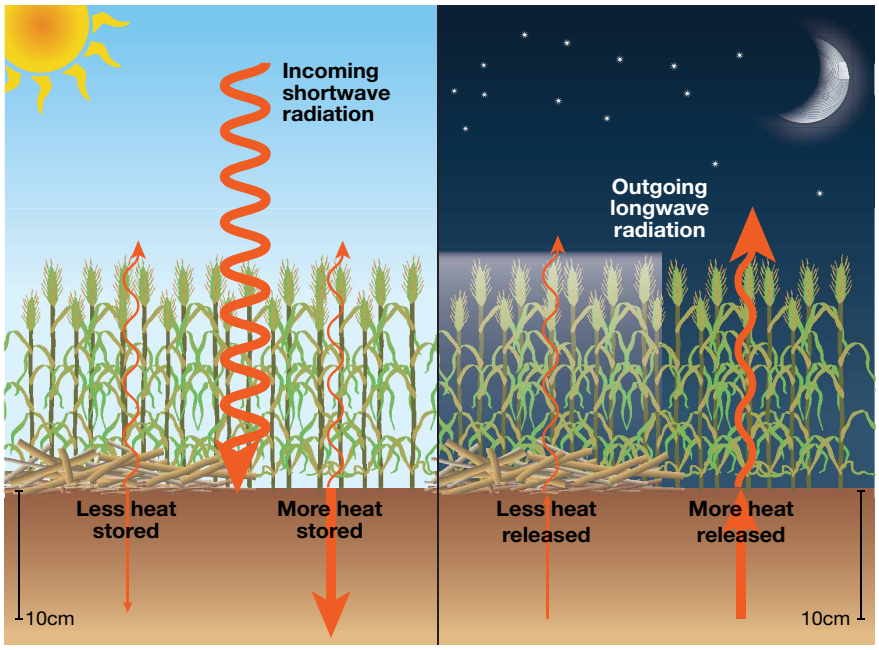

Figure 6: *The soil heat bank has an important role. It captures heat during the day and radiates heat into the crop canopy overnight to warm flowering heads and minimise frost damage. A range of farming practices can be utilised to increase the capacity of the soil heat bank.*

Source: GRDC

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

- Practices that alleviate non-wetting sands, such as clay delving, mouldboard ploughing or spading, have multiple effects. These include increasing heat storage, nutrient availability and infiltration rate.
- Rolling sandy soil and loamy clay soil after seeding can reduce frost damage. It also prepares the surface for hay cutting should 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.
- Halving the normal seeding rates 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.
- Cross-sowing/seeding: crops sown twice with half the seed sown in each direction have a more even plant density. Heat is released 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. Crops grown for hay are harvested for biomass and avoid grain loss from frost. 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.

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

Step 5: Manipulate flowering times

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

When wheat is sown in frost-risk areas, a good tactic is to ensure the flowering window of the cropping program is spread widely. This can be done by using more than one variety and choosing sowing dates 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 may result in lower yields in seasons with hot, dry finishes due to heat and moisture stress.

Staging sowing dates over a 3–6 week period is recommended. If sowing just one variety, this would provide a wide flowering window. If sowing more than one variety: sow winter cereal first, then a long-season spring cereal or a day-length-sensitive cereal, and lastly an early-maturing cereal. This sets the program up for flowering to occur over a two-week period, potentially exposing the crop to more frost risk but maximising the yield potential in the absence of frost. It is possible for crops to be frosted more than once but, flowering over a wide window will probably mean that some crop will be frosted but that losses are reduced.

Sowing time remains a major driver of yield in all crops, with the primary objective being to achieve a balance between crops flowering after the risk of frost has passed and before the onset of heat stress. Farmers who sow at the start of a variety's preferred window will achieve higher yields at the same cost as sowing late. 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.

In some trials, researchers 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 a second with another variety to spread risks.

Yield Prophet is a useful tool to match the flowering time of varieties to your own farm conditions.

IN FOCUS

Diversity the key to balancing frost and heat stress risks

Sowing a range of cultivars in their ideal sowing windows will give growers the best chance of balancing the increasing risks of heat and frost damage. It is more important than ever to optimise the sowing window so that, as much as possible, the entire crop flowers in its ideal window to minimise the risk of frost or heat damage.

Due to the effects of climate change, both heat stress and frost are likely to play an increasing role in the future and will require growers to take steps to manage the risks.

Growers who plant the majority of their cereal program using a single high-performing cultivar struggle to plant their whole program in a time close to the ideal sowing window. This can result in flowering occurring earlier or later than desired. This then leads to a higher heat stress risk if sowing is delayed or higher frost risk if planting too early.

For example, if the ideal sowing window is considered to be about five days either side of the target date, growers who sow a single cultivar over three weeks will have sown at least half of their crop (11 days out of 21) outside of this window. By comparison, if the cereal program was split up into two cultivars, almost 100% of the crop can be sown in its ideal window.

It would be impossible to choose a combination of sowing time and cultivars that would prevent exposure to heat and frost risk. However, time of sowing trials in South Australia and Victoria have shown that certain strategies will give crops the best chance. Depending on the local climate and duration of the sowing program, growers can take a few different approaches to optimise time of sowing.

In many regions of Victoria, growers can start with a winter cereal after a rain in April, then move onto slow-spring cereals and then mid-fast cultivars in May. The different maturity drivers of the cultivars mean that they still flower in the ideal window despite being sown at different times, meaning that overall yield is optimised and risk is minimised.

A time of sowing trial at Berriwillock in Victoria showed that where there is soil moisture, sowing early can provide higher yields than traditional sowing dates. In this trial, early rains were simulated with 8 mm of irrigation; most winter cereals should not be sown dry.

Currently, winter cereals do not perform particularly well in South Australia. However, three years of trials have shown that incorporating different cultivars improves overall results.

Three years of trials across multiple environments in SA have shown that yields decline at a rate of 28 kg/ha per day once sowing extends past the end of the first week in May. In order to maximize average yields, growers should therefore aim to finish seeding by mid-May.

The best strategy to manage heat and frost risk is diversity. By choosing a range of crops, cultivars with different maturity drivers and optimum sowing dates, growers will have the highest percentage of their program flowering in its ideal window.

The opportunities to take advantage of early sowing have never been better. Previous barriers have been overcome through no-till technologies, summer fallow management and cheaper chemistries to control early pests and diseases.

Researchers are working on developing new cultivars that are better suited for sowing early. But there is no reason most growers can't spread out their sowing by incorporating a few different cultivars with different maturity drivers.

While aiming for all of a farm's crop to flower at the same time runs against conventional wisdom of spreading flowering dates over a broad period to minimise exposure to single extreme frost or heat events, studies have shown the conventional logic is not the best approach.

Spreading flowering dates out so they are before or after the optimal period is a bad way of managing frost and heat risk, because the really extreme frost and heat events will affect crops at a very broad range of growth stages. Modelling shows that yields are maximised and variability minimised by getting as much crop to flower during the optimal window as possible.

Growers are better off managing risk by including a variety of crops into their program, including frost tolerant crops like rye, barley or oats, and considering further diversification such as the inclusion of hay or livestock into the business. [15]

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. A new variety should be managed based on how known varieties of similar ranking are currently managed.

Post-frost event management tactics

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

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

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

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

Source: DAFWA

Option 1: Take through to harvest

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

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

Option 2: Cut and bale

This is an option when late frosts occur during flowering and through grain fill. Assess crops for hay quality within a few days of a frost event and be prepared to cut a larger area than originally intended pre-season. Producing hay can also be a good management strategy to reduce stubble, weed seed bank and disease loads for the coming season. This may allow more rotational options in the following season to recover financially from frost, for example to go back with cereal on cereal in paddocks cut early for hay. Hay can be an expensive exercise. Growers should have a clear path to market or a use for the hay on farm before committing.

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. [16]

Table 2: *Management options for frost damaged crop, each with advantages and disadvantages.*

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

Source: GRDC

Useful tools

There are numerous useful tools that can help growers decisions about aspects of cropping to maximise yields in frost-prone areas. Among them are:

- Bureau of Meteorology's BOM Weather app

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

MORE INFORMATION

Managing frost risk—a guide for southern Australian growers.

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

GRDC Managing frost risk Factsheet.

VIDEOS

WATCH: GCTV3: Frost R&D.

WATCH: GCTV16: National Frost Initiative.

- Plant development and yield apps—MyCrop and Flower Power (both from DAFWA), Yield Prophet (although it does not cover cereal rye)
- Temperature monitors such as Tinytag

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:

1. Genetics: developing more frost-tolerant wheat and barley germplasm and ranking current wheat and barley varieties for susceptibility to frost.
2. Management: developing best practise crop canopy, stubble, nutrition and agronomic management strategies to minimise the effects of frost, and searching for innovative products that may minimise the impact of frost.
3. Environment: predicting the occurrence, severity and impact of frost events on crop yields and frost events at the farm scale to enable better risk management. [17]

14.2 Waterlogging/flooding issues for cereal rye

Key points

- Waterlogging occurs when roots cannot respire due to excess water in the soil profile.
- Though cereals can be more prone to waterlogging, rye can withstand some degree of waterlogging conditions. [18]
- Water does not have to appear on the surface for waterlogging to be a potential problem.
- Improving drainage from the inundated paddock can decrease the period at which the crop roots are subjected to anaerobic conditions.
- While raised beds are the most intensive management strategy, they are also the most effective at improving drainage.
- Waterlogged soils release increased amounts of nitrous oxide (N_2O), a particularly damaging greenhouse gas.

Waterlogging occurs whenever the soil is so wet that there is insufficient oxygen in the pore space for plant roots to be able to adequately respire (Photo 7). Other gases detrimental to root growth, such as carbon dioxide and ethylene, also accumulate in the root zone and affect the plants.

Plants differ in their demand for oxygen. There is no universal level of soil oxygen that can identify waterlogged conditions for all plants. In addition, a plant's demand for oxygen in its root zone will vary with its stage of growth. [19]

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

18 Agriculture Victoria (2013) Growing cereal rye, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

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

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

Source: Harden Express

Cereals can be sensitive to soil waterlogging, however, many rye cultivars show good tolerance to waterlogged conditions. Rye will grow in heavy clays and poorly drained soils, and many cultivars tolerate waterlogging. [20]

IN FOCUS

Comparison of waterlogging and drought tolerances among winter cereals

Researchers wanted to quantitatively evaluate the tolerance to waterlogging and drought of the winter cereals hulled barley, naked barley, wheat, rye and oats. They grew these plants under waterlogged (W) and drought (D) conditions from seven weeks after sowing up to maturity. During this time, they measured the growth, dry-matter production and transpiration coefficients, and compared them with those of the same plants grown under moderate soil-moisture (M) conditions.

Plant growth was relatively depressed under both W and D conditions compared with that under M conditions. Naked barley, wheat, rye and oats produced more dry matter of the whole plant under D conditions than under W, while hulled barley produced more dry matter under W conditions than under D. They considered that a crop was stable to W or D conditions when the ratio of its transpiration coefficient under W and D conditions to that under M conditions was close to or below 1.0, and was susceptible when the ratio was above 1.0. Therefore, naked barley, wheat, rye and oats were considered to have relatively large drought tolerance capacities (RLDTC), and that hulled barley had relatively large waterlogging tolerance capacities (RLWTC). Among the crops with RLDTC, rye and oats were very susceptible, and naked barley and wheat were relatively susceptible.

20 A Clark (ed.) 2007 Rye. In Managing Cover Crops Profitably. 3rd edn. Sustainable Agriculture Network, http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition

Hulled barley, which had RLWTC, was stable to W conditions. All of the crops were stable to D conditions. [21]

Where does waterlogging occur?

Waterlogging occurs:

- Where water accumulates in poorly drained areas such as valleys, at the change of slope or below rocks.
- In duplex soils, particularly sandy duplexes with less than 30 cm sand over clay.
- In deeper-sown crops.
- in crops with low levels of nitrogen.
- In very warm conditions when oxygen is more rapidly depleted in the soil. [22]

Waterlogging also greatly increases crop damage from salinity. Germination and early growth can be much worse on marginally saline areas after waterlogging events.

IN FOCUS

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

Annual cropping has been expanding in the high rainfall zone of southern Australia. The higher rainfall and longer growing season compared with the traditional wheat belt contribute to a much higher yield potential for major crops. Potential yields range from 5 to 8 t/ha for wheat and 3 to 5 t/ha for canola, although current crop yields are only about 50% of those potentials. The large yield gap between current and potential yields suggests that there is an opportunity to lift current yields. Both genetic constraints and subsoil constraints such as waterlogging, soil acidity, sodicity, and high soil strength contribute to the low yields. Waterlogging is a widespread hidden constraint to crop production in the region. Controlling waterlogging using a combination of raised beds and surface or subsurface drains is the first step to raise the productivity of the land. Increasing root growth into the subsoil remains a key to accessing more water and nutrients for high yield through early planting, deep ripping, liming and use of primer crops to ameliorate the subsoil. In order to realise the high yield potential, it is essential to achieve higher optimum dry matter at anthesis and high ear number through agronomic management, including early sowing with appropriate cultivars, a high seeding rate and application of adequate nitrogen along with other nutrients. Current cultivars of spring wheat may not fully utilise the available growing season and may have genetic limitations in sink capacity that constrain potential yield. Breeding or identification of long-season milling wheat cultivars that can fully utilise the longer growing season and with the ability to tolerate waterlogging and subsoil acidity, and with disease resistance, will give additional benefits. It is concluded that improving crop production in the high rainfall zone of southern Australia will require attention to overcoming soil constraints, particularly waterlogging, and the development of longer-season cultivars. [23]

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21 ' ' ' , ' ' ' ' , ' ' ' , & ' ' ' ' (Yamaneuchi, Kawano Komuro, Tatsurojiro, & Inayaki Hideo.) (1988) Comparison of the capacities of waterlogging and drought tolerances among winter cereals. Japanese Journal of Crop Science. 57 (1), 163–173.

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

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

Identifying problem areas

The best way to identify problem areas is to dig holes about 40 cm deep in winter and see if water flows into them (Photo 8). If it does, the soil is waterlogged. Digging holes for fence posts often reveals waterlogging. Some farmers put slotted PVC pipe into augered holes. They can then monitor the water levels in their paddocks.

Symptoms in the crop of waterlogging include:

- Yellowing of crops and pastures.
- Presence of weeds such as toad rush, cotula, dock and Yorkshire fog grass. [24]

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

Source: Soilquality.org

14.2.1 Symptoms and causes

Waterlogging occurs when the soil profile or the root zone of a plant becomes saturated. In rain-fed situations, this happens when more rain falls than the soil can absorb or the atmosphere can evaporate.

Lack of oxygen in the root zone of a plant results in anaerobic conditions that cause its root tissues to decompose. Usually this occurs from the tips of roots, and this causes roots to appear as if they have been pruned. The consequence is that the plant's growth and development is stalled. If the anaerobic circumstances continue for long enough the plant will die.

Most often, waterlogging does not last long enough for the plant to die, and once the water drains, the plants recommence respiring. As long as the soil is moist, the older roots close to the surface allow the plant to survive. However, further waterlogging-induced root pruning or dry conditions may weaken the plant to the extent that it will do very poorly and may eventually die.

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

What to look for in the paddock

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

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

- Early plant senescence in waterlogging prone areas.

Photo 9: *Pale plants in waterlogged areas.*

Source: DAFWA

What to look for in plants

- Plants are particularly vulnerable from seeding to tillering, with seminal roots being more affected than later forming nodal roots.
- Waterlogged seed will be swollen and may have burst.
- Seedlings may die before emergence or be pale and weak.
- Waterlogged plants appear to be nitrogen deficient with pale plants, poor tillering, and older leaf death.
- If waterlogging persists, roots (particularly root tips) cease growing, become brown and then die (Photo 10).
- Seminal roots are important for accessing deep subsoil moisture. If damaged by waterlogging the plants may be more sensitive to spring drought.

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

Source: DAFWA

How can waterlogging be monitored?

- Water levels can be monitored with bores or observation pits, but water tables can vary greatly over short distances.
- Plants can be waterlogged if there is a water table within 30 cm of the surface and no indication of waterlogging at the surface. Observe plant symptoms and paddock clues and verify by digging a hole. [25]

Other impacts of waterlogging and flood events

Heat from stagnant water

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

Chemical and biological contaminants

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

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

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

VIDEOS

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

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

Iron chlorosis or nitrogen deficiency

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

Soils with high clay content

High clay content means soils can become compacted and form a surface crust after heavy rainfall and flooding. Floodwater also deposits a fine clay layer or crust on top of the soil, which prevents oxygen penetration into the soil (aeration). This layer should be broken up and incorporated into the soil profile as soon as possible.

Pests and diseases

Many diseases are more active in wet, humid conditions and pests can also cause problems. Remove dying or dead plants that may become an entry point for disease organisms or insect pests. Apply suitable disease control measures as soon as possible and monitor for pests. [26]

14.2.2 Managing waterlogging

Key points

- Sow waterlogging tolerant crops such as oats and faba beans.
- Sow as early as possible with a higher cereal seeding rate.
- Drainage may be appropriate on sandy duplex soils on sloping sites.
- Raised beds are more effective on relatively flat areas and on heavier textured soils, but areas need to be large enough to justify machinery costs. [27] (For more information on raised beds see Cropping on raised beds in southern NSW).

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

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

Good drainage is essential for maintaining crop health. Wet weather provides a good opportunity to improve the drainage of your crop land, as it allows you to identify and address any problem areas.

There are several things you can do to improve crop drainage, immediately and in the longer term.

Drainage problems after flooding

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

Irrigation after waterlogging

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

Ways to improve drainage

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

- re-shaping the layout of the field

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

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

- improving surface drainage
- installing subsurface drainage.

If the drainage can't be improved, consider using the area for some other purpose (e.g. for a silt trap). [28]

Choice of crop species

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

Seeding crops early and using long-season varieties help to avoid crop damage from waterlogging. Crop damage is particularly severe if plants are waterlogged between germination and emergence. Plant paddocks that are susceptible to waterlogging first. However, if waterlogging delays emergence and reduces cereal plant density to fewer than 50 plants/m^2, re-sow the crop.

Seeding rates

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

Nitrogen fertiliser

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

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

Weed density affect a crop's ability to recover from waterlogging. Weeds compete for water and the small amount of remaining N, hence the waterlogged parts of a paddock are often weedy and require special attention if the yield potential is to be reached. [29]

MORE INFORMATION

Should waterlogged crop be top-dressed with N fertiliser?

VIDEOS

WATCH: The 2012 N story and planning for 2013.

14.3 Other environmental issues for cereal rye

14.3.1 Drought

Drought is one of the major environmental factors reducing grain production in rainfed and semiarid regions. Rye is quite drought resistant. Plants cope with drought stress by manipulating key physiological processes such as photosynthesis, respiration, water relations, antioxidant and hormonal metabolism.

As the most drought resistant of cereals, rye has an extensive root system and adjusts maturity to moisture (Photo 11). It uses 20–30% less water per unit of dry matter formed than wheat. Tetraploid varieties are more sensitive to drought than diploids. In Australia's extensive arid regions, rye withstands adverse conditions better than other cereals. Its drought resistance and ability to withstand sand blasts enable it to produce soil-binding cover on land where other cereals will not grow.

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

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

VIDEOS

WATCH: MEF research breaking ground in drought tolerance.

Dr Pattison drills into drought tolerance

Under conditions where wheat, oat, or barley will grow only a few centimetres high, or may even be completely blown away, rye often grows vigorously and reaches a height of a metre or more. [30]

Photo 11: *Cereal Rye showing large root system during a drought year with less above ground plant growth.*

Source: Kauffman Seed

IN FOCUS

The influence of the autumn and spring drought on the development of winter rye and barley.

Researchers reported on their experiments on how autumn soil dryness influenced the development of winter rye and barley. The experiments were carried out in different years. Some plants were grown in the autumn in dry soil (about 25% of water capacity), and were compared with others grown in wetter soil (60% or 70% of the soil water capacity). The first group showed greater resistance against the winter period. The plants dried up in the autumn, but in the spring they grew rapidly and produced higher stems and bigger yields of straw and grain than the plants that had been grown in wetter soil.

They concluded that when drought occurs during gametogenesis (the formation of gametes in the anther and ovule), the sensitivity of plants is not affected by autumn drought. In fact, autumn dryness allows the plants to recover quickly once spring arrives and growth accelerates. In natural conditions, soil dryness is linked with atmospheric dryness, which may cause damage if it is prolonged. However, under normal conditions dry soil stimulates rye and barley to a quicker growth in the depth of the root system, which may make the plants less sensitive to spring-time drought. [31]

30 RH Schlegel, (2013) Rye: genetics, breeding, and cultivation. Crc Press.

31 H Domanska (1960) The influence of the autumn and spring drought on the development of winter rye and barley. Rocz Nauk Rolniczych. Ser A, 229–241.

Managing drought

Because drought events can be unpredictable and can last for extended periods of unknown length, it is difficult to prepare for them.

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

Step One: Check the most limiting farm resources:

- mental and physical energy to do the continuous tasks required;
- funds available;
- stock and domestic water available;
- surface/subsoil moisture for crop leaf and root growth;
- need to service machinery – breakdowns cost time, money and frustration.

Audit sheets are provided on the following pages to assist in guiding you through the resource audit.

Step Two: Set action strategies, considering:

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

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

- using your established network to stay informed about key factors that affect your drought strategies;
- being proactive about the decisions made;
- being prepared for change;
- remembering that the impact falls very heavily not only on the decision makers but on the whole farm family. [32]

Soil management following drought

The principal aim after rain should be to establish either pasture or crop as a groundcover on your bare paddocks as quickly as possible. This is especially important on the red soils, but is also important for the clays. After drought, many soils will be in a different condition to what is considered to be their 'normal' condition. Some will be bare and powdery on the surface, some will be further eroded by wind or water, and some will have higher levels of nitrogen (N) and phosphorus (P) than expected. Loss of effective ground cover (due to grazing or cultivation) leaves the soil highly prone to erosion by wind and water. Research by the former Department of Land and Water Conservation's Soil Services showed that erosion due to drought-breaking rain can make up 90% of the total soil loss in a 20–30 year cycle. Following a drought, available N and P levels in the soil are generally higher than in a normal season. However, most of the N and P is in the topsoil, so if erosion strips the topsoil much of this benefit is lost. [33]

MORE INFORMATION

Drought planning

Soil management following drought

Herbicide residues after drought

Winter cropping following drought

14.3.2 Heat stress

Key points:

- Heat stress is a key yield limiting factor in crop production.

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

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

- Heat stress has been shown to adversely affect yield as early as growth stage 45.
- Delayed sowing increases the chance of the crop being exposed to heat stress, particularly at the vulnerable pre-flowering growth stages.

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

Rye is more sensitive to hot weather than oats and barley. [34]

The direct effects of heat stress are estimated to cost grain growers in south-east Australia almost $600 million per year and about $1.1 billion nationwide. Due to the effects of climate change, both heat stress and frost are likely to play an increasing role in the future and will require growers to take steps to manage the risks. [35]

Heat-stress affects crop and cereal production in all regions of the Australian wheat belt. 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 in the order of 190 kg/ha for every 1°C rise in average temperature, in some situations having a more severe effect on yield loss than water availability.

The reproductive stages of growth have greater sensitivity to elevated temperatures, with physiological responses including premature leaf senescence, reduced photosynthetic rate, reduced seed set, reduced duration of grain-fill, 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]

In some cereals heat stress can be identified by the withering and splitting of leaf tips (Photo 12). Tips of the leaves can also turn brown to grey in colour. Some or all grains fail to develop in a panicle. [37]

34 A Clark (Ed.) (2007) Managing Cover Crops Profitably, 3rd ed. Sustainable Agriculture Network, Beltsville, MD, http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition

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

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

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

Photo 12: *Withered and split tips in heat stressed cereal.*

Source: DAFWA

Managing heat stress

Key points:

- Choose varieties more tolerant to heat stress
- Sowing crops early may reduce the exposure to very hot conditions and heat stress.

Trials were conducted in South Australia in 2013 to test whether strategic sowing time and variety selection can reduce yield loss due to heat stress in wheat. The research suggests that variety selection and early sowing remain the most effective means to reduce the risk of a crop being damaged by excessive heat. A later sown crop will have an increased likelihood of being exposed to the heat stress at more sensitive growth stages, particularly pre-flowering, and will have greater consequences to the potential grain yield. [38]

MORE INFORMATION

Managing heat stress in wheat

14.3.3 Salinity

Water moves into plant roots by a process known as osmosis, which is controlled by the level of salts in the soil water and in the water contained in the plant. If the level of salts in the soil water is too high, water may flow from the plant roots back into the soil. This results in dehydration of the plant, causing yield decline or even death of the plant. Crop yield losses may occur even though the effects of salinity may not be obvious. The salt tolerance of a specific crop depends on its ability to extract water from salinised soils.

Salinity affects production in crops, pastures and trees by interfering with nitrogen uptake, reducing growth and stopping plant reproduction. Some ions (particularly chloride) are toxic to plants and as the concentration of these ions increases, the plant is poisoned and dies. [39]

Cereal Rye is thought to be relatively tolerant on saline soils, similar to barley, but will be affected in highly saline soils (8-16 ECe (dS/m)). [40]

38 Telfer P, Edwards J, Bennett D, Kuchel H. (2014). Managing heat stress in wheat. Australian Grain Technologies. http://www.msfp.org.au/wp-content/uploads/Managing-heat-stress-in-wheat.pdf

39 Queensland Government (2015) Impacts of salinity, https://www.qld.gov.au/environment/land/soil/salinity/impacts/

40 PIR.SA, Testing for soil and water salinity. Factsheet No:66/00.

IN FOCUS

How salinity affects the emergence, growth, yield and quality of rye

Researchers wanted to know how rye would respond to saline conditions. To find out, they conducted a two-year field study in the arid south-west of the USA, where some soils have become highly saline. They gave six salinity treatments to rye grown on a Holtville silty clay by irrigating with Colorado River water made artificially saline with sodium chloride (NaCl) and calcium chloride ($CaCl_2$) (1:1 by weight). The electrical conductivity of the irrigation waters were 1.1, 4.0, 8.0, 12.1, 16.0, and 20.1 dS/m−1 in the first year, and 1.1, 3.9, 7.5, 11.6, 15.6, and 19.8 dS/m−1 in the second year. The researchers measured vegetative growth and grain yield. Relative grain yield of two cultivars, Maton and Bonel, was unaffected up to a soil salinity of 11.4 dS/m−1 (electrical conductivity of the saturation extractKe). Each unit increase in salinity above 11.4 dS/m−1 reduced yield by 10.8%.

These results place rye in the salt-tolerant category.

The researchers found that both cultivars were slightly less salt tolerant during plant emergence than during subsequent stages of growth. (Seeds were planted in greenhouse sand cultures.) They found that straw yield was more sensitive to salinity than was grain yield. They attributed the reduction in yield primarily to reduced spike weight and individual seed weight, rather than to the number of spikes. They also found that bread quality decreased slightly with increasing levels of salinity. [41]

The arid climate and sandy soils of the Mallee render it readily susceptible to land-use change with the result that wind erosion and salinity are common outcomes of vegetation clearance. Dryland salting in the Mallee Region is a mixture of Primary and Secondary types; the former mainly occurring as evaporation salt pans or playas on broad flat plains while the latter has developed at the base of east-west dunes as a result of clearing of native vegetation causing rising ground-water and seepage. Continuous cropping and fallow management of interdune areas (swales) in the past have exacerbated the problem. [42]

Symptoms

What to look for in the paddock

- Moist bare patches where seed has failed to germinate or seedlings have died (Photo 13).
- Patches of stunted and apparently water stressed or prematurely dead plants in areas subject to salinity.
- Most crop weeds will also be affected with the exception of salt tolerant species.
- Salt crystals may occur on dry soil surface.

41 LE Francois, TJ Donovan, K Lorenz and EV Maas (1989) Salinity effects on rye grain yield, quality, vegetative growth, and emergence. Agronomy Journal. 81 (5), 707–712.

42 Victorian State Government (2015) Salinity in the Mallee region, http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/sss_salinity_mallee_region

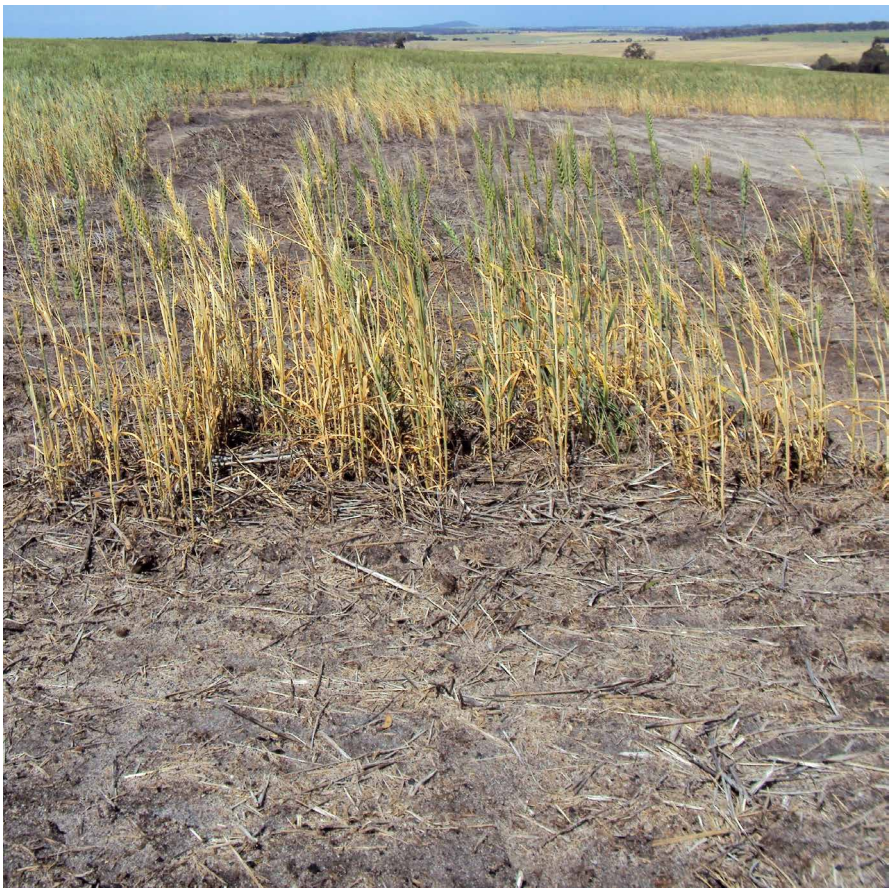

Photo 13: *Bare saline area with surviving plants dying prematurely.*

Source: DAFWA

What to look for on plants

- Plants have a harsh droughted appearance, and may be smaller with smaller dull leaves (Photo 14).
- Old leaves develop dull yellow tips and die back from the tips and edge.
- Heads are smaller with small grain.
- Plants die prematurely.
- Root growth is reduced, and may be brown and poorly branched or die if the plant is also waterlogged.

Photo 14: *Surviving plants appear to be limp and water stressed.*

Source: DAFWA

Management strategies

The amount of crop yield reduction depends on such factors as crop growth, the salt content of the soil, climatic conditions, etc. In extreme cases where the concentration of salts in the root zone is very high, crop growth may be entirely prevented. To improve crop growth in such soils the excess salts must be removed from the root zone. The term reclamation of saline soils refers to the methods used to remove soluble salts from the root zone. Methods commonly adopted or proposed to accomplish this include the following:

Scraping:

Removing the salts that have accumulated on the soil surface by mechanical means has had only a limited success although many farmers have resorted to this procedure. Although this method might temporarily improve crop growth, the ultimate disposal of salts still poses a major problem.

Flushing:

Washing away the surface accumulated salts by flushing water over the surface is sometimes used to desalinize soils having surface salt crusts. Because the amount of salts that can be flushed from a soil is rather small, this method does not have much practical significance.

Leaching:

This is by far the most effective procedure for removing salts from the root zone of soils. Leaching is most often accomplished by ponding fresh water on the soil surface and allowing it to infiltrate. Leaching is effective when the salty drainage water is discharged through subsurface drains that carry the leached salts out of

MORE INFORMATION

Preventing and managing salinity

Managing saline soils

the area under reclamation. Leaching may reduce salinity levels in the absence of artificial drains when there is sufficient natural drainage; i.e. the ponded water drains without raising the water table. Leaching should preferably be done when the soil moisture content is low and the groundwater table is deep. Leaching during the summer months is, as a rule, less effective because large quantities of water are lost by evaporation. The actual choice will however depend on the availability of water and other considerations. In some parts of India for example, leaching is best accomplished during the summer months because this is the time when the water table is deepest and the soil is dry. This is also the only time when large quantities of fresh water can be diverted for reclamation purposes. [43]

43 FAO. Saline soils and their management. http://www.fao.org/docrep/x5871e/x5871e04.htm