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GRDC GROWNOTES™

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

CEREAL RYE

SECTION 14

ENVIRONMENTAL ISSUES

FROST ISSUES FOR CEREAL RYE | WATERLOGGING AND 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.
- Rye is less sensitive to frost and more sensitive to hot weather than oats and barley.
- 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. Cereal rye is thought to be relatively tolerant of saline soils, similar to barley, but will be affected in highly saline soils (8-16 ECe (dS/m)).

14.1 Frost issues for cereal rye

Key points:

- Although frost events can have major and sudden impacts on cereal yields (Photo 1), rye is more tolerant of frosts than other cereals.
- 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—and a decrease in other areas.
- In the event of severe frost, monitoring needs to occur up to two weeks after the event to detect all the damage. [1]
- Cereal rye is one of the least susceptible cereals to frost, and is renowned for its tolerance to cold. Crop susceptibility to frost from most to least susceptible is triticale, wheat, barley, cereal rye, and oats. [2]
- Flowering about two weeks later than SA Commercial, Bevy is less prone to frost, which often affected yields of the SA Commercial variety. [3]

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

2 GRDC (2009) Managing the risk of frost. Fact sheet. GRDC, https://grdc.com.au/__data/assets/pdf_file/0020/202826/frost-factsheet.pdf.pdf

3 Agriculture Victoria (2013) Growing cereal rye. Note AG0403. Updated. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

Photo 1: *Cereal heads showing frost damage.*

Source: DAFWA

VIDEOS

WATCH: Plant frost mechanisms with Glenn McDonald

Rye is the most frost-tolerant cereal species. During winters it can survive intense frosts. Winter hardiness is a complex feature that involves resistance to the cold and 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 in their growth processes and respiration in a more economical way than other plants.

Cold temperatures induce cold-tolerance and antifreeze activity in rye. Antifreeze proteins are found in a wide range of overwintering plants; they work by inhibiting the growth and recrystillisation of ice that forms in intercellular spaces. In rye, antifreeze proteins accumulate in response to cold, short days, dehydration and ethylene. [4]

Clear, calm and dry nights following cold days are the precursor conditions for a radiation frost (or hoar frost). These conditions most often occur during winter and spring where high-pressure air masses follow a cold front, bringing cold air from the Southern Ocean and settled, cloudless weather (Figure 1). A frost occurs when daytime heat is lost from the earth during the night, and the temperature at ground level reaches 0°C. 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 drops to zero, the length of time its stays below zero, and the how far below zero it gets.

4 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

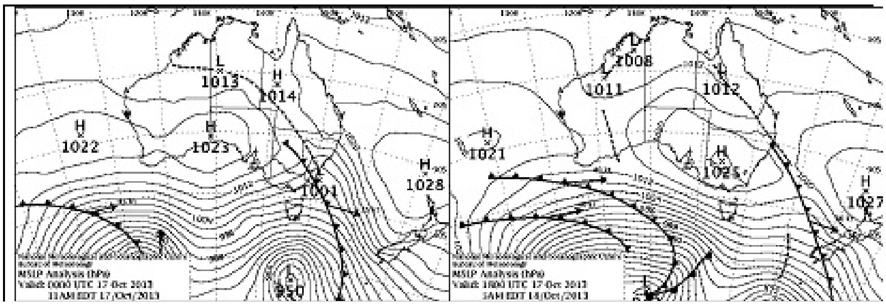

Figure 1: *A cold front passes through, injecting cold air from the Southern Ocean the day before frost (left). Overnight the high pressure system stabilises over SE Australia, bringing clear skies and no wind, and leading to a frost (right).*

Source: GRDC

Though temperatures generally (particularly those in winter and spring) are getting warmer, frost is still a major concern. The pattern of its occurrence seems to be changing. CSIRO researchers have found that, in some areas of Australia, the number of frost events are increasing (and are greatest in August). However, the crop-growing areas of central western NSW, the Eyre Peninsula, Esperance, and the northern Victorian Mallee have been less affected by frost in the period 1961–2010. This increase in frost events seen in areas of northern NSW and elsewhere (Figure 2), is thought to be caused by the latitude of the sub-tropical ridge of high pressure drifting south (causing more stable pressure systems), and the existence of more El Niño conditions during this period. [5]

VIDEOS

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

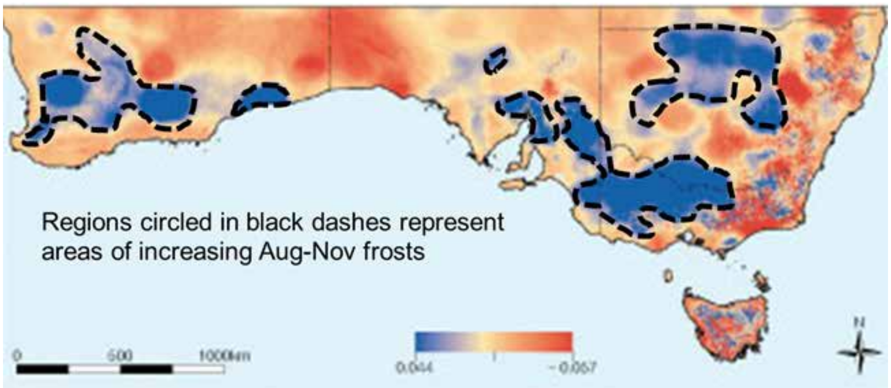

Figure 2: *Region of increasing August–November frost events.*

Source: GRDC

14.1.1 Diagnosing stem and head frost damage in cereals

In the paddock

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

In the plant

- Before flowering:

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

- Freezing of the emerging head by cold air or water is caught next to the flag leaf, or travels down the awns into the boot. Individual florets or the whole head can be bleached and shrivelled, stopping grain formation. Surviving florets will form normally.
- Stem frost by a small amount of water that has settled in the boot and frozen around the peduncle shows in 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 normal flowers the ovary is bright white and 'crisp' when squeezed.)
- Anthers are dull coloured and are often banana shaped. As the grain develops it turns green. Anthers are green to yellow before flowering, and yellow, turning white, after flowering
- Grain:
- At the milk stage, frosted grain is white, turning brown, with a crimped appearance. It is usually spongy when squeezed, and doesn't exude milk (or dough). (Healthy grain is light to dark green and plump, and exudes white milk or dough when squeezed (Photo 2). [6])
- At the dough stage, frosted grain is shrivelled and creased along the long axis, rather as if a pair of pliers has crimped the grain (Photo 3). [7]

Photo 2: *A normal cereal head (left) compared to frost-damaged cereal showing discoloured glumes and awns.*

Source: DAFWA

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

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

VIDEOS

WATCH: GCTV15: Frost ratings

WATCH: GCTV15: The frost ranking challenge

WATCH: GCTV12: Frost susceptibility ranked

Figure 3: *The typical crimped look of frosted grain.*

Source: GRDC

IN FOCUS

New insight into managing for frost in a changing climate

- Growers need to consider carefully whether earlier sowing is justified in seasons where warmer temperatures are predicted.
- Warmer temperatures may reduce the frequency of frosts, but they 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, with an average of approximately 10%.
- In the northern region, losses were much higher, between 23% and 38%, due to late sowing.
- These results indicate that, despite increasing temperatures overall, continued research into reducing frost risk remains a high priority.
- Variety guides and decision-support software are useful for matching cultivars to sowing opportunities.
- Current variety ratings based on floret damage may not provide a useful guide to frost damage to heads and stems.
- Crops are most susceptible to frost once awns emerge.
- If crop temperature at canopy height drops below –3.5°C after the awns emerge, crops should be assessed for damage.
- To spread risk, consider multiple sowing dates and/or crops of different phenology.

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 a GRDC-funded project, climate data from 1957–2013 were used to assess the frequency and severity of frosts in each region of the Australian cropping belt. [8] Night-time minimum temperatures were observed to have increased over much of the Australian cropping region during that period. However, when the researchers analysed the data, it showed that neither the risk nor the impact of frost was reduced over the whole cropping area. It turned out that warmer temperatures accelerate plant development, causing crops to develop to the frost-susceptible, heading stages more

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

rapidly. So, counterintuitively, planting earlier or even at the conventional date during warmer seasons may sometimes increase frost risk.

The researchers used historic climate data from a grid database at 60 locations in the four major cropping regions of Australia to determine the frequency and severity of frosts (Figure 4, top). They used the modelling program Agricultural Production Systems sIMulator (APSIM) to estimate crop yields, and expert knowledge and data from frost trials to estimate crop losses (Figure 4, bottom). The computer simulation allowed them to use this data to predict crop losses, and also potential yields. For the yields, the researchers used sowing dates optimised for yield in the hypothetical absence of frost risk, something that had not previously been achieved experimentally.

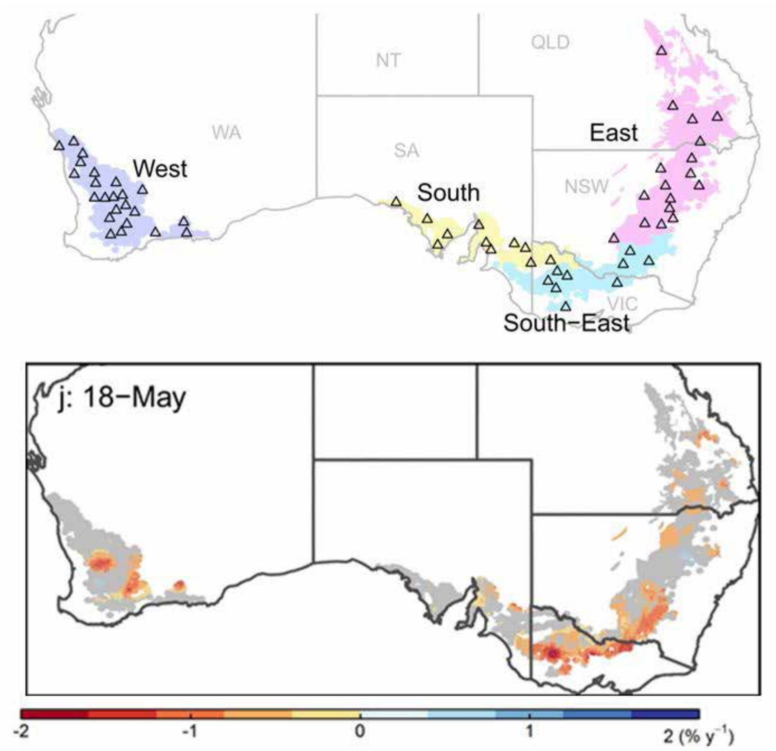

Figure 4: *Maps showing sites and regions for which climate data were analysed for the frequency and severity of frosts (top); and annual percentage change in yield loss due to frost from 1957 to 2013 (bottom). In the bottom panel ,areas coloured yellow, orange and tan are negative values that show where yield loss became worse in recent decades. Estimations in the lower panel were for the cultivar Janz, which was sown on 18 May and are based on a ~5 km x 5 km grid of climatic data. (Gridded climate data may not reflect the climatic conditions of particular paddocks within each grid, as frost is highly variable in an area.)*

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 (Figure 5).

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 5, 'direct + indirect' impact). In the eastern grains region (Queensland to central NSW), 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 5).

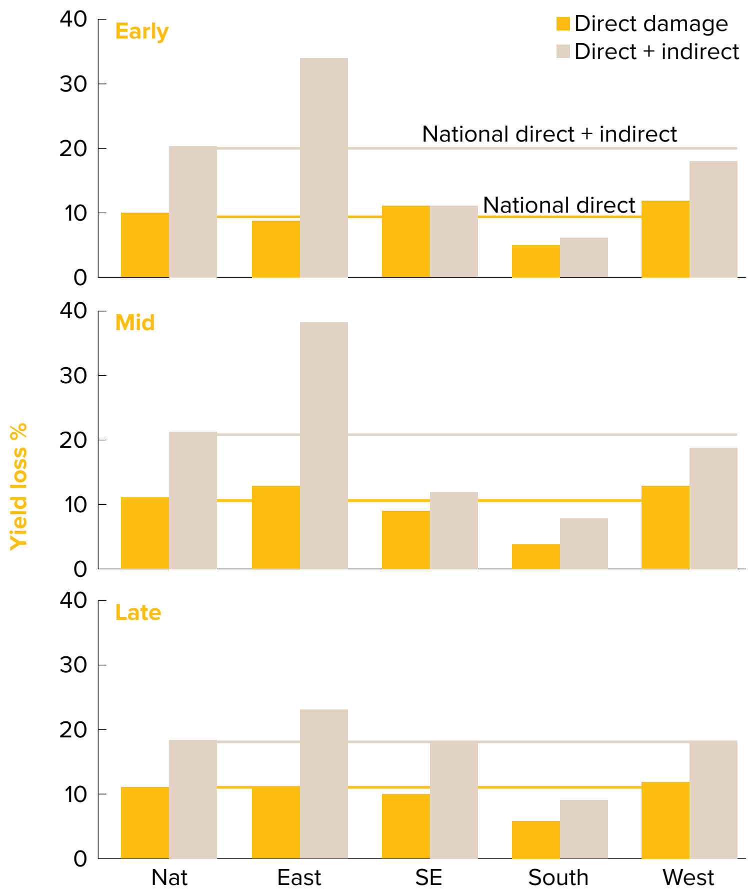

Figure 5: *Estimated wheat yield losses (%) due to frost damage for crops sown at the current best sowing date (labelled 'direct damage'); and crop losses due to both direct damage and delayed sowing currently necessitated to manage frost risks (labelled 'direct + indirect') for early, mid and late flowering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

Match 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.

Measure 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; thus, in many instances, the recommendations likely err on the side of caution.

Stevenson screen temperatures measured at Bureau of Meteorology stations do not fully explain frost risk, either. In crops, the temperature can vary 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 6). The crop temperatures recorded can vary widely due to differences in topography, micro-environment and recording method.

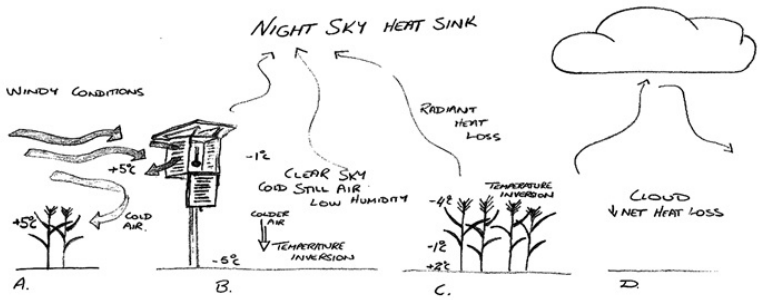

Figure 6: *If clear skies and still, cold, dry air coincide, heat can be lost rapidly to the night sky, resulting in a radiant frost. Minimum air temperatures measured at head height can be several degrees colder than those recorded in screened boxes. Some indicative temperatures are illustrated for (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 3) give a much more accurate indication of the likelihood of crop damage. [9]

Photo 3: *Canopy temperature measured using a calibrated minimum/maximum thermometer. For best results, a minimum of two or three field thermometers are required to give representative temperatures for a crop. In undulating country, more thermometers should be used to record temperatures at various heights in the landscape.*

Source: GRDC

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

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 the damage it causes to grain crops are determined by a combination of environmental and management factors including: temperature; humidity; wind; topography; soil type, texture and colour; crop species and variety; and how the crop is managed.
- The greatest losses in grain yield and quality are observed when frosts occur between the booting and grain-ripening stages of growth.
- Frost damage is not always obvious, and crops should be inspected within five to seven days after a suspected frost.
- Methods to deal with the financial and personal impact of frost need to be considered in a farm management plan.
- Careful planning and zoning, and choosing the right crops, are the best options to reduce frost risk. [10]

The variability in the incidence and severity of frost means that growers need to have on hand a number of tactics they can employ as part of their farm-management plan. These include pre-season, in-season, and post-frost actions.

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

- at the level of the whole farm; and
- within identified frost zones on a farm.

Farm-management planning tactics

Step 1: Assess personal approach to risk

The first step is to consider your personal approach to risk in your business; every individual will have a different approach. Identify and measure the extent of the risk, evaluate risk-management options, and tailor the risk advice according to individual attitude to risk. The risk of frost can promote conservative farming practices, which should be carefully and regularly reviewed in light of the latest research.

Step 2: Assess frost risk of property

Carefully consider the risk of frost on your property due to its location. Use historical seasonal records and forecasts, and consider spatial variability (topography and soil type) across the farm landscape. 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 skill set of the manager but the largest financial losses with frost have occurred among growers who have a limited range of enterprises or crop types. For example, intensive-cropping systems where the focus is 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.

10 GRDC (2016) Managing frost risk: northern and southern regions. Tips and Tactics. GRDC, www.grdc.com.au/ManagingFrostRisk

Step 4: Zone the property and paddocks

Paddocks or areas in paddocks that are prone to frost can be identified through past experience, and the use of precision tools such as topographic, electromagnetic and yield maps, and temperature monitors. Knowing precisely the pattern of frost on a farm can help a grower determine the specific management practice needed to mitigate damage. 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 use within a zone

The use that frost zones are put to should be carefully considered; for example, using them for grazing, or hay or oat production, so as to avoid 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.

VIDEOS

WATCH: Frost initiative: Do micronutrients reduce frost risk?

WATCH: MPCN: Copper and frost relationship investigated

Step 2: Review nutrient management

In high-risk paddocks, target the amount of fertiliser (nitrogen, phosphorus, potassium) used and seeding rates to achieve realistic yields that minimise financial exposure, and that simultaneously reduce frost damage, and increase the profitability of the whole paddock over time. Fertiliser not used in these paddocks could be reallocated for use on lower-risk paddocks.

While high nitrogen (N) increases yield potential, it also promotes the production of vegetative biomass and thus increases the susceptibility of the crop to frost. Using 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 a crop's susceptibility to frost events. Levels of these elements can be assessed from initial soil tests and with plant-tissue testing. Copper deficiency can be ameliorated with a foliar spray before flowering starts, 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, which may influence a plant's 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 an increase in 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 cannot 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

The soil heat-bank is important element of reducing the risk and severity of frosts (Figure 7). 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.

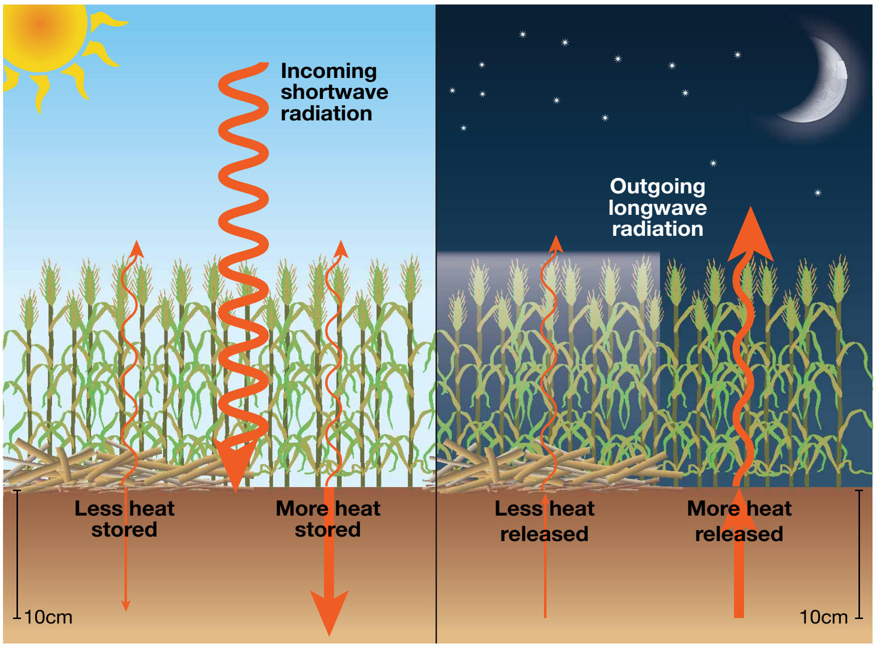

Figure 7: *The role of the soil heat-bank: soil captures heat during the day and radiates it back into the crop canopy overnight. to warm flowering heads and minimise frost damage. A range of farming practices can be utilised to increase the capacity of the soil heat-bank.*

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, including increasing heat storage, nutrient availability and infiltration rate.
- Rolling sandy soil and loamy clay soil after seeding, which 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.
- Halving the normal seeding rates, which can reduce frost severity and damage by creating a thinner canopy and more tillers, which results in a spread of flowering time. However, weed competitiveness can be a problem.
- Cross-sowing—crops sown twice with half the seed sown in each direction have a more even plant density. This practice increases sowing costs.

Step 4: Select appropriate crops

Crop selection is an important factor to consider for frost-prone paddocks. There are numerous options available to farmers. For example, crops grown for hay are harvested for biomass, and so avoid the problem of grain loss from frost. Pasture rotations are a lower-risk proposition. Oats are the most frost-tolerant crop during the reproductive stage; barley is more tolerant than wheat at flowering, but it is not known if barley and wheat have different frost tolerance during grainfill. Canola is an expensive crop to risk on frost-prone paddocks, due to the high input costs.

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.

MORE INFORMATION

Yield Prophet

Flower Power

Step 6: Fine-tune cultivar selection

Cereal rye has relatively good tolerance to frost. When planting other, more susceptible cereals, consider using 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 frost is unlikely, because then there is an opportunity cost of achieving lower yields.

Preliminary information that ranks some of the current cereal varieties for susceptibility to reproductive frost is available from the National Variety Trials website. A new variety should be managed based on how known varieties of similar ranking are managed.

Post-frost management tactics

Once a frost event (especially at or after flowering) has occurred, the first step is to inspect the crop and collect a random sample of heads to estimate the yield loss incurred. In the event of severe frost (Photo 4), 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.

Photo 4: *Severely frosted areas mature later and are often stained or discoloured.*

Source: DAFWA

Option 1: Take through to harvest

If the frost occurs before or around growth stages GS31 and 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. Compensatory tillers will mature later, but where reserves of soil moisture 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

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

MORE INFORMATION

For more information on varietal susceptibility to frost, see the GRDC Update Paper; Ranking cereals for frost susceptibility using frost values: northern.

Managing frost risk: northern, southern and western regions

VIDEOS

WATCH: GCTV3: Frost R&D

WATCH: GCTV16: National Frost Initiative

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. Spray-topping 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 returns organic matter and nutrients to the soil, manages crop residues and weeds, and improves soil fertility and structure. The economics need to be considered carefully. [11]

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
- 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

Frost has been estimated to cost Australian growers around $360 million in direct and indirect yield losses every year. To help the grains industry minimise the damage frost causes, the GRDC has invested about $13.5 million in more than 60 frost-related projects since 1999. In 2014, it began the National Frost Initiative, to provide the Australian grains industry with targeted research, development and extension solutions to manage the impact of frost and maximise seasonal profit. [12]

The initiative is addressing frost management through multidisciplinary research 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 strategies for crop canopy, stubble, nutrition and agronomic management so growers can 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 mapping frost events at the farm scale to enable better risk management. [13]

14.2 Waterlogging and 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 prone to waterlogging, rye can withstand some degree of waterlogging. [14]
- Water does not have to appear on the surface for waterlogging to be a problem.
- Improving drainage from inundated paddocks can lessen the time that 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.

11 GRDC (2016) Managing frost risk: northern, southern and western regions. Tips and Tactics. GRDC, www.grdc.com.au/ManagingFrostRisk

12 T March, S Knights, B Biddulph, F Ogbonnaya, R Maccallum and R Belford (2015) The GRDC National Frost Initiative. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative

13 GRDC (2016) Managing frost risk: northern, southern and western regions. Tips and Tactics. GRDC, www.grdc.com.au/ManagingFrostRisk

14 Agriculture Victoria (2013) Growing cereal rye. Note AG0403. Updated. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

Waterlogging occurs whenever the soil is so wet that there is insufficient oxygen in the pore spaces between soil particles for plant roots to be able to adequately respire. It commonly happens as a result of floods and periods of unusually high rainfall (Photo 5) or in areas with poorly draining soils. Other gases detrimental to root growth, such as carbon dioxide and ethylene, also accumulate in the root zone and harm plants. As plants differ in their demand for oxygen, there is no one universal level of soil oxygen that can be used to identify when a soil is waterlogged. In addition, a plant's demand for oxygen in the root zone will vary with the stage of growth. [15]

Photo 5: *The 2016 July wet caused waterlogging in crops, like this one at Murrumburrah.*

Source: Harden Murrumburrah Express

14.2.1 Occurrence of waterlogging

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. [16]

IN FOCUS

Waterlogging and drought tolerances of winter cereals compared

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

15 Soilquality (2016) Waterlogging. Fact sheet. Soilquality, http://soilquality.org.au/factsheets/waterlogging

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

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. Hulled barley, which had RLWTC, was stable to W conditions. All of the crops were stable to D conditions. [17]

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. [18]

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

Identifying problem areas

The best way to identify problem areas is to dig holes about 40 cm deep in winter, and see if water seeps or flows into them (Photo 6). If it does, the soil is waterlogged. Some farmers put slotted PVC pipe into augered holes. They can then monitor the water levels in their paddocks. Digging holes for fence posts often reveals waterlogging.

Symptoms in the crop of waterlogging include:

- Yellowing of crops and pastures.
- The presence of weeds such as toad rush, cotula, dock and Yorkshire fog grass. [19]

Photo 6: *Water fills a hole that has been dug in waterlogged soil.*

Source: Soilquality

17 山内章，河野恭広，巽二郎，& 稲垣憲孝 (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.

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

19 Soilquality (2016) Waterlogging. Fact sheet. Soilquality, http://soilquality.org.au/factsheets/waterlogging

14.2.2 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 7).
- The presence of wet soil and/or water-loving weeds.
- Early plant senescence in waterlogging-prone areas.

Photo 7: *Pale plants in waterlogged areas.*

Source: DAFWA

What to look for in the plant

- Plants are particularly vulnerable from seeding to tillering, with the seminal roots being more affected than the 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 death of the older leaves.
- If waterlogging persists, roots (particularly root tips) cease growing, become brown and then die (Photo 8).
- Seminal roots are important for accessing deep, subsoil moisture. If damaged by waterlogging the plants may be more sensitive to spring drought.

Photo 8: *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 so siting needs to be done care.
- Plants can be waterlogged if there is a water table within 30 cm of the surface. There may be no indication at the surface that water is lying in the root zone. Observe plant symptoms and paddock clues, and verify by digging a hole to test for water seepage. [20]

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

Other impacts of waterlogging and floods

Heat from stagnant water

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

Chemical and biological contaminants

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

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.

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 by fertilising.

Soils with high clay content

Soils with a high clay content can become compacted and form a crust after heavy rain and flooding. Floodwater also deposits a fine clay layer or crust on top of the soil, and this can prevent oxygen penetrating into the soil (aeration). Clay layers 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. [21]

VIDEOS

WATCH: GCTV3: Big wet—managing strategies after flooding

14.2.3 Managing waterlogging

- Sow waterlogging-tolerant crops such as oats and faba beans.
- Sow as early as possible with a higher cereal seeding rate.
- It may be appropriate to build drainage on sandy duplex soils on sloping sites.
- Raised beds are more effective on relatively flat areas and on heavier-textured soils, but areas need to be large enough to justify the machinery costs. [22]
- Reduce the impact of waterlogging through the choice of crop, seeding, fertiliser and weed control.

Drainage is usually the best way of reducing waterlogging. 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 problem areas.

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

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

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

MORE INFORMATION

Cropping on raised beds in southern NSW

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 (e.g. by digging drains) to improve the drainage of these areas so that the water can get away.

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 include:

- reshaping the layout of the field
- improving surface drainage
- installing subsurface drainage

If the drainage can't be improved, consider using the area for some other purpose (e.g. as a silt trap). [23]

Choice of crop species

Some species of grains crop are more tolerant to waterlogging and being flooded 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. Damage will be particularly severe if plants are waterlogged between germination and emergence. Plant first those paddocks that are susceptible to waterlogging. However, if waterlogging delays emergence and reduces cereal-plant density to fewer than 50 plants/m^2, resow the crop.

Seeding rates

Increase sowing rates in areas susceptible to waterlogging to give some insurance against uneven germination, and to reduce the dependence on 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 if they previously had a good nitrogen level. Applying nitrogen at the end of a waterlogging period can be an advantage if nitrogen was applied at or shortly after seeding because it avoids loss by leaching or denitrification. However, as nitrogen cannot usually be applied from vehicles when soils are wet, consider aerial applications.

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

Weed density affects the ability of a crop to recover from waterlogging. Weeds compete for water and the small amount of remaining nitrogen, hence the

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

waterlogged parts of a paddock are often weedy and require special attention if the yield potential is to be reached. [24]

14.3 Other environmental issues for cereal rye

14.3.1 Drought

Drought is one of the major environmental factors reducing grain production in rain-fed and semi-arid regions. 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 the time it takes to mature to the amount of moisture available (Photo 9). It uses 20–30% less water per unit of dry matter 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. [25] Under conditions where wheat, oats or barley will grow only a few centimetres high, or may even be blown away, rye often grows vigorously and reaches a height of a metre or more. [26]

Photo 9: *Cereal rye during a drought year: it develops a large root system and less above-ground growth.*

Source: Kauffman Seed

VIDEOS

WATCH: MEF research breaking ground in drought tolerance

Dr Pattison drills into drought tolerance

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

25 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

26 RHJ Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press, Boca Raton, Florida.

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. [27]

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.

27 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.

MORE INFORMATION

Drought planning

Soil management following drought

Herbicide residues after drought

Winter cropping following drought

DPI NSW Drought Hub

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. [28]

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 droughtbreaking 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. [29]

28 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

29 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

14.3.2 Heat stress

Key points:

- Heat stress is a key yield limiting factor in crop production.
- Heat stress has been shown to adversely affect yield as early as growth stage 45.
- 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 can be as damaging as drought and frost. Varieties that are better adapted to drought also generally perform better in heat-stress conditions.

Rye is more sensitive to hot weather than oats and barley. [30]

Heat-stress affects crop and cereal production in most cropping regions in Australia. 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 does.

The reproductive stages of growth are more sensitive 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. [31]

In some cereals heat stress can be identified by the withering and splitting of leaf tips (Photo 10). The tips of the leaves may also turn brown to grey in colour. Some or all grains fail to develop in the panicle. [32]

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

Source: DAFWA

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

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

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

MORE INFORMATION

Managing heat stress in wheat

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. [33]

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, which causes yield decline or even the death of the plant.

As a result of rising water tables in irrigated as well as non-irrigated cropping lands, or because of the use of saline water supplies, salinity has become a major form of land degradation in Australia.

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 soils that are have become saline.

As well as affecting osmosis, 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 becomes poisoned and dies. [34]

Cereal rye is thought to be relatively tolerant to saline soils, similar to barley, but will be affected in highly saline soils of 8–16 ECe (dS/m). [35] Rye can tolerate acid soils better than wheat, barley or canola. [36]

CASE STUDY

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

33 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

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

35 C Henschke and T Herrmann (2007) Testing for soil and water salinity. Fact sheet. No. 66/00. Agdex 533. PIRSA

36 Alberta Agriculture and Forestry (2016) Fall rye production. Revised. AgDex 117/20-1. Alberta Agriculture and Forestry, http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex1269/$file/117_20-1.pdf

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. [37]

Symptoms

What to look for in the paddock

- Moist bare patches where seed has failed to germinate or seedlings have died (Photo 11).
- Patches of stunted and apparently water stressed or prematurely dead plants in areas subject to salinity.
- Most crop weeds, with the exception of salt-tolerant species, will also be affected.
- Salt crystals may occur on the dry soil surface.

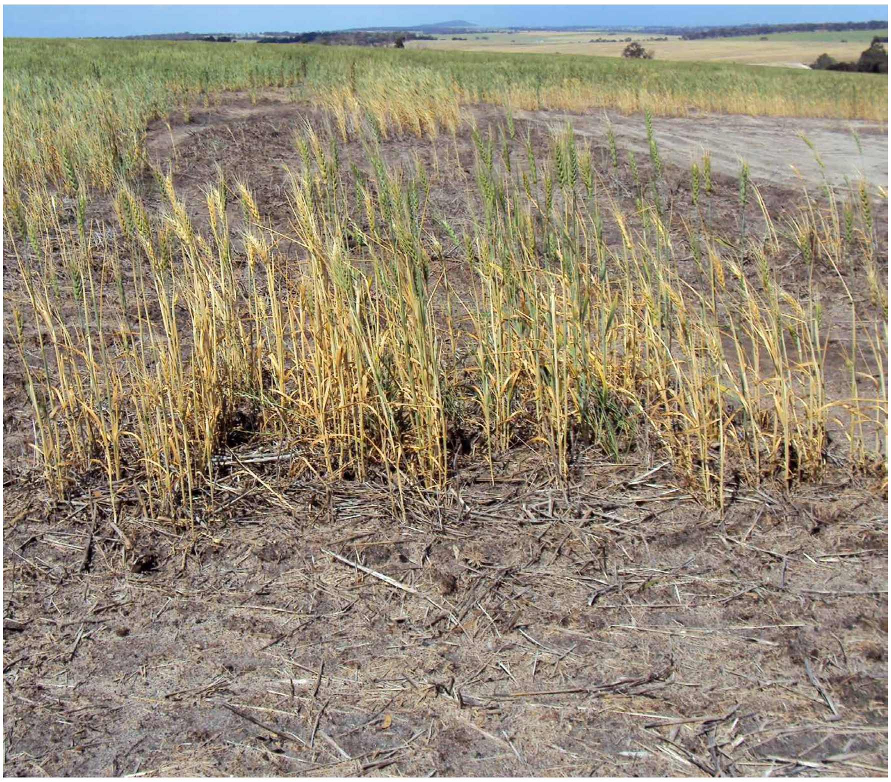

Photo 11: *Bare saline area with surviving plants dying prematurely.*

Source: DAFWA

37 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.

What to look for in the plant

- Plants have a harsh, droughty appearance, and may be smaller with smaller dull leaves (Photo 12).
- 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. Poor root development may mean that the plant dies if it is also waterlogged.

Photo 12: *Surviving plants are limp and look water stressed.*

Source: DAFWA

Management

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 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. [38]

MORE INFORMATION

Preventing and managing salinity

Managing saline soils

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