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FROST INJURY to wheat

By Stephen Loss, Research Officer, Division of Plant Industry

Frost injury has not been a major concern to the Western Australian wheat industry despite causing spectacular but irregular crop losses on some farms.

The development of suitable herbicides, direct drilling technology and the adoption of early flowering varieties in the late 1970s and early 1980s led to wheat crops being sown and flowering earlier than previously. This resulted in an increase in the incidence of frost damage.

Large areas in the Great Southern suffered frost damage in 1981 and 1985, with smaller areas affected in 1977, '79, '80, '82, '84 and '88. Wheat crops in the eastern wheatbelt were also damaged in 1987 and 1988. The frosts occurred from late September to late October and are estimated to have cost the State's wheat industry about $1.2 million per year in lost production.

Research into frost damage indicates that most wheat producers face low to moderate risks of yield loss caused by frost. However, individual farms in particular years can suffer devastating widespread losses. Frost injury can be reduced in the long term by sowing a longer maturing variety later than usual, but the increase in yield is more often outweighed by yield lost because of delayed sowing and flowering.

Frost injury

Freezing damages plant tissues in two ways. When the tissues of cold-tolerant plants freeze slowly, ice crystals usually form in the spaces between the cells. The cells remain alive in a supercooled state but since ice extracts water from supercooled solutions, the cells begin to dehydrate. In the short term this process is reversible with no permanent damage.

When the tissues of cold-sensitive plants freeze rapidly, the developing ice crystals rupture the cell membranes and the tissue dies almost immediately. The growing points of the wheat plant, including the elongating nodes, reproductive parts and developing grain, are highly sensitive to freezing because their cells are closely packed, unlike the cells of leaf or stem tissue which have large spaces between them. Ice crystals form within these spaces without rupturing the cells.

Plant development

Soil type, soil moisture content, cloud cover, wind speed, the position of the crop in the topography, crop moisture status, crop density and crop nutrition all influence the amount of frost injury to wheat crops. Many of these factors are difficult to investigate and hence are poorly understood. Of particular importance is the crop's stage of development at the time of frost (Figure 1).

Pre ear emergence

Before stem elongation frost rarely kills the growing points of the wheat plant, even at air temperatures of nearly -8°C. Such temperatures will blight leaves, but if the soil remains unfrozen the growing point of the wheat plant remains protected below the soil surface.

Stem elongation

During stem elongation and booting the developing ear within the stem is forced away from the protection of the soil, towards the top of the crop canopy. Hence its susceptibility to freezing increases during these stages of development.

Severely distorted heads with some or all of the florets blighted will emerge from the boot. Stem tissue just above or below the nodes may blister and crack. The distortion of stem growth or damage to heads caused by frost can look like that caused by the ill-timed use of hormonal herbicides. Ambient air temperatures need to fall below -4°C for such damage to occur; this is rare in the Western Australian wheatbelt.

Mature heads of wheat showing severe distortion of the stem and head caused by frost. These symptoms are easily mistaken for herbicide damage. A normal head is on the far right.
Post ear emergence

Wheat crops are most susceptible to frost injury after ear emergence because the floral tissues become directly exposed to the freezing air.

Flowering is not the only sensitive stage of development as ambient air temperatures of -2°C can cause widespread damage to wheat crops from ear emergence to grain growth. Such temperatures sometimes occur in Western Australian wheat crops at these stages of development during September and October.

If the damaging frost occurs within three or four days of ear emergence, blighted florets may be visible at the base, middle or tip of the ear, or the entire ear may be damaged. Severe moisture stress can damage ear tips and this may be mistaken for frost injury, however frost rarely damages all ears solely at the tip. Occasionally a white ring around the stem below the ear is associated with frost damage. Stems may also be damaged after ear emergence, causing a reduction in the movement of sugars to the ear and pinched grain.

Alternatively, only the sensitive floral tissues may be frozen, leaving the more tolerant glumes and chaff apparently unaffected. Such damage may be total or random within the ear and may go undetected until harvest. The damaged grain stops growing immediately, resulting in empty or partially empty heads at harvest. This may be confused with copper deficiency which causes empty heads. Frosting in the late stages of grain growth may also result in pinched grain.

Delaying ear emergence

The only economical method for farmers to reduce frost losses at present is to delay the timing of ear emergence by planting a wheat variety which matures later than those currently sown and by delaying sowing. Farmers need to assess the benefits and risks of sowing early, including the risk of frost damage (See "Early sowing - one key to improved yields of cereal crops" on page 26 of this Journal.)

Sowing late enough to totally eliminate frost damage will not produce the highest long-term yields because of the rare and irregular incidence of frosts. For example, a farmer may produce high long-term yields by sowing early, even though one year in ten frost will destroy the whole crop. The frost loss that the farmer incurs in one year may be outweighed by the benefits of early sowing in the other nine frost-free years. The level of risk a farmer will accept will be a personal decision, and an analysis of temperatures records can help by defining the levels of risk for a particular district.

Frost analysis

The Bureau of Meteorology has determined the incidence of frosts for Western Australia. Air temperatures are measured within standard Stevenson screens and those below 2.2°C (36°F) recorded at all MET stations are defined as being potentially damaging to plants. Temperatures below about 0°C recorded at MET stations are more likely to correspond to potentially damaging temperatures of wheat plants in the field, but they will vary from station to station depending on the crop's location.

To account for the variation in temperatures recorded between MET stations, an attempt was made to calibrate the temperatures recorded at each MET station to observed freezing injury to wheat crops in the surrounding districts.

In 1986, farming communities were asked for actual dates when frost caused damage to cereal crops. Only 29 reports of freezing injury to cereal crops were collected. Most farmers probably didn't realize their crops had been frosted until harvesting and hence could not recall when the damaging frost had occurred.

The minimum temperature recorded at the nearest MET station was examined for each report and the average temperature below which damage had been observed in the surrounding districts (the critical temperature) was determined for each MET station. The average critical temperature was then used to calculate the risk of a damaging frost occurring after a specific date in the surrounding district.
Frost risks

There are considerable differences in the risks of damaging minimum temperatures between districts, however the risks generally were low by late October. At Merredin there is a 10 per cent risk (that is 1 year in 10) of a damaging frost occurring after September 30, whereas at Wandering, the 10 per cent risk occurs after October 29 (Table 1).

The map shows the regional frost risks in the wheatbelt. The region between York, Corrigin and Katanning experiences a high risk of frost damage to wheat. There is a low risk of frost damage in the wheatbelt north of Moora and along the south coast.

This type of analysis can also be used to gauge the effect of the crop's position within the topography on the risk of damaging temperatures. At Wandering in 1987, minimum temperature differences of 4°C were recorded between two sites about 400 m apart. If we consider the critical temperature for the ridge to be 2°C and that of the valley floor -2°C, the risks change dramatically (Table 1). In districts where the land is more steeply undulating, the risk of damaging temperatures can vary as much within the lay of the land as between regions.

Maximizing long term yields

The analysis of the frost risk indicates that most Western Australian wheat producers face low to moderate risks of frost damage. The Department of Agriculture's FLOWER computer program has been used to assess which varieties face the greatest risks (See “FLOWER: predicting flowering times of cereal crops” on page 35 of this Journal). At the average location in the topography at Merredin (a moderate risk district) which emerges from the boot on September 21, then the risk of a damaging frost occurring after this date is 20 per cent (Table 1). If a similar crop were sown later and emerged from the boot on September 30, the risk falls to 10 per cent. Assuming the average damaging frost reduces the yield of a crop by a half, and all other factors are equal, then in the long term the earlier sown crop is likely to yield 5 per cent less than the later sown crop because of greater frost damage. However the later sown crop will incur a yield penalty of 9 per cent (that is, 1 per cent per day delayed ear emergence, a conservative estimate). Hence, on average, the later sown crop will yield 4 per cent less than the early sown crop.

If we consider a wheat crop sown in the average location in the topography at Merredin (a moderate risk district) which emerges from the boot on September 21, then the risk of a damaging frost occurring after this date is 20 per cent (Table 1). If a similar crop were sown later and emerged from the boot on September 30, the risk falls to 10 per cent. Assuming the average damaging frost reduces the yield of a crop by a half, and all other factors are equal, then in the long term the earlier sown crop is likely to yield 5 per cent less than the later sown crop because of greater frost damage. However the later sown crop will incur a yield penalty of 9 per cent (that is, 1 per cent per day delayed ear emergence, a conservative estimate). Hence, on average, the later sown crop will yield 4 per cent less than the early sown crop.

Minimizing frost injury

Farmers at high to moderate risk sites should be aware of how frost can damage crops and what can be done to minimize losses. Maximum and minimum thermometers can be fixed on a fence post or board in an exposed position representative of the crop's location. For recording minima, the thermometer doesn’t need to be shaded by a Stevenson screen.

They could sow ridges and other low risk sites first, progressing to sites of higher risk later.

Oats, a much more frost tolerant crop than wheat, could be sown in very high risk paddocks.

Crops should be checked for damage when they are near ear emergence and when temperatures fall below 2°C at the nearest Bureau of Meteorology weather station. If flowering has occurred, it may be possible to inspect and tag about six heads and return five or six days later to determine whether grain growth has ceased. Damage is likely to be sporadic and the overall loss of whole paddocks difficult to assess. Some compensatory growth in unaffected grains occurs and higher yields may be achieved than first estimated.

The decision to cut a crop for hay depends upon the potential yield of the crop (that is, the probable unfrosted yield), the proportion of damaged grain and other considerations such as hay markets and availability of machinery for cutting hay. In some situations the returns from cutting a frosted crop for hay may be greater than that of harvesting a similar but unfrosted crop.

Acknowledgements

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Further reading


Table 1. The dates after which the risk of a damaging frost is equal to 1 in 10, 5 and 3.3 years at various locations in the central and southern wheatbelt. The estimated critical temperatures for each MET station are also shown.

<table>
<thead>
<tr>
<th>Location</th>
<th>Critical temperature (°C)</th>
<th>10% (1:10)</th>
<th>20% (1:5)</th>
<th>30% (1:3.3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Katanning</td>
<td>2.0</td>
<td>Oct. 24</td>
<td>Oct. 17</td>
<td>Oct. 9</td>
</tr>
<tr>
<td>Kondinin</td>
<td>0.5</td>
<td>Oct. 17</td>
<td>Oct. 8</td>
<td>Oct. 1</td>
</tr>
<tr>
<td>Lake Grace</td>
<td>2.0</td>
<td>Oct. 13</td>
<td>Oct. 5</td>
<td>Sep. 28</td>
</tr>
<tr>
<td>Merredin</td>
<td>0.5</td>
<td>Sep. 30</td>
<td>Sep. 21</td>
<td>Sep. 15</td>
</tr>
<tr>
<td>Northam</td>
<td>2.0</td>
<td>Oct. 8</td>
<td>Sep. 30</td>
<td>Sep. 24</td>
</tr>
<tr>
<td>Wandering</td>
<td>0.0</td>
<td>Oct. 29</td>
<td>Oct. 21</td>
<td>Oct. 15</td>
</tr>
<tr>
<td>(average)</td>
<td>-2.0</td>
<td>Nov. 22</td>
<td>Nov. 16</td>
<td>Nov. 11</td>
</tr>
<tr>
<td>Wandering</td>
<td>2.0</td>
<td>Sep. 22</td>
<td>Sep. 15</td>
<td>Sep. 2</td>
</tr>
</tbody>
</table>