Dr Simon Bowen
Head of Knowledge Exchange, BBRO

The Frost Report

In December 2022, cold weather brought on by an arctic airmass descending on the UK, resulted in what was for many one of the most significant spells of low winter temperatures since the exceptional cold Decembers of 2001 and 2010. Daytime temperatures struggled to rise above freezing, and night-time temperatures were down to -12°C, the impact on the UK crop was the worst we have experienced since 2010.

Cases of frost damage were reported widely across the UK beet area, with crop canopies decimated and frozen roots which subsequently broke down to varying degrees in fields. Yields were severely limited and processing quality was massively reduced. In the worst-case scenarios, it was not possible to harvest and process crops, leading these to be abandoned and left in the ground.

We have received many questions relating to the frost damage, in particular asking what we could have done differently to avoid or minimise the impact. This article attempts to answer some of the more frequently asked questions.

At what temperature does freezing damage occur and what happens inside leaves and roots?

Whether a plant cell is located inside the root or a leaf, the effect of freezing temperatures is broadly similar. If water freezes either around or within a plant cell, the sharp ice crystals will seed across cell membranes and damage internal cell contents.

Pure water freezes at 0°C however, water in plant cells has dissolved salts, which means it freezes at temperatures a few degrees below, typically this is -3/-4°C. Once damaged, cell contents including water and sugar will leak from the cell, leading to a loss of turgor and cell death. The membrane and cell structures can sometimes repair themselves, but this requires energy (sugar) and temperatures of >5°C. The water content of roots is considered to influence the extent of freezing damage with more hydrated roots (higher water content) being more susceptible.

Of course, the severity of damage will depend on many other factors:

- The actual temperature level and the duration of exposure (the intensity of freezing) is of course key.
- Repeated freezing and thawing is often more damaging than a constant sub-zero temperature, as this involves more individual freezing events and more ice crystals being seeded within cells.

For leaves it will depend on the age of the leaf and position in the canopy and for roots, the position and height of crown and, of course the extent of protection provided by the canopy.

Why was the frost damage so variable within fields?

Variation in canopy cover across fields will partly explain differences. Sugar beet canopies will act as a short-term insulating blanket to help minimize freeze damage to the roots. Just how effective the canopy protects the beet root will depend on the density of the canopy. This was a significant factor in 2022, as many canopies had been compromised by the drought and some further affected by beet moth damage, all to varying degrees across fields. Where new growth had been produced, this was relatively young leaves and were probably less hardy than a more mature canopy.

The development of foliar disease, especially later developing rust also compromised canopy cover and again this may have varied across field. Ensuring canopies were protected with a fungicide will have helped reduced frost damage in some crops.

Fig.1 & 2. BBRO fungicide trials 2022: left fungicide protected, right unprotected

The incidence of frost is also determined by location and landscape factors as well as canopy growth. Soils have a large heat storage capacity and cool more slowly relative to air temperatures. However, local topography is also important. Cold air tends to run down slopes and drainage ditches, pooling in flatter or basin areas. Barriers such as tree or fence lines can also impede flow and allow cold air to accumulate in these areas of fields.

Were there differences between varieties in terms of susceptibility to frost damage?

We've received a lot of questions about this. BBRO checked various variety trials and strips, assessing variation between and within fields, being very careful to assess overall site impact. Our conclusion was that we did not see any consistent or significant differences between varieties across the multiple sites.

There were differences in canopy vigour of some varieties, related to the impact of the frost, but it was very difficult to identity whether this was due to variety characteristics or to the earlier impact of drought, beet moth or foliar disease. There were no consistent differences between varieties grown on the same site in terms of crown height. Where crowns protruded more, this tended to be site related, indicating that soil management factors were more important than variety.

Is it possible to predict the severity of frost in order to take more preventative action?

Freezing damage in roots occurs if sugar beet is subjected to temperatures below -3°C, the lower the temperature and the longer the duration will increase both the likelihood and severity of physical damage and chemical changes.

Fig 3. & 4. The range of canopy cover in January 2023 across varieties at BBRO's Lincolnshire variety demonstration site. It was difficult to separate varieties due to impact of multiple factors on canopies such a drought, foliar disease, and beet moth.

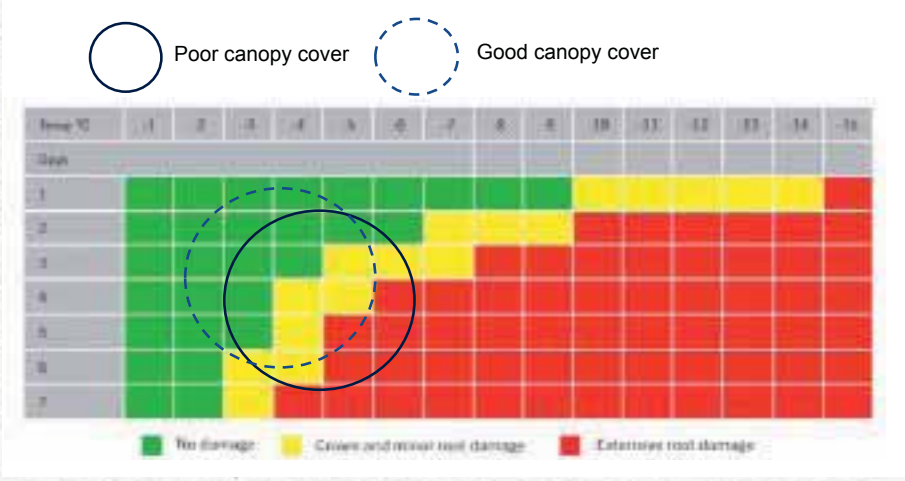

Fig 5. BBRO frost risk chart.

The BBRO risk chart in the Reference Book uses a relationship between minimum temperature and the intensity of root freezing to estimate likelihood of damage. This is based on controlled environment experiments in 2002 which quantified the relationship between intensity of freezing air temperatures and the visible damage to the crown and root using a degree hour below freezing (Fig 5).

The relationship between intensity of air freezing (degree hours) and minimum temperature was then established so that weather forecasts and records could be used to estimate potential damage. This work forms the basis for the BBRO chart (Fig 6).

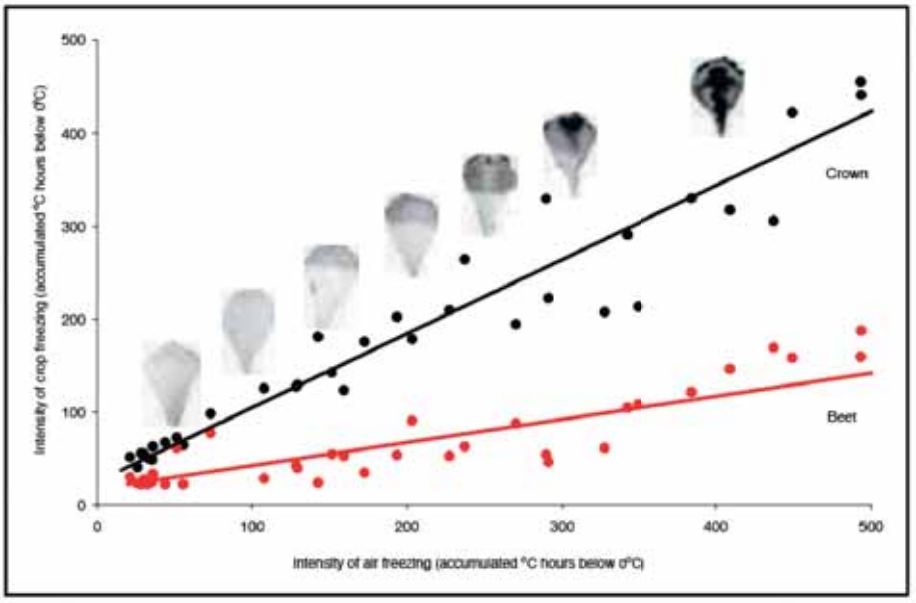

Fig 6. Table shows the relative position of crops with and without good canopy cover.

Temperature records from December 2022 indicated that many crops would have been within the solid circled area and were borderline for more extensive root damage. Remember that the extent of crop canopy that was present to insulate and protect the crop had a considerable influence on this. Those crops with good leaf cover had a reduced risk, as shown in the broken line circle. Unfortunately, there will be outliers to this where temperatures were lower than those recorded, and damage will be more severe. So, the answer to the question is that it is possible to predict the likelihood of damage.

Fig. 7. (cred: Simon Smith)

Fig. 8. (cred: Andrew Dear)

Fig. 9. (cred Simon Smith)

Fig. 10. (cred: Simon Smith)

Slicing affected beet showed the extent of damage. Typically, the top third of crowns were affected (see the limit of the dark 'tide mark' far right) and this was broadly in line with predictions.

Unfortunately, what this chart does not predict is the impact of temperature post-frost. Experience in Europe where frosts are more common is that the consequence of frost damage depends very much on the conditions afterwards. Where temperature result in rapid thawing, damage and processing quality are worse than where temperatures remain colder. This is exactly what happened after the frost in December 2022.

Was it better to leave crops in the ground or harvest and clamp them?

Harvesting frozen and frost-damage roots into roadside piles deteriorated faster than crops left in the ground or those that had been harvested prior to the frost. This was undoubtably compounded by rapid thawing and the mild temperatures experienced after the cold spell. This would have accelerated both the breakdown of cells and of course any secondary microbial infection.

Frost damaged beet generates heat as they respire in an attempt to heal themselves and microbial action will

also generate heat. Any fresh root damage will have also increased the likelihood of further breakdown. Even a small quantity of frost damage beets can cause a hot spot in piles and jeopardize surrounding beets.

Moving to a 'just in time' harvest and delivery basis, especially when temperatures are milder, is key to minimising the amount of roadside stock of beet with fresh frost damage.

Why was there such a large drop in my sugar content?

Once damaged by frost, there will be some direct loss of sugar due to leakage from the cells. This will be lost to the outside environment or the water during processing. Additionally, the sugary juice from these cells converts to dextran, a gum-like substance which not only makes processing very difficult but also provides a good food source for bacteria and fungi.

A large amount of sugar is also used to drive respiration which is essential to provide energy for repairing cells. Cells can start to repair very quickly (where temperatures permit). Respiration rates have been shown to increase within 24 hours of thawing. Remember that respiration rate increases linearly with temperature, so when it is warmer there will be more sugar respired. This can result in reductions in sugar content of up to 3%.

Additionally, if the frost damage to the crown (where the new leaves are formed) is not too severe, the plant may retain the ability to re-generate leaves. Some work shows that plants can re-grow new leaves after temperatures have been as low as -6°C and where only minor symptoms of frost damage to the crown are visible.

The extent of new leaf growth will clearly depend on temperatures in the days after thawing. New leaf growth requires sugar, a decline in root sugar content can occur within a few days of the re-growth process starting. On average sugar level reductions of 1-3% have been associated with leaf regrowth. Remember this may be greater where temperatures (as they have been this season) are high following the frost event.

Overall, this can amount to an overall reduction in sugar content of up to 6%.

Why were frost-affected crops so difficult to process?

Associated with the more physical damage cause of freezing, there are some complex biochemical changes that also occur. In particular, the formation of invert sugars and complex polysaccharides such as dextran and levan. Both are not present in healthy beet but once cell rupture occurs, microbiological action on the sugary liquid released results in their formation, especially at higher temperatures. These cause problems during beet processing. The pH may also decrease, and ethanol may be produced in conditions of low oxygen content explaining why there is sometime a 'winey' or vinegar odour to roots.

Raffinose is also reported to increase in cold conditions, possibly to function as an anti-freeze, but does so at the expense of sucrose. These chemical changes can be detected within a few days of thawing and will have greater effect depending on the higher the temperature is and the longer the period after thawing.

Would clamp sheets have helped to protect the crop?

Covering crops would have helped protect those crops lifted before the frost. This is one of the reasons that the predictive chart was developed so it could be linked to the weather forecast as an advance warning on potential frost damage. The cold spell in December caught us all 'off guard'.

However, as it was so mild after the frost in December it would have been important to remove any clamp sheets as soon as possible, to avoid temperatures increasing, losing sugar and encouraging secondary breakdown. Maus clamps have a larger surface area than traditional clamps and will be most susceptible to frost damage and may need protecting as a priority.

Covering with and removal of clamp sheets is a time-consuming activity and whilst there are some mechanised solutions, may be this is an area that the industry should look at more closely. A good place to start may be looking at how beet growers in north-west Europe manage this.

Summary of key points

- Keep crop canopies as healthy as possible, maintain foliar disease control.
- Early warning - use the weather forecast and damage prediction information to provide more advance warning.
- Avoid building large roadside stocks. Crops are more insulated and protected in the ground.
- Cover any clamps where the risk is high.
- Respond to risk and move to just in time harvesting and delivery ASAP.
- Assess the extent of damage, slice beet at different locations across field to identity priorities.
- In cases of limited frost damage, top crops harder in order to remove the damage.