Basics of Cold Tolerance and Winter Survival in Winter Wheat

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Winter wheat, and other winter annual crops, need to be very hardy to survive the harsh winter environment on the Northern Great Plains. Winter wheat has evolved adaptive mechanisms that are temperature regulated and involve cold acclimation processes that enable seedlings to survive numerous stresses during the over-wintering period. The process of cold acclimation and the maintenance of winter hardiness are very complex, and are not well understood by most farmers and agronomists. As a result, concerns about the risk of winter injury continue to be one of the main reasons cited by farmers for not including winter wheat in their cropping rotation. An understanding of the basics of cold tolerance, and the influences of agronomic management practices on cold hardiness, can greatly assist farmers in reducing the risk of winter injury and in assessing crop condition in the early spring.

The Basics of Cold Acclimation

In order for winter wheat to survive the cold winter conditions on the Canadian prairies, it has to "acclimate" or acquire cold tolerance during the fall growing period. This cold acclimation process is governed by a genetic system that is induced by exposure to low temperature. In simple terms, the plant tissue must be exposed to cold temperatures in order to "harden off" and survive colder temperatures! Different plant parts, such as leaves, roots and crown tissue, can have different levels of cold hardiness, depending on the temperature to which each plant part has been exposed. Since the crown of the plant contains the tissues that are necessary for plant survival and regeneration of roots and leaves (Figure 1), it is the soil temperature at the depth of the crown tissue that determines critical cold acclimation rates.

Under normal field conditions, eight to 12 weeks of growth are usually required for the full development of winter hardiness. The first four to five weeks is a period of active growth when the average daily soil temperature at the depth of the crown is above 9^{o} C. The next four to eight weeks allows the plants to vernalize (the signal to produce flowers next spring) and acclimate. Both the cold acclimation process and winter survival require energy. The fall growth period is important in ensuring that healthy vigorous plants with well-developed crown tissue are established by freeze-up.

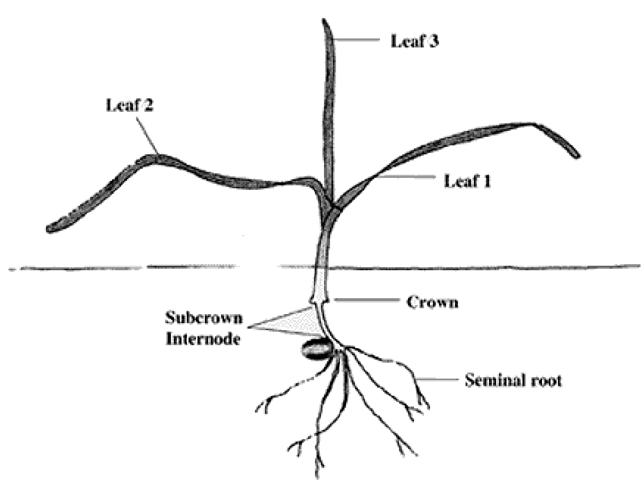

Figure 1. Schematic of a winter cereal plant showing the development of the over-wintering crown tissue below the soil surface.

Cold acclimation begins in the fall once soil temperatures drop below +9° C. At temperatures below this level there is an inverse relationship between temperature and the rate of cold acclimation. Winter wheat plants will acclimate twice as fast at crown temperatures of 0° C compared to +5° C. Once this process starts, the degree of cold hardiness, and the maintenance of low temperature tolerance, are directly related to the sequence of temperature changes that the crown tissue is exposed to during the fall and winter. Cold acclimation can be stopped, reversed or restarted by changes in temperature! The optimal soil temperature for acclimation is thought to be near +3° Celsius. Winter wheat normally does not reach its maximum cold hardiness potential until after freeze-up in late fall. In Saskatchewan and Manitoba, full acclimation is usually achieved by mid to late November (Figure 2).

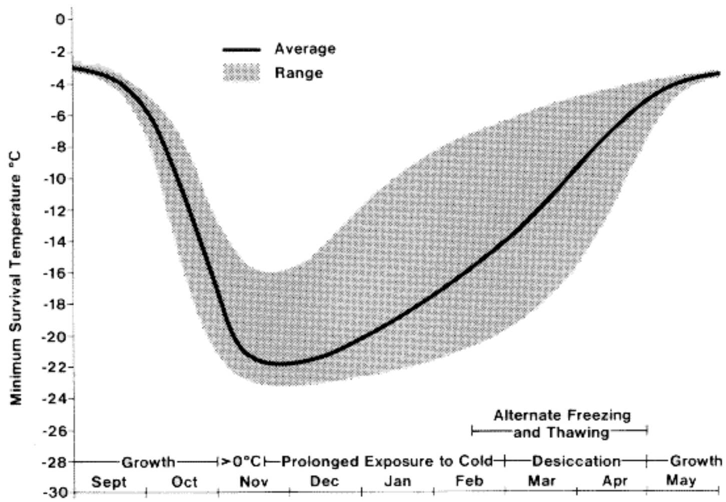

Figure 2. Changes in cold hardiness (minimum survival temperature) of winter wheat for the period September to May. Maximum cold hardiness is achieved by mid-November.

The optimal conditions for developing the full genetic potential of cold hardiness and maximizing winter wheat's yield potential would be as follows:

- Late August or early September seeding into standing zero-till stubble, with adequate moisture and temperature conditions to develop plants with 3 to 4 leaves and well-developed crown tissue.
- Open field conditions, with little or no snow cover until freeze-up, allowing soil temperatures to gradually decline to freezing levels.
- A minimum of 4" of trapped snow cover through December to early March to buffer soil temperature changes and provide protection for the crown tissue.

Maintaining Cold Hardiness

Once fully acclimated, winter cereals are very tolerant to cold stress as long as crown soil temperature remains below freezing and the plants have an adequate energy supply. Soil temperature is the dominant factor influencing both the amount of overwinter stress and the plant's ability to tolerate the stress. Loss of cold tolerance and injury of the crown tissue will result if the soil temperature falls below the plant's minimum survival temperature (Figure 2), or if plants are subjected to long periods when soil temperatures approach the minimum survival temperature. In other words, it's not only how cold that counts, but also how long it's cold! This is why it is important for winter wheat to be zero-till seeded into standing stubble that has the ability to trap snow. Snow cover insulates the soil surface, retaining some of the heat accumulated in the soil over the growing season, and buffering the soil against the effects of air temperature changes throughout the winter.

Critical Stress Periods

By comparing long term soil temperature records with the general pattern of cold acclimation and maintenance of cold hardiness, Dr. Brian Fowler, of the University of Saskatchewan's Crop Development Centre, has identified the critical stress periods for winter wheat and other winter cereals. These comparisons indicate that prolonged spells of cold weather in January and February are the most damaging periods for winter wheat in Western Canada.

- Seeding to late fall (prior to December 20th): During this period, the soil has a large heat capacity and decreases in soil temperature lag considerably behind decreases in air temperature. Plant cold tolerance is at a maximum and low temperature damage to winter wheat is improbable.
- Calendar winter (December 20th to March 20th): Prolonged periods of cold weather increase the potential for low temperature stress. In the absence of a protective snow cover, the soil gradually loses its ability to buffer the effects of low air temperature and winter injury occurs when soil temperatures at the depth of the crown tissue fall below the minimum survival temperature.
- Spring (after March 20th): Prolonged periods of extremely cold weather are rare, therefore there is a low probability that spring soil temperatures at crown depth will drop below the minimum survival temperature for winter wheat.

Dehardening and Spring Regrowth

Cold hardiness gradually decreases as spring approaches in order to allow the plants to "deharden" and resume growth (Figure 2). This process is also governed by soil temperature at the depth of the crown tissue. A return to crown temperatures above +9^{o} C accelerates plant growth and results in the complete dehardening of winter wheat. This process may take several weeks, because frozen soils warm very slowly depending on how warm the air temperature is. The first signs of new growth will be the development of new root tissue at the crown. The aboveground portion of the plants may still appear brown and dead. New leaf growth will not be initiated until crown roots have established. Producers are often too hasty in deciding that slow growth in the spring indicates winter injury. In most instances, provided that proper agronomic practices were used, the crop has survived and the crown tissue just needs a few days of warm weather until soil temperatures increase to levels where growth will resume.

Management Factors Influencing Cold Tolerance and Winter Survival

The acreage sown to winter wheat in Western Canada declined sharply through the late 1980's and early 1990's due to the negative experiences many growers had with rust, lodging and winter injury problems. However, in the past five years winter wheat acreage has almost tripled, and average yields are almost 23% higher than for spring wheat. The greatest increase in winter wheat production has occurred in Manitoba, where acreage has quadrupled. What has happened to bring about the renewed success with winter wheat? Most farmers would suggest that the varieties we grow now are much better than Norstar, the variety grown in the 1980's. Over the past decade several new varieties have been registered, offering improvements in yield, straw strength, rust resistance and other agronomic traits. However, to the surprise of most farmers, the new varieties are **NOT** more winter hardy than Norstar! How can this be, given that over the last five years, we have lost less than 2% of our crop to winter injury annually? The answer is that over the past decade a great deal has been learned about winter wheat agronomy, particularly the importance of seeding practices. The losses experienced in the 1980's had as much to do with management practices as they did with the shortcomings of the varieties.

Dr. Brian Fowler has devoted considerable time and effort into understanding and promoting the "best management practices" for winter cereal production in western Canada. His research and observations have been compiled into the Winter Wheat Production Manual, a comprehensive how-to guide for winter cereal growers. Producers can manage winter survival and improve the success of their winter cereal crops by following the proven agronomic guidelines that Dr. Fowler has developed:

- *Plan Ahead* - Successful winter cereal growers all have one thing in common; they know that winter cereal production begins with the spring crop they intend to seed their winter cereal into in the fall.

Think about the fields that will be seeded, how the spring crop residues will be managed, and what weed control practices will be needed. Make sure seeding equipment is ready, and that seed and fertilizer needs have been arranged well before seeding. Consider how equipment and labour needs will be managed, given that seeding will occur at the same time as spring crops are being harvested. Planning ahead reduces the time conflicts (and the stress) and increases the probability of getting a winter cereal crop seeded on time with optimal agronomic practices.

- *Direct seed (zero-till) into standing stubble* - Winter cereals, particularly winter wheat and winter triticale, require a protective blanket of snow cover through the winter period. As a result, they must be direct seeded into the standing stubble of the preceding spring crop. The snow trapping potential of the spring crop stubble must be taken into consideration. The snow trapping potential (STP) index, a simple method of estimating the snow trapping potential of any standing stubble prior to seeding winter cereals, can be determined as follows:

$$\text{STP} = \frac{\text{Stubble height (cm) x Stubble stems per metre}^2}{100}$$

Dr. Fowler's research has determined that the risk of winter injury to winter wheat is significantly reduced in stubble fields with a post-seeding STP index of 20 or greater. Taking stubble disturbance at seeding time into consideration, pre-seeding STP targets should be 40 or higher to ensure adequate stubble density (Figure 3). As a general guideline, cereal crops such as wheat, oats and barley often have pre-seeding STP's of 90 or higher, while oilseed crops such as canola, mustard and flax are often in the 35 – 40 range.

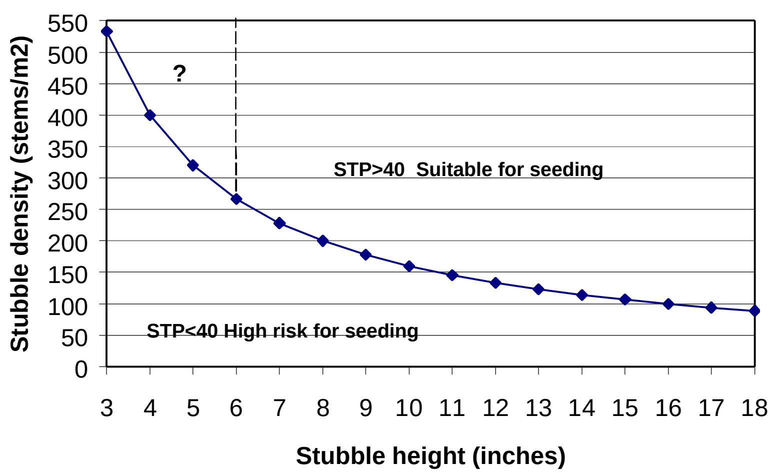

Figure 3. Snow Trapping Potential (STP)

- *Seed Shallow* – Winter cereals should never be seeded more than one inch (2.5 cm) deep, even when the soil is dry. Deeper seeding delays emergence and results in weak, spindly plants that are more susceptible to winter injury. Research indicates that improper seed placement usually results in later maturity and reduced yield potential.

A common mistake made by inexperienced growers is "seeding to moisture". In most stubble fields, soil moisture is often depleted, leaving a dry seedbed for winter cereals. Moisture conditions do not improve dramatically with depth, so there is no advantage to seeding deeper than the minimum depth required to provide good seed-to-soil contact. Moisture in the fall comes from above, in the form of rain. Shallow seeding allows the seeds to take advantage of small rainfall events. As little as 1/3 inch of rain is enough to successfully establish a winter cereal since they exhibit very little seed dormancy and are ready to germinate immediately after seeding.

- *Seed on Time* – In order for winter cereals to achieve maximum cold tolerance, healthy, vigorous plants must be established before freeze-up. Fall soil temperatures influence optimal seeding dates. As a result, the optimal timing for seeding differs in each production region of Western Canada. As a general guideline, research has demonstrated that seeding during the period from late August to early September (approx. August 25^{th} to September 5^{th}) consistently produces the best crops in terms of both yield and quality. It is always better to seed early as late seeding often results in reduced winter hardiness (Figure 4).

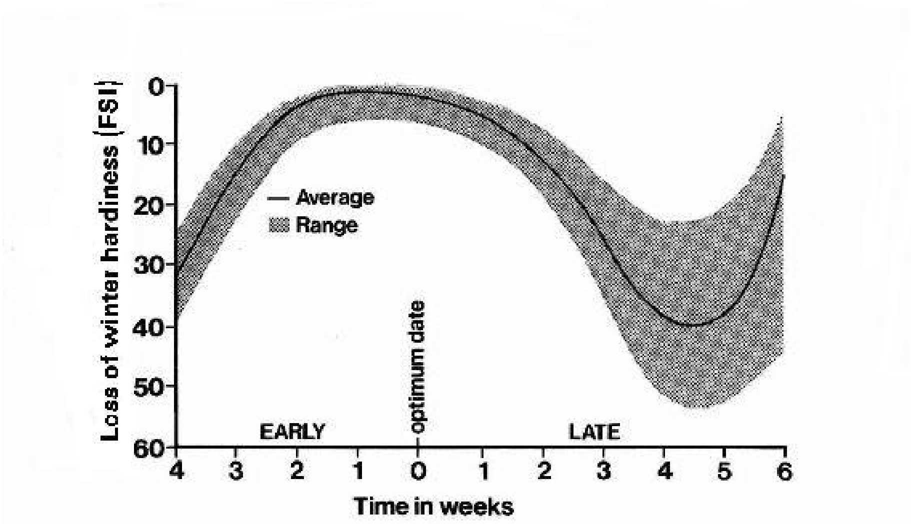

Figure 4. Influence of seeding date on winter hardiness in winter wheat.

The stage of plant development prior to winter freeze-up also impacts the agronomic performance of the crop during the following growing season. Seeding too early often results in yield reduction and smaller seed size. Late seeding results in significant yield reduction, delayed heading, later maturity, lower bushel weights and increased problems with weeds and other crop pests such as insects and disease organisms. All this being said, there are several uncontrollable factors that impact the crop's potential. This includes soil temperature, moisture and weather conditions the following growing season. Responses to seeding date cannot always be determined simply by looking at a calendar!

- *Fertilize appropriately* – Nitrogen and phosphorus are essential for successful winter cereal production. Soil nitrogen levels do not normally affect the winter hardiness potential of winter wheat unless the nitrogen has been applied in the seed row at the time of seeding. Seed row nitrogen reduces winter hardiness (Figure 5) and can reduce seedling number and size, especially when the soil is dry at the time of seeding. Nitrogen applied at seeding time should be separated from the seed row to minimize the risk of seedling damage. Phosphorus enhances winter survival by promoting early plant development as well as vigorous root and shoot growth. The phosphate requirements should be seed placed or side banded at seeding time. Research indicates that phosphorus deficiencies have an impact on winter hardiness (Figure 6). Winter wheat seeded into soils with low residual phosphate levels that do not receive sufficient seed placed phosphorus can be subject to significant reductions in winter hardiness. The risk of winter injury increases, and adequate insulation from snow cover becomes more critical.

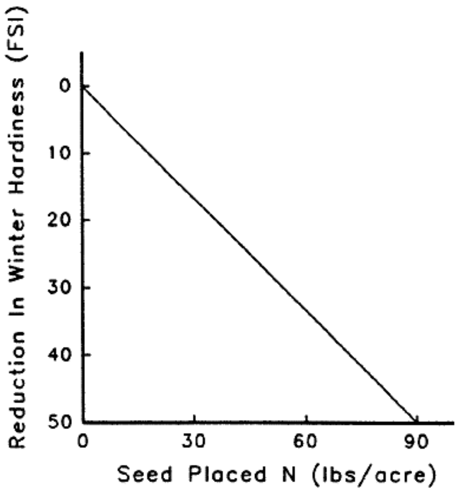

Figure 5. Impact of seed placed nitrogen on winter hardiness

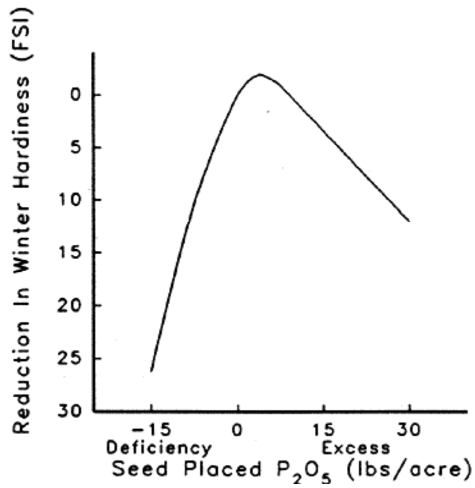

Figure 6. Impact of seed placed phosphorus

Soil temperatures are normally very cool when winter wheat crop is establishing in the fall and regenerating in the spring. The cool soil temperatures not only slow the rate of root growth and the subsequent exploration for nutrients, but can also slow the movement of potassium (K) and phosphorus (P). The soil supply of P, K, and most micronutrients may be greatly limited by the cool temperatures that winter wheat encounters during the fall and early spring.

Potassium fertility is often thought to not be an issue in Western Canada since conventional soil testing often reports extremely high "extractable K" levels and a low probability of yield responses to applied K. However, research has shown that there is often a significant proportion of these "high extractable K" soils that can respond to added K. Information summarized for Montana indicates that more than 50% of the soils thought to be high in K by conventional soil test still show a yield response to K.

With this understanding of restricted nutrient movement in cool soils and the need for winter wheat to develop strong crown tissue prior to freeze-up, it is apparent that inadequate soil supply of phosphorus and potassium may cause delayed development and dissappointing winter survival and yield. Nutrient application can therefore be used to increase the chances of winter wheat success. Fields that are low in P and K, or that might be seeded later than the recommended dates, are good candidates for fertilization with P and K.

Assessing Winter Injury and Spring Stand Establishment

Producers can have a large influence on winter survival by taking steps to ensure that their crop is well established in the fall and that adequate snow trapping potential has been provided to protect the crop from the extremes of winter. With a little experience, it is possible to assess the condition of the crop, and the risk of winter injury, throughout the winter and early spring. The health and vigour of the crop when it goes into the winter is the first measure of its ability to withstand cold stresses. Crops that had a poor start in the fall have the highest risk of winter injury. A record of crop condition in the fall, the winter stresses experienced (temperature records), and observations regarding the areas of the field that were least protected by snow cover, can assist producers in obtaining accurate early assessments of the risk of winter injury. Without this information, the first observations of the plants in the spring can be quite misleading. Brown, dried leaves do not necessarily indicate winter injury, and an initial flush of new top growth is not a sure sign that the crop has survived. The only way to properly assess the condition of individual plants is to examine the crown for the development of new white roots. If the crown appears white and healthy, and new roots are developing, the plant is in good condition. As stated earlier, growth of new crown tissue is soil temperature dependent. A lack of new growth does not necessarily indicate winter injury; it may be that soil temperatures have not increased enough to completely deharden the crown. Be patient!

Dealing with Dry Conditions

One of the challenges of winter cereal production is dealing with dry seedbed conditions at seeding time and the implications of poor fall establishment. The fall of 2001 was extremely dry in most regions of Western Canada, and there were numerous reports of poor germination and establishment, with plant development in individual fields ranging from ungerminated seed to plants in the 2 or 3 leaf stage. Many producers are wondering if their crops will survive the winter and what type of stand they can expect in the spring of 2002. The stage of development in the fall influences not only winter survival and yield potential, but also crop competitiveness, maturity and the risk of infection with diseases such as rust and fusarium head blight (Table 1).

Table 1. Potential Impacts of Fall Growth Stage on Winter Wheat Production Factors

Growth Stage	Date of Germination	Yield Factor	Competition Factor*	FSI**	Rust Risk***	Relative Maturity
3 Leaf + Tiller	5-Sep	100%	5	514	1	0 days
1 - 2 Leaf	15-Sep	90 – 100%	4	510	2	+ 4
Sprouted (not emerged)	1-Oct	80 – 100%	2	476	4	+ 8
Not Germinated (imbibed)	15-Oct	60 – 100%	1	499	5	+ 10

* Competition Factor: 5 = Most competitive, 1 = Least competitive
** FSI: Field Survival Index; a measure of cold tolerance (514 is maximum for winter wheat)
*** Rust Risk: 1 = Lowest risk; 5 = Highest risk

Well-developed plants will have the highest yield potential and winter survival ratings, will be more competitive and less likely to be impacted by rust and other disease organisms. The 1 to 2 leaf stage plants will have retained most of their yield potential and their winter survival ratings will only be slightly lower. Competitiveness with early spring annual weeds will be slightly less so more attention must be paid to early germinating weeds. Maturity will be slightly delayed and the crop will be more susceptible to rust, assuming there is no varietal resistance.

Seeds that have sprouted and not yet emerged have lost slightly more yield potential and will be much less competitive with early weeds. Wild oats and early broadleaf weeds will have to be eliminated early to avoid further yield losses. Maturity will be extended, creating higher risk of rust infection. The greatest risk for sprouted seeds is their lower level of winter hardiness. Most of the energy reserves in the seed were utilized to initiate germination and no additional energy was assimilated through photosynthesis. Germinated seeds that have not emerged require adequate snow cover to ensure winter survival.

Seeds that have not sprouted will have the lowest yield potential and will be the most susceptible to early weed competition. Their winter hardiness is better than sprouted seeds due to the energy reserves remaining in the seed. Relative maturity is extended and harvest dates may only be a week earlier than spring cereals. Rust, and other plant diseases, are more likely to be a concern due to the delay in maturity. Winter wheat crops that did not germinate and establish uniformly in the fall are at a disadvantage, but with timely management in the spring and some co-operation from Mother Nature, excellent crops are still possible. Winter wheat has an unmatched ability to compensate by producing tillers, and it is often the most ragged looking crops that produce the best yields! Don't be too hasty to write off a poor looking stand in the spring. Wait until at least mid-May to give the crop an opportunity to recover. There will still be time to reseed if necessary.

Summary

There are two opposing views of winter injury and the risk of growing winter wheat. Producers who have never grown the crop, or grew it back in the mid-1980's when agronomy practices were not well understood, perceive the risk to be high and are reluctant to include winter wheat in their cropping rotations. Conversely, experienced winter wheat growers report that the incidence of significant winter injury is very low, and that growing winter wheat actually reduces their production risks. By including winter wheat in their rotation, spring cropping operations such as seeding, spraying and harvesting occur on a more timely basis, resulting in lower losses due to pests and less risk of weathering losses at harvest time. This is a significant advantage when the economic consequences of grade losses in crops such as malt barley, durum wheat and pulse crops are considered.

Winter wheat, and other winter cereals, are "systems" crops that have an excellent fit in direct seeding and zero tillage production systems. As more producers adopt these systems, the opportunity to successfully produce winter cereals will grow, and the perception of risk associated with winter cereal production will change. To achieve this success, producers must become familiar with the agronomic management practices that have been developed specifically for these crops, and commit the same level of planning and preparation to winter cereals as they do for all other crops in their rotation.

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