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Winterkill of fall-seeded winter wheat

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SUMMARY

Although fully hardened winter wheat plants are killed by a few hours of exposure to $-20^{\circ}C$, winter wheat is currently grown successfully in extreme southern Alberta in spite of air temperatures which fall to $-30^{\circ}C$ in many winters and to $-45^{\circ}C$ in extreme winters. Soil temperature data for Lethbridge show that wheat crowns are protected from extreme air temperatures by snow cover and rarely fall to $-15^{\circ}C$. Killing has been observed at sites where temperatures have not fallen to $-15^{\circ}C$. The effects of various temperatures on hardening and hardiness are described and used to explain such observations and suggest which conditions are likely to cause killing. Cultural practices, diseases, and the role of vernalization are also described briefly.

RESUME

Bien que des plantes de blé d'hiver parfaitement endurci meurent après quelques heures d'exposition à $-20^{\circ}C$, on reussit actuellement à cultiver du blé d'hiver dans l'extrême sud de l'Alberta en dépit de températures de l'air parfois inférieures à $-30^{\circ}C$ au cours de l'hiver et même à $-45^{\circ}C$ quand celui-ci est particulièrement rigoureux. Les données sur les températures du sol à Lethbridge montrent que le collet des plantes de blé est protégé du froid glacial de l'air par la couverture de neige et que sa température tombe rarement sous $-15^{\circ}C$. On a observé une destruction hivernale à des endroits où la température hivernale n'avait pas descendu à $-15^{\circ}C$. Les effets des diverses températures sur l'acquisition d'une résistance au froid sont décrits dans le présent article et servent à expliquer ces observations ainsi qu'à prévoir quelles sont les conditions aptes à détruire les plantes. Les méthodes culturales, les maladies et le rôle de la vernalisation y sont aussi décrits brièvement.

WINTERKILL OF FALL-SEEDED WINTER WHEAT

Introduction

Farmers experienced in growing winter wheat know from observation which practices improve the winter survival of fall-seeded wheat. Scientific research has verified many of their observations, revealed new information, and identified problems that require solutions. Research on winter wheat cold hardiness at the Lethbridge Research Station has now reached a plateau. The report that follows summarizes the findings to date and suggests areas requiring further research.

Winter wheat has been grown commercially in southwestern Alberta for over 75 years, mostly on dry land in the area south of a line running from Claresholm through Lethbridge to Medicine Hat. Some winter wheat is grown in the Shaunavon, Val Marie, and Govenlock area of southwestern Saskatchewan and sporadically in many other parts of the Canadian Prairies. In these outlying areas, winter wheat will often produce an excellent crop. Unfavorable years causing severe winterkill occur often enough to discourage farmers and thus prevent winter wheat from being grown continuously on a large scale.

A major advantage of winter wheat over spring wheat is an increase in yield, often more than 20% in favorable years. The increased yield of winter wheat comes partly from earlier maturity, about 2 weeks in southern Alberta. This allows it to use the spring moisture more effectively, and it often suffers less than spring wheat from summer droughts and extremely high temperatures. At higher elevations it escapes late summer frosts. In areas along the foothills, where excess moisture prevents early spring seeding, fall seeding may be essential.

Developing cultivars that can survive our severe winters will be the key to expanding the winter wheat area in the future. The basic factors involved in the overwintering of perennial and fall-seeded crops have been known for a long time. Crops sown in the autumn develop a resistance to low temperatures which allows them to survive. In wheat, this resistance starts to develop when the air temperature falls below 10°C. Its full development also requires light, carbon dioxide, and proper plant nutrition. Fully hardened plants of hardy varieties will withstand temperatures as low as -20°C for a few hours.

Air temperatures below -20°C in the regions where winter wheat is successfully grown often persist for days at a time. To understand why winter wheat plants can be grown successfully in such cold climates, we must know the actual conditions experienced by the crowns, since winter survival is dependent on crown survival.

Experiments at the Lethbridge Research Station have shown that the effect of temperature on the development and retention of cold resistance in winter wheat is complex. The results of these experiments will be used to describe what happens to winter wheat in the field.

Then, we shall consider a number of factors other than temperature that are known to affect winter wheat survival. Finally, vernalization will be discussed since, in rare instances, fall-sown winter wheat does not germinate until spring.

Winter conditions in the field

Winter wheat crowns usually will be about 2-5 cm below the soil surface if the wheat has been sown as recommended into a firm seedbed in early September. During winter, temperatures at 5 cm below the soil surface are recorded at a number of locations in western Canada. These indicate the temperatures experienced by the crowns of wheat plants.

During January and February, the daily fluctuation in soil temperature at 5 cm rarely exceeds 1 degree at Lethbridge (Fig. 1) and at other locations in western Canada. Because this fluctuation is of little importance in the survival of winter wheat, and to simplify presentation, only minimum daily (8:00 a.m.) temperatures are depicted in Figs. 2, 3, and 4. Two factors are probably responsible for the reduction in range of daily soil temperature. First, the lower elevation of the sun in the winter reduces its ability to heat the soil. Second, snow cover often provides an insulating blanket that prevents heat loss from the soil and reflects much of the sunlight, further reducing daytime soil heating. As a result, soil temperatures at the 5-cm depth change much less under snow, particularly deep snow, than they do under bare ground. Soil temperatures in the winter are also moderated by small amounts of heat continuously escaping from within the earth.

During the winter of 1981-82 at Lethbridge, low air temperatures (-20 to -31°C) and little snow cover resulted in a soil temperature of -10°C by early January (Fig. 1). On January 4, snow fell on this cold soil. Soil temperatures under this snow cover remained below -5°C until the snow melted in mid-February when soil temperatures rose. A subsequent snowfall covered this warm (near 0°C) soil in mid-March. Soil temperatures at 5 cm remained constantly just above the freezing point even though the air temperature fell to -20°C on March 20. We conclude that snow provides sufficient insulation so that soil temperatures change only slowly or not at all in response to air temperatures.

The winter of 1980-81 at Lethbridge was very mild with frequent chinooks that removed the snow cover. On several occasions, minimum air temperatures exceeded the soil temperatures (Fig. 2). On December 15 and 16, minimum air temperatures exceeded minimum soil temperatures of 4.5°C while maximum air temperature on December 16 was 18°C. On January 20, when the soil was frozen and remained frozen at 5 cm, minimum air temperatures rose above the freezing point while maximum air temperatures rose to 16.5°C. These examples indicate that soil temperatures at Lethbridge in midwinter do not warm up to the same extent as air temperatures. In fact, the soil may remain frozen during chinooks when air temperatures reach 10-15°C.

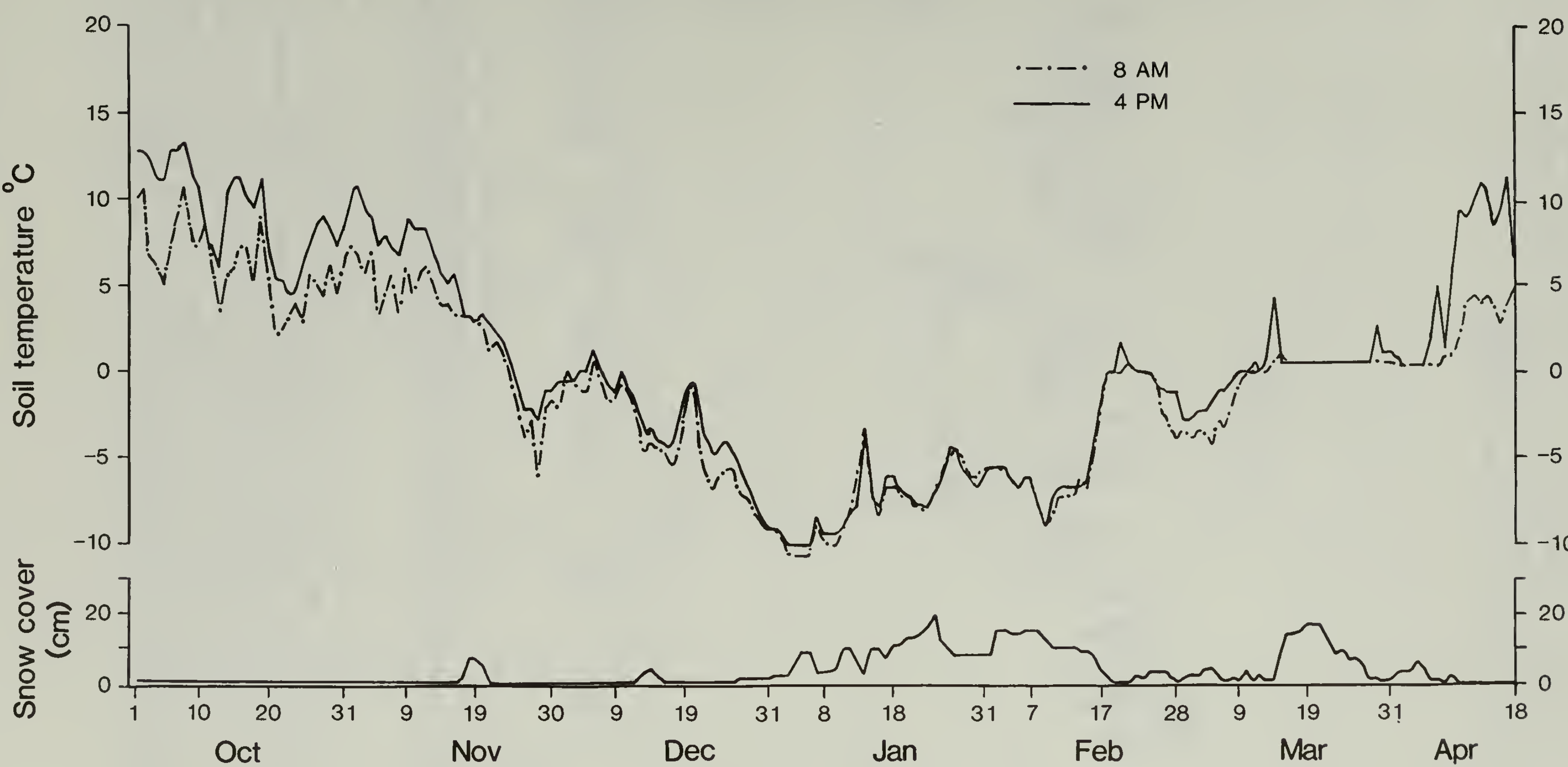

Fig. 1. Snow depths and soil temperatures at 5 cm at Lethbridge Research Station throughout the winter of 1981-82. Upper line: temperatures at 4:00 p.m.; lower line: temperatures at 8:00 a.m.

In the Lethbridge area, snow usually falls at the beginning of a low-temperature period. Consequently, the snow cover protects the wheat plants during the coldest parts of winter. The winter of 1980-81 provides several typical examples (Fig. 2).

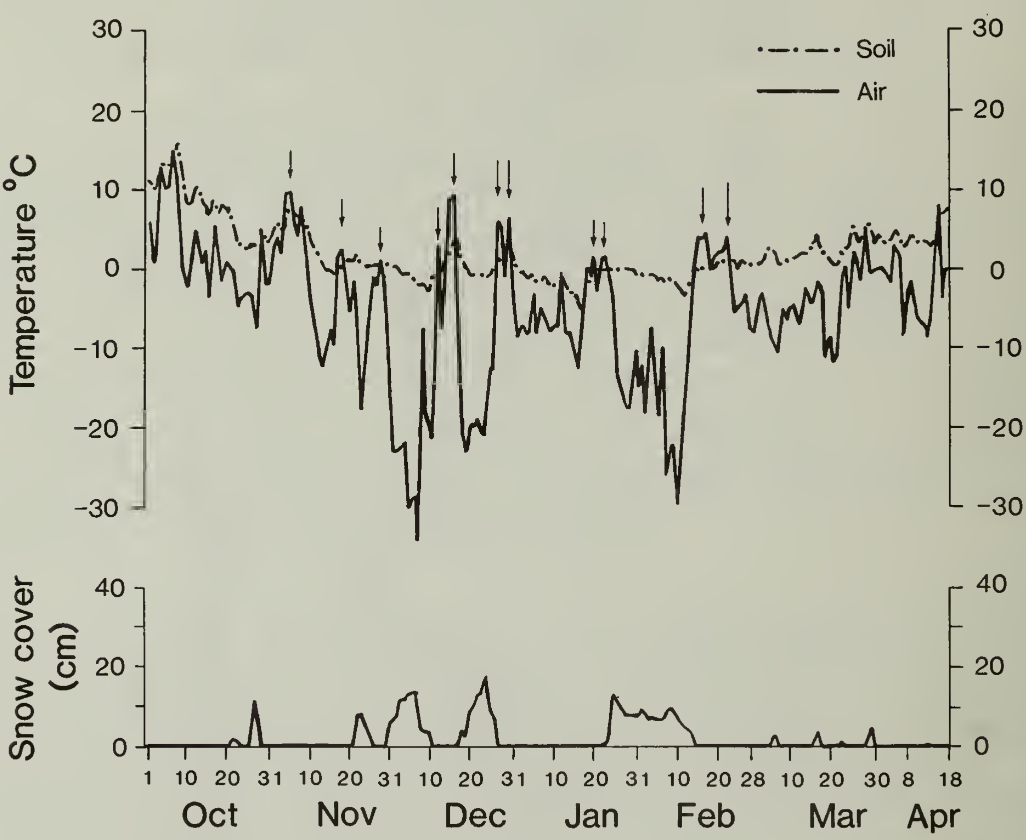

Fig. 2. Snow depths, minimum daily air temperatures, and soil temperatures at 5 cm at 8:00 a.m. at Lethbridge Research Station throughout the winter of 1980-81. Arrows indicate when air temperatures exceeded soil temperatures.

To indicate the local variations in soil temperatures, data taken at the Research Station and the airport at Swift Current, Saskatchewan, are presented in Figure 3. Winter soil temperatures at the Research Station site are usually colder than those at the airport and this difference may exceed 5 degrees. During the winter of 1981-82, minimum daily soil temperatures at 5 cm fell to -20°C or colder on two occasions and remained below -15°C for two separate periods of 10 days each at the Research Station site. Winter wheat on fallow frequently winterkills at this site.

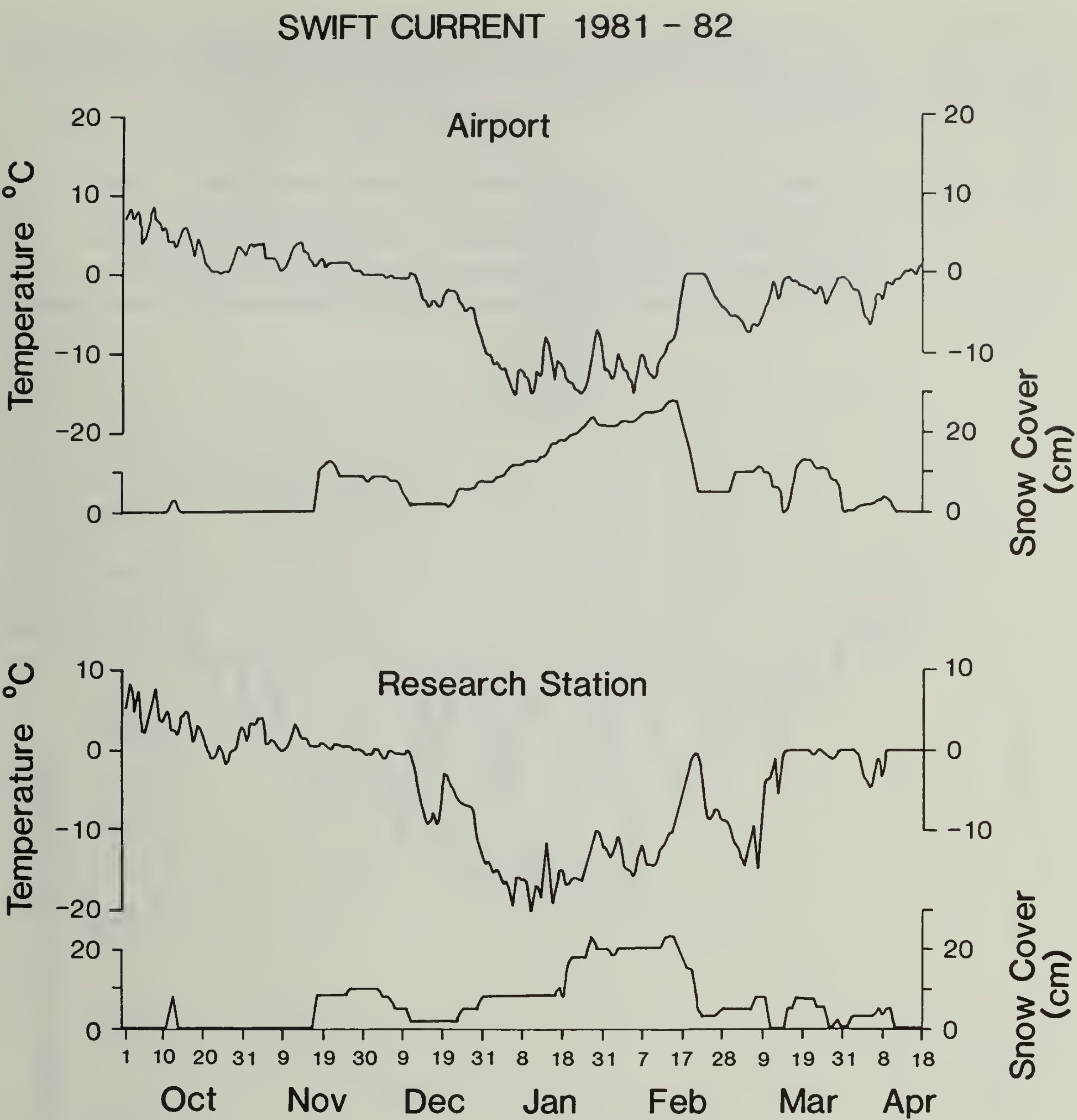

Fig. 3. Snow depths and 8:00 a.m. soil temperatures at 5 cm at Swift Current airport and Research Station: an example of the great local variability of soil temperatures.

Data for the winter of 1979-80 at Lacombe, Alberta, provide an example of what happens under deep, persistent snow (Fig. 4). The snow fell on frozen soil that remained frozen under the snow until nearly mid-April. Although minimum air temperatures were almost continuously below -10°C from November 28 to March 30 and fell to or below -35°C on six occasions, soil temperatures at 5 cm did not fall below -8°C all winter. Furthermore, soil temperatures usually changed slowly and fluctuated less than at Lethbridge and Swift Current, where snow cover was less persistent.

In summary, soil temperatures at 5 cm, approximately the levels of wheat plant crowns, vary much less than air temperatures in winter. They are warmer than air temperatures during cold weather and colder than air temperatures during chinooks, even in the absence of snow cover. Snow acts as an insulator and reduces the effect of air temperature on soil temperatures. However, local differences in snow cover can produce important differences in soil temperatures and, consequently, the survival of winter wheat. These differences between air and soil or plant crown temperatures explain why winter wheat can survive where air temperatures may fall as low as -45°C and remain below -20°C for a week or more.

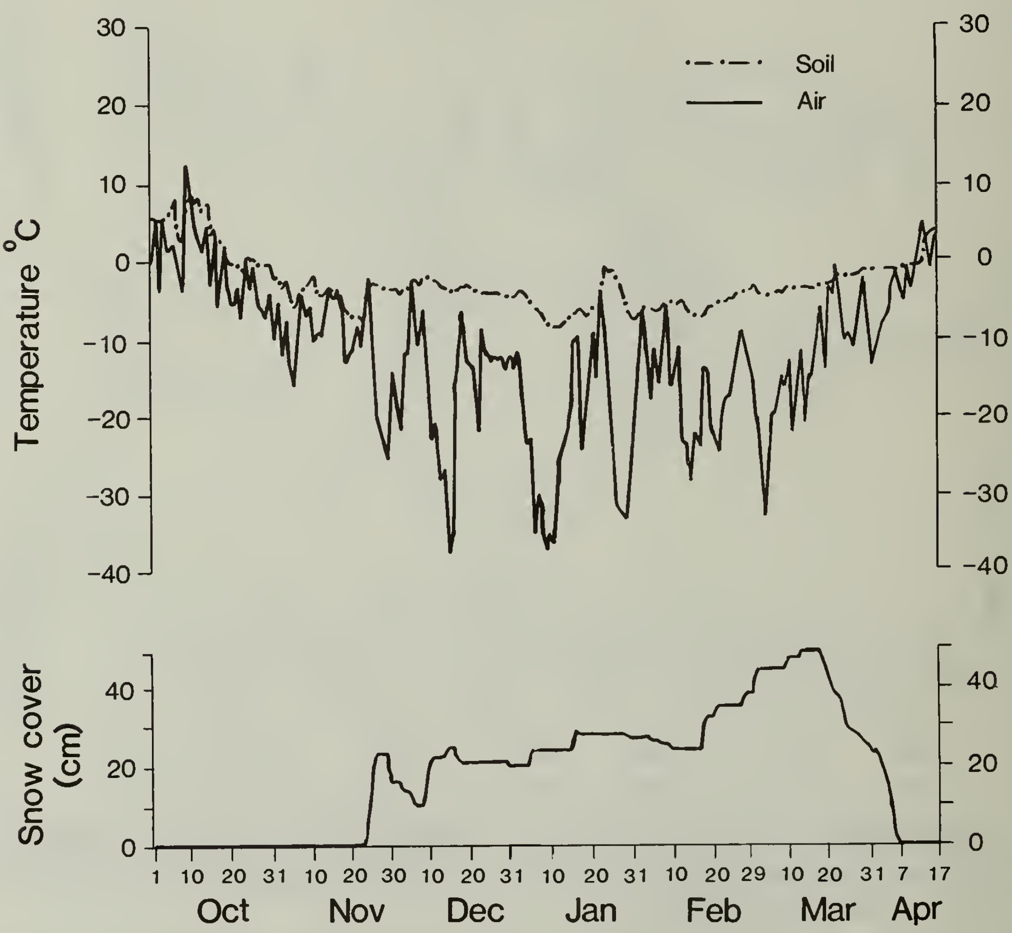

Fig. 4. Snow depths, minimum daily air temperatures and 8:00 a.m. soil temperatures at 5 cm at Lacombe Research Station. An example of conditions at a site with deep, persistent snow cover.

Hardening of winter wheat under controlled conditions

Exposure of germinating seeds or growing plants to nondamaging temperatures of 10°C or lower induces cold resistance or cold hardiness. Lower temperatures result in greater hardiness.

When seed is germinated and subsequently grown at 3°C under 16 hours of light per day (referred to as a 16-h day), the cold-resistant winter wheat undergoes a predictable pattern of changes in hardiness (Fig. 5). Dry seeds are very cold hardy. This hardiness decreases as the seeds take up moisture and begin to germinate. After about 2 weeks, this drop in hardiness ceases and the plants increase in hardiness for approximately 3 weeks. At that point in time, the plants have maximum cold hardiness. The actual level of cold hardiness depends on cultivar, hardening temperature, daily supply of light, and other factors such as nutritional state. The maximum level of hardiness may last from 1 to 6 weeks, depending on cultivar, light, and other growing conditions. In Winalta, this plateau of hardiness is relatively short-lived compared with that of Kharkov 22MC. After the plants have passed through this period of maximum hardiness, cold resistance starts to decline even though the plants are maintained under the same hardening conditions. Plants removed from the field in April are in this condition and will not reharden when transferred to 3°C under a 16-h day.

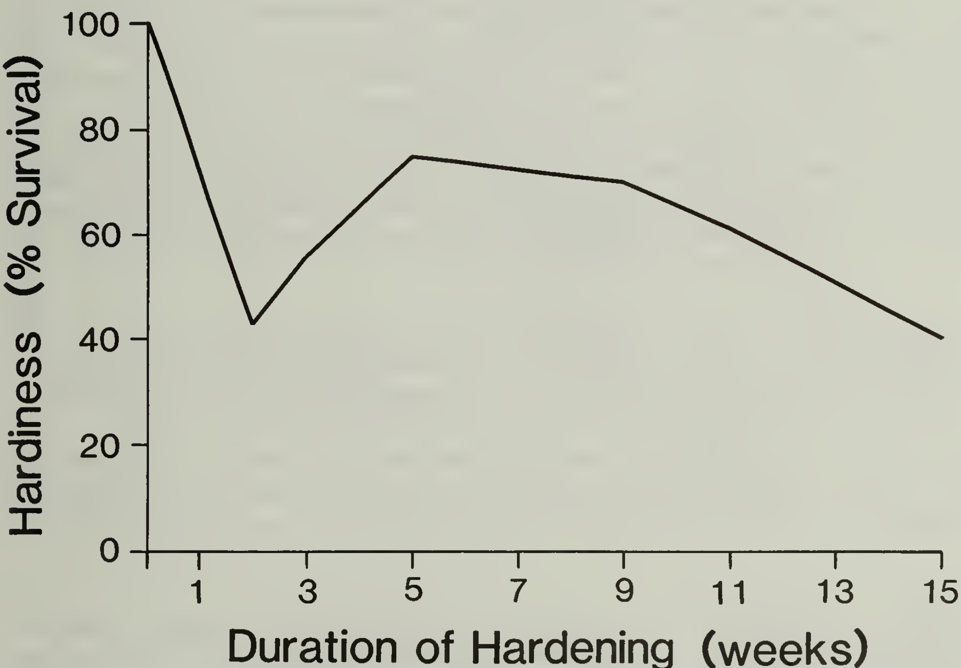

Fig. 5. Changes in cold resistance of Winalta wheat with changing duration of hardening at 3°C. Plants were grown with 16 h of 1500 ft-c of light per day. Hardiness was measured as mean percent survival after 2 days exposure to -10°C and -15°C.

Research at Lethbridge has shown that winter wheat should be seeded during the first 2 weeks of September to obtain maximum yield and winter survival. These plants grow at above-hardening temperatures for a time before intensive hardening starts. Wheat plants grown at 15°C or 20°C for 1-3 weeks before hardening (at 3°C) are hardier and retain their hardiness longer than those which have had no growth at above-hardening temperatures. If growth at above-hardening temperatures lasts more than 4-5 weeks, development of hardiness and its retention at hardening temperatures will be reduced.

The biochemical basis of this phenomenon is unknown. In practical terms, this response dictates the optimum date of seeding. Either insufficient or excessive growth time before hardening begins will increase winterkilling from low temperatures.

Wheat plants grown in the field need considerable cold resistance from early October to late March or into April in many parts of the prairies. Plants subjected to hardening temperatures for 15 weeks at 3°C have already lost their maximum hardiness (Fig. 5). Plants moved in early February from the field to a growth cabinet at 3°C lose their hardiness more rapidly than plants left in the field.

To explain this observation, experiments on long exposure to low hardening and sub-hardening temperatures were conducted in the dark. Winter wheat seedlings were germinated at 0.8°C, and groups were transferred to -2.5°C, -7.5°C, and -10°C environments. Hardiness was tested at the time of transfer and every 4 weeks for 20 weeks. Seedlings kept at 0.8°C steadily lost hardiness after the transfer date (Fig. 6) as did those transferred to -10°C. The hardiness of seedlings transferred to -2.5°C changed little during the 20 weeks. Seedlings transferred to -7.5°C showed evidence of increased hardiness after transfer but later began to lose hardiness.

Apparently, the rate of loss of hardiness after long exposures to hardening temperatures can be reduced by lowering the temperature to values just below the freezing point. At temperatures around -2.5°C there is no loss of hardiness for at least 20 weeks. Since soil temperatures usually remain just below freezing in February and March, plants in the field retain their hardiness, whereas similar plants moved to a growth cabinet at 3°C in early February rapidly lose their cold resistance.

At crown temperatures below -5°C, loss of hardiness and damage result from long exposure to cold. The damage increases progressively as the duration of exposure is increased. Very hardy, well-hardened varieties will be severely damaged by about 12 weeks of continuous exposure at -10°C, 1 week continuously at -15°C, and 2 days continuously at -20°C.

Relationship of hardening to events in the field

As stated before, in the Lethbridge area, winter wheat should be seeded during the first 2 weeks of September for maximum yield and winter survival. This practice allows the seedlings a few weeks of growth at higher temperatures before efficient hardening gradually sets in during the latter part of October. Such a period of growth results in development of extra hardiness during the subsequent hardening period. The optimum duration of growth at higher temperatures needed before hardening commences determines the optimum seeding date.

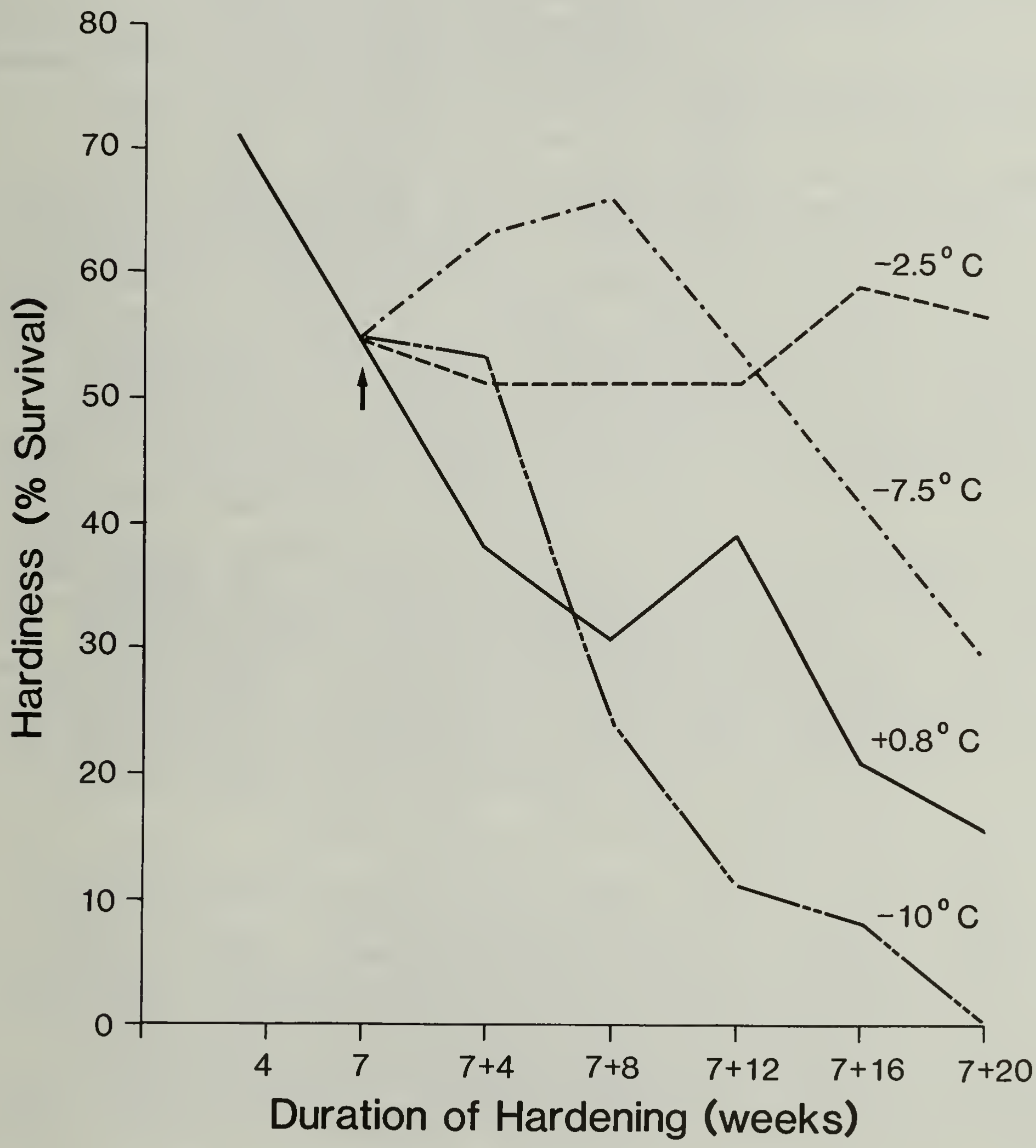

Fig. 6. Changes in hardiness of Winalta wheat during hardening in the dark. Plants were grown at 0.8°C in darkness for 7 weeks and then left at 0.8°C, or transferred to −2.5°C, −7.5°C or −10°C for periods up to 20 weeks. Time of transfer marked with arrow.

Use of this optimum seeding date assumes that soil moisture levels are adequate for germination. If soils are very dry, germination will be delayed until rain or snow provides sufficient moisture. If germination is delayed into October, particularly late October, plants will only develop low levels of hardiness and the chances of winterkilling will be greatly increased. Under such conditions, patchy winterkilling may occur if germination was patchy in the fall. Another cause of patchy winter-kill is local differences in soil temperatures caused by differences in snow cover.

In a severe drought, the soil may not have enough moisture for germination in the fall. The seed may not germinate until early spring when moisture becomes available. These plants will subsequently set seed and produce an acceptable yield, provided the stand is sufficient and no other unfavorable conditions occur.

When seed germinates in early September, it rapidly loses hardiness as water is taken up (Fig. 5). As the air and soil temperatures gradually drop during the autumn, plants start to redevelop cold resistance. Very high levels of hardiness are reached by late November and often persist for several months in the field. However, in the field, plants gradually lose their ability to retain their hardiness if they are exposed to temperatures at or above 0°C. Plants transferred in late November to a growth cabinet at 3°C will retain their hardiness for several weeks whereas plants transferred to a growth cabinet at 3°C in late December lose some hardiness within a week of transfer from the field. A similar loss does not occur in the field. Retention of hardiness in the field is a result of the temperatures being lower there than in the growth cabinet (compare 0.8°C with -2.5°C data in Fig. 6). Soil temperatures in the field often fall below -5°C and even below -10°C. While short periods (up to 1 week) at these temperatures have little effect on well-hardened hardy wheats, long periods of -10°C (2 months or more) can cause severe damage. Temperatures of around -10°C in late March or April also will damage winter wheat if they persist for a few days. By late winter the plants will have lost much of their hardiness, either by exposure to above-freezing temperatures or by long exposure to temperatures consistently in the -6°C to -10°C range.

In the Lethbridge area, where winter wheat is grown successfully, air temperatures in January and February often rise to 5°C or 10°C and remain above freezing for several days at a stretch. Why does this not cause loss of hardiness and injury during the subsequent cold weather? The soil and air temperature graph for the winter of 1980-81 (Fig. 2) at Lethbridge shows several occasions (chinooks) when air temperatures remained above 0°C for 2 or 3 consecutive days. During chinooks, soil temperatures at Lethbridge are much colder than air temperatures and the soil at plant crown levels usually does not thaw. This prevents the serious and irreversible loss of cold hardiness that would occur during chinooks in January, February, or March if the plant crowns experienced air temperatures. We believe that late spring killing may occasionally result from severe cold spells following periods of warm (above-freezing) soil temperatures in late winter. Such events appear to be rare in the traditional winter wheat area of southern Alberta because snow cover usually insulates the wheat plants from the cold air.

Some other factors influencing survival

In addition to the temperature effects described above, other factors affect winter wheat survival. These include depth of seeding, fertility, snow cover, and diseases.

SEEDING DEPTH Winter wheat should be seeded shallowly (2.5-4 cm) into a firm seedbed. Seed planted deeper produces less vigorous plants which exhibit poor winter survival. Uneven depth of seeding, often coupled with a loose seedbed, is one common cause of spotty winterkilling. If the survivors show a depth of seeding greater than 4 cm, the crop was probably seeded too deeply.

FERTILIZER Winter wheat yields will be increased on many soils by the use of proper fertilizers. Much experimental work has produced no consensus as to the effect of fertility on survival, however, proper nutrient balance is believed to be important. Work at Lethbridge suggests that high ratios of nitrogen to available phosphorus will reduce winter survival.

SEEDING IN STUBBLE In areas where low soil temperatures cause winterkilling of winter wheat (e.g., Swift Current area) seeding into standing stubble will increase winter survival. Stubble traps snow which acts as an insulator to reduce the variation in soil temperatures. The extra snow held on the fields will provide added moisture for subsequent growth and may increase yield. Of course, seeding into stubble will not help if there is no snow nor will it protect plants from snow molds.

DISEASES Among the diseases of wheat, two groups (virus diseases and snow molds) are of special interest to winter wheat growers.

Fields with a high incidence of wheat streak mosaic and wheat spot mosaic viruses will be unthrifty in the spring and produce very low yields. These diseases can be controlled by eliminating all green wheat, barley, or rye plants from the immediate vicinity of the fields to be planted in the fall. Fall planting dates for the Lethbridge area should be the first 2 weeks in September to reduce the chances of fall infestation of the crop from adjacent late-sown spring cereals or from volunteer plants harboring the mites that spread these viruses.

Snow mold is caused by any one of several different and unrelated fungal pathogens. These fungi thrive under deep, persistent snow cover at soil temperatures near and just below the freezing point. Under conditions favorable to them, they can completely kill all plants in a field. Snow mold is a major limiting factor to winter wheat production in central Alberta and the Peace River Region. At present, there are no resistant varieties hardy enough for the Canadian Prairies and, as yet, no other practical control measures.

Vernalization

Winter wheat seeded in May either will not head out or will do so very late with only a few tillers heading on each plant. In order to overcome this problem, winter wheat must be grown at low, above-freezing temperatures for several weeks before transfer to warmer growing conditions. This low-temperature treatment is called vernalizing. The plants are said to undergo vernalization and such vernalized seedlings will head much sooner than unvernalized seedlings. All tillers on these plants will head at about the same date and all plants will head at nearly the same time.

Experiments at Lethbridge show that vernalization will occur, in the dark or under lights, at temperatures between approximately 0°C and 10°C. Furthermore, alternating the temperature daily between 2°C for 16 h and 20°C for 8 h with light does not delay vernalization seriously. However, if the warm part of the daily cycle is 8 h at 35°C, the vernalization requirement is increased by several weeks. Therefore, exposure to high temperatures, but not to moderate temperatures, inhibits or even reverses the vernalization process.

Vernalization occurs gradually. In varieties with strong vernalization requirements, the first few weeks of cold treatment (up to week 3 in the variety Westmont, Fig. 7) produce no acceleration of heading while the final few weeks (weeks 4, 5, 6 in Westmont) produce a gradual acceleration of heading. Fully vernalized plants show very little reduction in days to head with increasing cold treatment. The reduction that does occur is probably caused by growth at vernalizing temperatures.

In experiments where winter wheat was sown in mid-September in the field at Lethbridge, then transferred to growth cabinets at 20°C to check for days to head, Winalta was fully vernalized by the end of October, Kharkov 22MC by the end of November, and Sundance by early December. At Lethbridge, winter wheat sown in the field in February or early March behaves as if it had vernalized fully and will ripen in August to produce a crop. If wheat seeded into dry soil in the fall fails to germinate until spring, it still can be expected to produce a crop, if the stand is good after germination and favorable growing conditions prevail.

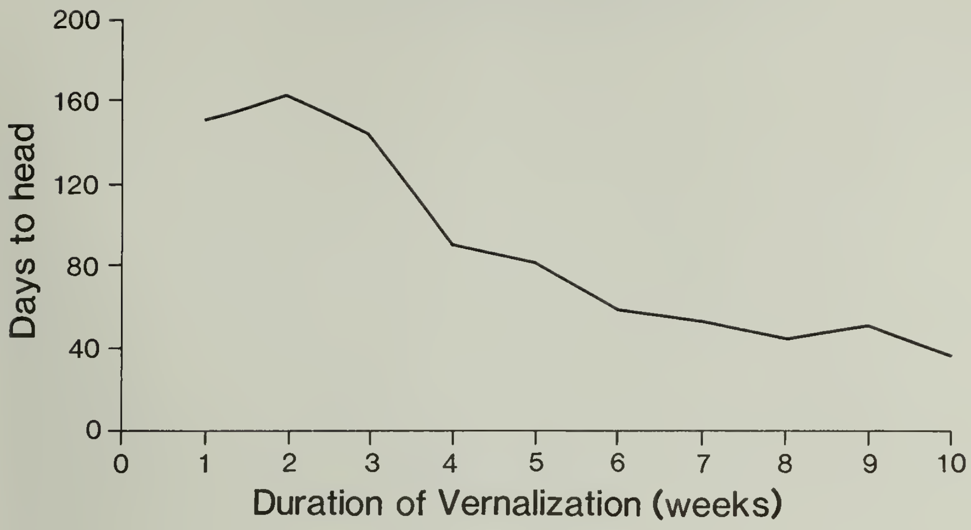

Fig. 7. Effect of vernalization on days to head of Westmont winter wheat after transfer to 20°C. Plants were vernalized at 6°C day, 4°C night temperatures with 16 h of 900 ft-c light per day for 1 to 10 weeks, then transferred to constant 20°C and 16 h light exposures of 1500 ft-c per day.