Several characteristic symptoms of freeze injury develop at each growth stage (Table 1). Although continued cold weather after freeze damage may delay symptom development, moderate to severe damage can usually be identified by careful examination of the vital plant parts. For proper diagnosis, you must know the plant parts that are most vulnerable at each growth stage, their location and their appearance when they are normal as well as when they are injured. See Fig. 2 for the growth stages of cereal grain.

Table 1. Spring freeze injury to cereals at various growth stages.

Growth stage	Primary symptoms	Yield effect
Tillering (Zadoks 12-25)	Leaf chlorosis, burning of leaf tips, silage odor, blue cast to fields	Slight to moderate
Jointing (Zadoks 31-39)	Death of growing point; leaf yellowing or burning; lesions, splitting or bending of lower stem; odor	Moderate to severe
Boot (Zadoks 41-49)	Floret sterility, head trapped in boot, damage to lower stem, leaf discoloration, odor	Moderate to severe
Heading (Zadoks 51-59)	Floret sterility, white awns or white heads, damage to lower stem, leaf discoloration	Severe
Flowering (Zadoks 61-69)	Floret sterility, white awns or white heads, damage to lower stem, leaf discoloration	Severe
Milk (Zadoks 71-77)	White awns or white heads; damage to lower stems; leaf discoloration; shrunken, roughened or discolored kernels	Moderate to severe
Dough (Zadoks 83-89)	Shriveled, discolored kernels; poor germination	Slight to moderate

Source: Paulsen, G. M., E. G. Heyne and H. D. Wilkins. 1982. Spring freeze injury to Kansas wheat. Kansas State University Cooperative Extension Service C-646.

Emergence to tillering — Zadoks scale 10-25

During the seedling and early tillering stages, the growing point is below the soil surface and protected from freeze injury. The growing points of wheat and barley are generally located deeper in the soil than the growing point of oats.

Most damage occurs to leaves, which may have distinct light-yellow bands and which become chlorotic or necrotic and usually twisted. Banding usually appears on smaller plants and reflects the pattern of daily growth and nighttime freezing (Fig. 3). Leaf tips and occasionally whole leaves may die within 1 to 2 days after freezing. A strong odor of dehydrating vegetation may develop several days after severe freezes.

Plants in these stages are rarely completely killed although individual tillers may be killed and total tiller numbers may be reduced. Most often injury only slows leaf growth. Generally, growth of new leaves and tillers resumes with warmer temperatures.

Jointing — Zadoks scale 31-39

Leaves of freeze-injured plants develop damage symptoms similar to those of the tillering stage. The most serious injury can occur to the growing points,

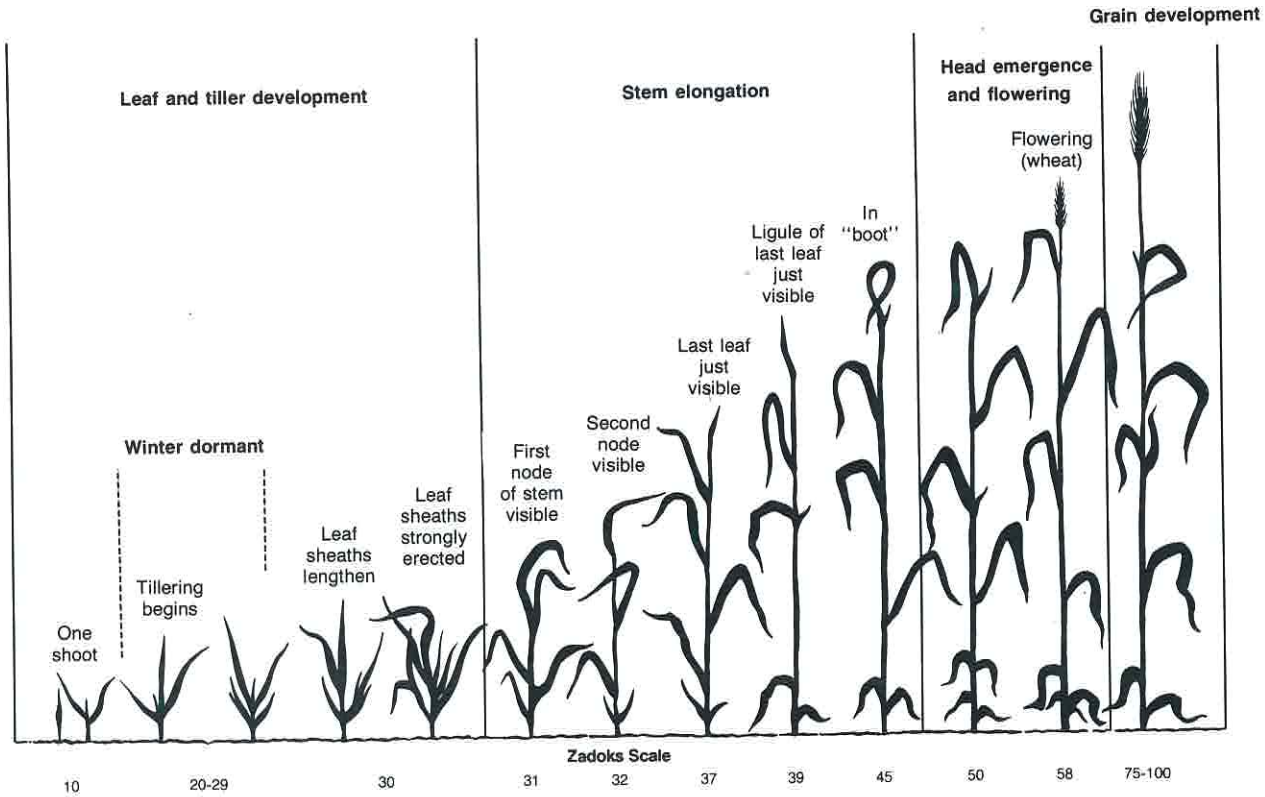

Fig. 2. Zadoks scale for cereal grain development.

Fig. 3. Freeze bands on spring barley seedlings.

Fig. 4. Spring-freeze-damaged winter wheat stems showing discoloration below the nodes.

Fig. 5. Distorted heads of winter barley caused by spring-freeze-induced "trapping."

Fig. 6. Freeze ring on winter wheat stem shows junction of stem and leaf sheath collar at time of freeze.

Fig. 7. Sterile wheat heads have awns bent at 90 degrees to the rachis.

which are now 1 to several inches above the soil surface. The growing point in a stem is located just above the uppermost node you can feel when you run the stem between your thumb and forefinger. To observe the growing point, split the stem lengthwise with a sharp blade to expose the developing head.

A normal, uninjured growing point is bright pearl white to yellow green and turgid. Freeze injury causes the growing point to turn dull white or brownish and water soaked. Injury to the growing point can occur in plants that appear to be otherwise normal because the growing point is most sensitive to cold.

When a growing point has been injured, stem elongation stops, but later, uninjured tillers continue to grow and may mask the damage. Injury at this stage usually results in a mixture of normal and late tillers, uneven maturity and a corresponding decrease in grain yield.

Lower-stem injury at this and later stages can result in stem discoloration, roughness, lesions, splitting, collapse of internodes or enlargement of nodes. Stem damage is often not visible until after the boot or later stages.

Stem discoloration is associated with reduced metabolite transport through the nodes (Fig. 4). Metabolites collecting under the nodes cause the discoloration. Injured stems often break over at affected areas so that one or more internodes may be parallel to the soil surface. In stems with no discoloration, injury does not appear to interfere with the plant's ability to take up nutrients from the soil and translocate them to the developing grain. Injured areas are more likely than healthy tissue to become infected with microorganisms, which also may cause stem discoloration and deterioration. Wind or hard rain will easily lodge these plants, decreasing grain yields and slowing harvest.

Boot — Zadoks scale 41-49

During the boot stage, the heads are enclosed in the sheaths of the flag leaves. Freezing causes varied symptoms. Freezing may cause heads to be trapped inside the boot so that they cannot emerge normally (Fig. 5). The heads may remain in the boot, split out the side of the boot or emerge from the boot base first. Often the "peduncle" or stem supporting the head continues to elongate normally, causing crimps in the stem that can inhibit normal transfer of photosynthates. The result is light test weight grain.

Heads that emerge normally from the boot may turn yellow or white instead of their normal green. These heads have been killed, and grain will not form.

Often, the head appears normal from the outside even though the male parts of the flower (anthers) are dead. Because wheat, barley and oats are mostly self-pollinated, male sterility causes poor seed set and low grain yield. Anthers are more sensitive to freezing temperatures than are the female flower parts.

Injury to the anthers can be detected soon after the freeze. Normal anthers are light green, full of developing pollen grains and turgid. They turn yellow when they mature and shed pollen. There is also some degree of anther extrusion from the floret, especially in wheat and oats. Freeze injury causes anthers to turn white and shrivel. It usually prevents them from shedding pollen and from extruding.

Freeze symptoms described for earlier stages of growth may also appear at this time. Leaves and lower stems may exhibit symptoms described for the tillering and jointing stages. However, these plant parts are more resistant to freezing temperatures than are the floral parts. Freezing temperatures that are severe enough to injure leaves and lower stems are nearly always fatal to male flower parts. Less-severe freezing may sterilize the male part of the flower without producing any symptoms on the leaves and stems. It is important, therefore, to examine the anthers.

Heading — Zadoks scale 51-59

Most symptoms of freeze injury at this stage are similar to those of earlier growth stages — sterility, leaf burn and stem lesions. The most apparent symptom, however, is chlorosis or bleaching of awn tips. White-tipped awns (beards) usually indicate that floral parts have been injured. Awn tips may have a purple cast before turning white.

A light-green or white freeze ring may encircle the stem below the head several days after exposure to freezing temperatures (Fig. 6). This ring marks the juncture of the stem and flag leaf at the time of the freeze. The freeze ring may appear on plants that show no other symptoms of freeze injury. The freeze ring may impede movement of metabolites from the plant to the developing grain. As plants mature the straw may break at the freeze ring. Breaking is more likely when heads are well filled, particularly during windy conditions.

Sterility in a head may be complete or localized in a seemingly random pattern (see cover). This sterility pattern probably is due to differential maturity of individual florets within a head. Floret maturity proceeds from near the middle of a head to the top and bottom of the head over 2 to 4 days. Maturity also proceeds from the primary spikelet of a floret to its tertiary and quaternary spikelets. More-mature florets are more likely to be damaged. Even slight differences in maturity of individual florets will result in some being damaged and others left intact.

Flowering (Anthesis) — Zadoks scale 61-69

Wheat and oats flower several days after the heads