Winterkill

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Winter is always a tough time for golf course turfs because some turf loss is almost inevitable. Turf dies during the winter due to one or more factors termed collectively as "winterkill". In no particular order, the six mechanisms of winterkill are 1) frost heaving, 2) low temperature fungi, 3) anoxia or toxic gas accumulation, 4) desiccation, 5) indirect low temperature injury, and 6) direct low temperature injury.

Frost heaving is mostly a problem on immature turf swards established too late in the growing season. Often the soil is fairly porous (i.e., low bulk density) due to tilling prior to seeding and lack of compacting forces (i.e., traffic). Winter rains fill up the air pores in the soil. As the soil temperatures decline below 32°F the water freezes and expands as ice, which pushes outwards on the soil. Since the path of least resistance is towards the surface, the majority of expansion occurs upwards essentially causing eruptions at the soil surface because the limited root system does not effectively bind plants to one another. The small root systems of the young turf are exposed to air which causes desiccation (drying) of the plants. While soil ice can still cause an upheaval in mature turf, the roots bind the plants to one another and the turf is easily pushed back into the soil by traffic. Smoothing out the minor hills caused by frost heaving is one of the reasons a lightweight rolling in the spring has long been a tradition in turf management.

Most years in Wisconsin various snow mold fungi can cause severe injury to turf stands. In many cases entire stands of turf can be lost unless a protective fungicide is applied in the autumn. In 1997 Dr. Millet, formerly of the UW-Madison Plant Pathology Department, surveyed several golf courses in Wisconsin for the prevalence of snow mold fungi. Dr. Jung followed up on the initial survey work and collected snow mold samples from 100 golf courses in 2001. Using molecular markers, Dr. Jung has verified the presence of at least four fungal species that can cause snow mold in Wisconsin: *Microdochium nivale, Typhula incarnata, T. ishikariensis,* and *T. phacorhiza* (Scheef and Jung, 2002; Rangel and Jung, 2002). *Microdochium* patch, sometimes known as pink snow mold or *Fusarium* patch, infects turf at higher temperatures than the *Typhula* species, occasionally as high as 70° F. The *Typhula* species can be considered colder-weather pathogens and, unlike *Microdochium*, seem to require a snow or leaf cover for infection. Dr. Jung's work to identify the species and biotypes of the snow mold pathogens will help superintendents to develop site-specific fungicide treatments to manage the snow mold pathogens on individual golf courses.

Ice often causes concern for superintendents. Ice can result in turf death by any of three means: 1) anoxia (lack of oxygen), 2) accumulation of toxic gas, or 3) crown hydration. (Crown hydration is explained later in the article as it occurs after ice melts and is a form of direct low temperature kill.) Recent research at Laval University and the University of Guelph has shown that toxic gases such as carbon dioxide from root or microbial respiration in soil can accumulate under ice sheets (Dionne et al., 2002). Oxygen levels decline during respiration under ice, potentially causing turf root death since roots and crowns need oxygen for respiration. Even if sufficient oxygen exists near the surface to keep the crown alive, a loss of oxygen deeper in the soil causes anaerobic conditions and a shift in the microbial population. Fermenting microorganisms increase in number and produce methane which can be toxic to turf plants when it accumulates under ice. Grasses vary in their capacity to survive under ice with creeping bentgrass able to withstand up to 150 days under ice cover while *P. annua* may die between 45 to 60 days (Beard, 1964).

Desiccation injury is a common form of winterkill. Desiccation occurs when transpiration and/or evaporation rates withdraw too much moisture from the turf. Usually exposed turf leaves die from the combination of cold temperatures which prevent chlorophyll production and sunlight which degrades chlorophyll. Leaf death virtually eliminates transpiration and provides a natural blanket to reduce evaporative losses from the soil. In some cases, however, wind moving across a green turf in a frozen soil removes moisture from the plant which cannot be replaced and the plants die from desiccation injury. Desiccation can still occur when the leaves are dead as the crowns remain alive and may transpire at a low rate, especially when the temperature exceeds 32° F, throughout the winter.

The other two forms of winterkill, indirect and direct low temperature kill, are less obvious than frost heaving or snow mold diseases. Indirect low temperature kill is basically a form of desiccation (drying) injury. Indirect low temperature kill occurs when ice forms between cells, causing a lower water potential than that inside the cells. Moisture from inside plant cells moves towards the ice between the cells. If enough moisture moves out of the cell, cell turgor is lost and the cell membrane essentially collapses (plasmolysis). When plasmolysis occurs in enough cells in the crown the plant dies because the crown is responsible for both new leaf (upper crown) and root (lower crown) formation.

Direct low temperature kill occurs when temperatures decline below some threshold value which kills the plant. Direct low temperature kill is less common than indirect low temperature kill but can result in large areas of turf death rather rapidly. Water in the plant freezes, forming ice, which destroys cell membranes when freezing occurs rapidly or at excessively low temperatures. The low temperature threshold varies by species and sometimes by cultivar. The low temperature threshold is usually defined as the Lethal Temperature to kill 50 percent of the population (LT_{50}). Determination of the LT_{50} values uses laboratory methods to test freezing tolerance. Freezing tolerance values derived in the laboratory tend to overestimate the likelihood for death at any specific temperature, but provide useful comparisons between species and cultivars for breeding or establishment purposes. The most common method for determining LT_{50} values is to remove the crowns from turf plants and subject them to a range of sub-freezing temperatures in a methanol or glycol (antifreeze) bath (Gusta et al., 1980). Afterwards the crowns are potted in soil and checked for regrowth in greenhouse conditions. Numerous studies have shown that freezing tolerance increases during the fall, peaks around December-January, then declines by spring. In other words, turfgrasses have the best freezing tolerance in early to mid-winter; by late winter (March) freezing tolerance is little better than in summer.

Sometimes turf comes out of the winter looking green only to die a few weeks later. *Poa annua* is especially susceptible to this phenomenon.

We recently published evidence to explain why turfgrass leaves may appear green in the spring following snow melt only to die several weeks later. The answer is that the turfgrasses can freeze from the bottom up. We used an infrared video camera to detect temperature changes in turfgrass plants. Both cold-acclimated and non-acclimated plants were placed in a cold room and subjected to a decreasing temperature from 32° F to -18° F. The camera detected heat which indicated where ice was forming and how it was moving through the plant (heat is emitted as water freezes). The freezing events were recorded on videotape (examples of color images can be found at http://crop.scijournals.org/, then selecting the January/February

	Temperature at which tissue froze (F)	
Tissue type	**Perennial ryegrass**	**Supina bluegrass**
Roots	26.1	28.0
Crowns	23.9	23.5
Leaves	21.6	22.1
LSD (0.05)	0.7*	

***LSD value is for comparing temperatures between species or between tissue types within a species.**

Table 1. Differences in freezing temperatures among leaves, crowns, and roots of two cool-season turfgrasses (adapted from Stier et al., 2003).

issue, then selecting Notes). Freezing events were conducted several times then the videotapes reviewed to analyze the temperatures at which freezing occurred. The results for supina bluegrass (*Poa supina*, a close cousin of *P. annua*) and perennial ryegrass (*Lolium perenne*) are shown in table 1.

The results showed that roots always froze at higher temperatures than either crowns or leaves. The camera showed that ice formed first in small roots then moved quickly throughout the root system, eventually reaching the lower crown. The crown tissue appeared to inhibit ice formation. As the temperature continued to decrease, ice slowly worked its way to the upper crown where new leaves form, then into the shoots and eventually the leaves. We never saw leaves or crowns freeze independently of roots. Ice-nucleating bacteria were placed on plant leaves, crowns, and roots: while the water droplets containing the bacteria froze, the bacteria did not cause ice formation in the plants as has been reported for some plants (Lindow et al., 1982).

What are the implications of our study? Although roots are protected from air temperatures by the soil, surface soil will be significantly colder during the winter than soil at a two or four inch depth. Our study showed that small roots close to the surface could freeze, allowing ice to propagate (move) into the lower crown where roots are formed. When the lower crown is frozen and the cells responsible for root formation die, new roots cannot be formed. Thus, it is possible for new leaves to be produced early in the spring as long as there is sufficient moisture in the soil surface for direct absorption by the crown. Without new root formation, though, the plants eventually die because they can't absorb enough moisture and nutrients to keep the plant growing. Beard and Olien (1963) proposed that lower crown death was responsible for winterkill in *P. annua* but only recently was the technology developed to test their hypothesis and explain how lower crown tissue could be killed while upper crown tissue was left intact.

Freezing injury to the lower crown through roots near the surface may be an important factor in what is often referred to as "crown hydration" [injury]. Direct low temperature kill occurs most often during late winter or early spring freeze-thaw events. During cold acclimation in the fall turf plants reduce the amount of free water in their tissues by slowing water absorption rates and by reducing [free] water potential by accumulating salts and/or sugars or by binding water with special proteins. These molecules are degraded during the winter and cold acclimation decreases with the approach of spring. In "crown hydration", water is absorbed by the plant during snow or ice melt and the amount of free water in the plant is greatly increased. When exposed to freezing conditions, the free water in the plant freezes, resulting in direct low temperature kill.

Understanding the phenomenon of winterkill allows supertintendents to develop strategies for dealing with winter injury. New turf should be established early enough before winter to allow a sufficient root system to develop and reduce the potential for frost heaving injury. Fungicides are used to prevent snow mold diseases. Ice can be physically broken up or melted using dark-colored substances such as Milorganite™ to absorb solar heat and melt ice (salt is not useful as too much can kill the turf). Desiccation can be prevented by a heavy topdressing during late autumn or by using an insulating blanket such as an Evergreen™ cover which allows only limited air exchange. Indirect and direct low temperature kill can be minimized by ensuring adequate surface drainage as internal drainage is prohibited when soil is frozen but snow or ice are melting on the surface. Maintaining a healthy turf going into winter is important for avoiding all types of winterkill, and this of course requires a growing season-long effort.

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