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PATHOLOGY

Winter Injury

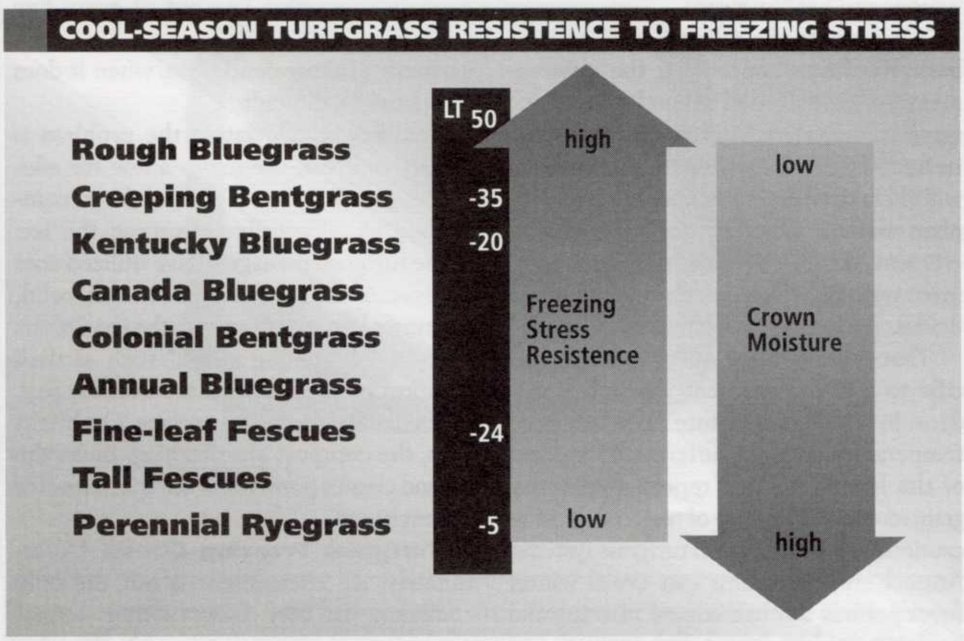
Understanding the Effects and Research Efforts

by Dr. Frank S. Rossi, Cornell University

Over the years, golf course management has been impacted by the introduction of various technologies. Technology has enabled the golf course superintendent to maintain higher quality conditions than would be expected if the technology was not available. Does it then follow that technology gives us control?

The answer is different depending on who you ask. Certainly, mechanical and chemical technology have provided tools used to achieve superior putting surfaces. Still, one must wonder how much we can actually control. When it comes to the various aspects of winter injury on our northern golf turf, the last few winters provided the harsh reality of exactly how much we can control — precious little.

Recent devastating losses from winter injury have revitalized interest in this otherwise neglected area, as evidenced by articles in popular trade magazines, conference topics and



Winter hardiness is extremely dependent on the species of turf.

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TURFGRASS TRENDS

Executive Editor
Sue Gibson
440-891-2729; 440-891-2675 (fax)
sgibson@advanstar.com

Managing Editor
Bruce F. Shank, BioCOM
805-274-0321

Technical Editor
Nancy Stairs
440-891-2623

Senior Science Editor
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Consulting Editor
Chris Sann

Group Editor
Vern Henry

Production Manager
Karen Lenzen
218-723-9129; 218-723-9576 (fax)
klenzen@advanstar.com

Circulation Manager
Frank Christopherson
218-723-9271

Group Publisher
John D. Payne
440-891-2786; 440-891-2675 (fax)
jpayne@advanstar.com

Corporate & Editorial Office
7500 Old Oak Blvd.
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university research programs over the last few years.

Minimizing turf loss in the winter requires an improved understanding of the processes at work. Simply put, you can not protect what you do not understand.

Overview

Each year, throughout the northern United States, thousands of acres of turf are lost to what has been termed "winter injury." The irony of the situation is that estimates from industry surveys indicate 35 to 75 percent of all energy inputs in turf management in northern areas are as preparation for, and recovery from, the effects of winter. Despite these efforts, substantial turf loss can, and does, occur. The winter of 1992-93 in the Midwest U.S. and 1993-94 in the Northeast U.S. are just two examples.

Extensive turf loss from "winter injury" holds substantial environmental and economic consequences to the functional and aesthetic quality of recreational turf areas. Turf loss from winter injury, evident in the spring, results in increased weed encroachment, greater soil erosion and requires energy intensive re-establishment procedures to restore the environmental benefits of a contiguous and healthy sward.

What is needed is research: to answer the basic questions concerning the environmental and physiological conditions which result in freezing stress injury in cool-season turfgrasses. Understanding these conditions will aid in the development of winter-hardy plant material and allow for more energy-efficient, environmentally sound management systems, which are less reliant on pesticides.

That there is a lack of information specific to turf management research is evident. In a recent literature review of low-temperature stress in turfgrass, 85 percent of the literature cited represented cereal grain research. This type of research must be cautiously extrapolated to turfgrass systems. Annual crop programs can avoid winter stress periods through annual planting and harvesting practices, while perennial turf must suffer injury, enter dormancy or otherwise survive low-temperature stress.

Mechanisms of Injury

Ice Encasement: Turfgrasses respire energy throughout the winter. This physiological process requires gas exchange. Therefore, when winter conditions result in ice formation on the turf surface, the necessary gas exchange cannot occur and the area beneath the ice becomes anaerobic (lacking oxygen). In addition to the trapped gas from the turf, there is a substantial amount of gas given off from the soil since some microbes, such as the snow mold organisms, remain active in cold weather. This combines to create an environment that is hostile to turfgrasses.

Cool-season grasses have varying abilities to tolerate the conditions of ice encasement. For example, under research conditions, annual bluegrass can survive up to 60 days under ice, Kentucky bluegrass 100 days and creeping bentgrass 150 days. This turf loss is probably consistent with what most turf managers have experienced with the periodic damage to annual bluegrass under winter ice conditions.

Severe incidents of ice encasement are sporadic, occurring one out of every five years in most northern regions. But, management of these conditions, when it does occur, can be difficult.

The key to alleviating the problem is simply to break the ice to allow for adequate gas exchange. This can be accomplished by physically disrupting the ice. Some turfgrass managers have utilized core cultivation equipment fitted with solid, "hammer-like" tines to break the ice. Others apply a "blackening agent," such as dark compost or natural organic fertilizers (e.g. Milorganite), to the ice surface. On bright days, the compost absorbs heat, melts the ice and creates pores in the ice that allow for gas exchange.

Turfgrass Freezing Stress: Unfortunately, ice encasement is not the only challenge to turf from winter injury. Turfgrasses can be injured or killed during winter in the northern climates as a result of the singular or interactive effects of ice encasement, freezing stress, traffic, desiccation, soil frost-heaving and low-temperature fungi. Despite the multitude of interactive, low-temperature stresses, freezing stress is thought to be the major factor affecting the survival of turfgrasses in the northern U.S.

During the transitional period between late winter and early spring, when freezing and thawing can occur, the plants can alternately experience warm, saturated conditions followed by rapidly freezing temperatures. These conditions can lead to freezing stress, where ice forms within the plant, causing severe cell dehydration.

Turfgrass injury from freezing stress is directly related to how, where and whether or not ice forms in cells of the turfgrass stem apex (a.k.a. crown); the primary region of the grass plant that overwinters.

Specifically, if temperatures drop rapidly and water is available for freezing inside a plant cell, that cell will die. If several cells in the crown die, the grass plant may not be able to recover. This direct form of freezing injury is thought to be rare, because temperatures generally decline between 1° to 2°C per hour, thus allowing the cell time to adapt. However, when the temperature falls rapidly following warm or wet periods, freezing stress damage within the cell is possible.

Freezing stress is thought to be the major factor affecting the survival of turfgrasses in the northern U.S.

The more common scenario for ice formation is between the plant cells or intracellularly (Figure 1). As the ice crystal forms, it draws water molecules from inside the cell to expand the size of the crystal. As water is drawn from the cell, the cell becomes dehydrated. Dehydration causes a number of problems for the cell, not the least of which is membrane dysfunction, which allows even more water to flow out. Dehydration causes the degradation of other cellular components resulting in death of the cell. If enough cells in the crown are killed, the grass will not recover.

ICE FORMATION & PLANT CELLS

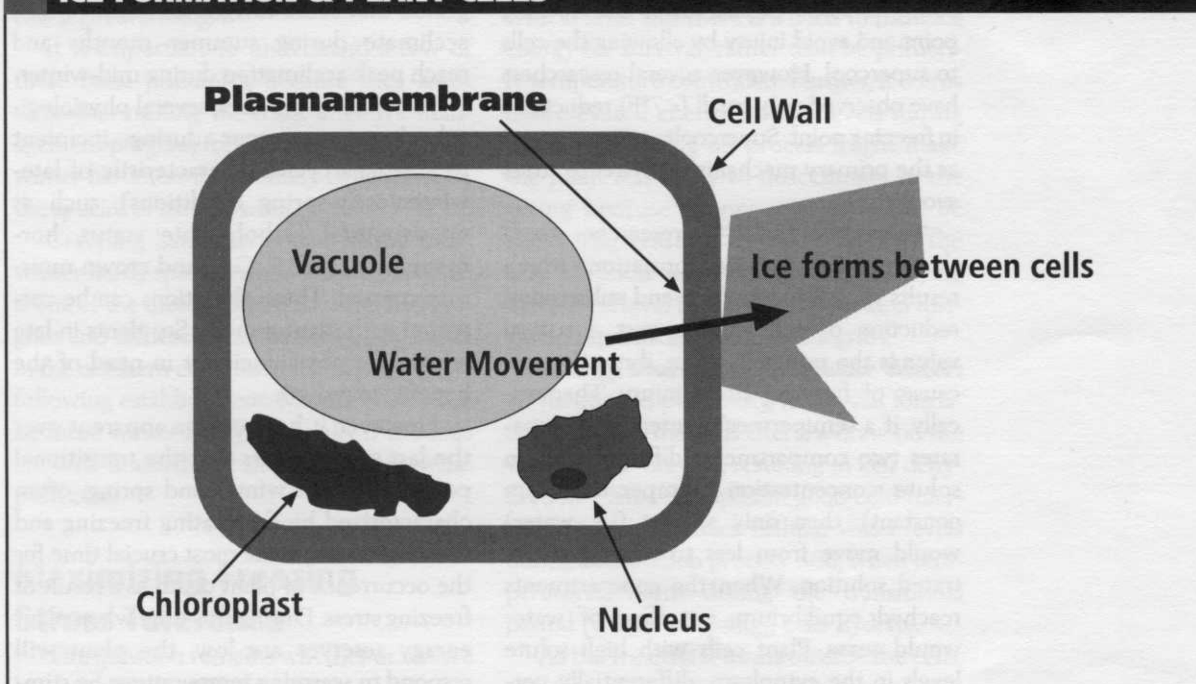

Figure 1. As ice crystals form between cells, they draw water molecules from inside the cell to expand the size of the crystal. As water is drawn from the cell, the cell becomes dehydrated and can die. If enough crown cells are killed by ice crystals, the plant will die.

Freezing Stress Resistance

Plants naturally utilize various mechanisms to minimize intracellular ice crystal formation by holding water inside the cell tighter than the ice crystal can draw it out. These mechanisms of freezing stress resistance lie at the heart of strategies for survival.

Palta and Simon (1993) defined freezing stress resistance in plants as the plant's ability to achieve its genetic potential for growth, development and productivity by surviving freezing temperatures. They proposed avoiding extra- or intracellular ice formation and tolerating extracellular ice formation as the two primary survival mechanisms.

Avoidance: An interesting mechanism of avoidance called deep supercooling has been demonstrated with insects, mammals and some woody species. Deep supercooling occurs when the concentration of the soluble material in a liquid is raised to the point where temperatures below 32°F are needed for ice formation.

It seems reasonable that intracellular sugar accumulation during cold acclimation could, to some extent, lower the freezing point and avoid injury by allowing the cells to supercool. However, several researchers have observed only small (<7°F) reductions in freezing point. Supercooling is not viewed as the primary mechanism of freeze stress avoidance.

Tolerance: In 1980, a researcher stated that extracellular ice formation which results in cell plasmolysis and subsequent reduction of cell volume past a critical value is the principle cause, if not the sole cause, of freezing stress injury. Theoretically, if a semipermeable membrane separates two compartments differing only in solute concentration (temperatures are constant), then only solvent (i.e. water) would move from less to more concentrated solution. When the compartments reached equilibrium, net flow of water would cease. Plant cells with high solute levels in the cytoplasm, differentially permeable membranes and relatively rigid cell walls would permit net water movement to the interior, away from ice crystals forming extracellularly. Also in 1980, it was demonstrated that alteration of membrane function by incipient freezing injury could occur without changes in water permeability. Therefore, this would allow for a pressure which could resist plasmolysis and thus aid in maintaining membrane integrity under freezing stress.

Several turfgrass researchers have demonstrated a correlation between crown moisture content and turfgrass freezing stress resistance. However, the results were presented in a manner that made it difficult for the confirming researchers to detect small but important differences in freezing resistance. Clearly, however, an important tolerance mechanism is the reduced crown moisture levels that coincide with acclimation.

Cold Acclimation

Cold acclimation, or a plant's capacity to cold acclimate (enter dormancy), and later to deacclimate (break dormancy), has long been considered a significant factor determining freezing resistance. It has been suggested that some turfgrasses begin to cold acclimate during summer months and reach peak acclimation during mid-winter.

As winter progresses, several physiological alterations occur during incipient freeze-thaw cycles (characteristic of late-winter/early-spring conditions), such as nonstructural carbohydrate status, hormone levels (ABA, GA) and crown moisture content. These alterations can be corrected with plant growth. So, plants in late winter are physiologically in need of the benefits of growth.

However, it has become apparent over the last several years that the transitional period between winter and spring, often characterized by fluctuating freezing and thawing events, is the most crucial time for the occurrence of plant death as a result of freezing stress. During this time when plant energy reserves are low, the plant will respond to warming temperatures by stimulating or increasing growth.

When growth is stimulated, several physiological changes occur. The most significant effect is the hydration of the plant tissues by water. As the crown hydrates to grow, it becomes more susceptible to freezing than it would be in a hardened state, since more free water is available.

Typically, we associate these situations with low, poorly drained areas, but tissues hydrate after the plant begins to grow from increased soil temperatures. This association with low areas may occur as a result of the standing water which is warmed by solar radiation. Once the water warms, heat is transferred to the soil, growth is stimulated, and the water is taken up. However, crown hydration is not confined to low areas; it will occur anywhere growth is stimulated and water is available for uptake.

Researchers have speculated for years that one of the single most important aspects for enhancing winter hardiness is delayed deacclimation or breaking of dormancy. This is most difficult with annual bluegrass, which is likely to break dormancy rapidly in the spring. In fact, researchers at the Prairie Turfgrass Research Center have quantified reduced hardiness of annual bluegrass following only eight hours of temperatures above 40°F. It was concluded that freezing tolerance was reduced 5° to 10°F following this slight warming.

It is important to understand a few of these basic principles, because they assist with determining the most effective management program for ensuring survival. Still, winter hardiness is extremely dependent on the species of turf growing.

Creeping bentgrass is one of the most winter-hardy species, while annual bluegrass is one of the more susceptible. Perennial ryegrass and tall fescue can be marginally hardy in the northern climates in the first few years following establishment. Mature stands can be more winter-hardy, especially if the soils are well drained and the area is somewhat protected.

Maximizing Freezing Stress Tolerance

The question remains whether or not we have the technology to protect turfgrasses from freezing stress injury. Maximizing freezing stress tolerance would focus on several physiological areas, including crown moisture, acclimation-deacclimation mechanisms, cell membrane integrity and energy storage. Understanding the contributions and interaction of each of these areas to the overall freezing stress response can provide information for management strategies to minimize injury.

Energy Storage: Turfgrasses are not entirely dormant during the winter. The plants continue to respire or deplete their energy supply as they overwinter, similar to how human physiology, especially breathing, is altered when we sleep. Therefore, entering winter with high levels of stored energy could provide several protective strategies.

Warming temperatures in late winter/early spring are thought to stimulate growth. This stimulation of growth sets the grasses up for winter injury.

The warming temperatures during the late winter/early spring transitional period are thought to stimulate growth. This stimulation of growth sets the grasses up for the winter injury. Because not all types of turfgrasses deacclimate (or green-up) under the same temperature regimes, it seems reasonable that they would deacclimate because energy storage is below some critical level and there is a need to produce energy for survival, rather than be primarily temperature controlled. Further, it seems that elevated energy storage levels during the fall hardening-off process might make the plant less likely to deacclimate in the spring because energy storage would be above the critical level. Research at the UW-Madison was pointed at quantifying the critical level for several cool-season turfgrasses, specifically annual bluegrass.

Energy Storage and Cellular Water: As mentioned previously, ice crystal formation between the cells exerts a draw on the water inside the cell, resulting in cell dehydration. Plants that exhibit good cold tolerance appear to reduce cellular water levels during acclimation process. Still, when temperatures warm during the transitional period (winter to spring), cells hydrate.

As the ice crystal forms outside the cells, the area of formation has a lower concentration of water than inside the cell and water moves out of the cell to equalize the water concentrations. Late season maximizing of solutes in the cell, like energy sources such as sugars and fructans, could reduce the concentration of water in the cell. This reduced concentration would prevent the water from passing through the membrane for ice crystal enlargement and the cell would stay hydrated and survive.

Management to Enhance Energy Storage: Several researchers working with cereal grasses (wheat, oats, barley) have correlated freezing stress tolerance with energy storage levels. Increased energy storage in the grasses resulted in greater freezing stress tolerance. If the cereal grasses are not bred with the ability to store high levels of energy, the stress level will be high because cereal production strategies to maximize energy (late fertilization) are not practical. However, turfgrass management provides several potential strategies to enhance energy storage.

As with the cereal grasses, turfgrass managers can start with plant material that has demonstrated good freezing stress tolerance. However, because infestations of relatively unresistant annual bluegrass easily invades highly managed turf stands, using resistant varieties as the sole means of reducing winter injury makes this approach difficult at best.

It is possible, through primary cultural practices (mowing, fertilization and irrigation), to maximize energy storage during cold acclimation periods. Several researchers have investigated the role of potassium (K) with freezing stress tolerance. Since the role of K in plant energy production and storage remains unclear and information for testing has been conflicting and often inconclusive, just what role K plays in enhancing the cells' ability to retain water is unclear.

Factors that Influence Plant Winter Hardiness

Drainage: One of the most critical influences on winter injury, whether it is ice encasement, cell freezing, crown hydration (cell dehydration) or snow molds, is free-standing water available for freezing or to enhance disease activity. (Excessively wet fall periods prior to winter will also reduce winter hardiness.) The importance of proper surface drainage cannot be stressed enough, especially on turf areas such as athletic fields and golf greens that are subject to high traffic in the late winter/early spring.

Fertility: For the grasses to maximize photosynthetic activity as stored carbohydrates, adequate, well-balanced nutrition must be available. Many studies have shown increased energy (carbohydrate) storage following late-fall fertilization.

Fertilizer products that have a high percentage of water-soluble nitrogen are ideal for this purpose. However, on sandy soils, care should be taken to use more moisture-dependent, slow-release materials such as IBDU to ensure water quality.

The late-fall fertilizer treatment is best applied after top growth has ceased, which typically coincides with 7 to 10 days of a mean daily average temperature of 50°F or when nighttime temperatures fall below 30°F. This will ensure that any warming periods, which might stimulate top growth (Indian summer) and reduce hardiness, have passed. Depending on where you are in the north, this usually translates into late October. The carbohydrates developed from fertilizing prior to this temperature range are usually used up or may be used to increase leaf length going into winter.

Many turf managers apply excessive amounts of potassium (K) in the late season to enhance winter hardiness. Keep in mind, there is no conclusive evidence that indicates K levels above that which is required for adequate growth (indicated by soil test) will enhance winter hardiness. Furthermore, there may be severe consequences from excessive application of high salt content fertilizer, as suggested by researchers investigating bentgrass decline in the southeastern U.S.

Mowing Height: If we accept that grass leaves are where the energy is produced that enhances hardiness, it is then essential to have as much leaf surface area as possible available late in the growing season. Excessive close mowing, at or below the acceptable range for a particular species, will compromise energy production and reduce winter hardiness. It is advisable to raise the mowing height on putting greens if golfers will tolerate reduced ball roll distances.

Thatch: Excessive thatch accumulation will reduce winter survival. Thatch is less buffered from extreme temperatures, and plant crowns and other perennial structures which are elevated above the soil/thatch interface will be affected. In addition, thatch levels above one inch can promote desiccation and turfgrass disease incidence. Late season core cultivation to incorporate the soil from the cores into the thatch layer can assist with thatch decomposition and can also improve drainage by breaking through layers which can lead to increased hardiness.

Disease Management: Two research projects from Japan suggested that low temperature pathogens "sense" weak plants that may be more susceptible to infection. Subsequently, as previously indicated, maximizing plant health through proper acclimation with water management, fertility and mowing height could result in reduced snow mold activity. Nevertheless, species such as perennial ryegrass, creeping bentgrass and annual bluegrass are highly susceptible to disease and will still require preventative management to ensure survival.

Topdressing: Many turfgrass managers have used heavy, late season topdressing that serves to insulate the turf and protect the crown from desiccation in open or snowless winters. However, golf turf managers in the north-central U.S. have experienced problems with late-season sand topdressing that might be dragged or brushed in. Researchers at the University of Wisconsin-River Falls have started a study investigating this management practice. Although results from the first year were inconclusive, it may be wise to avoid topdressing with highly angular/sharp sand and then brushing it in. This practice can abrade the leaf surface and may accelerate desiccation.

Traffic: Of all the management factors that are under the control of the turfgrass professional, minimizing traffic during periods when the soil is frozen or just when turf is not actively growing can be the most difficult. Players want to use the turf and that conflicts with what is known regarding maintaining healthy plants. While there is limited data on early season play, estimates suggest that active play during the "shoulders" of the growing season can subsequently require many weeks of active growth for recovery. Therefore, if possible, minimize traffic when the plants are dormant or the soil is frozen.

The importance of proper surface drainage cannot be stressed enough, especially on turf areas such as athletic fields and golf greens that are subject to high traffic in the late winter/early spring.

Turf Covers: The use of synthetic, protective turfgrass covers for enhancing winter survival, has provided variable results over the years. Recent studies from Laval University in Quebec have indicated that snow is the best insulator and should be kept on as long as possible. The next best thing is any cover that uses an air layer to insulate the turf from extreme temperature and moisture. Keep in mind that covers accelerate green-up in the spring and can result in reduced winter hardiness if temperatures drop suddenly.

Plant Growth Regulators

Plant growth regulators (PGRs) were introduced more than 40 years ago for application to utility turf to reduce their mowing requirements by inhibiting turfgrass shoot growth. Today, plant growth regulators are used to improve turf color, reduce clippings, suppress seedheads and improve green speed.

A field study of fall-applied PGRs on cereal hardiness resulted in an increase in the average survival of winter cereals. These effects, however, were not consistent from year to year, indicating the complexity of the problem. Winter cereals, especially the less hardy genotypes, are known to have reduced freezing stress tolerance from January to March, even though they are constantly exposed to subzero temperatures. It is possible that the regulation of the acclimation and deacclimation process through the use of PGRs may involve a component of a complicated stress response. Still, the interaction of freezing stress and PGRs might provide insight to solving the previously uncontrollable problem.

Certain classes of PGRs increase cold hardiness or winter survival by reducing the production of gibberellic acid and could increase the photosynthate partitioning (storage) in the crown of the plant. Research in 1993 indicated that a post growth-inhibition period, six to eight weeks following a PGR application, resulted in a resurgence of growth and a concomitant decrease in total carbohydrate levels. This resurgence of growth would need to be minimized through the timing and rate of applications, in order to avoid any inappropriate growth activity.

Trinexapac-ethyl is a class A plant growth regulator labeled for use in turfgrass management for reducing shoot growth without causing significant injury. Trinexapac-ethyl inhibits the gibberellin biosynthesis process late in the pathway. This results in an increase in abscissic acid (ABA) levels that decrease shoot growth and increase carbohydrate storage, which may improve freezing stress tolerance.

Triazole plant growth regulators such as paclobutrazol are class B PGRs that act much earlier in the gibberellin biosynthetic pathway. It has been reported that ABA levels are increased in plants grown under triazole regulation. It has also been suggested that the combination of lowered gibberellic acid and increased ABA levels increase stress tolerance during chilling or freezing.

Theoretically, late fall applications of a plant growth regulator could improve the winter hardiness of plants by altering their carbohydrate status during cold acclimation when energy is being produced and used for storage, rather than for top growth. This treatment could coincide with the gradual cessation of shoot growth, the initiation of the hardening process, membrane alteration and accumulation of photosynthate. This could lead to a plant with enhanced cryoprotective features and an increased energy source, allowing it to withstand the incipient freeze-thaw periods.

Controlled Environment Studies: Plant growth regulator effects on winter injury of annual bluegrass were studied in a growth room at the University of Wisconsin-Madison's Biotron.

The objectives of this project were:
(1) to determine if commonly used plant growth regulators affect the winter hardiness and turf quality of annual bluegrass throughout the fall and spring;
(2) to determine the relative freezing tolerance of annual bluegrass during fall and winter acclimation while under growth regulation; and
(3) to determine if trinexapac-ethyl increases carbohydrate concentrations, thereby improving winter hardiness under controlled environment conditions.

Preliminary studies indicated that in general, lower rates of PGRs enhanced winter survival, while higher rates had a detrimental effect. It was also evident that wet conditions during acclimation made the plants more susceptible to injury. Subsequent experiments simulated fall and winter acclimation, and the late winter/early spring deacclimation process on plants maintained in relatively saturated soil.

For the experiment, 7-cm plugs of annual bluegrass were extracted from the same fairway where a field study was being conducted concurrently to ensure consistency in biotype population between the field and controlled environment studies.

The plants were then maintained in a greenhouse with 12-hour day length for a month, simulating summer conditions. The plants were hand-watered to prevent moisture stress and mowed with a clipper approximately every other day. Pots were then treated with trinexapac-ethyl and permitted to acclimate. Then temperatures were reduced two degrees per hour to 5°C day temperature and 2°C nighttime temperature. This daily regime was maintained for three weeks.

Secondary acclimation was attained by lowering the temperature of the room one degree per hour to 0°C, where it was maintained as both the daytime and nighttime temperature for three weeks. Secondary acclimation conditions were then followed by a 48-hour warm up to 8°C daytime temperature and 5°C nighttime temperature, permitting deacclimation.

Finally, plants were removed from the Biotron after one and three weeks of primary hardening, one and three weeks of secondary hardening, and after the 48-hour deacclimation. A variety of freezing temperatures were then imposed to determine the tolerance of the plants untreated and treated with trinexapac. At the same time, plants were being harvested to determine carbohydrate content, to correlate with changes in freezing stress tolerance.

Results from the controlled environment experiments indicated that freezing stress tolerance could be enhanced with ultra-low rates of trinexapac. The amount of enhancement appeared to be slight and not well correlated with observed increases in carbohydrate content. Plants treated with trinexapac seemed to deacclimate more rapidly when exposed to warming temperatures than untreated plants. However, at the lowest rate, treated plants had a greater relative freezing tolerance than untreated plants.

The variability we observed with the carbohydrate concentration was consistent with results observed by previous researchers. Further experimentation under controlled environmental conditions will be needed to specifically quantify the physiological state of the plant prior to PGR application.

Field Studies: Field experiments to evaluate winter injury and spring green-up were conducted on a golf course fairway composed primarily of annual bluegrass. Plant growth regulator applications were made at various rates and times throughout the fall at Nakoma Country Club in Madison, WI, from 1994-96. (This particular area is a regular site of significant winter injury.)

Plots were rated for injury related to the application in the fall and subsequently for winter injury and recovery in the spring.

Significant injury occurred in each of the three years we conducted the study. In year one, applications made in September and October at standard rates caused significant turf injury, evident by November. Consequently, most plots were killed by the spring. In years two and three, we reduced the rates to 6%, 3% and 1.5% of the normal rates and observed less injury in the fall. However, the winters were harsh and resulted in a widespread kill that was attributed to severe ice encasement.

Increased tillering evident in the spring on plots treated with growth regulators and results observed under controlled environment studies indicate that some benefits might be available using different timing, rates and products.

Interestingly, in year two, plots that survived the winterkill had been treated with low rates of PGRs and had produced significantly more tillers, which were more robust when compared to untreated plants. Nevertheless, in all three years, plots required over 8 weeks to recover to acceptable quality, a situation that would be completely unacceptable to golf superintendents.

As a result of the lack of field efficacy, we are hesitant to make strong recommendations for this strategy under field conditions. Still, increased tillering evident in the spring on treated plots and results observed under controlled environment studies indicate that some benefits might be available using different application strategies, i.e., timing, rate and product.

Summary

It is vital, when considering freezing stress, to maintain a broad perspective on this complex process. Simply, the most fascinating and, at the same time, most frustrating aspect of freezing stress and winter injury research is the endless number of potential interactive causes: from the inherent genetic potential of the plant material, to alterations of physiology, to the influence of management factors and the variable weather conditions that exist in any one winter.

Research programs throughout the world are tackling various aspects of freezing stress. Also, turfgrass researchers can draw on work from other crops and growing systems for some guidance. Each contribution enhances the understanding of the processes at work.

The goals of this discussion were to provide a general outline of the physiology of freezing stress and a look at an experimental management approach to enhancing tolerance. However, as of this writing, technology still only provides limited control of this type of stress. In the final analysis, each golf course superintendent and turf manager is challenged to accumulate and evaluate the available information on turfgrass winter injury to maximize survival of the turf at their managed site. Hopefully, this has provided some useful information on this important, and still poorly understood, area.

Frank S. Rossi, Ph.D., is the New York State Extension Turfgrass Specialist and assistant professor of turfgrass science at Cornell University, Ithaca, NY.

REFERENCES

Beard, J.B. 1973. Turfgrass Science and Culture. Prentice-Hall, Englewood Cliffs, NJ. pp.238-312.

Beard, J.B. 1966. Direct low temperature injury of nineteen turfgrasses. Mich. Quarterly Bulletin. 48(3):376-383.

Beard, J.B. and P.E. Rieke. 1966. The influence of nitrogen potassium and cutting height on low temperature survival of grasses. Agron. Abstr. 1966:34.

Brule-Babel, A.L. and D.B. Fowler. 1989. Use of controlled environments for winter cereal cold hardiness evaluation: controlled freeze tests and tissue water content tests. Can. J. Plant Sci. 69:355-366.

Carroll, J.C. 1943. Effect of drought, temperature and nitrogen on turf. Plant Physiol. 18:19-36.

Coleman, W.K. and E.N. Estabrooks. 1992. Enhancement of cold hardiness in apple trees by paclobutrazol, thidiazuron and flurprimidol. Can. J. Plant Sci. 72:1267-1274.

Cooper, R.J., A.J. Koski, J.R. Street and P.R. Henderlong. 1985. Influence of plant growth regulators on carbohydrate production of annual bluegrass. Agron. J. 79:929-934.

Costanzo, J.P., R.E. Lee and M.F. Wright. 1992. Cooling rate influences cryoprotectant distribution and organ dehydration in freezing wood frogs. J. Exp. Zoology 261:373-378.

DiPaola, J.M and J.B. Beard. 1992. Physiological effects of temperature stress. In: Turfgrass (ASA Monograph 32), eds. D.V. Waddington et al. Amer. Soc. of Agron., Madison, WI. pp.231-267.

Fry, J.D., N.S. Lang, R.G.P. Clifton and F.P. Maier. 1993. Freezing tolerance and carbohydrate content of low-temperature-acclimated and nonacclimated centipedegrass. Crop Sci. 33:1051-1055.

Gay, A.P. and C.G. Eagles. 1991. Quantitative analysis of cold hardening and dehardening in Lolium. Annals of Bot. 67:339-345.

Gusta, L.V., J.D. Butler, C. Rajashekar and M.J. Burke. 1980. Freezing resistance of perennial turfgrasses. HortScience 15(4):494-496.

Lee, R.E. 1991. Principles of insect low temperature tolerance. In: Insects at Low Temperature, eds. R.E. Lee and D.L. Denlinger. Chapman and Hall, NY. pp.17-46.

Levitt, J. 1980. Responses of Plants to Environmental Stresses. Vol.1.: Chilling, freezing, and high temperature stresses. Academic Press, New York, NY.

Levitt, J. 1978. Overview of freezing injury and survival and its interrelationships to other stresses. In: Plant Cold Hardiness and Freezing Stress, eds. P.H. Li and A. Sakai. Academic Press, New York, NY.

Olien, C.R. 1984. An adaptive response of rye to freezing. Crop Sci. 21:51-54.

Olien, C.R. 1980. Analysis of midwinter freezing stress. In: Analysis and Improvement of Plant Cold Hardiness. CRC Press Inc., Boca Raton, FL.

Olien, C.R. 1964. Freezing processes in the crown of "Hudson" barley Hordeum vulgare (L. emend. Lam.) Hudson. Crop Sci. 4:91-95.

Palta, J.P. and G. Simon. 1993. Breeding potential for improvement of freezing stress resistance: genetic separation of freezing tolerance, freezing avoidance, and capacity to cold acclimate. In: Advances in Plant Cold Hardiness, eds. P.L. Li and L. Christersson. CRC Press, Boca Raton, FL.

Rajashekar, C.B. 1989. Supercooling characteristics of isolated peach flower bud primordia. Plant Physiol. 89:1031-1034.

Roberts, J.M. 1993. Understanding crown hydration damage. Golf Course Manag. 10:48-55.

White, D.B. 1981. Cold acclimation in the cool-season turfgrasses. In: Proc. 4th Turfgrass Res. Conf., ed. R.W. Sheard. Intl. Turf. Soc., Ontario Agric. Coll., Univ. of Guelph, Guelph, ON. pp. 527-534.

Williams, R.J. 1980. Frost desiccation: an osmotic model. In: Analysis and Improvement of Plant Cold Hardiness. CRC Press Inc., Boca Raton, FL.

Winter/Spring Nutrient Use
By Cool- and Warm-Season Turf

by Dr. Richard J. Hull, University of Rhode Island

As the grip of winter begins to relax, thoughts of spring and your turf nutrient management program slowly invade your consciousness. The subject of turf nutrition is not as simple as it was a few years ago. Many conflicting priorities linked with minimizing water pollution, practicing sustainable turf management, integrating with turf IPM programs and maintaining good public relations all confuse the issue. Basic questions of how much fertilizer to apply, when to apply it, in what form and in what ratio no longer depend solely on your level of understanding of turfgrass nutrient requirements.

Now might be a good time to review some of the basics on how grasses utilize nutrients during this critical late winter/early spring season. It just might be that our older ideas of nutrient management were not so great and some rethinking is in order.

In decades past, most nutrients were applied at greater rates than are currently recommended, which means that, historically, nutrient use was not very efficient. Now we know a good deal more about seasonal nutrient use and this has allowed application rates to be lowered markedly. There may still be room for additional reductions.

Annual Growth Cycle of Turfgrass Roots

Cool-season turfgrasses exhibit a distinct bimodal pattern of root. During the heat of summer, root growth is very slow, often nonexistent. As the temperatures cool during September, root growth resumes, mostly from basal crowns and nodes on rhizomes or stolons. This fall flush of root growth gradually increases until cold soil temperatures slow it again. However, even during the heart of winter, root growth continues as long as the root zone is not actually frozen.

In areas where a substantial snow pack is retained throughout the winter, the soil is rarely frozen to any depth and root growth continues, if slowly, all winter. In southern New England, we have observed greater translocation of photosynthetic products to roots during mild days in winter than at any other time of the year.

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As the soil warms slightly during early spring, light levels increase and more photosynthesis occurs, providing a strong surge of root growth. This continues through the time when temperatures increase enough to stimulate shoot growth, about April or early May, depending on latitude and seasonal variation. Spring root growth continues until June when soil temperatures increase to levels that become inhibitory. Beard (1966) found temperature to be the single most important environmental factor controlling root growth and their physiological condition in cool-season grasses.

Warm-season turfgrasses exhibit a very different root growth cycle. Unlike cool-season grasses, where root growth is inhibited by temperature increases that stimulate shoot growth, warm-season grasses exhibit greatest root growth when shoot growth is also maximal. This means roots grow very slowly, if at all during late fall, winter and early spring, but resume growth at about the same time that shoot green-up occurs. Root growth increases as tempera-

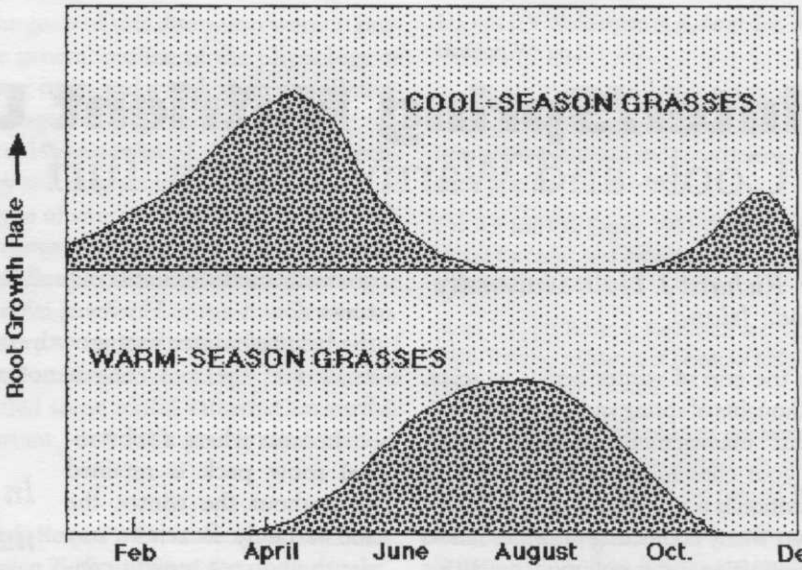

Figure 1. The annual root growth pattern of cool-season and warm-season turfgrasses.

ture and light increases, reaching a peak during mid- to late-summer. As temperatures decline during the fall, root growth slows and, following the first frost, all but stops. Thus, while cool-season grasses experience a marked mid-summer decline in root growth that recovers during the cold seasons, warm-season grasses grow roots primarily during the warm seasons when shoot growth also is greatest.

Resource allocation in cool- and warm-season turf

The integration of root growth and shoot growth activities is different between cool-season and warm-season grasses.

Because root growth in cool-season grasses is stimulated by lower temperatures than the temperatures that promote rapid shoot growth, there appears to be a seasonal division in resource allocation within the plant. When conditions are cold, all photosynthetic energy is diverted to root growth, while during the warm season, shoot growth is favored at the expense of roots. In warm-season grasses, there is sufficient photosynthetic energy to power both shoot and root growth simultaneously.

The reason for this difference is the draining effect of photorespiration on net photosynthesis in cool-season grasses during hot weather. Because mid-summer photosynthesis in cool-season grasses is not very efficient, there is normally not enough energy available to promote both shoot and root growth. During very hot weather, even shoot growth is seriously inhibited and cool-season grasses enter summer "dormancy." Because warm-season grasses lack photorespiration, their photosynthetic output increases with light and temperature, providing sufficient energy for both root and shoot growth.

Factors controlling nutrient uptake by roots

Root growth requires energy and carbon compounds — both of which are derived from sugars that are translocated to roots from leaf photosynthetic production. The energy is expended, generating electrochemical gradients across cell membranes that enable root cells to absorb nutrient ions from the dilute soil solution. This energy must be available for roots to function even if roots are not growing. Normally, root function takes priority over root growth when energy supplies are low but nutrient uptake still requires the expenditure of energy. If energy supplies are extremely low, roots will fail to absorb nutrients in amounts sufficient to support shoot growth and the plant begins to shut down or exhibit deficiency symptoms.

In cool-season grasses, roots have adequate energy to function and grow during times when soil temperatures are cool. The optimum temperature for root growth of Kentucky bluegrass is 10° to 15°F, which is considerably lower than the optimum for shoot growth. Consequently, roots will grow and function at near optimum rates when shoot growth is limited by suboptimum temperatures. Conversely, when shoots are experiencing optimum temperatures, root growth may be inhibited by temperatures that are supraoptimal for them.

However, there is a normal delay in soil warming, and roots frequently experience cooler temperatures than shoots during daylight hours. Because of this, field grown turf can, and often does, experience temperatures near optimal for both roots and shoots during spring and fall. Thus, temperature is the primary condition explaining the bimodal growth curve of roots in cool-season turfgrasses.

In warm-season grasses, the temperature effect is more direct and there is less difference in optimum temperatures for roots and shoots. Because shoots lose most of their photosynthetic tissues during the winter, both root and shoot regrowth in the spring depends upon energy (carbohydrates) stored in crown tissues and stolons from the previous summer and fall. This can present a problem for the grass if rapid spring warming stimulates growth of roots and shoots simultaneously.

The demand for energy may be greater than the rate that stored reserves can be mobilized and delivered to existing roots, and their rapid death may result. This spring root decline destroys over-wintering roots, so a new root system must be regenerated from grass crowns and stolon nodes. The result is a delay in green-up and resumption of shoot growth.

Nutrient availability

Nutrient availability in soils is also influenced by the seasonal cycle. Those nutrients which exist in soil primarily as organic residues and are not readily available in an ionic form, until they are released by microbial action, are most subject to seasonal availability. This primarily involves nitrogen and sulfur and, to a much lesser extent, phosphorus and iron. The availability of nutrients retained mostly on soil cation exchange sites (potassium, calcium and magnesium) is least affected by temperature.

Nitrogen is clearly the most important nutrient with respect to seasonal limitations on turf growth.

Nitrogen is clearly the most important nutrient with respect to seasonal limitations on turf growth. During the late summer and early fall, while the soil is warm, available nitrogen is released into the soil solution due to rapid microbial oxidation of organic matter. Because cool-season grasses lose most of their root system during the hot summer months, soluble nitrogen, mostly in the form of nitrate, accumulates within the soil solution to concentrations approaching 10 ppm nitrate-N. Warm-season grasses do not experience this summer root loss, so nitrogen is absorbed by roots just about as rapidly as it is mobilized from soil organic matter.

In cool-season grasses, roots regenerate during the fall into a soil enriched with available nitrate. Throughout the winter, this nitrate is gradually absorbed by the developing root system, although some may be leached from the root zone. The available nitrogen level declines until it reaches a very low concentration during April, just about the time when plant demand is greatest. Soils are still cold, so nitrogen mobilization by microbial action is slow and will not increase much for several weeks. It is for this reason that nitrogen deficiency symptoms are most often evident during the spring months. By late May and early June, soils have warmed enough that soluble nitrogen is being released from soil reserves and plant needs begin to be met.

Because warm-season grasses resume spring growth after soils have warmed substantially, this imbalance between plant needs and the rate of nitrogen release is much less dramatic. Consequently, spring nitrogen deficiencies are less likely to be obvious in warm-season turf, provided the soil contains sufficient organic matter through which microbial oxidation can release enough nitrogen to meet plant needs. In some sandy soils of southern regions, low soil organic reserves will not supply all the nitrogen required by a rapidly growing turf, and fertilizer nitrogen must be added if chlorotic turf is to be avoided. Other nutrients that are released to plant roots from decomposing soil organic matter show a similar pattern of availability but the impact of transient deficiencies is less dramatic on plant growth.

A late fall application of nitrogen will support winter and early spring root growth.

Nutrient management strategies to use

Based on the above discussion, we can consider how best to meet the nutrient needs of turf in the most efficient way possible.

Cool-season grasses: Nitrogen poses the greatest problem for cool-season grasses during the spring, when soil availability and plant growth rate are not well coordinated. Consequently, a modest nitrogen application during early spring will avoid deficiency conditions without excessively stimulating shoot growth. Once the soil warms, a mature turf will probably receive all the nitrogen it needs from microbial oxidation of soil organic matter.

A young turf or one growing on very sandy soils with limited organic matter will benefit from a light mid-June nitrogen application. Summer nitrogen applications are a waste, since soils are normally more than adequate and turf roots are declining, with limited capacity for nutrient uptake.

A light nitrogen application during early fall may be helpful in getting a root system to regenerate. Even though there may be adequate available nitrogen in the soil, emerging roots may not be able to reach it. A light application of a soluble nitrogen source at that time will give root regeneration a boost and promote fall recovery from summer injury. This may be especially important for athletic field turf.

Mid-fall fertilization is also not often helpful and may promote nitrate leaching. However, a late fall application of nitrogen, especially a mix of soluble and slow-release materials, will insure available nitrogen to support winter and early spring root growth. The quantity applied at this time need not be great. I personally question the wisdom of applying two-thirds of your total annual nitrogen allotment during late fall.

Phosphorous, however, is best applied during late fall. It will stimulate root growth and will have a chance to move into the root zone during the freeze-thaw cycles of winter. Phosphorous may not be needed at all in a mature turf that has been well fertilized for years. A similar case can be made for potassium, especially if clippings are normally retained on the turf. It is less likely to leach than nitrate and can also accumulate in medium texture soils.

Warm-season grasses: For warm-season grasses, nitrogen should be applied in small amounts, but as frequently as the turf needs it. A little nitrogen in the spring may get roots off to a good start but the grass demands may exceed soil supplies during the summer period of rapid growth. Consequently, several small applications should keep the grass going and well ahead of weeds and disease.

Fall nitrogen applications are of little value because the roots have or soon will decline and nutrient uptake will be limited. Nutrients such as phosphorus and potassium can be applied in the fall and will be well positioned in the soil during the following spring to meet turf needs.

In managing both cool- and warm-season grasses, calcium and magnesium are best applied in the fall or winter, so long as there is no snow cover. These nutrients do not move easily into the soil profile and will benefit from winter conditions to increase incorporation. Applying these elements just before aerification will also speed infiltration into the soil.

Conclusions

Fertilizing established turf is best when based on a sound knowledge of the annual cycle of turf needs and the availability of nutrients in the soil.

Cool- and warm-season turfgrasses differ in their root growth cycles and consequently require different strategies for applying nutrients.

The amount of fertilizer required by turf can often be reduced substantially if its application is properly coordinated with turf needs and soil nutrient availability.

No general suggestions should be taken without fully considering your situation and recognizing how it might differ from the so-called "typical" turf condition. In short, turf fertilization in the spring and at any time is largely a matter of common sense.

Dr. Richard J. Hull is professor of Plant Science and chairman of the Plant Sciences Department at the University of Rhode Island. His research has concentrated on nutrient use efficiency and photosynthate partitioning in turfgrasses and woody ornamental plants.

REFERENCES

Beard, J.B. and W.H. Daniel. 1966. Relationship of creeping bentgrass (Agrostis palustris Huds.) root growth to environmental factors in the field. Agron. Jour. 58:337-339.

Hull, R.J. 1992. Energy relations and carbohydrate partitioning in turfgrasses. In Turfgrass - Agronomy Monograph No. 32, eds. D.V. Waddington et al. ASA-CSSA-SSSA, Madison, WI. p. 175-205

Hull, R.J. 1997. Phosphorus usage by turfgrasses. TurfGrass Trends 6(5):1-12

Sifers, S.J., J.B. Beard and J.M. DiPaola. 1985. Spring root decline (SRD):: discovery, description and causes. In Proc. 5th International Turfgrass Research Conference, Avignon, France. 1-5 July., ed. F. Lemaire. Int. Turfgrass Soc. & Inst. Natl. de la Recherche Agron., Paris. p. 777-778.

Turgeon, A.J. 1999. Turfgrass Management, 5th Edition. Prentice Hall, Inc., Upper Saddle River, NJ. 392 p.

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