The Physiology of Low Temperature Stress (Winter Injuries!)

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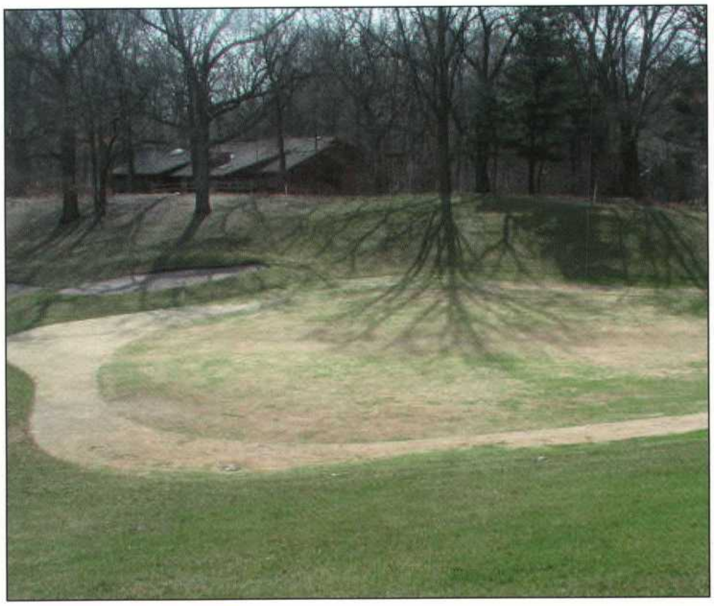
Low temperature stresses are not solely the problem of freezing, snow-laden climates. Low temperature stresses greatly affect the southern climes as well, particularly at transition zones and elevated areas. However, the physiology or mechanisms of low temperature stesses are very different between cool and warm season grasses. The actual mechanisms of low temperature injuries and low temperature stress resistance are quite complex but if I had to use one word to encapsulate the entire picture.....it would be "carbohydrates." The natural fluctuations (and unnatural fluctuations caused by turf managers) of simple and complex carbohydrates directly reflects the level of low temperature resistance and possible damage. In my past incarnation as a turf professor, I would classify turf managers as "carbohydrate managers". This pertains not only to low temperature stresses but to most all environmental stresses including high temperature, drought, salinity and light (shade) stresses. In fact, it could very easily be shown that these stresses directly affect carbohydrate/sugar levels which then can directly affect the water status of the plant. Unnatural or wide fluctuations in carbohydrate levels can substantially contribute to drought stress or the movement of water from healthy, living cells which then result in drought injuries. Low and high temperature and salinity stresses are, in great part, drought stress induced injuries!



In this series of articles, I will cover, in detail, what low temperature stress injuries are, how they are induced, what determines the extent of injury and how turfgrasses deal with low temperature stresses. I will also talk about the cultural practices associated with reducing injuries as well as how turfgrasses deal with low temperatures stress naturally....through resistance mechanisms that you can enhance.

Before launching into the subject, we need to define a few things. Those of you that were my former students, this will be a good refresher! First, let's define environmental stress resistance. The term "resistance" is the primary term all of us should use when talking about the ability of a turfgrass to naturally deal with temperature, drought, salinity, light or other environmental stresses.

Resistance can include one or more of the following:

Tolerance: Physiological mechanisms a plant uses to deal with the stress once it enters into the tissues. What I mean here is simple. If the stress gets into the plant....i.e. salt taken up into tissues, low or high temperature changes inside the plant, water deficits in the tissues, the plant must have "internal" mechanisms to deal with the intrusion and minimize injury. In other words, the stress becomes internal but the plant can "tolerate" the intrusion by various physiological/biochemical mechanisms induced by the stress.

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Avoidance: The ability of a plant to actually keep the stress outside the tissues and not let it enter the inside of the plant. A classic example of this would be the ability of certain plants to limit or even exclude the uptake of sodium thereby "avoiding" sodium toxicity stress. When we talk about low or even high temperature stresses in turfgrasses, we do not include avoidance since internal temperatures closely reflect ambient temperatures.

Escape: A term used to define those plants which can employ mechanisms to actually completely escape the stress. Not to be confused with avoidance. Escape is the predominant mode of resistance in annual plants (such as Poa annua) that are prolific seed producers which, if severely injured or even killed by the stress, the dormant seed simply waits until good conditions prevail again to germinate. This is also true of those plants that can be induced into dormancy by such stresses as drought and high temperature. Drought induced dormancy of cool season or even warm season turfs is a mechanism of escape. Stems (rhizomes/stolons/tillers) remain living while foliage and roots are killed. When wetter and/or cooler conditions return, the stems vegetatively produce another root system as well as foliage. Carbohydrates are absolutely necessary for this to occur. If there is a limited amount of carbohydrate in the stem tissues, then dormant plants will have a very hard time "coming back" and regrowing. Extensive dead areas due to drought stresses are a direct reflection of the amount of carbohydrate that was stored in stems prior to the drought stress.

So, in a nutshell, resistance is defined by either tolerance, avoidance or escape or any combination of the three. This may seem like a minor thing to understand, but if you are to fully understand each stress and ways to cope with environmental stresses, you need to understand these distinctions.

What I intend to do is make this a series of "short" papers which will cover the following:

1. Defining low temperature stresses
2. Discussing the associated injuries: intensity, duration and extent.
3. Natural resistance mechanisms.
4. Culturally induced resistance.
5. New technology

Low Temperature Stress: Part II

We need to get a handle on how carbohydrates naturally fluctuate in turfgrasses to fully understand and get an appreciation of how they greatly affect whether a turf undergoes low temperature stress and, if so, the extent of injury. Understanding carbohydrate fluctuations is also very important as related to virtually all other environmental and even biotic stresses. For those of you that have higher degrees and understand these principles -- have patience. There will be many parts/articles to this subject.

Carbohydrates are a major biochemical group in all living systems. As a group, they can be very simple (such as glucose, sucrose and other simple soluble sugars) or very complex such as the turf storage

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carbohydrates starch and fructosans which are very, very large, insoluble molecules. To take it even further, cell wall material is primarily cellulose...which is a very large and much more complex carbohydrate compared to the storage forms. You get the point, it's a large group. We will be only focusing on simple, soluble sugars and the storage forms of starch and fructosan.

Simple sugars are water soluble for the most part. Easy example is sucrose (table sugar). Another example is glucose, the most important sugar in most biological systems, the first product of photosynthesis (and the stuff they pump into your veins when you are at the hospital to give you more energy). Notice that they both end in the suffix "ose." In fact, all simple soluble sugars end in "ose." Easy to identify. Glucose, fructose, sucrose, maltose, dextrose, lactose, xylose, arabinose, they are a large group but we are only interested in glucose, fructose and sucrose since they are the "saccharides" that commonly accumulate to significant levels in plants. Simple, one molecule sugars are called monosaccharides such as glucose, fructose and lactose. A common "disaccharide" is sucrose which is composed of a glucose and fructose molecule bonded together. Sugars having more than a few simple saccharides are called "polysaccharides" and if they get complex they no longer have the saccharide label such as starch, fructosan, cellulose, hemicellulose etc.

A simple analogy is to think of carbohydrates like "chains". Two links are disaccharides, a few links are polysaccharides, long - multi-branched chains are complex carbohydrates (storage carbohydrates) such as starch and fructosan. In fact, the storage carbohydrates have many, many thousands of "links". Each "link" is a simple glucose or fructose molecule. It is critical to understand this since the first product of photosynthesis....glucose is not only the plant's primary energy source, but also a material building block to make all other complex biomolecules....such as starch. All plants must have large amounts of glucose to grow and maintain healthy physiology. A plant can, and does, store glucose for later use by making large chains of it called starch or fructosan. These "storage" forms

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accumulate in tissues during times when photosynthesis is at its greatest rate and glucose is being "overproduced" beyond what the fast-growing plant needs. In fact, during these high growth periods, so much glucose is being produced that if it were allowed to stay in the glucose form, it would get to be toxic and act like a salt in the tissues. That's why overproduction of glucose is immediately shunted into making very large starch or fructosan molecules which can be accumulated safely and not have a "salt" effect.

When is the rate of photosynthesis and glucose production at its greatest? For cool season turfs it is in the spring and fall months when temperatures average around 65-70F. For warm season grasses it is in the middle of the summer when high temperatures ranging from 90-100F prevail. These are the periods when turfgrasses have the capacity to store large amount of glucose as starch and/or fructosan for later use when photosynthesis and production of glucose is low like in the summer months for cool season grasses and the winter months for warm season grasses. This is a critical point to understand. When environmental conditions do not favor photosynthesis, the plant cannot produce enough glucose to maintain growth and good physiological health and is prone to environmental stress and biotic stress injuries. If, however, the plant has "stored" vast amounts of glucose as starch, then it will have a "reserve" to draw on during these stressful periods. The starch or fructosan will be broken down back into glucose for the plant to use since photosynthesis cannot supply enough.

These periods of high photosynthesis and low photosynthesis along with high and low levels of glucose production are natural and occur each and every year. You can imagine that if the plant is inhibited in some way during the spring from producing large amounts of storage carbohydrate (starch), then it will literally be "starving" come the summer months (winter months for warm season grasses). Just as importantly, if the turf does not accumulate enough storage carbohydrate in the fall months, it will not have enough glucose to maintain proper metabolism through the winter "dormant" months and be very prone to winter-low temperature stresses. Remember, dormancy is not death. All cells and tissues, particularly in stems, remain alive and etabolizing...albeit very, very slowly. The turf needs glucose throughout the winter months and photosynthesis is either very, very slow or not functioning under snow/ice covers.

It is very important to understand these basic principles.

Low Temperature Stress III: Freezing Stress

Now we know that cool season grasses naturally accumulate large amounts of storage carbohydrate during the early to mid-fall when the rate of photosynthesis is at its greatest and overproduction of glucose is normal. This reserve carbohydrate is not only used as a "food" source for dormant tissues, it also acts as an "anti-freeze" as well as ensuring that cells and tissues maintain a high level of hydration.....keeps water in cells and avoids dehydration. Remember that winter months are very, very dry with low relative humidities which can, and do, dehydrate turfs, particularly when there is no snow or artificial cover. How the reserve carbohydrates, starch and fructosan, do this is really very clever. As you remember, reserve carbohydrates are very large molecules and, as such, do not act like salts in the tissues as pure glucose would. This is a protective mechanism that the turf uses so it will not

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be "osmotically" stressed during the high period of photosynthesis, growth and glucose/starch accumulation. Now the interesting part...at the end of the fall season and beginning of winter when things are beginning to freeze and growth virtually stops, the turf begins to go dormant. Precisely at this time, the starch and fructosan that has been stored gets "hydrolyzed" or broken down by enzymes (alpha amylase) back into huge pools of free glucose within each living cell. Uh Oh you say...toxicity and osmotic stress! But no, at this time the plant's metabolism and growth slows to literally nothing and goes into a sort of "suspended animation.". Because of this, the high concentrations of glucose will not be toxic or osmotically stressful since normal growth/life functions have almost stopped. Each and every living cell in the plant at this time is only using glucose, very, very slowly for respiration to just maintain life. This will go on throughout the winter months. You can imagine, if the glucose runs out, the cells and tissues will virtually starve and start using other cellular components to maintain life, not good and results in large areas of winter/freezing injuries. Also, the large free pools of glucose in dormant tissues acts as a "salt" so to speak and protects or does not allow cellular water to move out and evaporate, thus maintaining the proper level of life-sustaining hydration (water levels). As the plants use up the glucose throughout the winter, the less "salty" the cellular fluid becomes and the tissues are much more prone to water losses in the late winter months. This would be particularly the case if you, as a manager, did all the wrong things and limited or inhibited the accumulation of carbohydrates in the fall. The reserve levels will not be enough to sustain the turf throughout the winter and will be prone to freezing injuries earlier in the winter...January, February instead of March and April.

The main point is....if the turf does not accumulate carbohydrates to a large degree in the fall you will certainly have a lot of winter stress injury and large areas of dead turf. The technical term for reserve carbohydrate accumulation is "hardening off." There are so many things that superintendents do that limit this process and they don't even know it. Remember, it is a natural physiological process that happens each and every fall for cool season grasses. You can either help it along or inhibit it depending upon your cultural activities and, most importantly, timing.

One more thing before I go: reserve carbohydrates accumulate only in stem tissue -- crowns, rhizomes and stolons. They do not accumulate in roots or leaves to any significant extent. Just thought you might want to know!

Low Temperature Stress IV: Freezing Injuries

Since we now know how and why carbohydrates are accumulated in the fall and their nutritional and protective functions, we can proceed on to the actual stresses. The first is freezing stress of which there are two kinds: 1) Indirect Freezing Stress and 2) Direct Freezing Stress. Indirect occurs every single year where freezing temperatures occur. It is a stress that is unavoidable and will happen no matter what you do and does not necessarily result in death of the plant. Indirect can, however, lead to Direct Freezing Stress/Injury. Direct freezing

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stress only occurs when things are really bad and will result in death of the plant. Both stresses involve ice crystal formation inside the plant.

Indirect freezing stress starts when ambient temperatures go below the freezing point. When this happens, it is not long before ice crystals will form inter-cellularly or in between cells (as opposed to direct freezing injuries which involve ice crystal formation inside the cells or intra-cellularly). Intercellular ice's crystals will remain as long as freezing temperatures exist. You cannot avoid it and it will not result in injuries so long as you have high levels of reserve carbohydrates and a moderate winter. The key points of this stress (as in many other environmental stresses) are "intensity" and "duration" or how hard and how long.

The turfgrass plant is literally filled with water...not pure water, but water that has salts, biochemicals and the like dissolved in it. Believe it or not, water in between cells has some dissolved salts and the like....but not very much. Conversely, water in the cells (or cytoplasm) has a lot, I repeat, a lot of stuff accumulated and dissolved. Intra-cellular water is very, very, "salty" so to speak and, as such, has very low "water potentials." Inter-cellular water (in between) is comparatively very "fresh" with much less dissolved materials and, as such, has a "high" water potential. What freezes first? Obviously, the less "salty" or more fresh water! The lower the water potential....the lower the temperature it takes to freeze and form ice crystals. If you do it right, your plants will harden-off with lots of reserve carbohydrates and glucose which, as I mentioned, act like salt in the cellular fluid. That decreases the water potential tremendously and intra-cellular fluid (inside cells) will not freeze until temperatures are well below zero. Therefore, reserve carbohydrates, among other things, protect the interior of the cells from freezing. The inter-cellular fluid (in between) will, however, freeze as soon as temperatures go below 32F since it is very dilute or much less "salty."

When ice crystals form intercellularly (indirect ice crystal formation), all the water in between cells freezes to form ice crystals while the interior of the cells remain fluid. The ice crystals themselves do not really injure the plant at all unless the plant is moved in some way and the ice crystals can then puncture the cells and kill them. Even when that happens....such as when people walk on your turf in the morning while frost is apparent, not much of the tissue will die, the plant will get through the injury with no problems you will just see footprints and some discoloration. The real problem with indirect freezing stress is that once ice crystals form in between cells, the intercellular space (space between the cells) becomes instantly dry.....very dry....as in very, very low humidity. When that happens, if you don't have enough reserve carbohydrates (i.e. the intracellular fluid is not as "salty" as it should be), water will move from high water potential to low water potential. Very dry intercellular space equates to extremely low water potential. If the water potential intercellularly is lower than intracellularly, then water will move freely from inside the cells to outside the cells and then freeze to form more ice crystals. As water leaves the inside of the cells, the remaining cellular fluid necessarily becomes more and more "salty" and lower in water potential until it equals

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the low water potential outside the cells in the intercellular spaces. Then water will from inside will remain and stop moving.

I am fully aware that the subject of water potentials is hard to grasp for most people, but I think you can see that precious water from inside cells can be drawn outside the cells and evaporate away if there is not enough reserve carbohydrate to make the cellular fluid "salty." The more reserve carbohydrate.....the less water loss and.....the less drought stress. Yes, drought stress. Remember, this occurs each and every winter. Injury will depend upon how much water is lost from the tissue which is a function of how much carbohydrate is accumulated in the tissues. As winter progresses, what do you think happens to the reserve carbohydrates? They are depleted because they are slowly used by the dormant....living, I repeat, living tissues that require a constant but low level of carbohydrate to survive throughout the winter. Do you see what happens now?? As winter progresses, there is naturally less reserve carbohydrate which, in turn, raises the water potential inside the cells and makes them less salty and much more prone to water loss and, heaven forbid, ice crystal formation inside the cells which will result in instant death -- Direct Freezing Stress!! When is the internal cellular fluid the most "fresh" or less salty? You got it! Toward the end of the winter in March/April when there still is a chance for a hard freeze after a thaw....really, really bad.

Direct freezing stress is much easier to grasp but remember this, indirect freezing stress can and will set the plant up for direct freezing stress and subsequent injuries.

Low Temperature Stress V: Direct Freezing Injury

We now know that reserve carbohydrates play a crucial role in indirect freezing stress by lowering internal cell water potentials (and hence, the freezing point) as well as providing energy/food for maintaining life during dormancy. We also know that reserve carbohydrates get used up during the course of the winter and, as such, late winter and early spring are the periods when turf has the least reserve carbohydrate and, as such, the least tolerance toward freezing stresses.....particularly direct freezing stress injuries which result in immediate death of the plant.

Remember, indirect freezing stress occurs every year during the entire winter/freezing months by freezing intercellular (in-between) water and forming ice crystals which result in "pulling" water out of the cells and inducing drought stress injury. The extent of this water loss depends upon how much carbohydrate (among other things) is stored in the tissues. The use of carbohydrate throughout the winter maintains life in dormancy and if carbohydrate levels are low to begin with, starvation, so to speak, will occur along with drought stress. Starvation, however, is not nearly as devastating as high water potentials inside cells (i.e. fresher water). The plant will start using proteins and other complex molecules for food which, in and of itself, is not good at all but before it gets to that point, direct freezing injuries and death will probably occur.

Direct freezing injuries occur when intra-cellular (inside) water/fluid freezes and instantly creates very sharp ice crystals which immediately tear apart the internal structure and organelles resulting in immediate death of the cells/ tissues/ plant. For this to occur, reserve carbohydrates need to be very low, typical of late winter and early spring (or typical of turf that is not properly hardened). Low carbohydrate levels equal "fresher" cell water which freezes much faster at higher temperatures (closer to 32F). Imagine the following scenario: It's late February or early March and carbohydrate levels are low because not enough was stored during hardening in the fall. We get a typical mid- to-late winter thaw that lasts several days which actually "hydrates" the plant tissue....in which a lot of water makes its way into the tissues. What happens to the water potential at this point? It rises dramatically since the cells are flush with new water which greatly dilutes any remaining carbohydrate. Then the worst happens, we get a deep freeze after several days of thaw....you don't realize it yet, but your turf is dead!! You will certainly notice it several weeks down the line when green-up is supposed to occur.

I think you can see that promoting a good and extensive hardening period in the fall greatly decreases the chances of direct freezing injuries from happening. That whole period when photosynthesis produces far more glucose than what is being used is the time to begin changes in management which enhance the rate of photosynthesis and overproduction of carbohydrate. The less reserve carbohydrate....the earlier the chances for direct freezing injury. I've greatly simplified what goes on here but I think the take home message is clear....do not do anything which inhibits hardening and do all that you can do to enhance it from late August to late November depending upon your location.

Ok, now the real meat. What should or shouldn't you do? There are a number of approaches, materials, applications and practices that should and should not be used during the hardening period. I will leave you with something you all know only too well. You need to increase the "leaf area index" or leaf area during the hardening period. Yes, I know, you can't raise mowing heights. You can decrease your mowing frequencies (accomplishes the same thing and also results in low handicapper complaints) and you can increase rolling frequencies (I never thought I'd be saying that!). Increasing the leaf area index is the single most important thing you can do. Sorry, but that is a fact. We will cover the multitude of other things you can do but, in a nutshell, the most effective is increasing mowing heights. I will also review all the current research on low temperature freezing stress (most of it emanating from our colleagues in Canada!) for you warm season people as well as the cool season group. I can assure you....low temperature research is very scant.

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Now think of freezing injuries and superimpose ice covers over your turf....cool, eh?

Low Temperature Stress VI: Ice Injuries

Without doubt, freezing stresses described in earlier articles are the most prevalent low temperature describedin earlier articles are the most prevalent low temperature stress/injury with ice covers coming in a close second and even the most primary concern in some regions of New England and Maritime Canada. Although ice cover stress seems to be pretty easy to get a handle on, there are a number of variables to take into consideration...such as turfgrass species and cultivar, soil type with regard to hydration levels and microbial activities, soil temperature, the duration and extent of sub-zero temperatures, amount of snow cover and numbers of thaw-freeze events. For the most part though, the number of days a turf is "under the ice" or encased in snow/ice will determine the extent of subsequent injuries at the end of winter. Every year is different and vigilance is the key word. Ice cover injuries can be extensive and devastating resulting in delayed openings and lost jobs. When you superimpose freezing stresses over ice covers you have the potential for a nightmarish spring. All of this happening while the turf is dormant, snow is falling and you are focusing most of your time on indoor equipment renovations or are on vacation.

Ice covers and encapsulation of turf with ice both result in the same stress: a lack of gas exchange. Dormant turf still needs oxygen for respiration and ice covers will literally stop diffusion of oxygen into the turf zone. Use of oxygen is, however, comparatively slow compared to the actively growing turf and in most cases there is enough oxygen under the ice for extended ice cover periods. However, since oxygen can get into the turf, any other gases formed under the ice cannot escape into the atmosphere and accumulate in the turf zone. Since dormant turf is still metabolizing it is slowly but constantly producing carbon dioxide as the waste product of respiration. What most of you probably didn't know is that the microbial population within the green profile is also dormant...but alive and metabolizing, using oxygen and giving off carbon dioxide. The slow and sure accumulation of carbon dioxide and depletion of oxygen results in an anaerobic turf zone. If that isn't bad enough, something else will most likely kill the turf before it gets anaerobic. That is the natural production of HCN (hydrogen cyanide) by the microbial population in the soil profile. You all know what cyanide is, don't you? In this case, it comes in gaseous form that can accumulate under ice and inhibit respiration if concentrations get big enough usually before the effects of oxygen depletion and carbon dioxide accumulation. Normally, during the growing season, the microbial populations produce surprisingly high levels of HCN which is immediately dispersed into the atmosphere causing no problems at all. The N of HCN is nitrogen -- fairy rings? Whatever the case, gaseous exchange is stopped and it is a matter of time before injuries occur. This will greatly depend upon species (bent vs. poa) and soil temperatures under the ice (which will affect microbial respiration). The colder the soil

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temperature under the ice....the less microbial respiration and subsequent production of HCN. Ice covers over partially thawed soil surfaces can be a big problem.

Ok, you all know that creeping bents are more tolerant than Poa with regard to ice cover stresses and injuries. You also know that alleviating the gaseous buildupby cracking or even removing the ice will greatly decrease the extent of injuries (mechanically or application of dark granular materials). However, removing ice covers in the middle of winter or at the tail end of winter I think is rather foolhardy. If you relieve the gas buildups, there is no reason to remove the ice. In fact, the ice acts as an insulating barrier which can prevent the dreaded late winter, early spring direct freezing stress. So long as the gas is exchanged, ice covers pose no problem. Once you adequately crack the ice to relieve the buildup, you are good to go for another month or two. This is particularly important when you don't have a snow cover for insulation and you are subject to high winds which can result in extensive dessication and death caused by drought along with freezing stresses. What about greens' covers? Good and bad and I will cover this practice in the next article.

As I mentioned before, research into low temperature stresses is scant. Most of the recent work has been done in Canada. The Prairie Turfgrass Research Centre at Olds College, Alberta published "Effects of Ice Cover on Annual Bluegrass and Creeping Bentgrass Putting Greens" in *Crop Science* in 2004. The research was to assess cold hardiness levels and injury of Poa and creeping bent under ice maintained for various periods of time under lab and field conditions. Both species were subjected to either snow-covered, ice covered or ice-encased treatments. Basically the laboratory results were:

Ice-encased Poa stored for 90 days were dead while ice covered and snow covered plants maintained cold hardiness levels.

After 150 days, ice-encased and snow-covered creeping bent retained cold hardiness levels of -18C and -27C respectively.

The field study included snow cover, ice cover and snow or ice removed at 45 days. Results were:

As expected and same as lab results, ice cover had less impact on creeper than Poa. At 90 days, creeper maintained cold hardiness levels of -29C while Poa was dead after 75 days.

Snow covered Poa still had cold-hardiness levels of -16C after 75 days.

Removing snow or ice after 45 days had little or not effect.

The Prairie Turfgrass Research Centre also published "Dehardening of Annual Bluegrass and Creeping Bentgrass during Late Winter and Early Spring" in *Agronomy Journal* in 2000. The results basically showed that maintaining a snow cover delayed the loss of cold hardiness by up to a week and a half and also delayed the devastating increase in crown hydration by a week. Plants were able to partially regain colder hardiness when soil temperatures dropped. Increase in soil temperature was the greatest contributor to the loss of hardiness in the spring....when you run the risk of direct freezing stress.

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What all this basically says is.....get rid of the Poa if you can. Velvet bentgrass anyone?

Low Temperature Stress VII: Cool and Warm Season Recommendations

This article will wrap up the series on low temperature stresses with culturalrecommendations, and a review of a new research report on green covers.

Once again our colleagues up in Quebec have published an on-line report in June of 2006 entitled: "Atmospheric Composition under Impermeable Winter Golf Green Protections" in *Crop Science*. The commercial covers tested included an impermeable cover on top of either curled wood shavings mat, 15 cm (about 4 inches) of straw mulch or a felt material, a clear polyethylene cover on top of a curled wood shavings mat and an unprotected control. The results basically said that anoxic conditions caused by high respiration rates lasted as long as 50 days out on actual green sites with no apparent damage to Poa annua. (These are most likely "biotypes" acclimated to lower temperatures; further south, less tolerant poa biotypes are most likely the norm). Further tests on problematic greens that experience recurrent damage from year to year had shown damage that could not be explained by freezing temperatures, ice, excess water or snow molds. It is very, very interesting that these problematic greens had much high "soil respiration" rates compared to non-problem greens. The problematic greens had much high soil biological activity while plant respiration was the same as non-problematic greens. They also correlated the higher levels of soil biological activity to higher levels of soil organic carbon. They concluded that greens profiles with high soil organic carbon levels and native soils were more likely to result in anaerobic conditions and subsequent damage. Sand-based greens with low organic C levels would experience much less biological activity under covers (and ice) resulting in less or no winter damage.

These results validate my reasoning for soil types and conditions playing a large, if not the most important part of ice cover damage. Obviously, impermeable covers act like ice in this report and there were no significant differences between material treatments. So.....what is the take-home message here? What should you be considering if you experience a lot of ice cover injury? Does this research mean that you should do everything you can to reduce organic carbon levels and soil microbial activities? Sure does sound like it. But that would definitely be the wrong thing to do.....wrong, wrong, wrong, wrong. Consider the following:

If, during the growing season, you have done all you could to enhance and increase soil microbial populations and activities, then you should not have an excess amount of soil organic carbon. The microbes should be breaking down and rapidly degrading all the organic material they come in contact with.....since you are doing all you can do to increase their populations....they remain hungry....very hungry. You get all the positive effects of high populations such as increased mineral nutrient recycling, much better physical soil conditions, less disease pressure and.......most importantly.....much less organic carbon buildup!! Consider the alternative...very low microbial activities and populations with the same organic carbon inputs from plant/root turnover. That would result in thatch as well as high levels of organic C in the profile. This in turn would set the stage for organic layering to begin resulting in very problematic

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greens with regard to oxygen prior to getting into the winter (amongst other horrible things). Thatch does not break down very rapidly since it is composed of lignin and has a high C/N ratio. If you add amendments to the soil that have high C/N ratios...you are effectively adding "thatch" or organic carbon that will remain in the profile and accumulate. Sawdust anyone? Considering all the above, it is my strong recommendation that you do all you can to enhance and increase your soil microbial populations and activities by adding low C/N organic fertilizer and amendments, keeping your turf thirsty and paying close attention to compaction. Remember the research that Dr. Bob Carrow from Georgia presented a couple of years ago? The results basically indicated that greens accumulating more than 3% organic matter were much more prone to layering and partial anaerobic conditions yada, yada, yada. High soil microbial activities will ensure that this does not happen. Well, enough said.

What to do overall for increasing low temperature stress tolerance? The goals are to increase the rate of photosynthesis and decrease the water potential in stem tissues during the fall months. Increasing the rate of photosynthesis greatly increases reserve carbohydrate levels. You guessed it....the impossible. Either increase your height of cut or decrease your mowing frequency or both. Couple that with increased rolling and you should decrease the number of complaints by high

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handicappers who leave you wallowing throughout the winter while they continue to play golf down south. Just a few thousands of an inch can make a huge, huge difference. Along with that, you should definitely reduce your irrigation levels/frequencies and keep your turf as thirsty as possible going into the winter to maintain a much low hydration level. Certainly reduce...as much as you can... inputs of soluble, inorganic nitrogen approaching dormancy. If you are dormant feeding, make sure the turf is actually dormant and do not use a soluble source. IBDU should be considered or a low C/N organic. Does foliar iron help? I think it does since the level of chlorophyll increases, making the plant more efficient in photosynthesis but, as you all know, I think that foliar iron is becoming very over-used and presents problems of it's own. How about potassium? Regardless of what you have heard, stick to very high inputs of potash going into dormancy. As much as you can. Remember "luxury consumption"? The more potassium salts that accumulate in the stem tissues prior to dormancy, the lower the water potential and freezing point. Potassium does more than that.

I know most all of you realize this but I have to say it. Applications of sugars or molasses foliarly will do nothing. I strongly repeat, nothing with regard to reserve carbohydrates. Plants do not absorb sugars. They were not meant to and not capable of it. They are "autotrophic," they make their own through photosynthesis. Do soil applications of molasses or sugars help? Only in the sense that you are increasing soil microbial activities (but pay attention that you don't over apply and cause nitrogen deficiencies).

Covers? Big topic. Lots of opinions and not nearly enough research. Lots of arguments. Lots of surprises....particularly if your goal is to open really, really early when the threat of surprise low temperatures and freezing can still occur. But you know all of that now. The end of winter and beginning of spring is the most critical 2-4 week period and when most, if not all, of your winter injuries occur. Covers naturally retain heat and make turf break dormancy earlier than normal. It becomes very hydrated once dormancy is broken. Reserve carbohydrates are literally non-existent. Even if you do replace your covers at the end of the day... a deep freeze, even for a few hours, can kill a lot of turf. Do covers protect your turf throughout the winter? In my opinion, that is a strong yes in areas of high wind and low snow cover. If you have typically deep and persistent snow cover...I would not consider them. Are permeable better than non? You bet. If I were going to use covers, they would be as permeable as possible. You still get the protection from winter dessication. How early should you consider removing your covers? That's a question only the odds-makers in Las Vegas can answer but I would be very cautious and make sure to put the covers back on when the possibility of freezing nighttime temperatures exist.

I would really like to know of your experiences with low temperature and ice problems and fixes. If you have the time, I very much would appreciate your input.

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