Survivability of Annual Bluegrass under Impermeable Winter Covers
The Glendale Study

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Introduction

Previous research conducted at the Prairie Turfgrass Research Centre (Olds, Alberta, Canada) showed that there was a rapid loss of relative hardiness of annual bluegrass plants between 45 and 60 days under continual ice cover (Tompkins, Ross and Moroz, 2004), while plants in non-iced conditions lost hardiness very slowly. The fact that air cannot be replenished under ice cover, or an impermeable covering of any sort, was thought to be a factor contributing to the injury. Research conducted in Quebec found that under an impermeable cover oxygen was depleted and carbon dioxide increased (Rochette et al, 2006). This increase was attributed to use by the plants and to low temperature microbes. When oxygen is completely depleted, the condition is known as anoxia.

In earlier research, Beard (1965) had similar results and found that injury to annual bluegrass occurred 75 days after continual ice cover. However, it seems that creeping bentgrass is affected much less and in our research was still alive after 120 days of continual ice cover. Other researchers found that differential sensitivity to conditions of anoxia was common amongst various plant species (Bertrand et al, 2001).

So what happens to annual bluegrass between 45 and 60 days when air cannot be replenished?

It seems that under conditions of anoxia a rapid depletion of stored foods occurs. We know that these stored foods act as an anti-freeze agent for plants so when they are completely depleted the plants have lost their ability to resist freezing. And, of course, once they freeze irreversible cell damage occurs and plants die.

At this point, we think that when oxygen is fully depleted rapid utilization of food reserves occurs, which in turn causes a rapid loss of hardiness (between 45 and 60 days). Once food reserves are depleted, the plant begins to utilize energy that is provided by a process called, glycolysis. However, the energy produced is not sufficient to sustain the plant. This deficit also leads to the induction of fermentation metabolism and to an increase in the production of potentially phytotoxic metabolites such as ethanol, lactic acid and carbon dioxide (Rochette et al, 2009).

So it appears that injury results from either a toxic build-up of these gases or from a complete depletion of food reserves. In the Quebec study, high levels of carbon dioxide did not produce mortality, so that may be an indication that the depletion of food reserves is the reason for the injury.

History of Winter Injury at The Glendale Golf and Country Club

The Glendale Golf and Country Club is a well established club in Edmonton, Alberta that has putting greens that are predominantly annual bluegrass. There has been a history of winter injury at The Glendale and many strategies have been tried over the years to effectively prevent the injury.

Prior to the winter of 2006-07 a system of covering was installed that had an impermeable white top cover over a 6mm insulating layer of closed cell foam. Covers were installed on unfrozen turf in late October just prior to a deep permanent snow cover. Injury in the spring was severe and was predominantly in the middle of greens. The injury was thought to be as a result of anoxic conditions that formed under the covers. Recovery time was lengthy.

The same covering system was installed in 2007-08, with one modification. In order to reduce the possible effects from anoxia, ventilation tubes were installed under the covers and the greens were ventilated on a regular basis by attaching leaf blowers to the tubes and circulating air under the covers. With respect to winter injury, one green had a small amount of damage while all other greens showed excellent winter survival.

The Need for Monitoring Conditions under the Covers
Superintendent, Darryl Asher, wanted to take the process a step further so that he might be able to determine critical levels of gas concentration under the covers and to determine the specific timing of ventilation events.

Objectives of the Glendale Study:

1. Develop a cover system that will prevent winter injury from desiccation, low temperature, anoxia and ice cover.
2. Develop a system to monitor temperature and gas concentrations under this cover system.
3. Determine relative hardiness of annual bluegrass plants in spring.
4. Determine organic matter levels on greens and compare with gas concentrations and relative hardiness.

Methodology
The greens at The Glendale Golf and Country Club were predominantly annual bluegrass with a small percentage of creeping bentgrass. The older greens were constructed with a high soil component that had been topdressed with sand for the last number of years creating a 75-100mm layer of sand at the surface. Five greens had been re-built with modified USGA specifications, and except for one green, were considered to be 'the best performers'.

In year one, a two layer covering system was installed with a white impermeable cover over a 6mm insulated closed-cell foam material (GreenJacket, Genoa, WI) on all but two greens. These greens used a 12mm bubble wrap material as the insulating material instead of the foam. Each bubble was approximately 25mm in diameter and was open on the bottom in order to provide air movement. In year two, bubble warp material was used on eight greens as the insulating material.

Prior to the installation of the covering system ventilation tubes and monitoring equipment was laid out on the putting green. Three collapsible vent tubes with 2.5cm holes punched every meter were installed on each green. These tubes were made of 6mil polyethylene and had a 15cm diameter when inflated. The collapsible vent tubes were attached to 10cm solid Big O drainage pipe which extended to the edge of the green. The solid pipe was connected to a leaf blower using a 4" straight connector. Three temperature meters (Johnson Controls A419) were installed per green and sensors (Johnson Controls A99BB-200C Silicon PTC Temperature Sensor) were placed in the front, middle and back of each green. The sensors sat on the surface of the turf, underneath the insulation and the cover. Carbon dioxide and oxygen were monitored using a Portable Multi-Gas Detector (RKI Instruments Inc. Model: Eagle 71-0028RK). A single sampling tube was laid out and extended to the middle of each green. Both temperature and gas concentration values were collected each week beginning in November and ending in April. Data collection was at a similar time of day each week.

Two of the eight greens with the bubble wrap insulation material, had a passive ventilation system installed where 60 cm (24”) roof turbines were installed on a wooden tower that was approximately 2 m (6’) tall. Two solid drainage pipes (10cm internal diameter) were attached to the tower and then extended under the cover for at least 1 m. At that point, the solid drain pipe was attached to perforated drain pipe that extended across the green. On the high side of the green, the drain pipe extended out beyond the cover and was attached to a snow fence t-post. The outlet end was covered in order to prevent snow accumulation inside the pipe. Two towers were installed per green which meant there were four individual drainage pipes spaced approximately 4-5m apart. In each year, the system was installed in early November.

In order to actively ventilate the greens, leaf blowers (model Stihl BR600) were attached to the solid drain pipe. Output of the blowers was 712cfm. The intent of the blowers was to inflate the covers and then let the gases exhaust through the solid drain pipe when the blowers were removed. However, over the course of winter, the snowpack became dense and ice formed, inhibiting the inflation of the covers.

Data was collected at the same time each week (10 AM Wednesday) for gas concentrations and turf surface temperatures. Those greens that had oxygen concentrations of concern were ventilated. In year one, following cover removal sample plugs were removed from each green and a freeze test was performed in order to determine relative hardiness levels.

In year two, multiple samples were collected from each of the greens in order to determine organic matter content and soil physical analysis. Cores that were 7.5cm deep were collected with a 1.8cm sampling tool. Organic matter was determined by weight loss on ignition (ASTM-F1647) while soil physical analysis was determined by sieve analysis of 300 grams of root zone material after organic matter had been removed by heating at 375^{o}C for two hours.

In addition to the above, weather data, including temperatures and precipitation, as well as winter survivability was assessed.

Results

Weather Conditions

In year one, permanent snow cover occurred on December 10 and all greens were completely clear by April 15, 2009. Maximum snow depth was approximately 40cm. Snow was not removed and was allowed to naturally melt. In year two, permanent snow cover occurred on December 4 and greens were clear by April 9. Maximum snow depth was about 50cm.

Survivability of annual bluegrass putting greens in spring

In both years of the study, survivability was excellent. Only one green in each of the two years had any damage and that was less than 5% damage (data not shown).

Temperatures under the covering system

In year one the coldest temperature was -7^{o}C under the covers, while in year two the coldest temperature was -8^{o}C. Temperatures under the cover were coldest when there was no snow cover. Temperatures were only monitored once per week and that was at 10 AM, so temperatures may have been colder at other times. The covering system provided sufficient insulation during this study.

In year one, temperatures under all covers were below freezing by November 26 and temperatures remained below freezing until April 1. All greens were frozen by November 25 in year two, and remained frozen until March 3. By March 31, green temperatures ranged from 1.3-5.0^{o}C in year two.

Gas concentrations between years

When comparing gas concentrations between years one and two, CO_2 was 3.8% in year one and 3.9% in year two so the winters were very similar and were not the reason for reported differences. When comparing the two years, O_2 levels were actually higher in year one than they were in year two, 14.0% versus 13.1%. This was in spite of three greens being treated differently. Green #2 had been re-built and had much higher oxygen, whereas, greens 7 and 16 had the passive ventilation system installed which increased oxygen contents.

Gas concentrations with and without snow cover

Generally, when there was no snow cover, gas concentrations under the covers were close to atmospheric conditions (21% O_2, 0.04% CO_2). However, as soon as permanent snow cover occurred O_2 concentrations decreased and CO_2 increased. Gas concentrations returned to near atmospheric conditions when snow melt occurred in the spring as evidenced by the March 31 rating in year two (Table 2). This would indicate that snow cover will seal the edges of the covers and that sufficient ventilation does not occur during periods of snow cover.

Gas concentrations as affected by insulating material

Carbon dioxide concentrations were slightly reduced when bubble wrap was used as an insulating material in comparison to the closed cell foam (Table 3). However, there was considerable variation from green to green.

Table 3 – Carbon dioxide levels for two covering systems with active ventilation.

Insulation Material	3rd green	9th green	15th green	Means
	——— % concentration ———			
Closed cell foam	5.0	5.1	5.8	5.3
Bubble wrap	4.8	5.4	5.0	5.1
Gas concentrations	+4%	+6%	-16%	-4%

Gas concentration differences between the two insulation materials were also minimal for O_2 (Table 4). Once again, there was considerable variation from green to green.

Table 4 – Oxygen levels for two covering systems with active ventilation.

Insulation Material	3rd green	9th green	15th green	Means
	——— % concentration ———			
Closed cell foam	11.9	11.5	11.2	11.5
Bubble wrap	12.1	9.7	11.9	11.2
Gas concentrations	+2%	-16%	+6%	-2.7%

These gas concentrations were measured over two years and over multiple rating dates, so it appears that there was no real difference between the two insulating materials. It was thought that the bubble wrap material would provide more air space between the turf and the cover, but this information would indicate that there was no difference between the two materials.

Gas concentrations as they relate to temperature

Temperatures above freezing appeared to have a greater impact on gas concentrations in comparison to temperatures below freezing. For instance, in year one when temperature rose from -1.2 to 0.1^oC, CO_2 rose from 4.4 to 5.0% (Table 1). In year two, a temperature of -0.6^oC had a CO_2 concentration of 4.8% and the next week, when temperatures rose to 0.8^oC, concentrations were 5.5%. For CO_2 these values showed an approximate 14% increase in a one week period when temperatures increased to above freezing.

Table 1 –Carbon dioxide levels in comparison to temperatures for various dates in March.

	Year	March 3	March 10	March 17	March 24	March 31
Carbon dioxide %	1	4.4	4.0	4.0	4.4	5.0
Temperature	1	-1.8	-3.2	-1.6	-1.2	0.1
Carbon dioxide %	2	4.4	4.8	5.5	5.3	0.8
Temperature	2	-0.9	-0.6	0.8	0.2	2.5

When temperature increased to above freezing, O_2 levels declined by 2% in year one and by 2.6% in year two (Table 2). This represented an 18% decline in year one and a 28% decline in year two. In year two, a temperature of 2.5^oC was recorded on the final rating date which would indicate that snow had melted. There was a corresponding 40% increase in O_2.

Table 2 – Oxygen levels in comparison to temperatures for various dates in March.

	Year	March 3	March 10	March 17	March 24	March 31
Oxygen %	1	12.8	14.5	14.5	13.4	11.4
Temperature	1	-1.8	-3.2	-1.6	-1.2	0.1
Oxygen %	2	12.3	12.0	9.4	12.5	17.4
Temperature	2	-0.9	-0.6	0.8	0.2	2.5

Gas concentrations as affected by passive ventilation

Two greens, #7 and #16, were tested because they were considered 'worst case' candidates. In year one, these greens had a covering system installed that consisted of a closed cell foam insulation layer under an impermeable cover. These two greens were actively ventilated with leaf blowers on a weekly basis. In year two, a passive ventilation system was installed on the same two greens which used a bubble wrap insulation layer under the impermeable cover. In early winter of year two, these greens were actively ventilated on a monthly basis, and then were not actively ventilated for the last two months.

The passive ventilation system that was installed was considerably more effective than was the active ventilation system. For CO_2 there was a reduction of 32% when the passive ventilation system was compared with the active ventilation system (Table 6). When comparing gas concentrations between years one and two, CO_2 was 3.8% in year one and 3.9% in year two so the winters were very similar and were not the reason for the difference.

Table 6 – Carbon dioxide levels for two covering systems with passive ventilation.

Insulation Material	7th green	16th green	Means
	% concentration		
Closed cell foam	5.2	5.5	5.3
Bubble wrap with passive ventilation	4.0	4.1	4.0
Gas concentration changes	-30%	-34%	-32%

There was an overall increase in O_2 levels of 19% when comparing active versus passive ventilation (Table 7). When comparing the two years, O_2 levels were actually higher in year one than they were in year two, 14.0% versus 13.1%. This would indicate that actual improvement was even greater with the passive ventilation system.

Table 7 – Oxygen levels for two covering systems with passive ventilation.

Insulation Material	7th green	16th green	Means
	%		
Closed cell foam	11.9	11.0	11.5
Bubble wrap with passive ventilation	13.9	13.3	13.6
Gas concentrations	+17%	+21%	+19%

Gas concentrations as affected by active ventilation

In order to actively ventilate the greens, leaf blowers were attached to ventilation tubes and were run for approximately 10 minutes for each ventilation period. When blowing, the cover would inflate and would rise almost one meter. When the blowers were turned off, the covers would deflate back to their normal height. If there was considerable snow on the covers, they would not inflate.

The effect of active ventilation on gas concentrations appeared to be quite variable (Table 5). On one occasion gas concentrations were measured one hour after active ventilation. At that time CO_2 concentrations had decreased by 39%, while O_2 concentrations increased by 37%. On another occasion gas concentrations were measured 24 hours after ventilation and the O_2 levels only increased by 2.1%, while CO_2levels only decreased by about 9%. When gas concentrations were measure 48 hours after active ventilation, CO_2 levels decreased -2.5% while O_2 increased by 10%.

Table 5 – Gas concentrations changes at various periods following active ventilation.

Gas measured	One hour	24 hours	48 hours	Twice per week
	% concentration			
Carbon dioxide	-39	-2.5	-9	+7
Oxygen	+37	+10	+2	+16

It was thought that there would be a greater effect from active ventilation. The fact that there was no way to exhaust the gases may have reduced the effectiveness of active ventilation. Future tests will incorporate an exhaust port to determine if greater changes in gas concentrations can be achieved.

Gas concentrations as affected by organic matter

For this trial, organic matter was determined by weight loss on ignition. Samples were heated to 375°C for two hours which burned off the organic matter. Samples were weighed before and after to determine % organic matter.

Organic matter contents were determined each year on each green. The data listed in Table 8 indicates that gas concentrations of both O_2 and CO_2 were similar when organic matter was below 3.3%. However, as soon as organic matter was higher than 3.3%, the increase in CO_2 was 25% and the decrease in O_2 was 13%.

There was a difference in organic matter between year one and two. It is not known whether there was an actual difference, whether there was a difference in sampling, or whether there was an error in the organic matter determination. Another year of study should answer the question.

Table 8 - Gas Concentrations for various organic matter levels.

Gases measured	< 2.8% O.M.	< 3.1% O.M.	< 3.3% O.M.	> 3.3% O.M.
	% concentration			
Carbon Dioxide	3.7	3.7	3.6	4.5
Oxygen	13.5	13.9	13.8	12.2

Gas concentrations as affected by soil physical analysis

A soil physical analysis was conducted on all greens and, surprisingly, all met USGA green construction specifications. The majority of the greens were originally constructed with soil and then topdressed with 100% sand for a number of years. Sampling to 7.5 cm revealed that the sand layer was at least that thick. This would indicate that soil physical analysis was not the reason for gas concentration differences.

Discussion

During the two years of this study, the lowest temperature recorded under the covering system was -8°C, while the coldest air temperature was -13°C. These temperatures were recorded at 10 AM and would not have been the coldest temperatures. Therefore, stating that this cover system would provide enough protection from cold temperatures to prevent injury is not appropriate, in spite of the fact that there was minimal injury over the two years. However, a comparison might be made with information from the Olds Golf Course where a similar covering system was installed. On one occasion (December 7) when air temperature was -35°C without snow cover, the temperature under the cover was -9.3°C. The top cover was the same as used in the Glendale study, however, the insulating layer of bubble wrap was slightly thicker, 12mm versus 18mm. This covering system provided sufficient insulation to prevent injury from cold temperatures. Critical temperatures for survival depend on the quantity of food reserves stored by the plants. In early winter food reserves are greater than they are in the spring, so a covering system that prevents injury in early winter may not prevent injury in late winter due to reduced food reserves.

Temperature effects on gas concentrations showed that above freezing temperatures produced greater fluctuations in gas concentrations than did temperatures below freezing. This means that decreases in O_2 and increases in CO_2 occurred more rapidly at temperatures above freezing than at temperatures below freezing. In a previous study conducted at the PTRC, it was found that there was a greater fluctuation in gas concentrations when temperatures rose from -2^{o}C to 0^{o}C. Other research (Rochette et al, 2006) showed that at temperatures of -2^{o}C that little change in gas concentrations occurred. Keeping plants frozen would result in minimal fluctuations in gas concentrations.

Rochette's study also discussed the relationship between greens that were recurrently damaged and organic matter. That research found that lower organic matter content in putting greens resulted in little gas concentration change. Our research found a similar relationship and actually pinpointed a number of 3.3% organic matter that appeared to be the critical point. However, the reliability of this number is questioned as there was a difference in organic matter between year one and year two. This may have been a result of differences in sampling techniques, or it may have been a difference in organic matter testing procedures that were different between years. The results do point out that there appears to be an organic matter content threshold below which gas fluctuations are minimal.

This study showed that gas concentration fluctuations are cumulative and would be more of a concern toward the end of winter than at the beginning. Between the years, CO_2 levels were similar but in year two O_2 concentrations were less despite that fact that three greens were considerably higher. Green #2 had been re-built and organic matter was low, while higher O_2 concentrations on greens #7 and #16 were attributable to the change in the ventilation system.

Gas concentrations changed only when snow cover was present on top of the covering system. It appeared that snow would seal the edges of covers and prevent a free exchange of gases to the atmosphere. In early winter prior to snow cover and following snow melt in the spring, gas concentrations were very similar to atmospheric conditions.

Physical analysis of samples of the growth media showed all greens met USGA specifications and were very similar in their sieve analysis. It would appear that topdressing with sand for a number of years altered the physical analysis and produced a green that met USGA specs when sampled to a 7.5cm (3”) depth. As there were no differences between greens, we could conclude that gas concentration fluctuations were not as a result of fine textured soils present in the top 7.5cm of growth media.

Passive versus active ventilation was compared in this study. Passive ventilation relied on the premise that gradual continual circulation would be effective in maintaining gas concentrations close to atmospheric conditions. Also, the fact that gases move from areas of high concentration to low concentration would also create some circulation. Active ventilation, on the other hand, was developed with the thought that by forcing air under the covers and then allowing the gases to be expelled, that gas concentrations would be restored to near atmospheric conditions. From the data, it would appear that passive ventilation was effective and active was not. However, the question remains for passive ventilation, ‘will this system be effective when gas concentrations are rapidly changing or when conditions are calm?’ With regards to the active ventilation ‘if there was an exhaust port, could the gases better be exchanged?’ There can be no dispute that passive ventilation saves manpower in comparison to active ventilation.

When this study was undertaken the reliability of the monitoring system was unknown. It was found that the monitoring system effectively quantified temperatures and gas concentrations and had the potential to establish critical thresholds when damage will occur. This would be a great benefit to the superintendent as a point could be established when intervention was necessary and it may also offer the potential to develop an alarm system. At less than $10,000 the monitoring system was cost effective in comparison to the repair of damages as a result of winter injury.