Evaluation of Ventilation Systems under Winter Covers on Annual Bluegrass Greens

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Summary

Winter damage to annual bluegrass (*Poa annua* L.) golf course putting greens often occurs in the cold climates of North America. The Glendale Golf and Country Club is a well established club in Edmonton, Alberta and has a history of winter injury on their putting greens that was caused by anoxia (a complete lack of oxygen). The objective of this study was to evaluate various ventilation systems under impermeable winter covers that would prevent gas concentration fluctuations that could result in injury due to anoxia. Three different ventilation systems were compared with a non-ventilated system and were installed in early November prior to permanent snow cover. Gas concentrations and temperature were monitored on a weekly basis throughout the winter. Once permanent snow cover occurred, gas concentrations began to fluctuate. Those greens that had the 'roof turbine vents' system had the least gas concentration fluctuations on each of the rating dates. The 'vent tube matrix' system also was also superior to those greens that had 'exhaust vents only' or 'no vents'. Although the survivability of the putting greens was excellent under all ventilation systems, it was expected that those greens that had the greatest fluctuation in gas concentrations would be the first to suffer damage from anoxic conditions.

Introduction

Winter damage to golf course putting greens can be caused by a number of different factors, but low temperature injury and injury related to ice covers are particular problems. Injury can be more serious if the predominant grass species is annual bluegrass (*Poa annua* L.), which typically infests older greens in the cold climates of the northern hemisphere .

Freezing injury occurs when cell contents within plants freeze causing damage to cell walls. Typically in the fall, plants accumulate food within the cells in the form of simple sugars, a process known as hardening. These accumulated foods serve to depress the point at which cell contents freeze, and the temperature at which cell contents freeze is dependent on the amount of food stored. When plants break dormancy in the spring following warm temperatures, they will rapidly utilize these stored foods and the plant's ability to resist freezing is reduced. At this time, temperatures just below freezing may be sufficient to cause damage particularly if plants are submersed in water.

Ice cover injury occurs as a result of either complete oxygen depletion (anoxia) or toxic gas build-up under the ice (Rochette et al, 2006). When ice forms as a result of a mid-inter thaw or rainfall event, it seals the surface and disrupt the normal flow of gases to and away from the plant. Although temperatures are cold and the turf is frozen, plants still require oxygen to utilize accumulated foods within the plant. In addition, microbes within the soil will utilize oxygen and, in turn, produce carbon dioxide and other gases, which can disrupt normal growth processes within the plants. Annual bluegrass is much more susceptible to ice cover injury than creeping bentgrass and can rapidly deteriorate after a short period of continual ice cover, particularly if the ice is dense in nature.

Previous research conducted at the Prairie Turfgrass Research Centre (PTRC, Olds, Alberta, Canada) showed that a rapid loss of relative hardiness of annual bluegrass plants began to occur somewhere between 45 and 60 days of continual ice cover (Tompkins, Ross and Moroz, 2004), while plants under non-iced conditions lost hardiness very slowly. The fact that air cannot be replenished under ice cover, or an impermeable cover of any sort, was thought to be a factor contributing to the injury.

It seems that once anoxia occurs, some plants increase their metabolic rate and a rapid depletion of stored food takes place. Once these stored foods are depleted the plant begins to utilize energy from other sources within the plant, a process called glycolysis. The energy that is derived from tis process is not sufficient to sustain the plant. This depletion 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).

This information indicates that factors that lead to injury are as a result of a complete depletion of food reserves or a toxic build-up of metabolites. The actual injury may occur from freezing injury, insufficient energy to maintain itself or toxic gas build-up. In the Quebec study, high levels of carbon dioxide did not produce mortality, which may indicate that the depletion of food reserves and insufficient energy are the reasons for the injury.

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).

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. Survivability was much improved, however, it was also felt that conditions were not as severe.

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 so that he might determine the specific timing of ventilation events. As a result of this, a study was initiated with the following objectives.

1. Develop a cover system that would prevent winter injury from desiccation, low temperature, and ice cover (anoxia).
2. Develop a system to monitor temperature and gas concentrations under this cover system.
3. Develop a system to continually ventilate air under the covers in order to prevent gas concentration fluctuations.

Methodology

The Glendale Study

This three year study was established in the fall of 2011 on predominantly annual bluegrass greens at The Glendale Golf and Country Club. Greens at this golf course are a mixture of new and old construction techniques. The older greens were originally 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, although only three of these were chosen for this trial. Two greens were excluded from this trial as they were newly constructed and, based on the previous year's data, did not have significant fluctuations in gas concentrations.

All greens were covered with a white impermeable synthetic cover that was laid over an insulating material. White was chosen as the colour of the covering material as it was most reflective and prevents large fluctuations in temperatures at the turf surface. The insulating material was a 12mm thick polyethylene bubble wrap type of material. Each bubble was approximately 25mm in diameter and was open on the bottom which provided an air space and the opportunity for air movement. Covers and the insulating materials were installed in early November.

Prior to the installation of the covering system, a supplementary ventilation system was laid out on each green in order to prevent injury from anoxia. This was one of the stipulations of the Club and it was agreed that the supplementary ventilation would only occur on those occasions when carbon dioxide levels were greater than 5%. The supplementary ventilation system consisted of three collapsible 6mil polyethylene vent tubes with 2.5cm holes punched every meter. The tubes were attached to 10cm solid flexible drainage pipes at the edge of the green just under the cover. The drainage pipe then extended out and was mounted on a snow fence t-post so that the ends would remain above the snow line. When supplement ventilation was necessary, the drainage pipe was connected to a leaf blower (model Stihl BR600 output 712 cfm). When started, the blowers would inflate the vent tubes and the gases would exhaust through the solid drain pipe when the blowers were turned off and removed.

In addition monitoring equipment was installed at this time to determine temperature and gas concentrations under the covers. One temperature meter (Johnson Controls A419) was installed per green and individual sensors (Johnson Controls A99BB-200C Silicon PTC Temperature Sensor) were placed in the front, middle and back on the turf surface under the insulating material. 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 at a similar time of day each week beginning in November and ending in April.

The sixteen greens were randomly assigned to each of four individual ventilation systems (treatments), so that the trial was replicated four times. The 'no vents' treatment was considered to be the standard treatment and did not have any additional venting. The next level of ventilation, 'exhaust vents only', had two solid drain pipes inserted under the cover on the opposite side away from the supplementary ventilation system. It was thought that these exhaust vents might provide some movement of gases from areas of high concentration to areas of low concentration. The third treatment, referred to as 'roof turbine vents' 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 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 opposite side of the green, the perforated drain pipe was attached to a solid pipe that extended out beyond the cover and was attached to a snow fence t-post. Two towers were installed per green which meant there were four individual drainage pipes spaced approximately 4-5m apart. The fourth treatment, call the vent tube matrix', consisted of a series of tubing under the insulation material that was expected to provide more inlets/outlets from which gas exchange could occur. Six solid drainage pipes were connected to perforated pipe that were interconnected under the covering system.

Results

Weather Conditions – Edmonton Area

Snow cover was much below normal for the winter of 2011-12. The first appreciable snow fall was November 17, but warm temperatures at the end of November and through December reduced the snow cover to almost nil. The next appreciable snowfall was the end of February and it was retained until the end of March. Generally, the winter was very mild with only a short period (5-6 days) of cold temperatures in mid-January. Temperatures at that time dropped to the mid -30's with little to no snow cover.

Overview of Winter Injury in Alberta 2011-12

Winter injury was severe in Alberta in the spring of 2012. Typically, the factors that increase winter injury are:

- Low plant hardiness levels due to insufficient duration of exposure to hardening temperatures
- Prolonged ice cover that produces conditions of anoxia (complete lack of oxygen)
- Temperatures that are sufficiently high to cause a loss of hardiness. These temperatures most often occur in the spring, but may also occur during a mid-winter thaw.
- Temperatures that are below the plants relative hardiness. When fully hardened annual bluegrass will withstand temperatures of -20^{o}C, while creeping bentgrass will withstand temperatures of -40^{o}C.

Two of the four factors that create injury occurred during the winter of 2011-12. The weather conditions in the fall allowed plants sufficient time to harden and reach full hardiness levels. However, warm temperatures in late November/early December caused snow to melt and produce an ice cover at many locations. In addition, the cold temperatures in mid-January were sufficiently low to cause freezing injury within plant cells. Many locations had little or no snow cover and this type of injury occurred at many golf courses.

Another observation from this past winter that may have caused injury to greens was ice formation under impermeable covers. Previously, a number of golf course superintendents had observed a heavy frost that developed between the bubbles of the insulation layer. Water vapour, which developed as a result of plant respiration and excessive soil moisture, condensed and formed frost. Some thought that the frost may have melted, flowed to low areas, and turned to ice. The other possible explanation was that water flowed from the edges or leaked through small holes in the covers. In either case, injury from anoxia resulted. Ensuring that covers are completely impermeable, particularly over low areas where water may collect, is critical.

Recovery from winter injury was a major budgetary expenditure for many golf courses. There were a number which sodded multiple greens to assist in the recovery. Other golf courses were very slow to recover due to cool temperatures in May and June, the time when annual bluegrass usually germinates. Golf courses in the Edmonton area overseeded greens as many as six times with creeping bentgrass and still only had partial recovery. One observation was that annual bluegrass, which usually germinates around the time of the flowering of Potentilla, was 3-4 weeks late this year.

A Note about Statistical Differences

The data listed in the tables below was compiled by first conducting an Analysis of Variance (ANOVA) test. In this test, individual values were collected from each of the treatments (in this case four different ventilation systems) and from each of the four replications. These values were entered into a computer program and average (mean) values were then computed. The variation in the means was then assessed in order to determine if there were actual statistical differences between the treatments or if the differences were due to chance. When values were statistically different, least significant difference (LSD) values were presented at the bottom of each table. In this study, these LSD values were calculated at the 5% (0.05) level of significance, where there was only a 5% likelihood that the results were due to chance. When differences were greater than the LSD value, there was a 95% probability that there were actual differences between the treatments. Therefore, within a column, if numbers were followed by a different letter, there was a statistical difference between treatments.

Effects of Various Ventilation Systems on Carbon Dioxide Concentrations under Winter Covers

Once permanent snow cover occurred on November 17, CO_2 levels consistently began to increase (Table 1). Those greens that had 'exhaust vents only' installed had the highest level of CO_2 on each of the ratings dates when there were statistical differences. The greens that had no ventilation had the highest or were considered to be equal to the highest levels of CO_2 on 10 of the 16 rating periods. On the other hand, the greens that had the 'roof turbine vents' system had the lowest levels of CO_2 on each of the rating dates. The 'vent tube matrix' system also had lower levels of CO_2 on 13 of 16 rating periods in comparison to those greens that had exhaust vents only.

Table 1 – Carbon dioxide concentrations under winter covers with various ventilation systems.

Treatment	Nov 7	Nov 14	Nov 21	Nov 28	Dec 7	Dec 14
	% CO_2					
No vents	0.60bc	2.40a	1.82a	3.17ab	2.40b	3.32ab
Exhaust vents only	1.37a	1.85a	2.32a	4.10a	4.12a	4.30a
Roof turbine vents	0.42c	1.27a	1.15a	1.70c	1.57b	1.67c
Vent tube matrix	0.75b	1.20a	1.17a	2.30bc	2.30b	2.65bc
$LSD_{0.05}$=	0.26	n/s	n/s	1.33	1.65	1.45

Treatment	Dec 22	Dec 28	Jan 3	Jan 9	Jan 16	Jan 21

	% CO_2					
No vents	3.45ab	3.75b	3.57ab	3.90ab	2.85b	4.67a
Exhaust vents only	4.60a	4.85a	4.77a	4.90a	4.45a	4.95a
Roof turbine vents	1.97b	2.20d	1.92b	2.22c	1.25c	1.62a
Vent tube matrix	2.80b	3.07c	2.50b	3.10bc	2.30bc	2.62a
$LSD_{0.05}$=	1.66	0.33	1.70	1.40	1.52	n/s

Treatment	Jan 27	Feb 2	Feb 8	Feb 15	Feb 22	Feb 29
	% CO_2					
No vents	3.05ab	4.05ab	3.02bc	3.0ab	3.12bc	3.20b
Exhaust vents only	4.57a	5.42a	5.22a	4.87a	5.05a	5.47a
Roof turbine vents	1.62b	2.20b	1.67c	1.72b	1.65c	2.02b
Vent tube matrix	2.82ab	2.72b	3.27b	3.75ab	3.40ab	3.15b
$LSD_{0.05}$=	1.79	2.14	1.52	1.94	1.71	1.47

Treatment	Mar 8	Mar 14	Mar 19	Mar 26	Apr 2	Mean (Nov 17- Apr 2)
	% CO_2					
No vents	4.27ab	6.15ab	5.45a	7.90a	2.22a	3.57ab
Exhaust vents only	5.87a	7.05a	4.65a	3.07a	3.20a	4.50a
Roof turbine vents	1.92c	2.65c	3.77a	3.67a	1.82a	1.95c
Vent tube matrix	3.47bc	3.90bc	4.55a	5.27a	3.42a	2.90bc
$LSD_{0.05}$=	1.99	2.93	n/s	n/s	n/s	1.45

* Numeric values followed by the same letter are not considered significantly different.

Effects of Various Ventilation Systems on Oxygen Concentrations under Winter Covers

Opposite to CO_2 levels, O_2 began to decline as soon as snow covered the greens. The ventilation system that had the lowest O_2 level was the 'exhaust vents only' system. Those greens that had no ventilation had the lowest or equal to the lowest level of oxygen on eight of the 15 rating periods. The 'roof turbine vents' and the 'vent tube matrix' ventilation systems had the highest levels of O_2. When examining the mean values for the whole rating period, the 'roof turbine vents' system was better than the 'vent tube matrix', but the values were not statistically different.

Table 2 – Oxygen concentrations under winter covers with various ventilation systems.

Treatment	Nov 7	Nov 14	Nov 21	Nov 28	Dec 7	Dec 14
	% O_2					
No vents	19.95a	15.92b	18.15a	14.77bc	16.40ab	15.75a
Exhaust vents only	18.17c	17.15ab	16.45a	12.57c	13.10b	12.90b
Roof turbine vents	19.82ab	17.92a	18.70a	17.87a	18.52a	17.77a
Vent tube matrix	19.25b	17.92a	18.80a	17.02ab	17.05a	16.40a
$LSD_{0.05}$=	0.68	1.46	n/s	2.93	3.50	2.44

Treatment	Dec 22	Dec 28	Jan 3	Jan 9	Jan 16	Jan 21
	% O_2					
No vents	14.87a	14.42a	14.67ab	14.07ab	15.65bc	16.47a
Exhaust vents only	12.97a	12.22a	12.95b	12.47b	14.25c	12.80b
Roof turbine vents	17.15a	16.65a	17.02a	16.47a	19.32a	17.45a
Vent tube matrix	16.15a	15.25a	16.75a	15.47a	18.20ab	16.52a
$LSD_{0.05}$=	n/s	n/s	2.80	2.41	2.93	1.83

Treatment	Jan 27	Feb 2	Feb 8	Feb 15	Feb 22	Feb 29
	% O_2					
No vents	16.27ab	15.27ab	16.25a	16.07ab	15.17b	15.80a
Exhaust vents only	14.65b	13.37b	13.55b	14.00b	13.20b	12.37b
Roof turbine vents	18.37a	18.25a	18.67a	18.17a	17.80a	17.27a
Vent tube matrix	17.02ab	17.52a	16.57a	16.30ab	15.60ab	16.40a
$LSD_{0.05}$=	2.53	3.60	2.68	2.74	2.45	1.95

Treatment	Mar 8	Mar 14	Mar 19	Mar 26	Apr 2	Mean (Nov 17- Apr 2)
	% O_2					
No vents	14.40bc	11.42bc	13.92a	10.47a	16.6a	15.25ab
Exhaust vents only	12.02c	9.22c	12.80a	11.42a	12.87a	13.17b
Roof turbine vents	17.70a	16.65a	14.90a	14.27a	16.97a	17.50a
Vent tube matrix	15.62ab	14.90ab	12.92a	11.62a	16.00a	16.27a
$LSD_{0.05}$=	2.80	4.91	n/s	n/s	n/s	2.20

* Numeric values followed by the same letter are not considered significantly different.

Temperatures under the various ventilation systems

Temperatures under the various ventilation systems were very similar and average (mean) values ranged between -1.3 and -1.6^{o}C (data not shown). Although these values were not considered to be statistically different, the lowest value occurred under the 'roof turbine vents' system.

On January 16 air temperature was recorded to be -26^{o}C when cover temperatures and gas concentrations were collected. The lowest temperature recorded under the covers was -9^{o}C at the back of #9 green. As temperatures under the covers were only collected once per week in the morning, temperatures may have been colder at other times.

Survivability of annual bluegrass putting greens in spring

Survivability of the annual bluegrass and creeping bentgrass was excellent. As mentioned above, the coldest temperature recorded under any one of the greens was -9^{o}C during the cold period of mid-January. This would indicate that there was sufficient insulation from the bubble wrap type of material to prevent injury from cold temperatures. In addition, anoxic conditions were never recorded at any time during the winter period, even under the 'no vents' system. However, it should be pointed out that greens received supplementary ventilation when CO^2 levels were above 5%, which may have improved survivability.

In fact, the only greens that suffered any damage were as a result of mouse damage that occurred on a few greens and were along the side of each perforated drain pipe.

Gas concentrations with various ventilation systems
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 consistently decreased and CO_2 increased. As in previous years, gas concentrations returned to near atmospheric conditions when snow melt occurred in the spring. The individual data points are not shown.

Discussion
In this experiment, the 'exhaust vents only' system did not perform as well as the 'no vents' system on many of the individual rating dates. This seemed to contradict the premise that, as the number of ventilation inlets/outlets increase, the gas concentration fluctuations would decrease. In order to establish this trial the 16 greens used were randomly assigned to individual treatments. However, when previous non-replicated data was examined, the 'no vents' treatment had the lowest CO_2 values, which may explain this contradiction.

Results of this study showed how quickly CO_2 concentration can change in a relatively short period of time. When examining gas concentrations from one individual green, CO_2 concentrations went from 2.7 to 15.9% in 30 days, with a one week change of more than 5% (data not shown). This fluctuation occurred during the month of March as temperatures increased. However, this particular green did not appear to be any warmer than the others, so temperature was not the only factor. CO_2 is produced by plant respiration and/or microbial activity and previous research showed that organic matter played a role. As the density of CO_2 is greater than air, a buildup may occur in low spots. These two points may account for these rapid fluctuations.

Previous research has shown that CO_2 concentration of 15% did not kill plants by itself. However, when it was combined with conditions of complete anoxia (0% O_2) mortality readily occurred. This would indicate that oxygen is critical for survival, and that CO_2 is a contributing factor. Further information in this area will help superintendents make decisions about various interventions that may prevent damage to their valuable turf.

One of the four greens that had the roof turbine ventilation system installed had greater gas concentration fluctuations than the other three. The green in question sits in a low area and is surrounded by trees. Those who did the data collections observed that these turbines turned more slowly. This would indicate that a certain wind speed is necessary for the roof turbines to be effective. Other means of creating air flow through the piping system may be necessary in these areas. One superintendent installed a solar powered fan in the piping system to assist air movement. Although, there was no data kept he felt that it did assist in air flow through the pipe.

Results from this test showed that the 12mm bubble wrap provided sufficient insulation to prevent damage from cold temperatures. In this study, the lowest temperature recorded under the covering system was -9^{o}C, while the coldest air temperature reported at the Edmonton International Airport (47 km from Glendale) was -35^{o}C in mid-January. Similar results were observed in previous years and at other sites, which would indicate that this level of insulation was sufficient to prevent injury.