

## **Survivability of Annual Bluegrass under Impermeable Winter Covers**

### **The Glendale Study**

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#### **Summary**

The Glendale Golf and Country Club is a well established club in Edmonton, Alberta that has a history of winter injury on their annual bluegrass putting greens. The objective of this study was to develop a cover system that would prevent winter injury to the putting greens at Glendale. A secondary goal was to establish a monitoring system that would quantify temperature and gas concentrations under this cover system. This report is the third and final year of this study.

A passive ventilation system was compared with an active ventilation system on the putting greens in order to assess their effectiveness in preventing winter injury from anoxia. Covering systems were installed in early November prior to permanent snow cover. Gas concentrations and temperature were monitored on a weekly basis throughout the winter. In addition, organic matter and soil physical properties were assessed and compared with gas concentrations to determine if there was a relationship.

Duration of snow cover was approximately 120 days for year one and two of this study. In year three, snow cover duration was 150 days and snow depth was much greater than the two previous years. This depth of snow provided sufficient insulation during periods of extreme cold. On one occasion at a local golf course, an extremely cold day (-35°C) occurred in early winter prior to permanent snow cover. At that time, the insulation that was provided by the covering system was sufficient to prevent injury from cold temperatures.

Generally, as oxygen levels decreased carbon dioxide levels increased. This was attributable to activity of plants and microbes. These gas concentrations did not begin to change until there was snow on top of the winter covers. When comparing the three years, carbon dioxide concentrations were higher and oxygen was lower in year three of this study. This was attributed to the long duration and deeper snow cover.

The two insulating materials that were used, closed-cell foam and bubble wrap, had minimal effect on gas concentration changes. Temperatures that were above freezing produced greater gas concentration changes than did temperatures below freezing. When considering the two ventilation systems, the passive system was more effective than was the active system. In year two, it appeared that when organic matter reached a certain threshold that gas concentration fluctuations were more rapid. However, in year three there did not appear to be a relationship between organic matter and gas concentration fluctuations.

At Greywolf, there were greater fluctuations in gas concentrations early in the winter. It was thought that an early deep snow cover may have caused frozen greens to thaw from underneath. These warmer temperatures used more oxygen and produced more carbon dioxide. These early conditions did not have a negative impact on the survivability of the greens.

The monitoring system that was used effectively quantified temperatures and gas concentrations and could be used to establish critical thresholds as to when damage would occur. As damage never occurred we were not able to establish these critical thresholds.

## Introduction

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 somewhere between 45 and 60 days after 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.

Research conducted in Quebec found that under an impermeable winter cover oxygen was depleted and carbon dioxide increased (Rochette et al, 2006). These gas concentration changes were attributed to use by the plants and to low temperature microbes. As air cannot be replenished oxygen is completely depleted, a condition known as anoxia.

It seems that once anoxia occurs a rapid depletion of stored foods takes place and that this occurs somewhere between 45 and 60 days. We know that these stored foods act as an anti-freezing agent for plants so when they are completely depleted the plants have lost their ability to resist freezing. Once a plant freezes irreversible cell damage occurs and the plant dies. Additionally, 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).

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 occurs from freezing injury, insufficient energy to maintain itself or toxic build-up. 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 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.

### **Insert Glendale injury 3 04-07**

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 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. Determine organic matter levels on greens and compare with gas concentrations and relative hardness.

### **Methodology**

#### *The Glendale Study*

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 two greens used the same white impermeable cover over a 12mm bubble wrap as the insulating material. Each bubble was approximately 25mm in diameter and was open on the bottom which could provide space for air movement. In year two, bubble wrap material was used on eight greens as the insulating material. These included the same two greens as the previous year, four greens that had been insulated in the previous year with closed-cell foam (#3, #9, #15 and #17), and two that had a passive ventilation system installed (#7 and #16). Covers were installed in early November in each of the three years.

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 beyond the edge of the green. For ventilation purposes, 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.

In year two, 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. This system was installed in early November.

### **Insert Glendale piping whirly1 11-09**

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 turned off and removed. However, over the course of winter, the snowpack became dense and ice formed, preventing inflation of the covers.

### **Insert Glendale blower pipes 04-09**

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 both years, following cover removal sample plugs were removed from each green to test for organic matter levels. In year two, samples were also collected in order to conduct a 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°C for two hours.

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

### *The Greywolf Study*

A study was also initiated at the Greywolf Golf Resort in Panorama, British Columbia in the fall of 2010. Greywolf has had a history of winter injury from snow moulds, freezing injury and ice cover injury. An adequate fungicide program has reduced snow mould damage to an acceptable level i.e. less than 5% on the worst green. However, recent winters have had occurrences of rainfall events or mid-winter thaws which have caused ice cover injury in the spring. For this reason, Greywolf made a decision to cover greens to prevent winter injury.

Impermeable white covers were installed over a large bubble wrap insulation material on 11 greens in early November, 2010. Some of the greens were unfrozen when installation occurred. Covers were sealed on sloped areas to prevent water getting under the covers from the top side. Carbon dioxide and oxygen were monitored using a Portable Multi-Gas Detector (RKI Instruments Inc. Model: Eagle 71-0028RK), the same unit used to monitor gases in the Glendale study. Temperature probes were installed under the insulation material so that temperatures could be monitored throughout the winter. Ventilation with leaf blowers began December 15 and continued on each of the sampling dates.

### **Insert Glendale sniffer 1 11-08**

Data was collected on a weekly basis for the first month and then on a bi-monthly basis until March, when weekly data collections resumed.

## **Results**

### *Weather Conditions*

In year one, permanent snow cover occurred on December 10 and all greens were completely clear by April 15. Maximum snow depth was approximately 40cm. In year two, permanent snow cover occurred on December 4 and greens were clear by April 9. Maximum snow depth was about 50cm. In year three, permanent snow cover occurred on November 17 and greens were clear by April 23. Snow fall recorded at Edmonton International Airport Snow was 156.5cm during the period mentioned. In years one and two, snow was not removed and was allowed to melt naturally. In year three, snow was removed from selected areas in early spring.

Greywolf received a permanent snow cover on November 20 and snow melt was complete by May 1. Duration of snow cover was approximately 160 days and maximum snow depth was 105 cm. Some greens were frozen by November 9 and all greens were frozen by November 17.

#### **Insert Greywolf 12G digging pit 02-11**

##### *Survivability of annual bluegrass putting greens in spring*

In all three years of the study, survivability was excellent. Only one green in each of the three years had any damage and that was less than 5% damage (data not shown). These results show that the covering system was very effective.

Year three had a long duration and deep snow cover, two factors that contribute to increased winter injury. The only other factor that was missing in the 'perfect storm' scenario was that the heavy snow cover occurred on unfrozen greens. This did occur in the winter of 2006-07 at Glendale and created considerable winter injury. It seems that a heavy snow/ice cover that is maintained for a long period of time will seal the edges of the winter covers resulting in greater fluctuations in gas concentrations.

#### **Insert Glendale 2G 28-04-10**

#### **Insert Glendale cover effects 28-04-10**

##### *Temperatures under the covering system*

The coldest temperatures under the covers were  $-7^{\circ}\text{C}$ ,  $-8^{\circ}\text{C}$ , and  $-4.3^{\circ}\text{C}$  in years one, two and three respectively. Temperatures under the covers were coldest when there was no snow. The covering system provided sufficient insulation during this study. However, as temperatures under the covers were only monitored once per week at 10 AM, temperatures may have been colder at other times. 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  $1.3$ - $5.0^{\circ}\text{C}$  in year two. In year three, all greens were frozen on the first temperature collection date, November 17, and all were thawed by April 6, in spite of a snow cover that was maintained until April 23.

##### *Gas concentrations between years*

When comparing average gas concentrations over the three years,  $\text{CO}_2$  was 3.5% in year one, 3.9% in year two and 4.3% in year three. When comparing  $\text{O}_2$  levels, mean values were 14.8% in year one, 13.6% in year two and 12.8% in year three. This data showed that the long duration and deep snow cover in year three had a great effect on changes in gas concentrations under the covers.

##### *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%  $\text{O}_2$ , 0.04%  $\text{CO}_2$ ). However, as soon as permanent snow cover

occurred O<sub>2</sub> concentrations decreased and CO<sub>2</sub> 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 3).

*Gas concentrations as affected by insulating material*

In year one, closed-cell foam was used as the insulating material on greens #3, #9 and #15, while bubble wrap was used in year two. Carbon dioxide concentrations were slightly reduced when bubble wrap was used as an insulating material in comparison to the closed cell foam (Table 1). However, there was considerable variation from green to green.

Table 1 – Carbon dioxide levels under two covering systems with different insulating materials.

Insulation Material	3 <sup>rd</sup> green	9 <sup>th</sup> green	15 <sup>th</sup> green	Means
	————— % CO <sub>2</sub> —————			
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<sub>2</sub> (Table 2). Once again, there was considerable variation from green to green.

Table 2 – Oxygen levels under two covering systems with different insulating materials.

Insulation Material	3 <sup>rd</sup> green	9 <sup>th</sup> green	15 <sup>th</sup> green	Means
	————— % O <sub>2</sub> —————			
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 the two insulating materials had minimal effect on gas concentration changes. It was thought that the bubble wrap material would provide more air space between the turf and the cover, but the results would indicate that there was no difference between the two materials.

*Gas concentrations as they relate to temperature*

Temperatures above freezing caused a more rapid change in gas concentrations than did temperatures below freezing. For instance, in year one when temperature rose from -1.2 to 0.1°C, CO<sub>2</sub> rose from 4.4 to 5.0% (Table 3). In year two, a temperature of -0.6°C had a CO<sub>2</sub> concentration of 4.8% and the next week, when temperatures rose to 0.8°C, concentrations were 5.5%. This was an approximate increase of 14% in a one week period when temperatures increased to above freezing. In year three, gas concentrations remained quite constant in the same time period in spite of the fact that the temperature rose.

Table 3 – Relationship between carbon dioxide and temperature in March over a three year period.

	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
Carbon dioxide %	3	5.3	5.5	4.8	5.1	5.2
Temperature	3	-1.5	-1.2	-0.6	0.1	0.4

When temperature increased to above freezing, O<sub>2</sub> levels declined by 2% in year one, and 2.6% in year two and three (Table 4). This represented an 18% decline in year one, a 28% decline in year two and a 20% decline in year three. In year two, a temperature of 2.5°C was recorded on the final rating date which would indicate that snow had melted. There was a corresponding 40% increase in O<sub>2</sub>.

Table 4 – Relationship between oxygen levels and temperature over a three year period.

	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
Oxygen %	3	12.5	11.1	13.0	12.6	10.4
Temperature	3	-1.5	-1.2	-0.6	0.1	0.4

*Gas concentrations as affected by passive ventilation*

Two greens, #7 and #16, were considered ‘worst case’ candidates and had the passive ventilation system installed in year two. In year one, these greens had the closed-cell foam insulation layer under an impermeable cover and were actively ventilated on a weekly basis. The passive ventilation system that was installed was considerably more effective than was the active ventilation system.

The closed cell foam with the active ventilation had CO<sub>2</sub> levels that were well above the mean value for all greens. When the bubble wrap was passively ventilated values were equal to the overall mean value in year two and well below the mean value in year three. As mentioned previously, there did not appear to be a difference between the two insulation materials, so the effect is likely attributable to the passive ventilation system.

**Insert Glendale under covers 11-09**

Table 5 – Carbon dioxide levels for two ventilation systems.

Insulation Material	7 <sup>th</sup> green	16 <sup>th</sup> green	Yearly Means
	————— % CO <sub>2</sub> —————		
Closed cell foam – active ventilation	4.5	5.1	3.5
Bubble wrap passive ventilation Y2/Y3	4.0	3.3	3.9
Gas concentration changes	-13%	-55%	

When comparing O<sub>2</sub> levels for active versus passive ventilation there was a 22% increase for green #7 and a 29% increase for green #16 in favour of the passive system (Table 6).

Table 6 – Oxygen levels for two ventilation systems.

Insulation Material	7 <sup>th</sup> green	16 <sup>th</sup> green	Yearly Means
	————— % —————		
Closed cell foam active ventilation	11.9	11.0	14.8
Bubble wrap passive ventilation Y2/Y3	14.5	15.4	13.2

Gas concentration change	+22%	+29%
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*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 7). On one occasion gas concentrations were measured one hour after active ventilation. At that time CO<sub>2</sub> concentrations had decreased by 39%, while O<sub>2</sub> concentrations increased by 37%. On another occasion when gas concentrations were measured 24 hours after ventilation, the O<sub>2</sub> levels had only increased by 10%, while CO<sub>2</sub> levels had only decreased by about 2.5%. When gas concentrations were measured 48 hours after active ventilation, CO<sub>2</sub> levels decreased 9% while O<sub>2</sub> increased by only 2%. On another occasion when greens were ventilated twice, CO<sub>2</sub> increased by 7% and O<sub>2</sub> increased by 16%.

Table 7 – 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

The active ventilation produced the expected results when measured one hour after. However, there was a minimal effect after 24 and 48 hours and when ventilated twice per week. 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. Previously, we had reported that there might be a relationship between organic matter and CO<sub>2</sub> and O<sub>2</sub> concentrations. However, when combining data over three years there did not appear to be a clear relationship between organic matter and gas concentrations changes.

*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.

### *Observations at Greywolf*

A heavy snow cover developed on top of the covers soon after installation. Gas concentration changes began to occur soon after and by mid-December carbon dioxide levels on a few greens had reached 5%. However, by early January levels began to stabilize and remained below 3% for the remainder of the winter. Survivability was excellent as no green had more than 5% injury. Temperature data was compromised by a malfunctioning data logger, so it is not certain whether the greens remained frozen.

Venting with the leaf blowers did reduce carbon dioxide levels when measured soon after the event. However, on one occasion a hole was cut into the cover at the back of a green and there was no air coming from the hole even when the blowers were at close to full throttle. This points out that there was minimal air movement under the insulation layer. A picture taken during the winter showed that there was considerable frost under the covers which may have inhibited air movement.

**Insert Greywolf ice between bubbles 01-11**

### **Discussion**

During the three years of this study, the lowest temperature recorded under the covering system was  $-8^{\circ}\text{C}$ , while the coldest air temperature reported at the Edmonton International Airport (47 km from Glendale) was  $-46.1^{\circ}\text{C}$  on December 13, 2009. Additional information from the Olds Golf Course, where a similar covering system was installed, showed that on one occasion (December 7, 2009) the air temperature was  $-35^{\circ}\text{C}$  without snow cover and the temperature under the cover was  $-9.3^{\circ}\text{C}$ . The top cover was the same as used in the Glendale study, however, the bubble wrap insulating layer was slightly thicker, 18mm versus 12mm. In three years of study, this covering system has provided sufficient insulation to prevent injury from cold temperatures that occurred in early winter.

Survival of putting greens depends on the quantity of food reserves stored by the plants. Accumulation of food reserves is triggered by temperatures that are near freezing for a period of 10-14 days and it is essential that greens store their maximum amount of food reserves prior to covering. Covering should be delayed until the accumulation of food reserves is complete and in our climate, that is usually the first of November.

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  $\text{O}_2$  and increases in  $\text{CO}_2$  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  $-2^{\circ}\text{C}$  to  $0^{\circ}\text{C}$ . Other research (Rochette et al, 2006) showed that at temperatures of  $-2^{\circ}\text{C}$  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. In year two, our research found a similar relationship and actually pinpointed a number of 3.3% organic matter that appeared to be the critical point. However, in year three of the study we were not able to confirm a relationship between organic matter and gas concentration changes. This may have been a result of differences in sampling techniques or testing procedures, or it may be that the quantity of organic matter that was present did not create gas concentration changes.

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. In year three, the duration of snow cover was approximately 30 days longer than the other two years. Oxygen concentrations were approximately 15% lower in year three than in year one, while CO<sub>2</sub> levels were approximately 31% higher.

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 Glendale data, it would appear that passive ventilation was effective and active was not. The observation at Greywolf where no air movement was detected when active ventilation was being conducted would also put into question the effectiveness of the active system. The question remains for passive ventilation, 'will this system be effective when gas concentrations are rapidly changing or when wind 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 would 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.