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. In year one of this study, 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. In year two of this study results were somewhat contradictory as the 'no vents' system showed the least gas concentration fluctuations, whereas the previous year it showed the greatest gas concentration change. For the Olds College portion of the study, anoxic conditions never developed so we were not able to test the ventilation system. The methodology for this study will be altered for 2013-14 to include a controlled environment study with a similar objective.

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 and no injury occurred 3-5m in from the edge of the covering material (figure 1). Although gas concentration measurements were not taken in this area, it is assumed that there was some air movement between the turf and the cover. The injury was thought to be as a result of anoxic conditions that formed under the covers. Recovery time was lengthy.

Figure 1 – Anoxia injury on annual bluegrass green covered with an impermeable cover and an early heavy snow cover on an unfrozen green. Note good survivability at outer edges.

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.

Field Trial – Olds College

This field trial was intended to be a two year study on a newly constructed annual bluegrass plots area on Olds College campus. These plots were constructed on black chernozemic soil in order to increase the likelihood of microbial activity.

A pilot study was initiated with plots that measured 3 x 3 meters in order to determine an appropriate method for sealing the edges of the covers so that gas concentrations could be elevated. It was intended that this trial be initiated in the fall prior to freezing temperatures but due to the lateness of receiving some of the materials for the trial it was not initiated until March 3, 2013. Edges of the covers were sealed with a heavy layer of sand and were compared with a treatment where snow alone was placed on the covers. It was thought that these materials would ensure that there would be no replenishment of air from the atmosphere. In order to keep temperatures near or slightly above freezing wood chips were placed over the cover.

The covering system consisted of an impermeable white polyethlene cover over a 1.2 cm thick bubble wrap insulation material. The bubbles were open on the bottom and that provided an approximate 50% air space between the turf and the cover. Ventilation systems were not installed for this pilot study. Gas sampling occurred throughout the month of March and into April to test for any gas concentration changes. Spring survival and turf quality will be evaluated.

The specific treatments are as follows.

1. Industry standard covering system – White impermeable cover, bubble wrap insulation, snow piled along the edges 40cm
2. Industry standard covering system – White impermeable cover, bubble wrap insulation, sand piled along the edges to a depth of 20cm

A single sampling tube through which gas samples can be extracted was placed under the cover in each plot and sealed along the cover edge. Carbon dioxide and oxygen were monitored using a Portable Multi-Gas Detector (RKI Instruments Inc. Model: Eagle 71-0028RK). Both temperature and gas concentration values were collected each week throughout March and April. Data collection was at a similar time of day each week. Soil temperature probes were loosely inserted into the turf and temperatures were recorded for each treatment using a data logger (CR10X, Campbell Scientific, Edmonton, Alberta) running thermocouples through a multi-plexer (AM25T, Campbell Scientific).

Methodology Changes for 2013-14

One of the main objectives of the field study that was conducted at Olds was to determine gas concentration values that would cause turf injury. As we were unable to obtain anoxic conditions under the covers we speculated that we may never be able to achieve these conditions because the covers are not large enough to create anoxic conditions. Previous observations at golf courses show that the damage only occurs in the middle of greens. This would indicate an edge effect where some air circulation would occur and as a result gases never got to a lethal concentration.

As a result, we have decided to initiate a controlled study where we will fill 1.9 l Mason jars with various concentrations of O_2 and CO_2. Jars will be hermetically sealed and luer fittings will be installed in the lids so that gas concentrations can be sampled. Jars will then be filled with various gas concentrations, at this point proposed to be 21/0.04, 10/5, 5/10 and 0/15 O_2/CO_2. Jars of different gas concentrations will contain a turf plug that will be destructively sampled at various time intervals and then subjected to a freeze test to determine their LT_{50} values. Prior to sampling gas concentrations will be measured with the Portable Multi-Gas Detector.

Golf Superintendents need to know what lethal gas concentrations are and how long plants can endure these lethal concentrations, if at all. At this point, recommendations to Superintendents are to ventilate their greens when O_2 levels fall below 8%. However, these recommendations may be too cautious and plants may be able to withstand far lower O_2 concentrations and for longer periods of time.

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.

Results

Weather Conditions – Edmonton Area
Snow cover was much above normal for the winter of 2012-13. The first appreciable snow fall was in early November and maximum snow depth was over 100cm. Snow melt was very late and greens were not completely uncovered until after mid-April. Temperatures were near normal and cold periods did not appear to adversely affect temperatures under the covers.

Effects of Various Ventilation Systems on Carbon Dioxide Concentrations under Winter Covers
The results from the winter of 2012-13 were very different than those from the previous year. Consistently throughout the winter, concentrations of CO_2 were lower for the treatment that had no exhaust vents, one that we considered to be industry standard control treatment. There was, on occasion, evidence that gas concentration readings were erroneous. For instance, one particular plot (green) showed consistently high CO_2 values for a number of weeks only to have those numbers drop and stay at a low level for a few weeks and then recover to previous levels.

Table 1 – CO_2 concentrations under winter covers with various ventilation systems, 2012-13.

Treatment	Nov 14	Nov 18	Nov 21	Nov 24	Nov 28	Nov 30

Treatment						
	% CO_2					
No vents	2.95a	2.90a	2.25a	2.90a	2.95a	2.97a
Exhaust Vents Only	3.95a	4.27a	3.02a	3.72a	4.15a	4.32a
Roof Turbine Vents	3.40a	3.65a	3.07a	3.60a	3.25a	3.32a
Vent tube Matrix	3.10a	3.60a	2.97a	3.60a	3.75a	3.90a
$LSD_{0.05}$=	n/s	n/s	n/s	n/s	n/s	n/s

Treatment	Dec 2	Dec 7	Dec 14	Dec 19	Dec 22	Dec 28
	% CO_2					
No vents	3.07a	3.27a	3.05a	3.00a	2.65b	2.72a
Exhaust Vents Only	4.42a	4.57a	4.10a	3.50a	4.55a	5.55b
Roof Turbine Vents	4.02a	4.37a	4.15a	3.72a	4.10a	4.50ab
Vent tube Matrix	4.55a	4.80a	4.07a	4.37a	4.60a	4.90b
$LSD_{0.05}$=	n/s	n/s	n/s	n/s	1.11	1.81

Treatment	Jan 3	Jan 5	Jan 9	Jan 16	Jan 21	Jan 27
	% CO_2					
No vents	3.32a	2.95b	4.25a	4.40a	3.12a	3.17b
Exhaust Vents Only	4.67a	5.25a	4.50a	4.45a	5.20a	6.20a
Roof Turbine Vents	4.62a	4.60a	3.90a	4.32a	5.10a	5.70a
Vent tube Matrix	4.92a	4.92a	4.90a	4.77a	5.42a	5.55a
$LSD_{0.05}$=	n/s	1.35	n/s	n/s	n/s	2.00

Treatment	Feb 2	Feb 8	Feb 15	Feb 22	Feb 28
	% CO_2				
No vents	3.57a	3.10a	3.65a	3.57a	3.87a
Exhaust Vents Only	5.37a	4.72a	5.07a	5.35a	5.15a
Roof Turbine Vents	5.52a	4.97a	5.37a	5.02a	5.37a
Vent tube Matrix	4.77a	4.95a	4.82a	5.00a	5.67a
$LSD_{0.05}$=	n/s	n/s	n/s	n/s	n/s

Treatment	Mar 8	Mar 14	Mar 19	Mar 22	Mar 28
	% CO_2				
No vents	3.12a	3.60a	3.35a	2.92a	3.97a
Exhaust Vents Only	5.67a	3.32a	5.00a	4.82a	4.77a
Roof Turbine Vents	5.45a	5.32a	5.75a	5.72a	5.52a
Vent tube Matrix	4.95a	5.17a	5.62a	5.42a	5.20a
$LSD_{0.05}$=	n/s	n/s	n/s	n/s	n/s

Treatment	Apr 1	Apr 9	Apr 15	Apr 22	Mean (Nov 14- Apr 22)
	% CO_2				

No vents	3.55a	3.30a	3.20a	2.22a	3.20a
Exhaust Vents Only	4.57a	4.72a	4.82a	3.85a	4.62a
Roof Turbine Vents	5.27a	3.77a	2.37a	1.90a	4.40a
Vent tube Matrix	5.22a	5.27a	4.87a	3.90a	4.65a
$LSD_{0.05}$=	n/s	n/s	n/s	n/s	n/s

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

Effects of Various Ventilation Systems on Oxygen Concentrations under Winter Covers

The same trend occurred with O_2 as the no vents treatment had the highest level of oxygen. Once again, this is difficult to explain. The exhaust vents only treatment consistently showed the lowest level of O_2 until February 8 when the level increased by a full 5% in a matter of days. Following that, the levels were amongst the highest. However, there were no clear trends that emerged that would allow us to make a definite statements about which covering system provided the most favourable oxygen conditions.

Table 2 – O_2 concentrations under winter covers with various ventilation systems, 2012-13.

Treatment	Nov 14	Nov 18	Nov 21	Nov 24	Nov 28	Nov 30
	% O_2					
No vents	16.00a	15.02a	16.12a	15.47a	16.22a	15.65a
Exhaust Vents Only	9.75b	9.50a	12.65a	8.75b	12.00a	10.60a
Roof Turbine Vents	13.17ab	11.87a	13.12a	11.75ab	14.45a	13.65a
Vent tube Matrix	13.65a	12.95a	13.72a	10.97ab	13.65a	12.50a
$LSD_{0.05}$=	3.66	n/s	n/s	4.56	n/s	n/s

Treatment	Dec 2	Dec 7	Dec 14	Dec 19	Dec 22	Dec 28
	% O_2					
No vents	15.72a	15.85a	15.35a	15.22a	16.32a	16.50a
Exhaust Vents Only	10.50a	10.97a	11.17a	13.40a	11.07b	8.70b
Roof Turbine Vents	11.75a	11.27a	11.82a	12.77a	12.27b	11.50b
Vent tube Matrix	11.15a	11.62a	12.55a	12.32a	11.82b	11.77b
$LSD_{0.05}$=	n/s	n/s	n/s	n/s	3.32	4.71

Treatment	Jan 3	Jan 5	Jan 9	Jan 16	Jan 21	Jan 27
	% O_2					
No vents	14.50a	15.77a	12.45a	12.27a	16.32a	16.07a
Exhaust Vents Only	10.47a	9.62b	10.95a	11.25a	10.27a	8.35b
Roof Turbine Vents	11.80a	12.20b	13.12a	12.70a	11.62a	10.97b
Vent tube Matrix	11.52a	11.37b	11.17a	12.15a	11.90a	11.32b
$LSD_{0.05}$=	n/s	2.74	n/s	n/s	n/s	4.35

Treatment	Feb 2	Feb 8	Feb 15	Feb 22	Feb 28

	% O_2				
No vents	14.55a	16.07a	14.8a2	14.75a	14.57a
Exhaust Vents Only	9.55a	14.45a	12.50a	12.00a	12.62a
Roof Turbine Vents	10.97a	12.60a	11.70a	11.70a	11.95a
Vent tube Matrix	12.32a	13.05a	12.57a	11.42a	10.80a
$LSD_{0.05}$=	n/s	n/s	n/s	n/s	n/s

Treatment	Mar 8	Mar 14	Mar 19	Mar 22	Mar 28
	% O_2				
No vents	16.35a	15.25ab	16.52a	16.37ab	14.47a
Exhaust Vents Only	17.32a	18.95a	17.30a	18.07a	16.97a
Roof Turbine Vents	12.20a	12.40b	11.40a	13.35bc	11.75a
Vent tube Matrix	12.77a	12.52b	11.77a	10.57c	11.75a
$LSD_{0.05}$=	n/s	3.95	n/s	4.27	n/s

Treatment	Apr 1	Apr 9	Apr 15	Apr 22	Mean (Nov 14- Apr 22)
	% O_2				
No vents	13.80a	14.40a	13.82a	17.70a	15.32a
Exhaust Vents Only	17.72a	17.20a	17.17ab	17.22a	12.77a
Roof Turbine Vents	15.60a	16.55a	18.75bc	18.00a	12.85a
Vent tube Matrix	11.67a	11.47a	11.95c	14.42a	12.10a
$LSD_{0.05}$=	n/s	n/s	3.81	n/s	n/s

*Temperatures under the various ventilation system*s

Temperatures under the various ventilation systems were very similar and average (mean) values were 0°C (data not shown). This compared with a range of -1.3 to -1.6°C in 2011-12. Even during a cold period in December temperatures were never below freezing. When considering all 48 sensors over many sampling periods, the coldest recorded temperature was -1°C. This shows the high level of insulation as a result of the snow cover.

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 -1°C, even during the cold period of mid-January. This would indicate that there was sufficient insulation from the bubble wrap 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.

Results Field Trial – Olds College

During the installation phase of this portion of the trial, it became quite apparent that sealing the covers was going to be problematic. In spite of the fact that a heavy application of sand was placed at the edge of the covers, anoxic conditions did not develop. Although, a longer incubation period may have increased the likelihood of the development of anoxia, installing ventilation tubes proved to increase the problem of sealing the edges of the covers. As a result, treatment differences appeared to be insignificant and the decision was made to alter the methodology.

Table 3 - Gas concentration levels under winter covers.

	March 5		March 8		March 12	
	$\%O_2$	$\%CO_2$	$\%O_2$	$\%CO_2$	$\%O_2$	$\%CO_2$
Rep 1: Cover with sand edging	21.1	0.0	20.9	0.7	21.0	0.1
Rep 1: Cover with snow edging	21.3	0.1	19.9	1.3	21.0	0.1
Rep 2: Cover with snow edging	20.1	1.4	17.7	2.2	21.0	0.1
Rep 2: Cover with sand edging	20.9	1.3	18.7	2.4	20.9	0.2
Atmospheric Reading	21.4	0.0	20.9	0.0	21.0	0.0

	March 19		March 26		April 2	
	$\%O_2$	$\%CO_2$	$\%O_2$	$\%CO_2$	$\%O_2$	$\%CO_2$
Rep 1: Cover with sand edging	21.4	0.0	19.1	2.0	20.9	0.0
Rep 1: Cover with snow edging	21.1	0.1	18.2	2.3	20.9	0.0
Rep 2: Cover with snow edging	21.0	0.0	20.1	1.2	20.9	0.0
Rep 2: Cover with sand edging	20.9	0.3	18.8	2.7	20.9	0.0
Atmospheric Reading	21.0	0.0	20.9	0.0	20.9	0.0

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.

Preliminary data for 2013-14 appears similar to the data in year one.