Evaluation of Air-infused Water Applied to Creeping Bentgrass Turf

Prairie Turfgrass Research Centre
Mark A. Anderson and James B. Ross
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Summary
This trial was developed in order to assess the effects of air-infused water on growth of creeping bentgrass on a sand based putting green. Applications of an air-infused water was applied at two different rates in conjunction with four different rates of fertilizer. These treatments were assessed for turfgrass colour and quality, growth response as measured by clipping yield, nutrient analysis of plant tissue, soil oxygen and carbon dioxide levels, soil volumetric water content, and light reflectance measurements. As rates of fertilizer increased, so did turfgrass colour, quality and clipping yield. However, the application of the air-infused water did not have an effect. Fertilizer applications also affected plant tissue content for nitrogen, potassium and sulphur i.e. as rates increased so did the plant nutrient content. On both rating dates, the higher water volume produced a lower oxygen concentration in the soil. Carbon dioxide was greater when the high rate of water was applied. Although, not statistically different, the air-infused water showed a trend towards lower carbon dioxide levels than did the untreated water. There was also a trend toward higher concentrations of carbon dioxide as fertilizer rates increased. Soil volumetric water content increased as water application volumes increased. The air-infused water applications did not appear to have an effect on the light reflectance measurements. The overall quality of this green was good and applications of the air-infused water may have a more profound effect on greens that are poorly drained and of lesser quality. Measurement of soil oxygen and carbon dioxide appears to be a promising method for the determination of soil gas differences.

Introduction
BioAdvanta Environmental Solutions has developed a water treatment system that infuses water with oxygen. The technology has been developed for wastewater treatment in remote locations that do not have access to a water treatment facility.

In a pilot study conducted at Olds College School of Innovation, an improved growth response was noted when the treated water was applied to turf grown in the greenhouse. The positive responses were for clipping yield and root production.

This field study assessed various growth characteristics of creeping bentgrass following application of the product.

Methodology
The objective of this trial was to determine if there were any positive effects on plant growth from water that was conditioned by an air-infusion process (BioAdvanta Environmental Solutions, Olds, Alberta).

Trial Design
This trial was established in early July 2011 at the Prairie Turfgrass Research Centre, Olds College (Olds, Alberta, Canada). Plots were laid out on a sand based green that conformed to United States Golf Association specifications and was seeded to Penncross creeping bentgrass. Plots, which were 1 by 2 metres in size, were replicated four times in a Randomized Complete Block Design.

The water treatments for this trial were sourced from the runoff fed irrigation ponds located on the Olds College campus and included an air-infused water and an untreated water. The air-infused water treatment was produced using an air-infusion process which conditioned the water for 30 minutes prior to application to the turf. The air-infused water was taken from the bottom of the production vessel, transported to the plots in 175 litre barrels, and applied within 10 minutes of conditioning. The untreated water was taken directly from the campus irrigation system. Weekly applications of both water treatments were applied with watering cans to the individual plots at two different rates (5 amd 10 l/m^2 beginning July 6 (table1).

Following application of the water treatments, Scotts Turf Builder Pro 34-0-4 granular fertilizer was applied with a drop spreader every three weeks beginning July 8. Four separate rates of application were applied and are listed in table 1.

Table 1 – Water treatments and rate of application for both water and fertilizer.

Water treatments	Water Rates	Fertilizer Rates
1. Untreated Water	$5L/m^2$	None
2. Untreated Water	$10L/m^2$	None
3. Air-Infused Water	$5L/m^2$	None
4. Air-Infused Water	$10L/m^2$	None
5. Untreated Water	$5L/m^2$	¼ X rate (0.08kg N/100m^2 every 3 weeks)
6. Untreated Water	$10L/m^2$	¼ X rate (0.08kg N/100m^2 every 3 weeks)
7. Air-Infused Water	$5L/m^2$	¼ X rate (0.08kg N/100m^2 every 3 weeks)
8. Air-Infused Water	$10L/m^2$	¼ X rate (0.08kg N/100m^2 every 3 weeks)
9. Untreated Water	$5L/m^2$	½ X rate (0.16kg N/100m^2 every 3 weeks)
10. Untreated Water	$10L/m^2$	½ X rate (0.16kg N/100m^2 every 3 weeks)
11. Air-Infused Water	$5L/m^2$	½ X rate (0.16kg N/100m^2 every 3 weeks)
12. Air-Infused Water	$10L/m^2$	½ X rate (0.16kg N/100m^2 every 3 weeks)
13. Untreated Water	$5L/m^2$	1X rate (0.33kg N/100m^2 every 3 weeks)
14. Untreated Water	$10L/m^2$	1X rate (0.33kg N/100m^2 every 3 weeks)
15. Air-Infused Water	$5L/m^2$	1X rate (0.33kg N/100m^2 every 3 weeks)
16. Air-Infused Water	$10L/m^2$	1X rate (0.33kg N/100m^2 every 3 weeks)

Data Collections

Data collections began on July 11 and included turfgrass colour and quality, growth response as measured by clipping yield, nutrient analysis of plant tissue, soil oxygen and carbon dioxide levels, soil volumetric water content, and light reflectance measurements. Light reflectance measurements were used to determine the normalized difference vegetative index (NDVI) and clipping yields were compared with the amount of water applied to determine the water use efficiency index.

The plots were evaluated on a weekly basis for three quality factors, colour, density and area cover. These ratings were based on the National Turfgrass Evaluation Program (www.ntep.org) protocols where numeric values were observed and assigned to individual plots where 9 was best, 1 was poorest, and 6 was considered acceptable. Colour was evaluated by 1 was a brown dormant turf and 9 was a very uniform dark green colour. Turf density, a measure of the number of shoots per unit area, was rated based on 1 was

a thin, weak turf stand and 9 was a very dense tight-knit stand. The third quality factor was area cover where values range from a 1 for a complete absence of turf to a 9 for complete cover with the desired turf. The presence of weeds or voids in the turf reduced this rating.

Clippings were collected each week with a reel mower that made one pass down the centre of each plot. Clippings were paced in a drying over for 24 hours at 75^{o}C and weighed to give a value for plant growth response. On two occasions, August 15 and on September 1, dried clippings were packaged and sent to Brookside Laboratories (New Knoxville, Ohio) for nutrient analysis of plant tissue.

Soil oxygen and carbon dioxide levels were sampled on two separate occasions, August 17 and September 2. Three readings were collected at the 12cm depth from each plot (bottom, middle, top) using a portable multi-gas detector (RKI Instruments Inc. Model: Eagle 71-0028RK) fitted with a hollow soil probe that was inserted into the soil.

Volumetric water content ratings were collected from each plot using a Campbell Scientific Hydro-Sense TDR 1000 water content moisture sensor (Campbell Scientific Edmonton, Alberta). Three moisture readings were collected from each plot (bottom, middle, top) on two occasions, July 25 and August 17.

Normalize Differential Vegetative Index (NDVI)

Chlorophyll content is mainly influenced by nitrogen availability (Moorby and Besford, 1983). Light reflectance by leaves in the visible region of the spectrum depends primarily on the concentration of chlorophylls and carotenoids. A deficiency in nutrients such as nitrogen decreases pigment formation and leaf color, which subsequently increases reflectivity, or irradiance, due to reduced radiation absorption.

The absorption of light in the red and near infrared bands is strongly influenced by chlorophyll content and plant cover. As chlorophyll content increases so does the absorption of light within the red band with peak absorption occurring at 670 nm. On the other hand, reflection of near infrared light, which is measured at 780nm, increases when chlorophyll contents are high. Green light when measured at 550nm is generally reflected and irradiance increases as chlorophyll content increases.

The normalized difference vegetative index (NDVI) was proposed by Rouse et al. (1974) and is commonly used to separate green vegetation from the soil background. In order to estimate the amount of chlorophyll present in the leaf the amount of absorption at the red band is compared with the amount of absorption in the infrared band. NDVI has a range of -1 to +1, with bare soil surfaces having an NDVI of approximately 0 and high vegetative cover having an NDVI of near 1 (Thiam, 1998).

Given these relationships, NDVI from vegetated surfaces is heavily influenced by chlorophyll content of materials in the vegetation. The following equations determine the NDVI in terms of irradiance from a target with $NDVI_{550}$ being a measurement of turf color and $NDVI_{670}$ being an indication of turf cover and density. The larger the index value the more efficient the turfgrass is in absorbing red spectrum light.

1. $NDVI_{550} =$

$$\frac{\text{(Near infrared irradiance – Green irradiance)}}{\text{(Near infrared irradiance + Green irradiance)}}$$

2. $NDVI_{670} = \frac{\text{(Near infrared irradiance – Red irradiance)}}{\text{(Near infrared irradiance + Red irradiance)}}$

Photospectrometer readings (Field Spec Spectroradiometer model HH), a measured of light reflectance from the turf surface, were collected on August 17. Data was collected under a full sunlight, between 1 and 2 PM to assure optimum reflectance values.

Water Use Efficiency Index
Water use efficiency index was determined by dividing clipping yield (g/m^2) per litre of water applied. The larger the index value the more efficient the turfgrass is in using water to produce a measured growth response.

Precipitation and temperature was recorded daily for the duration of the trial and is included in Appendix A.

The generated data was first analyzed using an Analysis of Variance (ANOVA) test. When statistically significant treatment differences are present, least significant difference (LSD) values are presented at the bottom of each table. Treatment differences that were greater than the LSD value indicate a strong probability that the differences were as a result of the treatment and did not occur by chance. Therefore, within a column, if the same letter follows numbers there is no significant difference between treatments.

Results
On only one rating date was there any colour difference between any of the treatments. At that time the treatments that were fertilized at the full rate had significantly higher colour ratings.

Table 2 – Observed turfgrass colour ratings.

Water Source	Rate	Fertilizer	July 11th	July 18th	July 25th	Aug 1st	Aug 8th
			1 – 9 scale				
Untreated Water	5L/m^2	None	7.0a	7.0a	7.0a	7.0a	7.0a
Untreated Water	10L/m^2	None	7.0a	7.0a	7.0a	7.0a	7.0a
Air-Infused Water	5L/m^2	None	7.0a	7.0a	7.0a	7.0a	6.7a
Air-Infused Water	10L/m^2	None	7.0a	7.0a	7.0a	7.0a	7.0a
Untreated Water	5L/m^2	¼ rate	7.0a	7.0a	7.0a	7.0a	7.0a
Untreated Water	10L/m^2	¼ rate	7.0a	7.0a	7.0a	7.0a	7.0a
Air-Infused Water	5L/m^2	¼ rate	7.0a	7.0a	7.0a	7.0a	7.0a
Air-Infused Water	10L/m^2	¼ rate	7.0a	7.0a	7.0a	7.0a	7.0a
Untreated Water	5L/m^2	½ rate	7.0a	7.0a	7.0a	7.0a	7.0a
Untreated Water	10L/m^2	½ rate	7.0a	7.0a	7.0a	7.0a	7.0a
Air-Infused Water	5L/m^2	½ rate	7.0a	7.0a	7.0a	7.0a	7.0a
Air-Infused Water	10L/m^2	½ rate	7.0a	7.0a	7.0a	7.0a	7.0a
Untreated Water	5L/m^2	Full Rate	7.0a	7.0a	7.0a	7.0a	7.0a
Untreated Water	10L/m^2	Full Rate	7.0a	7.0a	7.0a	7.0a	7.0a
Air-Infused Water	5L/m^2	Full Rate	7.0a	7.0a	7.0a	7.0a	7.0a
Air-Infused Water	10L/m^2	Full Rate	7.0a	7.0a	7.0a	7.0a	7.0a
			n/s	n/s	n/s	n/s	n/s

Water Source	Rate	Fertilizer	Aug 15th	Aug 22nd	Sept 1st	Sept 6th
			1 – 9 scale			
Untreated Water	5L/m^2	None	7.0a	6.7a	6.5a	6.0e
Untreated Water	10L/m^2	None	7.0a	6.5a	6.5a	6.2de
Air-Infused Water	5L/m^2	None	6.7a	6.2a	6.2a	6.0e
Air-Infused Water	10L/m^2	None	7.0a	6.2a	6.2a	6.2de
Untreated Water	5L/m^2	¼ rate	7.0a	6.0a	6.2a	6.2de
Untreated Water	10L/m^2	¼ rate	7.0a	6.5a	6.5a	6.2de
Air-Infused Water	5L/m^2	¼ rate	7.0a	6.7a	6.7a	6.2de
Air-Infused Water	10L/m^2	¼ rate	7.0a	6.5a	6.5a	6.0e
Untreated Water	5L/m^2	½ rate	7.0a	6.5a	6.5a	6.2de
Untreated Water	10L/m^2	½ rate	7.0a	7.0a	7.0a	7.7a
Air-Infused Water	5L/m^2	½ rate	7.0a	6.7a	6.7a	6.7cd
Air-Infused Water	10L/m^2	½ rate	7.0a	6.7a	6.7a	6.7cd
Untreated Water	5L/m^2	Full Rate	7.0a	7.0a	7.0a	7.7a
Untreated Water	10L/m^2	Full Rate	7.0a	6.7a	7.0a	7.5ab
Air-Infused Water	5L/m^2	Full Rate	7.0a	7.0a	7.0a	7.7a
Air-Infused Water	10L/m^2	Full Rate	7.0a	6.7a	7.0a	7.5ab
		$LSD_{0.05}$ =	n/s	n/s	n/s	0.5

* Values that have the same letter as a suffix are not significantly different from each other.

For turfgrass quality, the only significant differences between treatments occurred on the final rating date, September 6. At that time, those treatments that had higher rates of fertilizer also showed improved quality.

Table 3 – Observed overall turfgrass quality.

Water Source	Rate	Fertilizer	July 11th	July 18th	July 25th	Aug 1st	Aug 8th
			mean of three quality factors				
Untreated Water	5L/m^2	None	8.0a	8.0a	7.7a	8.0a	8.0a
Untreated Water	10L/m^2	None	8.0a	8.0a	7.7a	8.0a	8.0a
Air-Infused Water	5L/m^2	None	8.0a	8.0a	7.7a	8.0a	7.9a
Air-Infused Water	10L/m^2	None	8.0a	8.0a	7.7a	8.0a	8.0a
Untreated Water	5L/m^2	¼ rate	8.0a	8.0a	7.7a	8.0a	8.0a
Untreated Water	10L/m^2	¼ rate	8.0a	8.0a	7.7a	8.0a	8.0a
Air-Infused Water	5L/m^2	¼ rate	8.0a	8.0a	7.7a	8.0a	8.0a
Air-Infused Water	10L/m^2	¼ rate	8.0a	8.0a	7.7a	8.0a	8.0a
Untreated Water	5L/m^2	½ rate	8.0a	8.0a	7.7a	8.0a	8.0a
Untreated Water	10L/m^2	½ rate	8.0a	8.0a	7.7a	8.0a	8.0a
Air-Infused Water	5L/m^2	½ rate	8.0a	8.0a	7.7a	8.0a	8.0a
Air-Infused Water	10L/m^2	½ rate	8.0a	8.0a	7.7a	8.0a	8.0a
Untreated Water	5L/m^2	Full Rate	8.0a	8.0a	7.7a	8.0a	8.0a
Untreated Water	10L/m^2	Full Rate	8.0a	8.0a	7.7a	8.0a	8.0a
Air-Infused Water	5L/m^2	Full Rate	8.0a	8.0a	7.7a	8.0a	8.0a
Air-Infused Water	10L/m^2	Full Rate	8.0a	8.0a	7.7a	8.0a	8.0a
		$LSD_{0.05}$ =	n/s	n/s	n/s	n/s	n/s

Water Source	Rate	Fertilizer	Aug 15th	Aug 22nd	Sept 1st	Sept 6th
			mean of three quality factors			
Untreated Water	5L/m^2	None	8.0a	7.9a	7.9a	7.6d
Untreated Water	10L/m^2	None	8.0a	7.8a	7.9a	7.7d
Air-Infused Water	5L/m^2	None	7.9a	7.7a	7.8a	7.6d
Air-Infused Water	10L/m^2	None	8.0a	7.7a	7.8a	7.7d
Untreated Water	5L/m^2	¼ rate	8.0a	7.7a	7.7a	7.7d
Untreated Water	10L/m^2	¼ rate	8.0a	7.8a	7.9a	7.7d
Air-Infused Water	5L/m^2	¼ rate	8.0a	7.9a	7.9a	7.7d
Air-Infused Water	10L/m^2	¼ rate	8.0a	7.8a	7.9a	7.6d
Untreated Water	5L/m^2	½ rate	8.0a	7.8a	7.9a	7.7d
Untreated Water	10L/m^2	½ rate	8.0a	8.0a	8.0a	8.3a
Air-Infused Water	5L/m^2	½ rate	8.0a	7.9a	7.9a	7.9c
Air-Infused Water	10L/m^2	½ rate	8.0a	7.9a	7.9a	7.9c
Untreated Water	5L/m^2	Full Rate	8.0a	8.0a	8.0a	8.3a
Untreated Water	10L/m^2	Full Rate	8.0a	7.9a	7.9a	8.1b
Air-Infused Water	5L/m^2	Full Rate	8.0a	8.0a	8.0a	8.3a
Air-Infused Water	10L/m^2	Full Rate	8.0a	7.9a	7.9a	8.1b
		$LSD_{0.05}$ =	n/s	n/s	n/s	0.1

* Values that have the same letter as a suffix are not significantly different from each other.

For the growth response as measured by clipping yield, there were statistically significantly different values for the final two rating dates. Once again, the high rate of fertilizer produced the highest clipping yields. In addition, the high rate of air-infused water at the half rate of fertilizer was also considered to be significantly better than the other treatments.

Table 3 – Growth response as measured by clipping yield.

Water Source	Rate	Fertilizer	July 11th	July 18th	July 25th	Aug 1st	Aug 8th
			g/m^2/week				
Untreated Water	5L/m^2	None	30.4a	24.9a	21.3a	16.4a	14.6a
Untreated Water	10L/m^2	None	29.8a	21.0a	20.4a	16.9a	11.2a
Air-Infused Water	5L/m^2	None	30.7a	20.4a	19.0a	15.7a	11.9a
Air-Infused Water	10L/m^2	None	36.6a	20.8a	23.6a	26.5a	16.3a
Untreated Water	5L/m^2	¼ rate	32.6a	24.8a	20.7a	20.5a	16.8a
Untreated Water	10L/m^2	¼ rate	33.3a	26.4a	23.9a	23.8a	18.1a
Air-Infused Water	5L/m^2	¼ rate	35.3a	24.3a	20.9a	24.6a	15.0a
Air-Infused Water	10L/m^2	¼ rate	30.5a	26.3a	21.7a	22.7a	13.5a
Untreated Water	5L/m^2	½ rate	36.1a	24.1a	22.4a	19.6a	17.1a
Untreated Water	10L/m^2	½ rate	30.1a	25.7a	21.3a	17.2a	13.8a
Air-Infused Water	5L/m^2	½ rate	30.7a	25.2a	21.6a	22.4a	16.0a
Air-Infused Water	10L/m^2	½ rate	33.4a	22.4a	23.6a	23.9a	15.3a
Untreated Water	5L/m^2	Full Rate	31.1a	21.4a	21.8a	23.5a	15.0a
Untreated Water	10L/m^2	Full Rate	33.9a	23.3a	22.6a	16.9a	16.2a
Air-Infused Water	5L/m^2	Full Rate	34.9a	30.1a	23.4a	21.2a	19.8a
Air-Infused Water	10L/m^2	Full Rate	34.1a	24.8a	23.3a	16.4a	15.2a
		$LSD_{0.05}$ =	n/s	n/s	n/s	n/s	n/s

Water Source	Rate	Fertilizer	Aug 15th	Aug 22nd	Sept 1st	Sept 6th	Total Clipping Yield
			g/m²/week				
Untreated Water	5L/m²	None	17.0a	15.8a	6.0cd	12.4efg	159.0a
Untreated Water	10L/m²	None	16.9a	14.5a	4.6d	8.5g	143.9a
Air-Infused Water	5L/m²	None	14.4a	15.2a	5.1cd	9.7fg	142.2a
Air-Infused Water	10L/m²	None	19.7a	20.0a	4.8cd	11.6fg	180.2a
Untreated Water	5L/m²	¼ rate	19.7a	19.4a	7.8bc	12.7def	175.1a
Untreated Water	10L/m²	¼ rate	17.1a	16.5a	5.8cd	13.3cdef	178.6a
Air-Infused Water	5L/m²	¼ rate	19.3a	19.0a	5.7cd	9.3fg	173.7a
Air-Infused Water	10L/m²	¼ rate	16.0a	15.5a	4.4d	12.1efg	162.9a
Untreated Water	5L/m²	½ rate	16.5a	13.6a	11.4a	16.9bc	177.9a
Untreated Water	10L/m²	½ rate	19.3a	19.0a	10.3ab	16.1bcde	173.1a
Air-Infused Water	5L/m²	½ rate	19.8a	16.6a	11.2a	16.8bcd	180.5a
Air-Infused Water	10L/m²	½ rate	18.6a	18.5a	11.0a	17.4abc	184.3a
Untreated Water	5L/m²	Full Rate	19.1a	18.4a	13.4a	20.1ab	184.1a
Untreated Water	10L/m²	Full Rate	17.1a	17.1a	12.5a	21.5a	181.5a
Air-Infused Water	5L/m²	Full Rate	21.8a	19.6a	12.6a	19.6ab	203.2a
Air-Infused Water	10L/m²	Full Rate	23.3a	19.2a	12.1a	19.2ab	187.8a
		$LSD_{0.05}$ =	n/s	n/s	3.1	4.1	n/s

* Values that have the same letter as a suffix are not significantly different from each other.

On one occasion, clipping yield with the air-infused water was statistically higher than the untreated water (table 4). However, when all rating dates were totaled values were quite similar which might show that the air-infused water did not produce an additional growth response. When comparing the two rates of application of the water, there were no differences at any time during the course of the trial. For the various rates of the fertilizer, only the final two rating dates had higher clipping yields for the half and full rate in comparison to the lower rates.

Table 4 – Comparison of growth response for the main factors as measured by clipping yield.

	July 11th	July 18th	July 25th	Aug 1st	Aug 8th
	g/m²/week				
Water Source					
Untreated Water	64.4a	47.9a	43.6a	19.3b	23.0a
Air-Infused Water	66.4a	48.6a	44.3a	21.7a	23.1a
Water Volume Application Rate					
5L/m²	65.4a	48.9a	42.8a	20.5a	23.7a
10L/m²	65.5a	47.7a	45.1a	20.5a	22.4a
Fertilizer Application Rate					
None	63.8a	43.6a	42.1a	18.9a	20.2a
¼ rate	65.8a	51.0a	43.7a	22.9a	23.8a
½ rate	65.1a	48.8a	44.5a	20.7a	23.4a
Full Rate	67.1a	49.9a	46.1a	19.5a	24.4a

	Aug 15th	Aug 22nd	Sept 1st	Sept 6th	Total Clipping Yield
	g/m²/week				
Water Source					
Untreated Water	17.8a	16.8a	9.0a	15.2a	257a
Air-Infused Water	19.1a	17.9a	8.3a	14.5a	264a
Water Volume Application Rate					
5L/m²	18.4a	17.2a	9.1a	14.7a	261a
10L/m²	18.5a	17.5a	8.2a	15.0a	260a
Fertilizer Application Rate					
None	17.0a	16.4a	5.1b	10.6b	238b
¼ rate	18.0a	16.8a	5.9b	11.9b	260a
½ rate	18.5a	17.6a	10.9a	16.8a	266a
Full Rate	20.3a	18.3a	12.6a	20.1a	278a

* Values that have the same letter as a suffix are not significantly different from each other.

On both rating dates, the higher water volume produced a lower oxygen concentration in the soil (table 5).

Table 5 - Soil oxygen concentrations.

Treatments	August 17th	September 2nd
	% oxygen	
Water Source		
Untreated Water	17.1a	17.4a
Air-Infused Water	17.3a	17.5a
Water Volume Application Rate		
5L/m²	17.4a	17.8a
10L/m²	16.9b	17.1b
Fertilizer Application Rate		
None	17.3a	17.8a
¼ rate	16.9a	17.2a
½ rate	17.1a	17.6a
Full Rate	17.3a	17.5a

* Values that have the same letter as a suffix are not significantly different from each other.

Carbon dioxide was greater when the high rate of water was applied. Although, not statistically different, the air-infused water showed a trend towards lower carbon dioxide levels than did the untreated water. There was also a trend toward higher concentrations of carbon dioxide as fertilizer rates increased.

Table 6 - Soil carbon dioxide concentrations.

Treatments	August 17th	September 2nd
	——— CO_2 ppm ———	
Water Source		
Untreated Water	1.65a	1.30a
Air-Infused Water	1.58a	1.25a
Water Volume Application Rate		
5L/m^2	1.45a	1.10a
10L/m^2	1.78a	1.46b
Fertilizer Application Rate		
None	1.36a	1.24a
¼ rate	1.73a	1.48a
½ rate	1.60a	1.19a
Full Rate	1.78a	1.50a

* Values that have the same letter as a suffix are not significantly different from each other.

The air-infused water had a lower percentage of soil water on one of two occasions. On both rating dates, the percent moisture was, not surprisingly, higher for the higher application of water. Fertilizer application rates did not seem to have an effect on soil moisture percentage.

Table 6 - Volumetric water content of soils measured in percent.

Treatments	July 25th	August 17th
	———% VMC———	
Water Source		
Untreated Water	18.9a	23.4a
Air-Infused Water	18.9a	22.3b
Water Volume Application Rate		
5L/m^2	18.2b	22.0b
10L/m^2	19.6a	23.7a
Fertilizer Application Rate		
None	18.2a	22.7a
¼ rate	20.1a	23.7a
½ rate	18.6a	22.7a
Full Rate	18.6a	22.3a

* Values that have the same letter as a suffix are not significantly different from each other.

There were no differences between the various nutrients when the plant tissue was analyzed on the first rating date.

Table 7 – Nutrient analysis of plant tissue, August 15.

Water Source	Rate	Fertilizer	N %	P %	K %	Mg %	Ca %	S %
Untreated Water	5L/m^2	None	4.71a	0.35a	1.98a	0.22a	0.45a	0.41a
Untreated Water	10L/m^2	None	4.66a	0.36a	1.99a	0.21a	0.46a	0.41a
Air-Infused Water	5L/m^2	None	4.48a	0.35a	1.96a	0.21a	0.45a	0.41a
Air-Infused Water	10L/m^2	None	4.67a	0.38a	2.07a	0.22a	0.46a	0.42a
Untreated Water	5L/m^2	¼ rate	4.75a	0.37a	1.99a	0.23a	0.46a	0.42a
Untreated Water	10L/m^2	¼ rate	4.73a	0.35a	1.96a	0.22a	0.45a	0.42a
Air-Infused Water	5L/m^2	¼ rate	4.67a	0.35a	1.95a	0.21a	0.47a	0.40a
Air-Infused Water	10L/m^2	¼ rate	4.55a	0.36a	2.03a	0.22a	0.46a	0.41a
Untreated Water	5L/m^2	½ rate	4.71a	0.37a	1.98a	0.21a	0.45a	0.41a
Untreated Water	10L/m^2	½ rate	4.81a	0.35a	2.01a	0.21a	0.45a	0.42a
Air-Infused Water	5L/m^2	½ rate	4.61a	0.36a	2.00a	0.21a	0.46a	0.42a
Air-Infused Water	10L/m^2	½ rate	4.62a	0.37a	2.02a	0.22a	0.48a	0.42a
Untreated Water	5L/m^2	Full Rate	4.67a	0.37a	2.03a	0.22a	0.48a	0.43a
Untreated Water	10L/m^2	Full Rate	4.72a	0.38a	2.02a	0.22a	0.47a	0.43a
Air-Infused Water	5L/m^2	Full Rate	4.74a	0.35a	1.98a	0.22a	0.46a	0.42a
Air-Infused Water	10L/m^2	Full Rate	4.64a	0.39a	2.08a	0.22a	0.47a	0.43a
		$LSD_{0.05}$ =	n/s	n/s	n/s	n/s	n/s	n/s

Water Source	Rate	Fertilizer	B ppm	Fe ppm	Mn ppm	Cu ppm	Zn ppm	Al ppm
Untreated Water	5L/m^2	None	8.45a	221a	40.4a	14.7a	38.0a	100a
Untreated Water	10L/m^2	None	7.95a	191a	43.9a	14.3a	36.2a	86a
Air-Infused Water	5L/m^2	None	7.65a	240a	44.2a	14.3a	37.0a	120a
Air-Infused Water	10L/m^2	None	7.62a	230a	42.3a	15.3a	40.0a	106a
Untreated Water	5L/m^2	¼ rate	8.10a	217a	39.7a	16.0a	51.6a	98a
Untreated Water	10L/m^2	¼ rate	8.35a	228a	39.2a	15.3a	38.3a	103a
Air-Infused Water	5L/m^2	¼ rate	8.12a	238a	41.9a	14.4a	36.1a	114a
Air-Infused Water	10L/m^2	¼ rate	8.25a	250a	41.8a	15.1a	39.3a	102a
Untreated Water	5L/m^2	½ rate	7.70a	302a	43.5a	14.8a	36.7a	143a
Untreated Water	10L/m^2	½ rate	8.32a	269a	43.7a	15.4a	36.9a	150a
Air-Infused Water	5L/m^2	½ rate	8.00a	194a	41.3a	14.3a	35.2a	83a
Air-Infused Water	10L/m^2	½ rate	8.02a	223a	45.0a	15.3a	45.1a	103a
Untreated Water	5L/m^2	Full Rate	8.40a	255a	45.2a	14.7a	36.9a	135a
Untreated Water	10L/m^2	Full Rate	7.82a	198a	43.6a	15.1a	36.8a	88a
Air-Infused Water	5L/m^2	Full Rate	7.57a	206a	40.4a	14.7a	36.1a	97a
Air-Infused Water	10L/m^2	Full Rate	7.80a	228a	45.1a	14.9a	34.8a	107a
		$LSD_{0.05}$ =	n/s	n/s	n/s	n/s	n/s	n/s

* Values that have the same letter as a suffix are not significantly different from each other.

The higher fertility rates (half and full rate), produced higher nitrogen (N %) content values on the second rating date (table 8). Although, there were statistical differences between treatments for potassium (K %), sulfur (S %), iron (Fe ppm), manganese (Mn ppm), copper (Cu ppm) and aluminum (Al ppm) there were no differences between the main factors: air-infused versus untreated water, rates of water applications, and rates of fertilizer applications.

Table 8 – Nutrient analysis of plant tissue, September 1.

Water Source	Rate	Fertilizer	N %	P %	K %	Mg %	Ca %	S %
Untreated Water	5L/m^2	None	3.96def	0.36a	2.21abcd	0.23a	0.52a	0.40cd
Untreated Water	10L/m^2	None	3.82ef	0.38a	2.21abcd	0.22a	0.51a	0.40bcde
Air-Infused Water	5L/m^2	None	3.61f	0.34a	2.15cde	0.22a	0.50a	0.39cde
Air-Infused Water	10L/m^2	None	4.23bcde	0.36a	2.18abcde	0.23a	0.51a	0.38de
Untreated Water	5L/m^2	¼ rate	3.97def	0.36a	2.10de	0.24a	0.54a	0.38de
Untreated Water	10L/m^2	¼ rate	3.90def	0.32a	2.03e	0.23a	0.53a	0.37e
Air-Infused Water	5L/m^2	¼ rate	4.12cdef	0.35a	2.17bcde	0.21a	0.50a	0.38de
Air-Infused Water	10L/m^2	¼ rate	3.98def	0.34a	2.11cde	0.22a	0.52a	0.38e
Untreated Water	5L/m^2	½ rate	4.48abcd	0.38a	2.21abcd	0.24a	0.52a	0.42abcde
Untreated Water	10L/m^2	½ rate	4.51abcd	0.36a	2.33ab	0.24a	0.49a	0.44abc
Air-Infused Water	5L/m^2	½ rate	4.60abc	0.37a	2.35a	0.24a	0.51a	0.46a
Air-Infused Water	10L/m^2	½ rate	4.62abc	0.39a	2.28abc	0.25a	0.52a	0.44abc
Untreated Water	5L/m^2	Full Rate	4.73abc	0.38a	2.28abc	0.25a	0.53a	0.45ab
Untreated Water	10L/m^2	Full Rate	4.90a	0.39a	2.33ab	0.25a	0.51a	0.45ab
Air-Infused Water	5L/m^2	Full Rate	4.78ab	0.37a	2.26abcd	0.25a	0.51a	0.45ab
Air-Infused Water	10L/m^2	Full Rate	4.38abcde	0.37a	2.24abcd	0.24a	0.51a	0.43abcd
		$LSD_{0.05}$ =	0.61	n/s	0.17	n/s	n/s	0.04

Water Source	Rate	Fertilizer	B ppm	Fe ppm	Mn ppm	Cu ppm	Zn ppm	Al ppm
Untreated Water	5L/m^2	None	11.27a	431c	43.0c	15.6f	39.8a	279c
Untreated Water	10L/m^2	None	11.50a	463bc	46.0bc	16.6cdef	36.7a	286c
Air-Infused Water	5L/m^2	None	11.37a	519bc	45.3bc	16.1def	37.7a	336bc
Air-Infused Water	10L/m^2	None	11.30a	555bc	45.6bc	16.0ef	39.5a	349bc
Untreated Water	5L/m^2	¼ rate	11.07a	1029b	59.5bc	19.1abcde	53.8a	692b
Untreated Water	10L/m^2	¼ rate	11.25a	1637a	80.5a	21.7a	43.6a	1122a
Air-Infused Water	5L/m^2	¼ rate	11.60a	494bc	45.0bc	15.5f	35.7a	324bc
Air-Infused Water	10L/m^2	¼ rate	11.85a	814bc	54.9bc	18.0bcdef	43.5a	510bc
Untreated Water	5L/m^2	½ rate	10.60a	607bc	56.1bc	18.0bcdef	38.9a	434bc
Untreated Water	10L/m^2	½ rate	11.12a	362c	44.9bc	17.8bcdef	37.4a	263c
Air-Infused Water	5L/m^2	½ rate	11.62a	392c	45.4bc	18.2bcdef	39.0a	280c
Air-Infused Water	10L/m^2	½ rate	11.35a	457c	51.4bc	18.5bcdef	47.9a	315bc
Untreated Water	5L/m^2	Full Rate	11.25a	558bc	55.1bc	19.2abcd	40.8a	455bc
Untreated Water	10L/m^2	Full Rate	10.67a	399c	48.9bc	17.9bcdef	39.5a	277c
Air-Infused Water	5L/m^2	Full Rate	10.75a	639bc	53.8bc	19.3abc	41.0a	490bc
Air-Infused Water	10L/m^2	Full Rate	10.97a	772bc	61.6b	19.8ab	40.7a	592bc
		$LSD_{0.05}$ =	n/s	567	18.2	3.1	n/s	398

* Values that have the same letter as a suffix are not significantly different from each other.

The absorption of light in the red and near infrared bands is strongly influenced by chlorophyll content and plant cover. As chlorophyll content increases so does the absorption of light within the red band with peak absorption occurring at 670 nm. On the other hand, reflection of near infrared light that is measured at 780nm increases when chlorophyll contents are high. Green light when measured at 550nm is generally reflected and irradiance increases as chlorophyll content increases.

The values listed below would indicate that there was no difference in colour and area cover of turf when reflectance was determined at light spectral bands indicated (table 9).

Table 9 - Reflectance values for green, red and infrared bands, August 17.

Water Source	Rate	Fertilizer	Green Band	Red Band	Infrared Band
			550 nm ±10nm	670nm±10nm	780nm±10nm
Untreated Water	5L/m^2	None	0.116a	0.042a	0.785a
Untreated Water	10L/m^2	None	0.122a	0.051a	0.766a
Air-Infused Water	5L/m^2	None	0.110a	0.044a	0.731a
Air-Infused Water	10L/m^2	None	0.134a	0.052a	0.840a
Untreated Water	5L/m^2	¼ rate	0.103a	0.044a	0.768a
Untreated Water	10L/m^2	¼ rate	0.114a	0.044a	0.739a
Air-Infused Water	5L/m^2	¼ rate	0.108a	0.044a	0.750a
Air-Infused Water	10L/m^2	¼ rate	0.111a	0.041a	0.743a
Untreated Water	5L/m^2	½ rate	0.122a	0.049a	0.780a
Untreated Water	10L/m^2	½ rate	0.120a	0.047a	0.826a
Air-Infused Water	5L/m^2	½ rate	0.118a	0.046a	0.784a
Air-Infused Water	10L/m^2	½ rate	0.119a	0.052a	0.791a
Untreated Water	5L/m^2	Full Rate	0.124a	0.052a	0.811a
Untreated Water	10L/m^2	Full Rate	0.135a	0.051a	0.819a
Air-Infused Water	5L/m^2	Full Rate	0.124a	0.047a	0.801a
Air-Infused Water	10L/m^2	Full Rate	0.119a	0.046a	0.774a
		$LSD_{0.05}$ =	n/s	n/s	n/s

* Values that have the same letter as a suffix are not significantly different from each other.

The ratios of near infrared to green and red light spectrums did not reveal any differences.

Table 10 - Ratio of near infrared to green and red light spectrums.

Water Source	Rate	Fertilizer	NIR/Green (R_{780} / R_{550})	NIR/Red (R_{780} / R_{670})
Untreated Water	5L/m^2	None	6.7a	19.1a
Untreated Water	10L/m^2	None	6.3a	15.1a
Air-Infused Water	5L/m^2	None	6.6a	17.5a
Air-Infused Water	10L/m^2	None	6.2a	16.2a
Untreated Water	5L/m^2	¼ rate	7.5a	17.5a
Untreated Water	10L/m^2	¼ rate	6.6a	17.5a
Air-Infused Water	5L/m^2	¼ rate	6.9a	16.9a
Air-Infused Water	10L/m^2	¼ rate	6.6a	18.2a
Untreated Water	5L/m^2	½ rate	6.4a	16.3a
Untreated Water	10L/m^2	½ rate	7.0a	17.9a
Air-Infused Water	5L/m^2	½ rate	6.6a	17.1a
Air-Infused Water	10L/m^2	½ rate	6.8a	15.9a
Untreated Water	5L/m^2	Full Rate	6.5a	16.0a
Untreated Water	10L/m^2	Full Rate	6.1a	16.7a
Air-Infused Water	5L/m^2	Full Rate	6.5a	17.9a
Air-Infused Water	10L/m^2	Full Rate	6.6a	16.8a
		$LSD_{0.05}$ =	n/s	n/s

* Values that have the same letter as a suffix are not significantly different from each other.

When comparing treatments, there were no differences for the normalized differential vegetation index.

Table 11 - Normalized differential vegetation index (NDVI).

Water Source	Rate	Fertilizer	$NDVI_{550}$	$NDVI_{670}$
			$(R_{780} - R_{550}) / (R_{780} + R_{550})$	$(R_{780} - R_{670}) / (R_{780} + R_{670})$
Untreated Water	$5L/m^2$	None	0.74a	0.90a
Untreated Water	$10L/m^2$	None	0.72a	0.87a
Air-Infused Water	$5L/m^2$	None	0.74a	0.88a
Air-Infused Water	$10L/m^2$	None	0.72a	0.88a
Untreated Water	$5L/m^2$	¼ rate	0.76a	0.89a
Untreated Water	$10L/m^2$	¼ rate	0.73a	0.89a
Air-Infused Water	$5L/m^2$	¼ rate	0.74a	0.88a
Air-Infused Water	$10L/m^2$	¼ rate	0.73a	0.89a
Untreated Water	$5L/m^2$	½ rate	0.73a	0.88a
Untreated Water	$10L/m^2$	½ rate	0.74a	0.88a
Air-Infused Water	$5L/m^2$	½ rate	0.73a	0.88a
Air-Infused Water	$10L/m^2$	½ rate	0.74a	0.88a
Untreated Water	$5L/m^2$	Full Rate	0.73a	0.88a
Untreated Water	$10L/m^2$	Full Rate	0.72a	0.88a
Air-Infused Water	$5L/m^2$	Full Rate	0.73a	0.89a
Air-Infused Water	$10L/m^2$	Full Rate	0.73a	0.88a
		$LSD_{0.05}$ =	n/s	n/s

* Values that have the same letter as a suffix are not significantly different from each other.

The water use efficiency index showed that the higher water volume rate did not improve clipping yields but rather reduced the index value. The developed index value is a direct comparison between the amount of water applied and the clipping yield.

Table 12 - Water use efficiency index.

	July 11th	July 18th	July 25th	Aug 1st	Aug 8th
	$(g/m^2/week)/ L/m^2$				
Water Source					
Untreated Water	9.7a	7.1a	6.5a	2.9b	3.5a
Air-Infused Water	9.9a	7.3a	6.5a	3.2a	3.4a
Water Volume Application Rate					
$5L/m^2$	13.1a	9.7a	8.5a	4.1a	4.7a
$10L/m^2$	6.5b	4.7b	4.5b	2.0b	2.2b
Fertilizer Application Rate					
None	9.4a	6.6a	6.2a	2.7a	3.0a
¼ rate	9.9a	7.5a	6.4a	3.4a	3.5a
½ rate	9.8a	7.3a	6.6a	3.1a	3.5a
Full Rate	10.9a	7.5a	6.8a	3.0a	3.8a

	Aug 15th	Aug 22nd	Sept 1st	Sept 6th	9 Week Average
	——— (g/m^2/week)/ L/m^2 ———				
Water Source					
Untreated Water	2.6a	2.5a	1.3a	2.3a	4.3a
Air-Infused Water	2.8a	2.6a	1.2a	2.1b	4.3a
Water Volume Application Rate					
$5L/m^2$	3.7a	3.4a	1.8a	2.9a	5.8a
$10L/m^2$	1.8b	1.7b	0.8b	1.5a	2.9b
Fertilizer Application Rate					
None	2.4a	2.4a	0.7b	1.6b	3.9b
¼ rate	2.7a	2.7a	0.9b	1.7b	4.3a
½ rate	2.7a	2.4a	1.6a	2.5a	4.4a
Full Rate	3.0a	2.8a	1.9a	3.0a	4.6a

* Values that have the same letter as a suffix are not significantly different from each other.

Discussion

The method that was developed for measuring soil gas concentrations in this trial showed some potential for accurately measuring both oxygen and carbon dioxide. Values for oxygen in these soils ranged from 16.9-17.8%, while carbon dioxide ranged from 1.10-1.78%. Normal atmospheric values are 21% for oxygen and 0.04% for carbon dioxide.

The site where the assessments occurred was a high sand content putting green that was built some years ago to very tight specifications (United States Golf Association green construction specifications). This green was built in this fashion to ensure that there was a free flow of gases in and out of the soils.

The two assessments showed that there was some reduction in oxygen content and some increase in carbon dioxide. However, it is not known at what point normal growth processes would be negatively affected. However, this method appeared to measure these soil gases quite accurately and it may be a good method for future measurements. Future studies might compare good and poor quality putting greens for any differences in gas concentrations.

For this trial, the air-infused water showed a trend towards lower carbon dioxide levels than did the untreated water although it was not considered to be statistically different. This might indicate that the air-infused water actually reduced soil carbon dioxide levels, which would be a benefit to infusing water with air.

It also appeared that there was a trend toward higher concentrations of carbon dioxide as fertilizer rates increased. This might indicate that there was greater microbial activity in the soils from the application of the fertilizer.

Both of these results indicate that these factors might be easily measured with this gas detection system.

Appendix A

Olds Weather 2011 - Ag Canada Olds AGDM weather station

Date	Maximum Temperature	Minimum Temperature	Mean Temperature	Precipitation
	°C	°C	°C	mm
4-Jul	21.4	6.6	14	1
5-Jul	23.5	7.9	15.7	0
6-Jul	26	9.2	17.6	0
7-Jul	25.8	11.6	18.7	0
8-Jul	21.9	9	15.5	0.7
9-Jul	19.5	9.9	14.7	0
10-Jul	19.1	9.3	14.2	0
Week 0	22.5	9.1	15.8	1.7
11-Jul	21.1	11.5	16.3	6.3
12-Jul	19	12.2	15.6	M
13-Jul	20.5	12.3	16.4	3.2
14-Jul	21.7	9.2	15.5	0
15-Jul	24.3	7.2	15.8	0
16-Jul	23.7	7.4	15.6	0
17-Jul	27.7	9.7	18.7	0
Week 1	22.6	9.9	16.3	9.5
18-Jul	27.8	13.1	20.5	6.9
19-Jul	22.2	11	16.6	13.2
20-Jul	18.1	8.5	13.3	2
21-Jul	22	6.6	14.3	0
22-Jul	12.5	8.8	10.7	4
23-Jul	20.2	5	12.6	0
24-Jul	23	7.3	15.2	0
Week 2	20.8	8.6	14.7	26.1
25-Jul	25.2	9.3	17.3	0
26-Jul	18.5	10.7	14.6	6.1
27-Jul	18.6	9.8	14.2	4.8
28-Jul	21.5	10.6	16.1	0
29-Jul	20.5	7.9	14.2	0
30-Jul	24.7	5.9	15.3	0
31-Jul	26.9	11.8	19.4	0.5
Week 3	22.3	9.4	15.9	11.4
1-Aug	21.5	9.5	15.5	0
2-Aug	23.3	6.8	15.1	0.4
3-Aug	22.1	9.1	15.6	0

4-Aug	22.7	10	16.4	0.4
5-Aug	24.9	9.6	17.3	0
6-Aug	21.3	8.6	15	6.7
7-Aug	19.1	5.8	12.5	0
Week 4	22.1	8.5	15.3	7.5
8-Aug	23.2	7.8	15.5	0
9-Aug	25.2	8.4	16.8	0
10-Aug	23.7	9.7	16.7	1.6
11-Aug	20.3	9.5	14.9	0
12-Aug	23.1	8	15.6	0
13-Aug	25.9	7.1	16.5	0
14-Aug	24.1	8.9	16.5	0
Week 5	23.6	8.5	16.1	1.6
15-Aug	15.1	5.1	10.1	6.5
16-Aug	22.3	2.6	12.5	0
17-Aug	22.2	7.3	14.8	0
18-Aug	17.7	6.4	12.1	2.5
19-Aug	18.7	4.6	11.7	0
20-Aug	25.2	6.4	15.8	0
21-Aug	30.3	9.3	19.8	0
Week 6	21.6	6.0	13.8	9.0
22-Aug	29.8	10.5	20.2	0
23-Aug	23	9.9	16.5	M
24-Aug	29.4	7.6	18.5	0
25-Aug	22.5	9.8	16.2	M
26-Aug	23.7	8.4	16.1	0
27-Aug	M	8.6	M	M
28-Aug	M	M	M	M
Week 7	25.7	9.1	17.5	0.0
29-Aug	30.1	8.2	19.2	0
30-Aug	12.2	8.3	10.3	11.9
31-Aug	9.2	5.7	7.5	M
1-Sep	18.4	2.6	10.5	0.5
2-Sep	12.9	3.5	8.2	3.2
3-Sep	17.3	2.5	9.9	0
4-Sep	26.1	2.9	14.5	0
Week 8	18.0	4.8	11.4	15.6
5-Sep	26.4	7.6	17	0
6-Sep	26.6	6.9	16.8	0
7-Sep	28.1	7.4	17.8	0
8-Sep	28.5	7.3	17.9	0

9-Sep	29.4	8.9	19.2	0
10-Sep	24	8.6	16.3	0
11-Sep	20.9	8.4	14.7	0
Week 9	26.3	7.9	17.1	0.0