<국외우수논문>

CO_2 Content in Golf Green Rhizosphere

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ABSTRACT

Anaerobic soils limit the amount of free oxygen available in the rhizosphere and therefore will impede grass root development and restrain nutrient availability for turf growth. An in-situ study was conducted on existing greens to investigate the relationship between CO_2 content in the rhizosphere and turf quality. Nine greens were selected in the study. On each green, five 1-m diameter circular plots were randomly selected for conducting the experiment. The greens were sampled 7 times from August, 1998 to August, 1999. Data collected from each plot included turf quality index, CO_2 content, and physical properties of the rooting mixtures. Turf quality declined drastically when CO_2 content in rhizosphere increased to 5 to 6 μLL^{-1} during the late summer season. The CO_2 content increased as water content in the root zone increased, but was inversely related to infiltration rate. Cultivation of a golf green may reduce CO_2 content in the rhizosphere, but the benefit of cultivation decreased with time.

Introduction

Management of putting greens with high CO_2 content in the root zone has always been a dilemma to many the golf course superintendents and turf researchers (Bunnell and McCarthy, 1999; Chong et al., 2000). The composition of the atmospheric air has been described in detail (Brady and Weil, 2000; Bremner and Blackmer, 1982; Bunnell and McCarthy, 1999; Chong et al., 2000). In the air, nitrogen is dominant at about $0.78LL^{-1}$. The remainder of the air is primarily O_2, argon (Ar), and CO_2. These four gases make up

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over 0.9999LL^{-1} of the atmospheric air. However, the proportion of gases in soil air are different from that of the atmosphere. As a consequence of root respiration, microbial activity and poor air exchange in the profile, CO_2 concentration in the soil air is higher than atmospheric levels.

Both CO_2 and O_2 play very important roles in plant biological process (Kohnke, 1968). The main biological processes are photosynthesis and respiration. Reports (Currie, 1970; Jury et al., 1991) indicate that the O_2 consumption rate can be as high as 60 to 75% of the CO_2 production rate, reaching a maximum of 24gm^{-2} day^{-1}. It is important to note that CO_2 in the soil air is not only produced by plant root respiration, it also evolves from microbial breakdown of carbon-based organic compounds in the soil. The evolution rate of CO_2 may range from 1.2 to 35gm^{-2} day^{-1} (Ghildyal and Tripathi, 1983) and depends very much upon plant, soil and climatic conditions. However, it will be the highest when microbial and plant root activity is at a maximum, particularly in soils with poor drainage. Since soil air content in the root zone depends very much upon the aeration rate with the atmosphere, respiration rate of microorganism and plant roots, and solubility of gases in water, it is important to further understand the influences of soil air on turf growth. Most of the rhizospheric CO_2 and/or O_2 research has been conducted in agriculture fields. Only limited research on this topic has been conducted with recreation turf and sport fields.

Material and Methods

This was an in-situ study conducted on existing greens, therefore no control plot was set up for comparison in the experiment. The selected golf course is located in the Midwest which belongs to the transition zone. The construction of this 18-hole golf course was completed in 1993. The greens were constructed in California style (Davis et al., 1990) employed without a layer of gravel. The root zone mix was placed over a native Sexton silt loam (fine, montmorillonitic, mesic, Typic Ochraqualfs) (Herman et al., 1979). The green mix was designed to be 30cm deep. Located under the rooting mix are perforated plastic drainage tiles, 10cm in diameter, lying in the native soil.

The greens were cultivated using a hollow tine aerifier (1.2cm dia., 5×5cm spacing, and 7.5cm deep) in the first week of April and the last week of August in 1998. In 1999, the cultivation was performed again in the first week of April. In mid-June, the green was water-injection cultivated once using a hydrojet (Murphy and Rieke, 1994). No other cultivation was conducted until the end of experiment.

In the experiment, nine greens were randomly selected. On each green, five 1-m diameter circular plots were again randomly selected for measurement. All the plots were marked by referencing to the sprinkler heads. Data collected from each plot included water content, CO_2 content, turf quality index, and soil physical and chemical properties. In order to be consistent and to minimize the climatic influence on CO_2 content, all experiments were conducted between 6 to 10 a.m. with the condition that all greens had received regular irrigation and no rain three days prior to the measurement. Water content was detected by a time domain reflectrometry (TDR, Soil moisture Equipment, Santa Barbara, CA 93130). Moisture content (from 0 to 20cm) was measured at three different locations per plot and the mean value was used in the analysis. The in-situ CO_2 content in the root zone was measured using a portable infrared gas analyzer (purchased from the SubAir, Inc., Deep River, CT 06417). In the measurement, a 16-cm (depth) hole was prepared using a 1.2-cm diameter auger. Immediately after pulling the auger out from the green, a small plexiglass tube (8cm long, with 3.2 and 6.35mm inside and outside diameters, respectively) was inserted into the hole for extracting CO_2. The inlet of the tube was inserted into the hole and kept at 8cm below the green surface. The outflow of the tube was connected to a gas analyzer through a rubber stopper. The rubber stopper was used as a plug to prevent soil air contamination by the surrounding atmospheric air. Soil air was withdrawn directly from the hole by the infrared gas analyzer. CO_2 content was detected as the soil air passed through the gas analyzer. In the measurement, the reading of CO_2 content started from zero and gradually increased to a higher value and finally it decreased due to infiltration of surrounding atmospheric air into the rhizosphere. The highest value of the reading was recorded for analysis. The measurement was made one per plot and it took 2 to 3 minut

Turf quality was scored at the same time when CO_2 was measured. Turf quality was judged by visualization of percent of cover, vigor, and color of the turf by the same person for the entire study. In the assessment, percent of cover in each plot was scored from 0 to 100%. The turf vigor and color were combined into one single value and rated from 1 to 9 (with 9 the best). The turf quality index (TQI) was then calculated by (Boniak et al., 2001):

TQI = (Percent of Cover x Vigor and Color)/9

Totally, the experiment was conducted seven times for the entire study. The first measurement was conducted on August 29, 1998, the day before cultivation was performed. One month (on September 29, 1998) after the cultivation (using a 9-cm hollow tine), a second measurement was conducted. The last measurement made in 1998 was on November 23. In 1999, four measurements were conducted. These were on March 22, June 10, August 5, and August 26.

Infiltration was measured only once using a single-ring (12.7cm in diameter) infiltrometer on August 26, 1999. The infiltrometer was inserted 15cm into the soil. Prior to the measurement, in order to maintain an uniform antecedent condition, the soil profile was pre-wetted with 200ml of water. Immediately after the water disappeared from the surface, another 200ml of water was introduced into the infiltrometer. The infiltration time of the second water application was recorded for calculating infiltration rate.

Results and Discussion

Temperature can be critical to CO_2 content in soil air. Unfortunately, no climatological data was collected from the experimental site during the experimental period. However, in order to have some knowledge about the variations in air and soil temperature of each measurement in the region, the minimum, maximum and mean air and soil temperature three days prior to the measurement were obtained from a weather station located at about 4km south of the experimental site (Table 1). The data was published

Table 1. The minimum, maximum, and mean air and soil temperature in the studied region three days prior to each measurement of CO_2 content. These data was obtained from the bulletin published by the National Climatic Data Center (NCDC, 1998 and 1999).

Date	Air Temperature, ℃			Soil Temperature, ℃		
	Min	Max	Mean	Min	Max	Mean
Aug. 26 to 28, 98	15.1	30.3	23.7	22.3	26.3	24.3
Sept 26 to 28, 98	16.9	33.5	24.5	20.6	23.3	22.1
Nov. 20 to 22, 98	-3.0	16.1	6.8	8.3	9.9	9.7
Mar. 19 to 21, 99	-1.1	12.1	5.7	5.9	8.1	7.1
Jun. 7 to 9, 99	18.9	32.5	26.0	22.1	24.8	23.3
Aug. 2 to 4, 99	15.1	30.9	23.5	24.3	29.2	26.7
Aug. 23 to 25,99	15.0	28.9	21.9	22.6	27.3	24.5

Table 2. The range and mean value of turf quality index (TQI), water and CO_2 content in the root zone. The correlation coefficients (R) of CO_2 verses water content and TQI of each measurement are listed in the last two columns.

Sampling	Parameters									Correlation Coefficient	
Date	Soil water content, $cm^3\ cm^{-3}$			CO_2 Content, $\mu L\ L^{-1}$			TQI, %			R^H	R
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	CO_2 vs H_2O	CO_2 vs TQI
Aug. 29, 98	0.02	0.22	0.10(59)**	0.91	9.68	6.41(44)	36	100	78.5(22)	0.71****	-0.59***
Sept. 29, 98	0.09	0.29	0.20(23)	0.18	5.43	2.14(62)	29	99	72.8(21)	0.87****	-0.37*
Nov. 23, 98	0.16	0.37	0.24(19)	0.30	6.73	2.98(58)	65	94	82(10)	0.69****	-0.54***
Mar. 22, 99	0.15	0.39	0.25(23)	0.12	4.75	1.34(87)	54	87	74(10)	0.36*	-0.38*
Jun. 10, 99	0.11	0.28	0.19(22)	0.34	8.84	4.06(61)	90	100	98(3)	0.83****	-0.38**
Aug. 05, 99	0.10	0.27	0.18(22)	0.28	8.80	3.96(71)	67	100	92(8)	0.89****	-0.38**
Aug. 26, 99	0.11	0.27	0.19(21)	0.33	13.10	5.32(64)	69	100	92(8)	0.79****	-0.49**

H Correlation coefficient.

I Values in parentheses are coefficient of variation in %

*, **, ***, **** Significance of the regression at p # 0.05, 0.01, 0.001, and 0.0001, respectively.

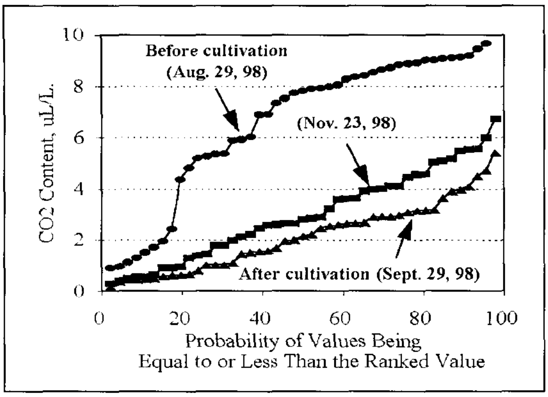

Figure 1. Changes in CO_2 content in golf green rhizosphere before and after cultivation in the Fall of 1998.

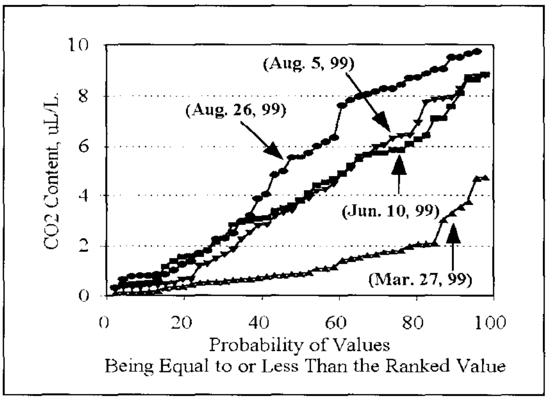

Figure 2. Variations in CO_2 content in golf green rhizosphere, 1999.

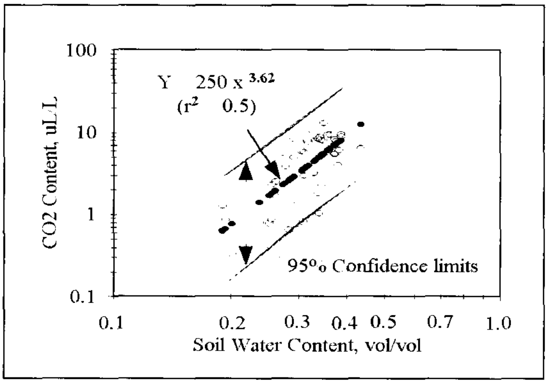

Figure 3. Relationships between water and CO_2 contents in golf green rhizosphere. The data presented were measured on Aug. 26, 1999 right before infiltration experiment was conducted.

by the Illinois Climate Network (WARMP, 1998 and 1999). Mean air and soil (at 10cm depth) temperature of first (Aug. 29, 1998) and second measurements (Sept. 29, 1998) were very close to each other. But, temperature of the third measurement (Nov. 23, 1998) was below 10℃ and close to the temperature of the late March measurement. The soil temperature of August 5, 1999 was the warmest among all measurements.

Large variations in CO_2 content were found during the experimental period (Table 2). Carbon dioxide ranged from 0.12 (in March) to 13.1 μLL^{-1} (in August). The golf green had high CO_2 content during the warm season particularly in late August. High accumulation of CO_2 may be attributed to high soil microbial activity in the golf green rhizosphere. Cultivation reduced CO_2 in the rhizosphere (Figure 1). CO_2 content measured on Aug. 29 and Sep. 29, 1998 had an average reduction from 6.4 to 2.1 μLL^{-1}. But, the results of Nov. 23 showed that CO_2 was higher than that of Sep. 29, 1998 with low soil temperature. The increasing CO_2 implied that benefit of cultivation decreased with time even under cooler temperature conditions. As expected, low CO_2 was detected in the early spring (Figure 2), perhaps due to slow root growth and minimum microbial activities. In addition, the spring

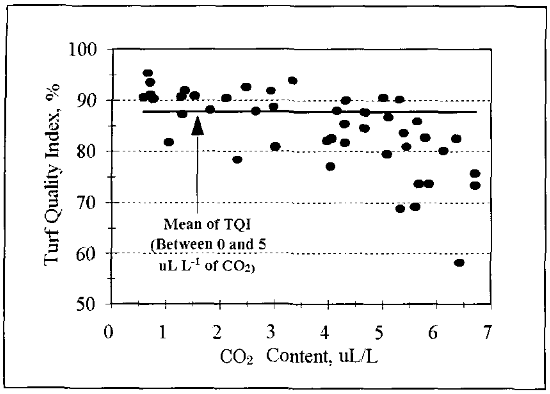

Figure 4. Responses of turf quality at various CO_2 contents in golf green rhizosphere mean of 7 measurements). The solid line represented the mean value of TQI calculated between 0 to 5μL L-1.

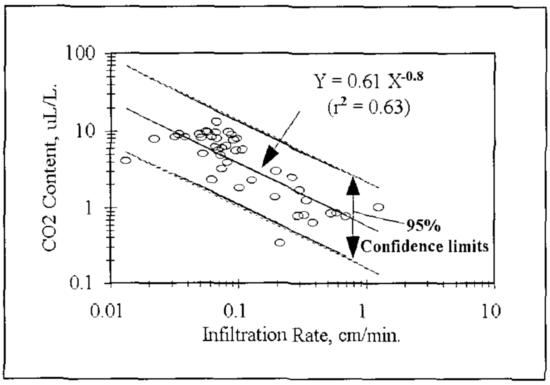

Figure 5. Relationship between infiltration rate and CO_2 content measured on August 26, 1999 in golf green rhizosphere.

rain may also displace CO_2 out of the rooting zone. As temperature became warmer, CO_2 content increased, especially in the late summer.

Statistical results showed a curve *linear relationship (see Figure 3 for* example) between soil moisture and CO_2 content. As water content in the rhizosphere increased, CO_2 also increased. The relationships were significantly related (P # 0.0001), except the measurement conducted on March 22, 1998. Conversely, CO_2 was negatively related to turf quality. Even though the correlation coefficients between CO_2 and turf quality index (TQI) were less than 0.6, they were statistically significant. Figure 4 shows the mean CO_2 and TQI values of the seven measurements of each plot. In Figure 4, the solid line was the mean value of TQI calculated with the CO_2 content ranged from 0 to $5\mu LL^{-1}$. It revealed that when CO_2 content reached $5\mu LL^{-11}$, TQI decreased drastically. The phenomena was particularly significant during the summer season.

Statistical results also showed that infiltration rate and CO_2 were inversely related (Figure 5) with a correlation coefficient of 0.79. It implies that a golf green with high infiltration rate will have a better aerated rhizosphere than *those greens with poor* drainage. In essence, soils with poor drainage will always result in poor turf quality.

Conclusion

Large variations in CO_2 content were found both spatially and temporarily in a golf green root zone. In general, CO_2 content in the golf green rhizosphere is low in the early spring. But, it increased to as high as $13\mu LL^{-1}$ during the late growing season. Results

indicated that when CO_2 content in the root zone accumulated higher than $5\mu LL^{-1}$, quality of the turf drastically declined. Cultivation of the green may reduce CO_2 content in the rhizosphere but the benefit of cultivation decreased with time. Soil physical properties likely play a very important role in CO_2 content. Soils with high water content and poor drainage resulted in high CO_2 content. Inversely, soils with high infiltration rates may reduce the accumulation of CO_2 content in the profile. Therefore, in order to maintain a healthy turf, good drainage with a well aerated rhizosphere is extremely important.

〈국문 적요〉

골프장 putting green 근권(根圈)에서의 이산화탄소 (CO_2) 함유량

Putting green의 높은 이산화탄소 함량은 많은 골프장 관리자들에게 있어서 green 관리시 항상 난제로 여겨져 왔다. 무기성 토양은 green 근권 (根圈:토양 중에서 뿌리의 영향이 미치는 범위)에서 이용 가능한 자유산소를 제한하며 그로 인하여 뿌리발달을 방해하며 잔디성장을 위한 영양분 이용도를 제지시킨다.

이 실험은 현 운영되는 골프장 (South Illinois, Carbondale, U,S,A) 에서 선택 되어진 아홉개의green 에서 근권의 CO_2 함유량과 잔디품질 (Turf Quality Index) 사이의 관계성을 조사하기 위하여 실행되어졌다. 아홉개의 putting green에서 각 green 의 다섯 곳의 소구획을 무작위로 선택하여 1998년 8월 부터 1999년 8월 까지 일곱번의 반복으로 잔디품질, CO_2 함유량, 수분함량과 수분 침투율 (Infiltration rate) 을 측정하였다. CO_2 함유량은 이른 봄 보다 늦은 여름에 높았으며 CO_2 함유량이 높아짐에 따라 잔디품질은 급격히 낮아졌다. 수분함량이 많을수록 CO_2 함유량이 높았으며 반대로 수분 침투율은 낮아짐을 보였다. 높은 수분 침투율은 CO_2 함유량을 감소시켰다. 결론적으로 알맞은 토양의 물리적 조건(수분 함량과 침투율)이CO_2 함유량과 잔디성장에 있어서 매우 중요한 역할을 함을 알 수있다. 잔디품질의 향상을 위해 putting green root zone의 알맞은 배수와 함께 근권의 공기 조건이 매우 중요함이 이 실험을 통해 조사되었다.

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