Carbon Dioxide Content in Golf Green Rhizosphere


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 CO2 content in the rhizosphere and turf quality. Nine greens were selected in the study. On each green, five 1-m-diam. circular plots were randomly selected for conducting the experiment. The greens were sampled seven times from August 1998 to August 1999. Data collected from each plot included turf quality index (TQI), CO2 content, and physical properties of the rooting mixtures. Turf quality declined drastically when CO2 content in the rhizosphere increased to 5 to 6 μL L⁻¹ during the late summer season. The CO2 content increased as water content in the root zone increased, but was inversely related to infiltration rate. Cultivation of a golf green may reduce CO2 content in the rhizosphere, but the benefit of cultivation decreased with time.

MANAGEMENT OF PUTTING GREENS with high CO2 content in the root zone has always been a dilemma to many 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 0.78 L L⁻¹. The remainder of the air is primarily O2, Ar, and CO2. These four gases make up >0.9999 L L⁻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, CO2 concentration in the soil air is higher than atmospheric levels.

Both CO2 and O2 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 O2 consumption rate can be as high as 60 to 75% of the CO2 production rate, reaching a maximum of 24 g m⁻² d⁻¹. It is important to note that CO2 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 CO2 may range from 1.2 to 35 g m⁻² d⁻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 CO2 and/or O2 research has been conducted in agriculture fields. Only limited research on this topic has been conducted with recreation turf and sport fields.

MATERIALS 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, smectitic, mesic, Chromic Vertic Epiaqualfs) (Herman et al., 1979). The green mix was designed to be 30 cm deep. Located under the rooting mix are perforated plastic drainage tiles, 10 cm in diameter, lying in the native soil.

The greens were cultivated with a hollow tine aerifier (1.2-cm diam., 5- by 5-cm spacing, and 7.5 cm deep) during the late summer season. The CO2 content included water content, CO2 content, TQI, and soil physical and chemical properties. To be consistent and to minimize the climatic influence on CO2 content, all experiments were conducted between 0600 and 1000 h with the condition that CO2 content in the root zone was measured at three different locations per plot and the mean value was used in the analysis. The in situ CO2 content in the root zone was measured with a portable infrared gas analyzer (Sub-Air, Inc., Deep River, CT). In the measurement, a 16-cm (depth) hole was prepared with a 1.2-cm-diam. auger. Immediately after pulling the auger out from the green, a small plexiglass tube (8 cm long, 3.2 mm i.d., and 6.35 mm o.d.) was inserted into the hole for extracting CO2. The inlet of the tube was inserted into the hole and kept at 8 cm 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. Carbon dioxide content was detected as the soil air passed through the gas analyzer. In the measurement, the reading of CO2 content started from zero...
Table 1. The minimum, maximum, and mean air and soil temperature in the studied region 3 d before each measurement of CO2 content. These data were obtained from the bulletins published by the National Climatic Data Center (Water and Atmospheric Resources Monitoring Program, 1998 and 1999).

<table>
<thead>
<tr>
<th>Dates</th>
<th>Air temperature</th>
<th>Soil temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>26–28 Aug. 1998</td>
<td>15.1</td>
<td>30.3</td>
</tr>
<tr>
<td>26–28 Sept. 1998</td>
<td>16.9</td>
<td>33.5</td>
</tr>
<tr>
<td>19–21 Mar. 1999</td>
<td>–1.1</td>
<td>12.1</td>
</tr>
<tr>
<td>7–9 June 1999</td>
<td>18.9</td>
<td>32.5</td>
</tr>
<tr>
<td>2–4 Aug. 1999</td>
<td>15.1</td>
<td>30.9</td>
</tr>
<tr>
<td>23–25 Aug. 1999</td>
<td>15.0</td>
<td>28.9</td>
</tr>
</tbody>
</table>

and gradually increased to a higher value, and finally 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 once per plot and it took 2 to 3 min to complete. The CO2 content collected from each measurement was plotted separately with the Weibull plotting position formula (Chow et al., 1988) for comparison.

Turf quality was scored at the same time when CO2 was measured. Turf quality was judged by visualization of percentage cover, vigor, and color of the turf by the same person for the entire study. In the assessment, percentage 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 TQI was then calculated by (Boniak et al., 2001):

\[
TQI = \left(\% \text{ of cover} \times \text{vigor and color}\right)/9
\]

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

Infiltration was measured only once by a single-ring (12.7-cm diam.) infiltrometer on 26 Aug. 1999. The infiltrometer was inserted 15 cm into the soil. Before the measurement, to maintain a uniform antecedent condition, the soil profile was wetted with 200 mL of water. Immediately after the water disappeared from the surface, another 200 mL 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 CO2 content in soil air. Unfortunately, no climatological data were collected from the experimental site during the experimental period. However, 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 temperatures 3 d before the measurement were obtained from a weather station located at about 4 km south of the experimental site (Table 1). The data were published by the Illinois Climate Network (Water and Atmospheric Resources Monitoring Program, 1998 and 1999). Mean air and soil temperature (at 10-cm depth) temperature of first (29 Aug. 1998) and second measurements (29 Sept. 1998) were very close to each other. But, temperature of the third measurement (23 Nov. 1998) was <10°C and close to the temperature of the late March measurement. The soil temperature of 5 Aug. 1999 was the warmest among all measurements.

Large variations in CO2 content were found during the experimental period (Table 2). Carbon dioxide ranged from 0.12 in March to 13.1 μL L−1 in August. The golf green had high CO2 content during the warm season, particularly in late August. High accumulation of CO2 may be attributed to high soil microbial activity in the golf green rhizosphere. Cultivation reduced CO2 in the rhizosphere (Fig. 1). Carbon dioxide content measured on 29 Aug. and 29 Sept. 1998 had an average reduction from 6.4 to 2.1 μL L−1. But, the results of 23 November showed that CO2 was higher than that of 29 Sept. 1998 with low soil temperature. The increasing CO2 implied that benefit of cultivation decreased with time even under cooler temperature conditions. As expected, low CO2 was detected in the early spring (Fig. 2), perhaps because of slow root growth and minimum microbial activities. In addition, the spring rain may also displace CO2 out of the rooting zone. As temperatures became warmer, CO2 content increased, especially in the late summer.

Statistical results showed a curvilinear relationship...
Fig. 1. Changes in CO₂ content in golf green rhizosphere before and after cultivation in the fall of 1998.

Fig. 2. Variations in CO₂ content in golf green rhizosphere, 1999.

Fig. 3. Relationships between water and CO₂ contents in golf green rhizosphere. The data presented were measured on 26 Aug. 1999, right before the infiltration experiment was conducted.

Fig. 4. Responses of turf quality at various CO₂ contents in golf green rhizosphere (mean of seven measurements). The solid line represented the mean value of TQI calculated between 0 to 5 µL. L⁻¹.
declined. Cultivation of the green may reduce CO₂ content in the rhizosphere, but the benefit of cultivation decreased with time. Soil physical properties likely play a very important role in CO₂ content. Soils with high water content and poor drainage resulted in high CO₂ content. Inversely, soils with high infiltration rates may reduce the accumulation of CO₂ content in the profile. Therefore, to maintain a healthy turf, good drainage with a well-aerated rhizosphere is extremely important.

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REFERENCES


