Carbon Dioxide – Friend or Foe?

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Bottom Line

Soil CO_2 levels above 3% will result in plant stress. To avoid accumulation of CO_2 in the soil, aeration and maintenance of low to moderate microbial activity is needed.

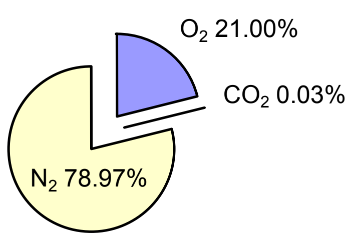
Carbon dioxide (CO_2) gas in the atmosphere is a critical component of our planet's existence. It is produced as a waste product by most living organisms. Plants, on the other hand, use photosynthesis to utilize CO_2 molecules and water to make carbohydrates (CH_2O) such as glucose, sucrose and starch – the primary energy storage molecules of plants. To complete the cycle, humans and other animals utilize plant-produced carbohydrates as an energy source to survive. From this perspective, CO_2 is an essential component of our survival.

Unfortunately, too much CO_2 can also be hazardous to plants. Based on our research and experience, we believe that the production of healthy turf depends very heavily on understanding, monitoring and keeping soil CO_2 levels low. This issue of *PACE Insights* will discuss the role of CO_2 in turf health and will present guidelines for monitoring CO_2. In addition, we will decribe a method that we have developed at PACE for measuring soil CO_2 levels that should aid you in management decisions such as timing and frequency of aerifications. But first, we'll present some background information on carbon dioxide.

Carbon dioxide and oxygen: a see-saw relationship.

The air that we breathe is made up of three main gasses – nitrogen, oxygen and carbon dioxide (Fig. 1).

Figure 1. The composition of the gasses in the atmosphere. Nitrogen, for the most part, consistently remains at 79%. Therefore, a decrease in O_2 results in an equal increase in CO_2



In the soil, CO_2 levels are typically higher than in the air, and can vary more as well, with levels as low as 0.3%, and as high as 10% recorded in the soil of Southern California golf course greens. These differences in soil CO_2 levels can make the difference between healthy turf and dead turf, as will be described below.

The relationship between CO_2 and oxygen (O_2) in both the air and the soil is tightly, and inversely linked. In other words, if oxygen levels decrease, then CO_2 levels will increase, as Figures 2 and 3 illustrate. In contrast, the level of nitrogen, the most plentiful of our atmospheric gasses, does not readily change, since nitrogen is inert – it does not react with most chemicals and only very few organisms can utilize nitrogen in their metabolic processes.

Because the quantity of CO_2 in the air and the soil is relatively low, seemingly small changes in oxygen levels can result in large increases in CO_2 percentages. For example, a drop in oxygen levels from 21% (the level normally found in air) to 18% reduces the amount of overall oxygen by 14%. This is calculated as follows:

$$\text{Reduction in } O_2 = \frac{\text{new } O_2 \text{ level} - \text{original } O_2 \text{ level}}{\text{original } O_2 \text{ level}}$$

Using the example above, we calculate:

$$\text{Reduction in } O_2 = \frac{18\% - 21\%}{21\%} \times 100 = -14\%$$

If oxygen goes down three percentage points as described above, then CO_2 will go up 3 percentage points – from the 0.03% normally found in air to 3.0%. Using an equation similar to the one above, we find that the increase in CO_2 from 0.03% to 3.0% results in a 100-fold increase, or a percentage increase of 9,900%!!! The way that a relatively small change in oxygen levels can result in a huge change in carbon dioxide is also illustrated in Figures 2 and 3 below.

Figure 2. Comparison between O_2 content of air (21%) to O_2 content of a soil with decreased oxygen levels.

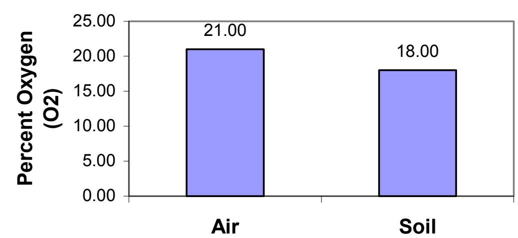
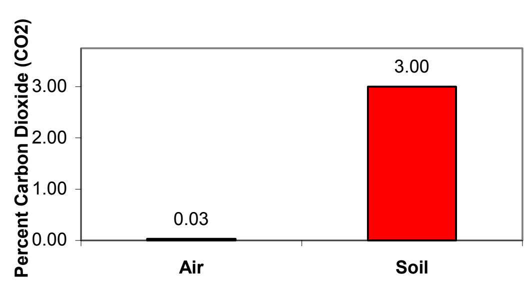


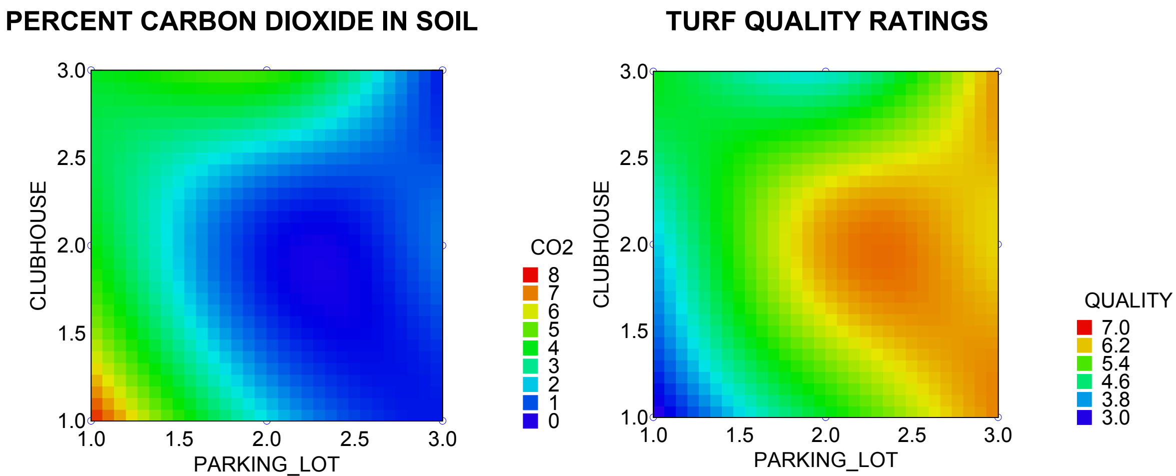
Figure 3. Comparison between CO_2 content of air (0.03%) to CO_2 content of a soil that may require aerification (3%).



The impact of high CO_2 levels on turf quality

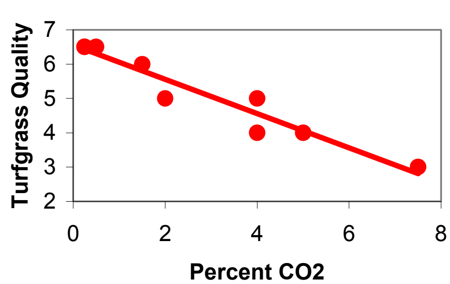
Why are we so concerned with the changes in CO_2 levels that can occur in soils? The reason is that high CO_2 in soils can have a serious and negative impact on turf health. This relationship is well illustrated through a study we conducted in cooperation with Candice Combs, superintendent at Balboa Park Golf Course in San Diego, CA. A bentgrass practice was evaluated for CO_2 levels and turf quality. Figure 4 illustrates the results of CO_2 and turfgrass quality ratings taken at nine locations on the green. At the time of the sampling, the bulk of the traffic entered the green at the corner where the parking lot and clubhouse walkway meet (represented by the lower left-hand corner of each graph in Figure 4 below). The highest soil CO_2 levels (up to 8% CO_2) were observed where the traffic was greatest. These same areas also reported the lowest turfgrass quality, illustrating what we already suspected – that high levels of CO_2 in the soil are injurious to turfgrass.

Figure 4. Relationship between soil CO_2 levels and turfgrass quality. Each graph represents the approximate layout of the practice green at Balboa Park Golf Course in San Diego, CA. "CLUBHOUSE" represents the location of the clubhouse, and "PARKING LOT" the location of the parking lot. Heaviest traffic occurs at the corner between the clubhouse and the parking lot. Nine soil CO_2 and corresponding turfgrass quality ratings (0 - 9 scale) were recorded in a 3 x 3 grid pattern. The data was smoothed using Distance Weighted Least Squares techniques to produce the geostatistical illustration of the CO_2 and turfgrass quality ratings.



Using the same data from the Balboa Park study, Figure 5 illustrates the very strong inverse correlation between CO_2 levels and turfgrass quality in a different way. By inverse correlation, we mean that as CO_2 levels increase, turf quality will decrease. Thus, high quality turfgrass (quality ratings of 6 or above) is associated with very low soil CO_2 levels (less than 1%), and low quality turf (quality ratings of 5 or below) is associated with CO_2 levels of 2% and higher. The take home message? Although there are many factors that influence turfgrass quality, the negative impact of high soil CO_2 levels on turf quality is difficult to ignore.

Figure 5. Correlation between soil CO_2 and turfgrass quality. The soil CO_2 and corresponding turfgrass quality evaluations illustrated in Figure 4 demonstrate the inverse correlation between soil CO_2 levels and turfgrass quality (quality = 6.6 - 0.5 * CO_2%, r^2 = 0.93, p<0.001).



Where does soil CO_2 come from?

Soil CO_2 is produced primarily by soil-dwelling microbes, insects and other invertebrates, with the majority of the CO_2 produced by microbes such as bacteria, fungi and algae. These organisms all consume O_2 and produce CO_2 as a by-product of their metabolism. As long as gasses in the soil can freely and rapidly diffuse and exchange with the air aboveground, a healthy balance of O_2 and CO_2 will result, and optimal root growth and development will occur. However, the thatch layer on the surface of a golf course green tends to act as a barrier for gas diffusion and is itself also a site for development of microbes and additional CO_2 production. And in addition to the thatch's interference with gas exchange, the compaction and high soil moisture that is frequently associated with golf course greens can further reduce the diffusion of soil gasses. Therefore, the soils under golf course greens frequently have elevated levels of CO_2.

In-field Monitoring

How can we monitor soil gasses, and which gasses should we focus on? It is commonly believed that reduced oxygen levels in the soil are responsible for decreased turf health. Although oxygen is important to the growth and development of roots, we now suspect that O_2 is present in sufficient levels under most conditions. Instead, we believe that it is the direct impact of elevated CO_2, and not reduced O_2 that causes the greatest root stress in turfgrass soils. This was illustrated in our study at Balboa Park Golf Course, and is corroborated by other researchers (Zobel, 1996) who indicate that soil CO_2 levels above 2% can modify or suppress root growth and development.

In order to manage soil gasses, an inexpensive monitoring system has been identified to help golf course superintendents and other professionals in the golf course industry evaluate soil CO_2 levels. The system is based upon a simple hand operated gas pump and gas detector tubes developed by Dräger (Drägerwerk Aktiengesellschaft, Lübeck) and distributed throughout the USA by a variety of companies including SKC-West, Inc., Fullerton, CA 714-992-2780 (Figure 6). The Dräger tube arrives as a glass cylinder with the ends melted closed. The ends are broken off the tube using a small breakage device built into the bottom of the pump. After breaking both ends of the tube, the tube is inserted into the rubber fitting on the pump with the arrow printed on the tube pointing toward the pump. A few easy adaptations should then made to make the system operable for soil sampling. A short piece of Tygon or vinyl tubing (available at most hardware stores) with a ¼ inch inside diameter (ID) is used to couple the tube to not more than 12 inches of vinyl tubing with a 1/8 inch ID (about ¼ inch outside diameter (OD). The small diameter and length of tubing is used to minimize the "dead-volume" of gas present between the Dräger tube and the soil. To aid in sampling the gas in the soil, a small section of 1/8 inch OD stainless tubing can be inserted into the end of the 1/8" ID vinyl tube. The end of the stainless tube is clamped shut and two holes are drilled into the side of the tubing to result in sampling at ½ and 1 inch in depth when the tube is inserted into the soil.

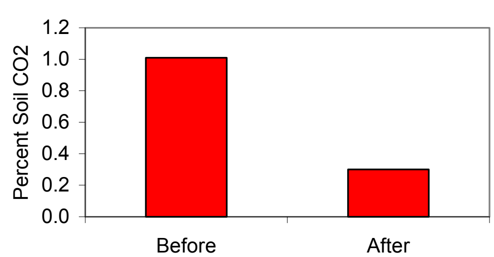
The Dräger pump is a precision gas pump that withdraws 100 cc of gas for each compression of the device. In this way, soil gasses are drawn into the CO_2-sensitive Dräger tubes. The instructions that accompany the tubes describe how many compressions of the pump are needed for the specific sensitivity of the tubes. When CO_2 enters the Dräger tube, a chemical reaction occurs, which results in a purple color inside the tube. The more CO_2 present in the soil, the higher the purple color will rise along a scale on the tube that reads from 0-10% (Figure 6). In this way, the percentage of CO_2 in the soil can be determined.

Figure 6. Dräger pump on the left side of the image and close-up of the CO_2 sensitive Dräger tube on the right. A piece of Tygon tubing is used to connect the tube with the soil probe. The damaged area of turf in the photograph below reported high CO_2 (6 - 7.5%), whereas the surrounding healthy area reported less than 3% CO_2.

Illustrating the benefits of aeration

Benefits of monitoring soil carbon dioxide include using your findings to help identify early warning signs that greens need to be aerified, or helping to determine which greens will require more frequent than scheduled aerations. Monitoring CO_2 can have another important benefit – it can visually illustrate to golfers, management and greens committees the value of aeration in reducing soil CO_2 levels. This can be accomplished by taking CO_2 readings before and after aeration and viewing the different readings that you obtain using the color sensitive Dräger tubes. An example of this type of demonstration is illustrated in Figure 7 below where the before-aeration soil CO_2 level was 1%.

Figure 7. CO_2 concentration before 1/4 inch solid tine aeration and 24 hrs after aeration (measured between the aeration holes). The average of nine replicate measurements before aeration was 1.0% CO_2 and the average after aeration was 0.3% CO_2. The means are significantly different using Fisher's LSD ($p<0.003$). Data from Balboa Park Golf Course, San Diego, CA.



Although 1% CO_2 is not considered damaging, it indicates that some restriction of gas exchange is present. Following aeration, the soil CO_2 level dropped to 0.3% between the aeration holes.

We do not recommend that you use CO_2 monitoring as your only indicator of the need for aeration, since there are many other reasons (compaction, scheduling, etc) why greens should be aerified. However, monitoring CO_2 is one additional tool you now have in your arsenal of management practices. Whether or not you choose to use the CO_2 monitoring system described above, we recommend that your management practices include:

- Aggressive spring aeration using 5/8 inch hollow cores to 3 inches, and removal of the cores followed by spreading ¼ inch depth of dry USGA specification sand (no organic matter). Immediately following application of the dry sand, vertidrain using ¾ inch solid tines to a depth of 9 inches.
- During the growing season, aerify monthly using ¼ inch solid tines on a 2x2 inch spacing.

These procedures will maintain a desirable physical and gaseous environment throughout the major stress period of the year. Of course, other management practices and nutrition factors are still important, but through better management of the physical and gas environment underneath your greens, it will be easier to maintain a healthy root zone.

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