Carbon dioxide monitoring for improved turf health: new information

by Wendy Gelernter, Ph.D. and Larry J. Stowell, Ph.D.

Bottom line: Under optimal conditions, carbon dioxide (CO_2) makes up less than 2% of the gasses found in the soil. But if there is interference with soil gas movement, CO_2 levels will begin to climb. For this reason, soil CO_2 levels above 2% are a good indicator that something is wrong with water and/or air movement in the soil, and that turf health and quality will soon be threatened. Regular monitoring of soil CO_2 can help warn you of impending problems such as poor drainage and waterlogged soils, excessively high numbers of soil microbes, compaction and surface sealing – all of which can lead to anaerobic soils and turf decline and death. Keeping track of soil CO_2 levels will also allow you to implement preventive measures (aeration, topdressing, proper amendment and fertilizer selection) before turf quality is damaged, and can help you to justify these preventive measures to golfers, managers and greens committees.

In October of 1998, we devoted an issue of *PACE Insights* to the topic of monitoring carbon dioxide in soils as a new tool for locating and managing incipient problem areas on the golf course. At that time, we suggested that monitoring for carbon dioxide (CO_2) and aerifying if levels became higher than 2% could help superintendents manage and even avoid serious problems such as compaction, poor drainage, surface sealing, excessive microbial populations, black layer and anaerobic soils. We also argued that, contrary to popular thought, it made more sense to monitor soil CO_2 than to monitor soil oxygen, because carbon dioxide levels are a much more sensitive indicator of soil health than oxygen.

Over the past three years, we have tested out these principles on several golf courses, and have had the opportunity to review additional data on soil carbon dioxide. We have also tested new methods for monitoring CO_2, and have investigated new strategies for improving turf health by reducing soil carbon dioxide levels. The good news, which we will summarize below, is that CO_2 monitoring and the measures used to keep CO_2 levels low continue to be valuable tools for preventing many turf health problems and that, thanks to some new products, these procedures are easier to conduct than in the past.

The split personality of carbon dioxide

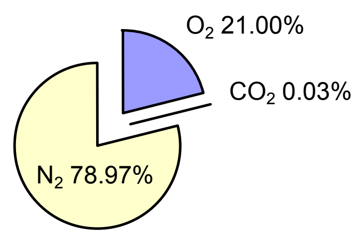
For animals, fungi, most bacteria and plant roots, carbon dioxide gas (CO_2) is a waste product that is produced during day-to-day respiration. As for other waste products, the build-up of carbon dioxide can be toxic to the organisms that produce it. But the opposite is true for green plants (except for plant roots) and algae. For these photosynthesizing organisms, carbon dioxide is not a waste product, but is instead essential for life. Along with sunshine and water, CO_2 is the fuel that allows plants to grow, to flower, to produce the grains, vegetables and fruits that we rely on for food, and to produce the oxygen that we rely on to breathe.

The pathway that carbon dioxide travels, from its production by animals as a waste product, to its consumption by plants as a life-giving fuel, is known as the **carbon cycle**. Keeping the proper balance between oxygen and carbon dioxide in both the air and the soil is critical to life.

Too much of a good thing

When the carbon cycle is in balance, our air contains about 0.03% carbon dioxide, 21% oxygen and 79% nitrogen (Figure 1). But when things get out of balance, problems result. The **greenhouse effect**, which has received scientific and media attention over the past several years, has resulted from increased levels of carbon dioxide in the atmosphere, probably due to increased burning of fossil fuels.

Figure 1. The composition of the gasses in air. Nitrogen (N_2) is nearly inactive and for the most part remains at 79%. But oxygen (O_2) and carbon dioxide (CO_2) levels are linked in such a way that if CO_2 levels go up, O_2 levels will go down, and vice-versa.



Increased levels of CO_2 in soils can cause problems too, though the impact does not have the worldwide significance of high CO_2 in the atmosphere. Nevertheless, the significance of high soil CO_2 can be just as devastating for plant health and growth. To understand why high CO_2 is an important indicator of soil and plant problems, let's first look at how carbon dioxide gets into the soil in the first place.

Soil organisms: bacteria, fungi, algae, earthworms and insects produce a great deal of the CO_2 that occurs in the soil, and aggressively compete with roots for oxygen. While the vast majority of these soil organisms benefit the soil by decomposing dead plant tissue, nitrifying the soil and in the case of earthworms, even aerifying the soil, their negative side effects are the production of CO_2 and consumption of oxygen.

<u>Plant roots</u>: unlike the green parts of plants which consume carbon dioxide, roots respire the same way that we do – by taking in oxygen, and by producing CO_2 as a waste product. Ironically, the healthiest plants with the biggest root systems will produce the highest levels of CO_2 in the soil.

<u>Thatch</u>: like plant roots, thatch also respires and produces CO_2. In addition, the thatch serves as a nutrient source for soil microbes, thus indirectly contributing to soil CO_2 levels in two different ways.

If soil were perfectly porous, this CO_2 wouldn't be a problem because soil gasses would move easily through the air-filled pores of the soil and up into the atmosphere. Unfortunately, soils on golf courses are not perfectly porous, and in fact suffer from many abuses that obstruct the movement of CO_2 and other gasses from the soil and into the atmosphere.

The ideal soil: not available for use on golf courses

Carbon dioxide levels in soils – even the healthiest of soils – are usually about 1- 2%, or at least 30 times higher than they are in the air. The solid nature of soil particles and the presence of water in soil both act to slow down gas movement. As a result, some of the CO_2 produced by the teeming life that lives underneath the soil surface gets trapped there, and is only able to seep out into the atmosphere very slowly. But there are additional obstructions to soil gas movement that are commonly encountered on golf courses including:

<u>Compaction</u>: when soil particles are packed too tightly together, the number and size of air filled pores is reduced, which blocks gas movement. Traffic is one of the culprits in this type of compaction. But another important contributor is the game of golf itself, which demands some level of compaction in order to provide an even, consistent and firm surface.

<u>Water</u>: in poorly drained and waterlogged soils, excess water can obstruct the free flow of gasses between the soil and the atmosphere.

<u>Silt</u>: fine particles of silt or organic matter can also fill up soil pores and make gas movement difficult.

<u>Surface sealing</u>: an almost impermeable barrier can form at the soil surface for a variety of reasons including the growth of bacterial and algal slime. CO_2 movement out of the soil can also be blocked by the thin layer of water at the top of the soil profile that is created when turf is watered in small and frequent bursts of irrigation.

<u>Thatch</u>: heavy thatch acts as a barrier to gas flow.

When any one of the above problems occurs, soil carbon dioxide levels can zoom up from the healthy range of 1-2% to as high as 10%. Data generated at PACE (Figure 2) and data generated by Dan Dinelli, CGCS (Figure 3, Table 1) confirm that when CO_2 levels are higher than 2%, turf quality problems result.

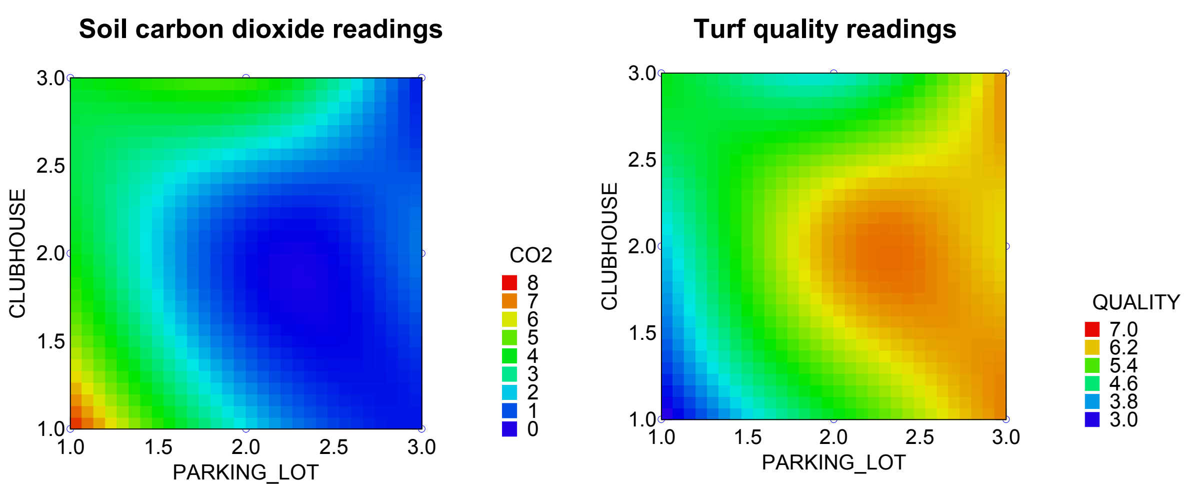


Figure 2. Relationship between soil CO_2 levels and turfgrass quality, Balboboa Park Golf Course, San Diego (Candice Combs, CGCS). This putting green suffers from heavy traffic where the parking lot and clubhouse walkway meet (lower left hand corner).

Note that the highest soil CO_2 levels (up to 8%) and the lowest turf quality were observed where foot traffic was greatest. Turf with acceptable quality occurred only when soil CO_2 levels were less than 2%.

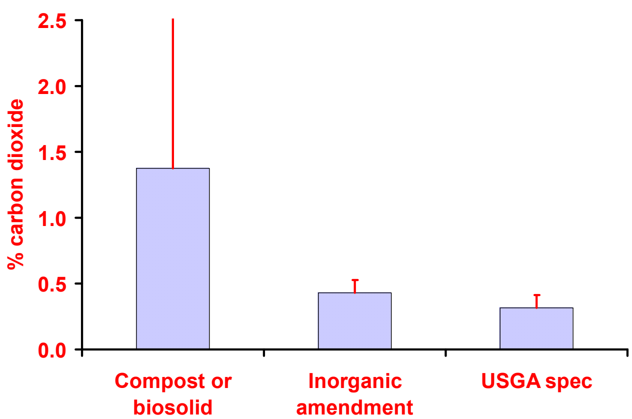
Innovation on the golf course: North Shore CC

Starting in 1998, superintendent Dan Dinelli, CGCS and assistant Dan Garling have investigated methods for improving water and gas movement at North Shore Country Club in Glenview, IL. Their results have confirmed and expanded our view of the utility of monitoring CO_2 for improved turf health, and have also provided insights on the best way to manage high CO_2 situations. Highlights of their work, which is still ongoing, include:

- When soil CO_2 levels reached 3-5%, turf thinning and loss of root mass were observed. This is similar to the pattern that we have seen in PACE studies, as illustrated in Figure 2 above.

- Push-up greens generally had higher concentrations of soil CO_2 than USGA sand greens. This illustrates that the higher proportion of fine soil particles and of organic matter typically associated with push up greens can cause problems (including compaction and poor drainage) that lead to the build-up of CO_2.
- Greens amended with organic materials (including biosolids, composts and seaweed meal) had much higher concentrations of soil CO_2 than either USGA greens or greens amended with inorganic materials (Figure 3). This is the result of a combination of factors, including the higher number of soil microbes that are supported by organic material.
- Methods that were successful in reducing soil CO_2 levels included aerification (hydroject or vertidrain) and sub-surface vacuum extraction (Figure 4)

Figure 3. The role of root zone amendments on soil CO_2 levels. Dan Dinelli, CGCS, North Shore Country Club. Purple bars represent the average percent soil CO_2 levels on greens amended with either: 1) compost, biosolid or other organic amendments; 2) inorganic amendments; 3) USGA spec materials. Data was taken on 4 dates during July and August, 1998. The red lines associated with each bar (standard deviations) indicate the variability, or spread of values associated with each average value. Note that soils amended with composts or biosolids had much higher CO_2 levels than soils amended with either USGA spec materials or with inorganic amendments (significant at P<0.001, Fischer's LSD).



In-field monitoring

Regular monitoring of soil CO_2 can help warn you of impending problems **before** turf health is seriously threatened, and for this reason can be a valuable tool for preventing poor drainage and waterlogged soils, excessively high numbers of soil microbes, compaction and surface sealing – all of which can lead to anaerobic soils, black layer, turf decline and death .

Keeping track of soil CO_2 levels will also allow you to implement preventive measures (aeration, topdressing, proper amendment and fertilizer selection) before turf quality is damaged, and can help justify these measures to golfers, managers and greens committees.

Table 1. Amendments tested in North Shore Country Club trial. Materials were incorporated into the top 6 inches of the rootzone in plots that measured 14 X 15 feet. The plots were sown with a 50/50 blend of L-93 and SR-119 creeping bentgrass.

Compost or biosolid (added to 90/10 Feltes sand + peat)
Optimil (seaweed meal + milorganite)
Sand-Aid (seaweed meal)
Greencycle yardwaste compost
Chicago water reclamation district biosolids
Yardwaste compost and biosolids
Earthworm castings
Inorganic amendment (added to 90/10 Feltes sand + peat)
Chip humate
25% Profile (porous ceramic)
15% Profile + Zeopro (modified zeolite)
10% Zeopro
10% Axis (diatomaceous earth)
10% Axis + Zeopro
Paramagnetic rock+hard rock phosphate+greensand
Hydrozone (water absorbing copolymer)
USGA spec
Unamended Feltes sand
85/15 Feltes sand + sphagnum peat
90/10 Feltes sand + reed sedge peat

Figure 4. Sub-surface vacuum extraction equipment used at North Shore Country Club (Soil Air Technology, Middlefield, CT. www.soilair.com). Soil CO_2 was significantly reduced after the system was run for one hour. Primarily used for dewatering greens with drainage problems, sub-surface vacuum extraction also improved infiltration rates by about two-fold. Note: this technology is covered by U. S. Patent No. 6,018,909, the use of which was licensed to North Shore Country Club by Soil Air Technology, LLC.

We have identified two CO_2 monitoring systems that are relatively easy to use. Previously (October, 1998 Insights) we described the use of a gas pump and detector tools developed by Dräger, which are distributed in the USA by a variety of companies including SKC-West, Inc., Fullerton, CA 714-992-2780 or www.skcwest.com (Figure 5). Although this equipment provides a good assessment of soil carbon dioxide levels, purchase of new CO_2 sensitive tubes are required for each reading, which can make the process expensive over time.

Figure 5. CO_2 monitoring with a Dräger pump. This precision gas pump withdraws 100 cc of gas for each compression of the device into the CO_2-sensitive Dräger tubes. When CO_2 enters the tube, a chemical reaction occurs which causes a purple color to form. 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%. In this way, the percentage of CO_2 in the soil can be measured. The damaged area of turf in the photograph below reported high CO_2 (6 - 7.5%), whereas the surrounding healthy area reported less than 2% CO_2.

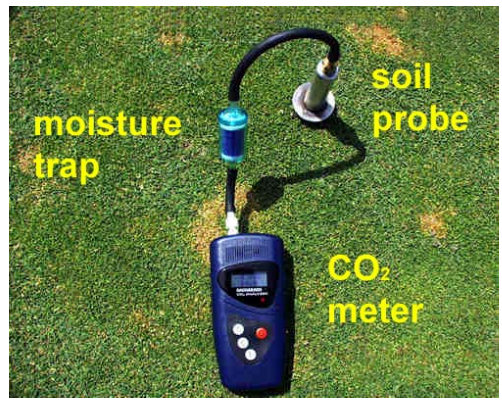
We have recently found an alternative to the Dräger pump which although initially more expensive ($1550), does not require the perpetual puchase of new CO_2 sensitive tubes. The Bacharach CO_2 analyzer (Figure 6) is a small handheld device that can detect CO_2 between 0 and 60% (model 2820, available from Bacharach: 800-736-4666 or www.bacharach-inc.com). When compared to the Dräger pump, the cost of the Bacharach analyzer breaks even if you anticipate conducting more than 250 analyses.

Reducing soil carbon dioxide

When soil carbon dioxide readings approach 2%, it's time to begin taking preventive action in order to avoid turf injury. Depending on the cause of the CO_2 build-up, some possible approaches include:

- Avoid the use of organic fertilizers and amendments on greens. These products can cause microbial populations to increase rapidly, thus robbing roots of oxygen and contributing to high CO_2 levels.
- Manage traffic to avoid compaction.
- Address drainage problems through leaching, topdressing, sub-surface vacuum treatments (see Figure 4 above).
- Avoid frequent and light irrigation.
- Regular "venting" of turf; in other words, aerification, aerification and aerification (see below).

Figure 6. The Bacharach CO_2 meter. Rubber tubing is used to connect the meter to the moisture trap and between the moisture trap (this analyzer will be damaged by moisture) and the soil probe (soil probe from Soil Air Technology). Press the red button to turn on the meter and record the maximum CO_2 reading seen within the first minute or two of operation.



The beauty of "venting"

Milt Engelke of Texas A and M first suggested the use of the term "vent" to describe the benefits of aerification, and we find it to be a very useful and also accurate way to illustrate those benefits. The best way to avoid the build-up of soil CO_2 is via monthly "venting" using small diameter (1/4") solid tines on a 2X2 spacing In heavily trafficked areas, or in areas that are prone to black layer, small tine aerification can be used even more frequently to keep greens breathing. The venting procedure may cause some bumpiness for one to two days, but recovery is rapid when the turf is healthy. But a word of warning about venting turf that is heavily stressed: although aerification can help stressed turf in the long-term, you may incur more damage in the short-term than you are willing to suffer with because the stressed turf will be slow to recover. For this reason, *venting should be used as a preventative strategy, and **not** as a remedial tool used after damage has occurred.*

Another innovative method for maintaining a healthy soil gas atmosphere is the use of subsurface air movement, as Dan Dinelli has illustrated in his research at North Shore Country Club (Figure 4). There is obviously a significant investment in equipment and time with this approach, but the benefits in terms of improved drainage, gas movement and overall turf health can be significant.