PACE INSIGHTS

It's the oxygen!

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

Bottom line: Several research studies conducted in the past few years have pointed to excessive carbon dioxide (greater than 2%) as a major contributor to turf quality declines on greens that suffer from compaction, poor drainage or excessive thatch. However, we have found, in a recent study, that CO_2 is probably only a symptom – and not the cause – of this type of turf quality decline. Instead, low levels of soil oxygen (less than 19%) are the culprit. A series of cultural practices that are targeted towards improved air and water movement can help keep soil gasses in the healthy range of greater than 19% oxygen. These practices include aerification, sand topdressing, traffic management, avoidance of light and frequent irrigation and cautious use of organic fertilizers on putting greens.

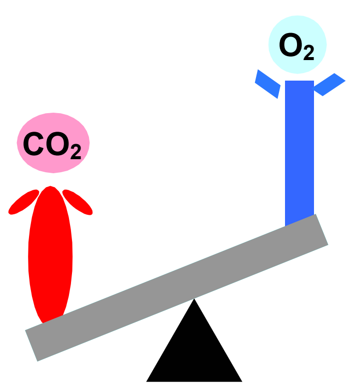
The 2% trigger point

For the past several years, we have been investigating the role of soil carbon dioxide (CO_2) in turf health. Over the course of several field experiments, we have found that by keeping levels of soil CO_2 below 2%, many of the problems that typically beset putting greens can be avoided (Table 1). Additionally, we have found that the 2% CO_2 trigger point is useful for initiating preventive practices (aeration and topdressing) that can help avoid development of these troublesome conditions.

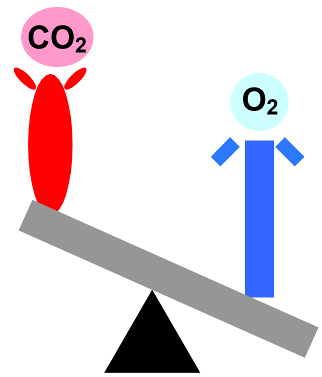
Table 1. Soil carbon dioxide readings above 2% are an indication that there is something amiss with either air or water movement on putting greens. Turf health and quality will soon be compromised unless remedial actions are taken. Some of the conditions which can lead to soil CO_2 readings above 2% include:

- **Poor drainage**
- **Waterlogged soils**
- **Frequent rain or light and frequent irrigation**
- **High levels of compaction (due to foot and vehicular traffic)**
- **High populations of soil microbes**
- **Surface sealing**
- **Anaerobic soils**
- **Heavy thatch accumulation**
- **Buildup of organic matter above 4%**

When one goes up, the other must go down



The air that we breathe is made up primarily of nitrogen, oxygen and carbon dioxide. Under normal conditions, nitrogen makes up almost 78% of the air, oxygen contributes almost 21%, and carbon dioxide is a mere 0.03%. Of these three gasses, the level of nitrogen is always constant. As a result, if the amount of oxygen goes down, the level of CO_2 will increase by exactly the same amount. The type of relationship demonstrated by oxygen and carbon dioxide is known as an inverse relationship – when one goes up, the other goes down by the same amount.



The most newsworthy example of this inverse relationship occurs in our atmosphere with **the greenhouse effect.** As the result of the burning of fossil fuels, the amount of carbon dioxide in our atmosphere is slowly increasing, while the amount of oxygen is decreasing, a situation that scientists have shown is related to global warming.

In the soil, we see this same inverse dynamic between carbon dioxide and oxygen – only in the soil, the levels of oxygen are lower and the concentrations of carbon dioxide are always higher (Table 2). In fact, even a healthy soil has almost 100 times more carbon dioxide than the air does.

Table 2. Gas composition of air and different soils. Note that nitrogen stays constant, regardless of the environment. Only oxygen and carbon dioxide change.

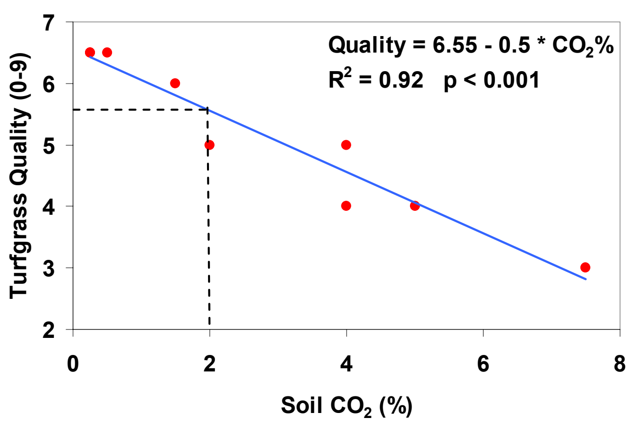
	Air	Healthy soil	Waterlogged soil	Anaerobic soil
% Nitrogen	77.97	77.97	77.97	77.97
% Oxygen	21.00	19.03	5.00	0
% Carbon dioxide	0.03	2.00	16.03	21.03
% Trace gasses	1.00	1.00	1.00	1.00
Total	100	100	100	100

Why is there such a big difference in CO_2 levels in air vs. soil? The primary reason rests with the fact that most living organisms take in oxygen, and produce carbon dioxide as part of their respiratory cycle. In other words, the plant roots, microorganisms, insects and earthworms that live beneath the soil surface are converting much of the oxygen in the soil into carbon dioxide. Under normal conditions, some of this CO_2 diffuses, or passively moves from the soil into the atmosphere; similarly, some of the oxygen in the atmosphere will diffuse back into the soil. But there are many barriers that can stand in the way of this movement of soil gasses (Table 1). Anything that causes the soil surface to seal, or causes the pores between soil particles to become clogged with either water, organic material or fine particles (thus stopping the movement of gasses) will allow oxygen (O_2) to become depleted, and CO_2 to rise.

Too much carbon dioxide, or too little oxygen?

Turfgrass quality typically begins to decline when soil CO_2 levels are greater than 2%, as illustrated in Figure 1. This graph shows the relationship between turfgrass quality (rated visually on a scale of 0 – 9, where 9 is the best possible turf) and soil CO_2. Turfgrass quality declines to below 6 (we usually consider 6 to be barely acceptable for putting greens) when soil CO_2 is higher than 2%.

Figure 1. Relationship between turfgrass quality and soil CO_2 levels. Data from Balboa Park Golf Course practice putting green. Candice Combs, superintendent. Note that soil carbon dioxide levels greater than 2% result in turf quality that is less than acceptable (less than 6 on a turf quality scale of 0 – 9).



As Table 2 shows above, problem soils result when carbon dioxide is too high and oxygen is too low. But which is responsible for the decline in turf quality – are the high levels of carbon dioxide toxic to the plant? Or is the plant merely deprived of the oxygen it needs to survive? The research on this question is sketchy. Some researchers believe that when CO_2 levels reach 10% and above, the carbon dioxide itself can be toxic to the plant (Brady and Weill, 1999), but it is not clear whether carbon dioxide is toxic to plants at levels lower than 10%. Carbon dioxide is thought to damage plants by reducing the pH of turf root cells to the point where they can no longer take up water or nutrients (Bunnell et. al., 2000). However, once again, there is not a lot of data to support this – we are in the realm of educated guesses, rather than hard data.

To get a better handle on this question, we initiated a research trial in 2002, with the cooperation of La Jolla Country Club superintendent Bruce Duenow.

Playing with air

As illustrated in Table 2 above, the concentration of nitrogen in the air and in the soil air tends to remain the same, at a solid 78%, with only carbon dioxide and oxygen changing as conditions change. But experimentally, we can create conditions that would never exist in Nature, including a soil environment where excess carbon dioxide causes nitrogen (which usually doesn't change in concentration at all) to decline, and oxygen (which usually declines inversely as carbon dioxide increases) to retain a more stable concentration. We did this by injecting CO_2 into the soil through a 3.2 mm (1/8") diameter stainless steel tube (Figure 2) that was inserted 2 inches below the soil surface. The turf used in the study was located in a Crenshaw bentgrass nursery that was mowed at greens height.

Figure 2. Metal tubing was used to deliver CO_2 two inches below the soil surface.

Figure 3. A pressurized gas tank was the source of the carbon dioxide, which was moisturized and adjusted to the soil temperature by bubbling it through a bottle of water placed in the root zone.

Figure 4. The flow rate of CO_2 was maintained at a constant 30 cc/minute using a gas flow controller.

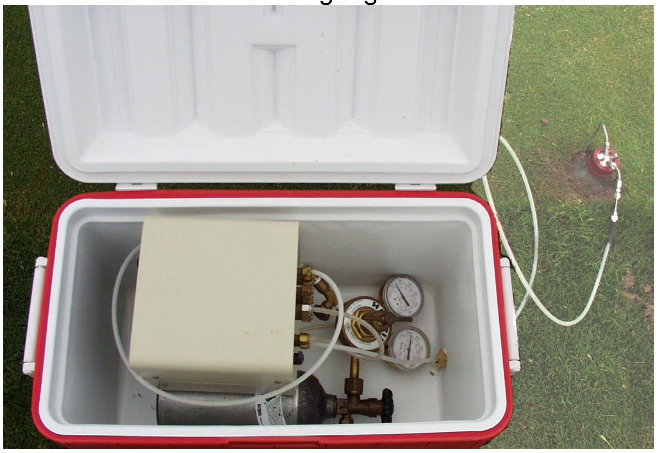


Figure 5. Using this method, we were able to elevate soil CO_2 levels to as high as 32%, while maintaining O_2 concentrations at just below 15%. Under natural conditions, 32% CO_2 would have been impossible to achieve, as it would have caused a hypothetical decline in O_2 to below zero. But in our artificial system, the level of O_2 was sufficient for plant growth, thus allowing us to de-couple high CO_2 away from life threateningly low levels of oxygen. The highest CO_2 and lowest O_2 values were seen right at the insertion point of the CO_2 delivery tube (0 inches in the graph below). As expected, as we measured further and further away from the CO_2 injection site, the CO_2 values went down, and the O_2 levels went up.

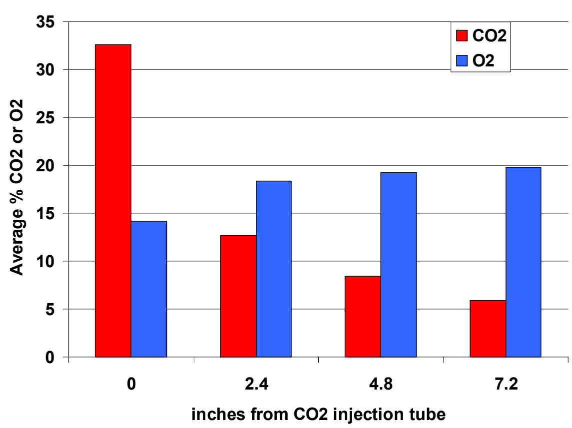
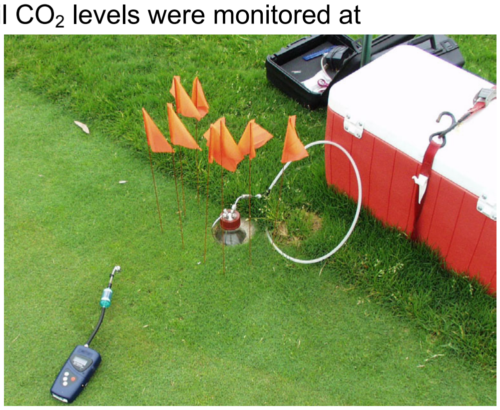


Figure 6. Soil CO_2 levels were monitored at increments of 2.4 inches from the carbon dioxide injection tube using a Bacharach CO_2 monitor.



The Bacharach CO_2 analyzer is a small handheld device that can detect CO_2 between 0 and 60%. Model 2820 is available from Bacharach: 800-736-4666 or www.bacharach-inc.com for approximately $1550. A total of 10 different locations were monitored on two sampling dates: 8/5/02 (4 days after CO_2 injection began) and 8/14/02 (13 days after CO_2 injection began.

Figure 7. To assess the effect of high CO_2 on turf health, two different measurements were taken -- turf root length and turf quality. Quality was visually determined, using a scale of 0 – 9. Turf root length was determined by taking profiler samples at 2.4 inch increments from the CO_2 source (the sample below was taken 2.4 inches away from the CO_2 source).

Figure 8. Roots were then washed and measured using Assess Image Analysis Software.

CO_2: a symptom, not the cause

The results are somewhat surprising, but easy to report. No matter how high the CO_2 readings got (and, as Figure 5 shows, they reached as high as 32%, which is more than 10 times higher than the 2% level that is thought to be the limit for healthy turf and much higher than would ever be observed in Nature), **we saw no effect on either turf quality or root length.** In other words, high CO_2 alone wasn't enough to damage turfgrass plants, despite some indirect evidence from past studies that this might be the case. Instead, it appears as though the low oxygen that occurs when soils are compacted, waterlogged or otherwise damaged is the culprit in increased turf damage.

So what?

This data gives rise to a number of questions, including:

Q. I have been monitoring CO_2 as a means of timing aerifications or other remedial actions on greens. Do the results of this study mean that CO_2 monitoring is the wrong way to go?

A. Not at all. Carbon dioxide monitoring is probably one of the best and most sensitive ways to monitor soils for development of low oxygen situations. Because CO_2 is present at relatively low levels (compared to oxygen) in the soil, small increases in its concentration (which are a signal that there are equivalent decreases in oxygen) are easier to detect than small changes in oxygen levels. The previously determined trigger point of 2% CO_2 or higher is still a useful value for triggering aerification or other remedial procedures.

Q. How would I go about monitoring for CO_2?

A. We have tested two systems, both of which give reasonably good data. The Bacharach CO_2 monitor mentioned above is relatively expensive ($1550), but requires no additional supplies for operation. In contrast, the Drager gas pump and carbon dioxide detection tubes (parts 800-801 and 8000-31401available from SKC West at www.skcwest.com or 800-752-9378) are initially less expensive, but require constant replenishment of the detection tubes.

Q. What if I don't have the tools available for monitoring CO_2?

A. While monitoring for CO_2 levels gives you great in-depth knowledge on greens performance, it isn't completely necessary. Probably the most important thing that you can do is to understand that your greens are constantly losing oxygen and gaining carbon dioxide. This assumption is based on the ongoing reality of factors such as traffic, compaction, buildup of organic matter and increased microbial activity – all of which increase as soils warm up in the summer -- and promote higher CO_2 and lower O_2 levels.

Once you make this assumption, it becomes obvious that preventive activities that help to bring more oxygen into the soil system are necessary, and on a regular basis. Some of these preventive measures include:

1. "Vent" greens at least monthly, during the months when turf (and soil microbes) are actively growing. This relatively non-disruptive activity (1/4" solid tines on a 2X2 spacing seems to work well in many locations) is one of the most important things you can do to promote better gas exchange. Monthly use of the HydroJect, operated in the up position to provide a hold of roughly ¼" has also been shown to improve gas exchange and water movement (Carrow, 2004).
2. Light topdressing every 14 days can help to limit organic matter accumulation to below 4%.

   Remember, though, that venting and topdressing of greens that are stressed will lead to further turf damage. It is always best to hold off on a venting procedure until greens are in relatively good shape.
3. Hollow core aeration (5/8") with the cores removed, followed by heavy sand topdressing (1/4" depth) using USGA spec sand. This should be followed by a deep tine aeration through the sand to an 8" depth, if possible, using 1/2" to 5/8" diameter solid tines. Sweep or blow to fill the holes. This procedure should be carried out at least annually, in the spring. If greens are not too stressed, and if the golfers can stand the disruption for a second time, schedule another aeration in the fall. This procedure will improve gas and water movement significantly.
4. We have also had several very positive reports about the use of 3/8" or 1/2" tines on a quad tine holder (2" X 2") for removal of surface organic matter once or twice a year. While this practice will not address all of the problems that the aeration described above does, it is much less disruptive and does an excellent job of improving gas and water relations in the top few inches of the profile.
5. Avoid the use of organic fertilizers and amendments on greens if you cannot aerify and vent frequently, or if your organic matter content exceeds 2%. These products cause an increase in soil microbial populations. While the microbes are not harmful in and of themselves, their hunger for oxygen (and their production of carbon dioxide as a waste product) can lead to turf quality problems.
6. Manage traffic and pin placements to avoid compaction.
7. Avoid frequent and light irrigation.

References

Brady, NC and RR Weill. 1999. The nature and properties of soils. Prentice-Hall, Inc., Upper Saddle River, NJ.

Bunnell, BT, B. McCarty and R. Dodd. 2000. Why is carbon dioxide bad in golf root zones? Golf Course Management, June, 2000.

Carrow, RN, 2004. Surface organic matte rin bentgrass greens. USGA Green Section Record, January – February 2004.

For more information on the operation of carbon dioxide monitoring devices, see PACE Insights Volume 8, number 2.