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APPLICATION NOTE

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# Diffusion-Based Soil Respiration Measurements

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Soils form the largest reservoir of carbon in our terrestrial ecosystems, containing more than two-thirds of the total carbon on our planet. Soil respiration, or surface $CO_2$ efflux, is one of the two main mechanisms by which carbon is transferred from the soil to the atmosphere. The other is the human-contributed burning of fossil fuels. A small change in the soil respiration rate can thus have a major impact on the whole atmospheric $CO_2$ budget and on the global ecosystem. Not surprisingly, ecologists, meteorologists, physiologists and scientists in research institutes throughout the world are keenly interested in measuring soil respiration. For these researshers, diffusion-based $CO_2$ measurement can provide advantages over traditional pump-aspiration systems.

Living organisms use oxygen and produce carbon dioxide in cellular respiration. Additionally, plants use $CO_2$, water and sunlight to produce carbohydrates and oxygen in photosynthesis. In other words, unlike animals, plants consume $CO_2$ which plays a role in keeping the global level of $CO_2$ in balance. Changes in this balance can be understood by studying the carbon cycles of the ecosystems of the world.

Since most of the carbon is stored below ground, soil has a central role in the carbon cycle. It is therefore important to measure how the carbon exchange of the soil varies in the short term, and to estimate its impact in the longer term. The concept of “soil respiration” refers to the efflux of carbon dioxide at the soil surface, quantified as the amount of carbon dioxide given off by living organisms and roots in the soil.

All-in-all, the soil respiration rate is the result of a combination of biotic, chemical and physical processes that take place in the soil.

The biotic processes are related to the respiration of plant roots, micro-organisms and larger fauna living in the soil. Plant roots contribute directly to soil respiration by releasing lots of easily decomposable carbohydrates. The soil’s microbiological properties, on the other hand, determine its potential to decompose organic matter and contribute to soil respiration.

The chemical processes that take place in the soil include the chemical oxidation of minerals. Although this is normally a relatively small source of $CO_2$ compared to others, it increases at higher temperatures. The physical processes consist of soil $CO_2$ degassing and the transport of $CO_2$ through the soil to the surface.

Continuous research is being conducted to find out how the soil respiration rate responds to changing temperatures and changing states of wetness or dryness. We know that the rate of $CO_2$ efflux varies seasonally and even during each day, due to changing environmental factors. In addition, the soil respiration rate is affected by the texture and quality of the soil, the vegetation and biome type, the topography and the geographical coordinates. Studies on how different factors affect the rate at which different soil types, under different conditions, store and release carbon are helping researchers to understand how carbon storage might change in the future.

## Soil Temperature and Moisture are Significant

One of the most dominant factors affecting the soil respiration rate is soil temperature. Typically, when soil temperature starts increasing, the soil respiration rate also increases. However, it must be pointed out that totally opposite results have also been recorded at certain conditions. One objective of scientists is to build a comprehensive model that predicts how increases in atmospheric temperatures will change the soil respiration rate and affect the carbon balance.

Soil moisture is another important factor influencing soil respiration. In dry conditions, root and microorganism activity is typically low, resulting in low soil $CO_2$ efflux. Increasing the soil moisture normally increases the bio-activity in the soil. But if there is very high soil moisture, total soil $CO_2$ efflux is reduced, because of limited diffusion of oxygen and subsequent suppression of $CO_2$ emissions.

The soil respiration rate is mostly controlled by the result of the interaction between soil temperature and moisture. It is often difficult to separate between these two influences. The influence of soil temperature and moisture on soil respiration is so strong that they must be considered together in order to predict the level of respiration. One of the reasons is that they affect soil microbial activity.

Usually soil respiration responds most to whichever of the two factors – temperature or moisture – is the more limiting.

If the soil is very dry, the soil respiration is not sensitive to temperature. When the moisture content increases, the level of respiration becomes much more sensitive to temperature. Similarly, at temperatures below 5°C soil respiration is not sensitive to moisture, but becomes increasingly responsive at higher temperatures.

## Soil Texture or Porosity Also Play a Role

Soil texture and type also have a strong effect on soil respiration because the diffusion of $CO_2$ is influenced by the soil porosity. Small pores, for instance, hold water well. Larger interconnecting pores allow water and air to move freely into and out of the soil. Many current studies are examining the effect of soil texture on the respiration rate not only at the surface of the soil, but also below it.

Basically, soil respiration measurements can be divided into two categories: below-ground $CO_2$ and soil respiration box measurements.

## Below-Ground $CO_2$ Measurements

The aim of below-ground $CO_2$ measurements is normally to measure the $CO_2$ profile at changing depths in the soil. Most measurements, particularly those with agricultural applications, are nowadays made fairly close to the surface layer of the soil.

The $CO_2$ concentration below ground increases with the depth and varies to a great extent according to the soil type and environmental conditions. In order to discover the $CO_2$ profile of the soil, several sensors can be buried below ground at different depths[1]. It is also important to record the exact depth to maintain the comparability of the measurements to other below-ground measurements. The challenge in below-ground $CO_2$ measurement is to prevent the sensors from changing the conditions inside the soil. Therefore, small, diffusion-based $CO_2$ sensors with low power consumption are preferable.

The $CO_2$ flux in the soil changes rapidly when it rains. After a shower, the humidity in the soil is very high for quite a long time. Sensor durability and stability are thus key issues in below-ground $CO_2$ measurements.

## Soil Respiration Boxes

In soil respiration measurements on the ground surface, the $CO_2$ efflux is measured inside a box that is placed on the ground at the site under examination. Although many different setups are possible, the measurement is typically made in a closed box that is pre-ventilated. During the measurement period, the $CO_2$ concentration increases or decreases inside the box depending on the type of box and the local environmental conditions.

Most scientists build their own respiration boxes using sheet metal, glass or transparent plastic. The size of the box is critical for many reasons. The spatial resolution of the respiration measurement depends on the shape and size of the bottom area of the box. The speed of the $CO_2$ build-up inside the box can be adjusted by changing the box volume – allowing for the fact that the box must be high enough for the ground vegetation growing inside it. In some cases, a small fan unit is needed in order to mix the air inside the respiration box.

For a correct measurement result, it is essential to ensure that the box is tight against the ground.

Different box sizes are needed because of different vegetation types and because the $CO_2$ efflux varies very much between soil types. In some cases the concentration increases from ambient by only 10-20 ppm, while sometimes readings as high as 300 ppm above ambient are recorded. The boxes vary from simple portable boxes to more complex ones that automatically close the cover periodically in order to make a measurement.

At present most soil respiration box measurements are conducted with pump-aspirated instruments. The pump aspiration method is problematic, since it induces pressure differences that can affect the $CO_2$ efflux inside the box. Most pump-aspirated $CO_2$ analyzers are also bulky, expensive and have a high power consumption.

A soil respiration box with diffusion-aspirated $CO_2$ measurement tackles the problem of pressure differences. Diffusion-aspirated $CO_2$ measurement is also less expensive and more mobile because it does not require a complex, bulky and power hungry sampling system. All this enables scientists to perform more frequent measurements in the field.

Vaisala offers $CO_2$ measurement instruments for a large variety of applications. The basic aspiration method for these instruments is based on diffusion. For further details, visit GMP343 product page.

**Reference**

Tang, J., D. D. Baldocchi, Y. Qi, and L. Xu, 2003. Assessing soil $CO_2$ efflux using continuous measurements of $CO_2$ within the soil profile with small solid-state sensors. Agricultural and Forest Meteorology, 118, 207–220.