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Measuring Soil Carbon and Soil Carbon Change

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Key Points

- Carbon is an abundant chemical element with properties that make it the common element of all life on the planet.
- The implementation of an international carbon trading scheme has made carbon measurement significant to the global economy.
- The accurate measurement of soil carbon in broad acre agriculture is routinely possible but it can be laborious and expensive and there is currently no meaningful way of measuring soil carbon in pastoral rangelands.
- The measurement of soil carbon change is made more complex when deep soil carbon and seasonal fluctuations are considered.
- The development of ways to measure soil carbon using satellite and drone based data collection is an emerging technology that may provide ways of measuring agricultural soil carbon accurately and at reasonable cost.

Summary

Carbon is one of the most abundant mineral elements in the environment. It displays unique diversity of form and can form large and complex molecules which makes it possible for it to serve as the common element of all life on the planet. Carbon is abundant in soil and soil carbon is broadly classified as organic and inorganic carbon. Soil organic carbon is a contributor and an indicator for healthy, fertile soils.

In the context of climate change and the creation of an international carbon trading scheme, the measurement of carbon has become economically significant to the global economy. It is possible to accurately measure soil carbon, however, when conducted to scientific standard large-scale measurement can be laborious and expensive. Deep measurements and the accounting for routine seasonal fluctuation in soil carbon content increase the complexity of soil carbon change measurement. Research developments in satellite and UAV (drone) data collection, however, may in the future, provide way to accurate and relatively inexpensive way to measure soil carbon.

Analysis

Definitions and Introduction

Carbon is a chemical element, like hydrogen, oxygen, lead or any of the other of the 90 or more naturally occurring elements in the periodic table. It is the 15th most abundant element in the Earth's crust, and the fourth most abundant element in the universe by mass after hydrogen, helium, and oxygen. It is the second most abundant element in the human body by mass (about 18.5 per cent) after oxygen. Carbon's abundance, its unique diversity of form (diamonds and graphite for example) and its unusual ability to form large and complex molecules at the temperatures commonly encountered on Earth enables it to serve as a common element of all known life on the planet.

Huge quantities of carbon are stored in soil in two principle forms: inorganic and organic. Soil inorganic carbon consists of mineral forms either from weathering of bed-rock or from the reaction of soil minerals with atmospheric carbon dioxide to produce carbonate compounds. Soil organic carbon (SOC) is present as living or decomposing biological matter. It includes relatively available carbon as fresh plant remains and relatively stable or recalcitrant forms in materials derived from plant remains such as humus and charcoal.

Stores of soil carbon are not static; they are being constantly cycled through the atmosphere, biological material, soil and the ocean. Biological processes such as photosynthesis are a major driver in the carbon cycle. The possibility of influencing the carbon cycle to facilitate the extraction of carbon based greenhouse gases from the atmosphere and promoting its long-term or permanent storage in the soil is considered a genuine mitigation to increasing global temperatures.

In the context of climate change, the motivation and justification for accurate measurement of carbon, in the soil and elsewhere, has dramatically changed. The possibility of an international carbon market that may include carbon taxes, carbon offsets and carbon credits has elevated the importance of carbon measurement to global economic importance.

Due to variability and complexity, existing methods for the accurate measurement of soil carbon can be laborious and expensive, particularly when conducted to scientific standards. Indeed, the only practical way to meaningfully assess and predict on what is happening with carbon in soils, or to design the proper accounting processes and incentives, is through computer modelling based on standardised agricultural practices, aided by remote sensing data collection.

Types of Soil Carbon

As stated, the element carbon exists in the soil in many forms but for the purposes of measurement and analysis there are three main forms: organic soil carbon; charcoal and inorganic soil carbon. All three forms can be important to soil health and fertility but it is soil organic carbon (SOC) that is often used as a gauge or indicator of healthy, productive soils. SOC is the carbon component of soil organic matter (SOM), material originating from biological material. Agricultural practices that retain and increase the amount of SOC in the soil provide the double benefit of improving sustainable productivity and assisting in the reduction of atmospheric greenhouse gas. The number one recommendation of the US Department of Agriculture, Natural Resource Conservation Service, Soil Quality Team is to enhance SOM.

SOM is derived from living tissue: plant leaves and roots, sap and exudates, microbes, fungi, and animals. It takes a bewildering variety of complex chemical forms, many of which remain unclassified. Much of it is a result of decay processes and microbial metabolisms. SOM contains 50 to 58 per cent carbon by dry weight.

SOM holds many times its weight in water. Its critical sticky components (such as glomalin) play an essential role in the formation of soil aggregates which give soil its stability against weathering and erosion, and its ability to hold water and air for plants and microbes.

SOM may be the most valuable form of soil carbon, but is generally the least stable, though some forms may persist for a thousand years. Many forms can be readily oxidized (turned into carbon dioxide) by common bacteria when in the presence of oxygen. It is also the form of soil carbon, however, that can be readily increased through plant growth, the root shedding of perennial grasses, the incorporation of manure or compost, the liquid carbohydrate exudates of plant roots and a range of microbial processes. Soil organic matter is the most abundant form of soil carbon.

Charcoal is derived from living tissue, so it is considered organic. It is often called biochar. It can range from 50 to 95 percent carbon by weight. It is more stable and more resistant to bacterial oxidation than most other forms of organic carbon, which is one reason why there is considerable interest in incorporating biochar into soil as a carbon sequestration strategy.

Inorganic soil carbon is mineralised forms of carbon, such as calcium carbonate. It is more stable than most organic carbon because it is not food or fuel for microorganisms. Calcium carbonate will dissolve in acid; therefore, it is not usually abundant in soils of pH7 or lower or in humid regions. Carbonates are common in more arid regions and alkali soils, and are a significant soil carbon pool worldwide, derived mostly from organic carbon fixed by photosynthesis.

Inorganic carbon, while it does not possess the water-holding and soil-enhancing properties of organic carbon, is nevertheless a significant sink for atmospheric carbon, though it typically changes at a relatively slow rate.

Purpose

There is no right or wrong way to measure soil carbon. What you measure, along with how you measure it, depends on your purpose—why you are doing it, and what you are going to do as a result. The questions you are trying to answer will depend on the purpose. So, do the likely sources of uncertainty or risk. For example, measuring soil carbon and soil carbon change for improving soil health and fertility does not require the same level of accuracy.

Some may have mixed or multiple purposes, or may be measuring soil carbon change for other reasons than what are listed here. Here are four of the most common results from (or purposes for) measuring soil carbon change. The incentive to measure soil carbon has, in recent times increased significantly.

Soil Carbon Measurement Methods

Soil carbon cannot be measured directly. Some methods are far more direct than others, however, and involve fewer assumptions and sources of error. Though there has been considerable buzz about the possibilities of remote sensing or high-tech field methods of assessing soil carbon, and some of these show promise, the gold standard remains careful, repeated field sampling followed by laboratory analysis by the dry combustion method, often called elemental analysis.

The dry combustion or elemental analysis procedure is the most accurate common test for soil carbon, and is often cheaper than other tests. Most research indicates that change in soil carbon occurs most readily in the soil organic matter fraction, so that if you detect change, it is likely to be in the organic carbon.

If carbonates are a significant percentage, however, the ability to detect change will be better if there is at least some idea of how much soil carbon is organic and how much is inorganic.

Dry combustion or elemental analysis. The most accurate standard laboratory test for soil carbon is dry combustion using an elemental analyser. These instruments heat a small sample (usually a fraction of a gram) of dry pulverized soil to around 900 degrees C and measure the carbon dioxide gas that is a combustion product. (They usually measure nitrogen as well.) The results are expressed as the percentage of carbon in the sample. The dry combustion test oxidizes and measures total soil carbon: organic matter, charcoal, and carbonates.

Acid treatments. If the soils you are testing contain carbonates or inorganic carbon, and you wish to distinguish organic and inorganic carbon, many labs have an acidification option, in which a sample or subsample is treated with hydrochloric acid to remove carbonates, and then subjected to dry combustion to measure remaining organic carbon. Measuring organic and inorganic carbon separately thus requires acidification plus two dry combustion tests.

Loss on ignition and the Walkley-Black Measurement. Less accurate are the more traditional loss on ignition (LOI) and Walkley-Black tests. LOI measures the weight loss of a dry soil sample after it is heated in an oven or muffle furnace to 360–450C for a couple of hours. Walkley-Black is a chemical method using potassium dichromate. Some researchers have recently promoted the use of potassium permanganate wet chemistry to measure active carbon in soil, which may give an improved indication of soil carbon change.

Neither of these tests measure total carbon. The Walkley-Black test does not usually give a full accounting of charcoal, and may miss some types of organic matter. Neither measures inorganic carbon.

The interest in soil carbon from the perspective of environmental sustainability or climate change is relatively recent. Many labs are accustomed to testing for soil organic matter for the purposes of calculating effective rates of herbicide application. For this purpose, soil organic matter is a liability because it lessens the effectiveness of herbicides on living vegetation, and loss on ignition or Walkley-Black tests are typically used.

Carbon fractions. Recently there has been increasing interest in classifying various types or fractions of soil organic carbon such as active, labile, particulate, occluded, light, or heavy, with various residence or turnover times ascribed to the various fractions. The CSIRO identifies four biologically significant fractions of soil organic carbon as follows:

- Crop residues – shoot and root residues less than 2 mm found in the soil and on the soil surface.
- Particulate (matter in the form of separate particles) organic carbon – individual pieces of plant debris that are smaller than 2 mm but larger than 0.053 mm.
- Humus – decomposed materials less than 0.053 mm that are dominated by molecules stuck to soil minerals. Humus represents the most stable forms of SOC as it can persist it the soil for decades or even centuries.
- Recalcitrant organic carbon – this is biologically stable; typically, in the form of charcoal.

The different types of SOC not only differ in size but are also composed of different materials with different chemical and physical properties and different decomposition times.

Soil respiration. Soil respiration, the emission of carbon dioxide by microbial respiration, is a good indicator of microbial biomass, but may not correlate well with SOC or total carbon. It can provide an indication of the microbial activity in the soil which can be an indicator of soil fertility.

Bulk density. The density of soils can vary over a wide range. Water has a density of 1 gram per cubic centimetre. Soils can have densities ranging from .1 for light peats to 1.8 for very dense, compacted mineral soils, often with little pore space for water and air. Organic matter is lighter than most mineral matter, so if organic matter increases in a soil, the density will likely decrease.

The test for bulk density is simple: oven-dry a sample of known volume to remove all moisture, and weigh it. The bulk density is the dry weight in grams divided by the volume in cubic centimetres. It is a useful guide to soil quality but not an accurate assessment of carbon content.

Form or Aspect of Soil Carbon	Tests	Comment
Soil Organic Carbon	Dry combustion (prior acidification of sample will remove inorganic carbon), loss on ignition, Walkley-Black, soil respiration, active carbon tests	The largest and most important soil carbon pool.
Soil Inorganic Carbon	Dry combustion after the SOC has been removed.	An important soil carbon pool which is slow to change.
Charcoal	Dry combustion. Walkley-Black test.	The recalcitrant form of organic matter.
Total Carbon	Dry Combustion	For most purposes, dry combustion is the best and most accurate test.
Bulk Density	Oven drying followed by weighing a sample of known volume.	

Table 1. Summary of the methods available to measure the various forms of soil carbon.

Satellite Mapping of Soil Carbon

There is a growing body of scientific research into the possibility of calculating soil carbon change using satellite data or other forms of aerial data collection such as UAVs (drones). Typically, these technologies use analysis of light spectrum data to assess changes in vegetation or soil surface followed by the application of sophisticate algorithms that calculate changes in soil carbon content. There are still, however, barriers to general application. The need for accurate benchmarking data from which to calculate change can only be obtained by laboratory methods. Seasonal variations in carbon content and carbon measurement to depths of up to a metre continue to be problematic and require advance technological solutions that are currently unavailable.

Currently no accurate, affordable method of measuring carbon on a broad-acre scale is sufficiently accurate in a pastoral rangeland environment and this deficiency is particularly relevant to northern Australia. In time, however, researchers believe technological developments will enable the use of data collected on an ongoing basis by satellites and drones for soil carbon analysis. This should lead to reduction in cost and the amount of time spent calculating baseline carbon estimates. Researchers and pastoralists believe the development of this measurement tool is an essential step towards the approval of a rangeland soil methodology under the Carbon Farming Initiative.

Conclusion

The discussion above has focused on the establishment of a global carbon trading scheme as the principle driver for finding new methods to accurately measure soil carbon. There are, however, other compelling reasons to track the quantity of organic carbon in our soils, particularly when steps are being actively taken to increase it. For much of the 20th century, agricultural practises in Australia tended to deplete soil carbon. In recent decades, these practices have been improved, however, in many regions there is still the potential to significantly improve the productivity and sustainability of our agricultural soils by increasing levels of SOC. A second compelling reason to actively increase SOC is for the environmental benefits. Regardless of general opinions on human induced climate change, levels of atmospheric greenhouse gases have increased since the start of the industrial revolution. If this trend continues there will be detrimental side effects. Many scientists believe atmospheric greenhouse gases increase can be reduced, halted or even reversed by the sequestration of carbon into soil. This would provide a double benefit of improved soil and atmospheric quality.

The motivations for measuring soil carbon, notwithstanding, it's regular, accurate measurement, deep into the root zone across the full extent of cropping and pastoral lands currently remains a technological aspiration. The barriers to achieving a cost-effective solution are challenging but hopefully not unsurmountable. There has been a strong commitment globally to carbon accounting and if these schemes are to be broadly successful, agriculture must be able to take advantage of, and contribute to, the economic and environmental benefits.

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