

by Lawrence Mayhew

Introduction

If a golf course supernatant applied diamonds to turf grass, was carbon applied to the turf? The answer is YES! Nitrogen and boron were also applied!

Using diamonds as a source of “carbon” for turf grass is obviously silly, but the point is to emphasize the absurdity of using the word “carbon” as if it means something significant. The word “carbon” does not reveal the incredibly complex carbon compounds that are important to plant and soil microbial growth. “Carbon” critical to soil health and crop production is not a simply “carbon”, but a complex conglomeration of carbon-based substances referred to as soil *organic carbon*. Organic carbon combined with hydrogen, oxygen and nitrogen in an infinite number of ways, is the basis of all life as we know it.

The most important aspect of sustainable plant production in soils is the conservation and building up of soil organic matter. However, the term *soil organic matter* on a soil analytical report is *operationally defined* using numerous methods of analyses. The most common analytical method is measuring the amount of “organic carbon” burned off in a soil sample, which is a very broad definition with numerous interpretations. Organic carbon may be small bits of stubble or roots that haven’t broken down, microbial remains, pesticides, or it may be humus, which is a mixture of simple carbons, complex brown colored carbons, and dark-colored highly stable carbon-based substances.

Simple Carbon



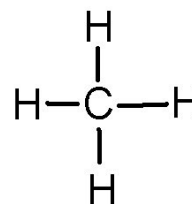
Carbon is an element, number six on the Periodic Table. Carbon in soil organic matter may consist of charcoal from burning, or synthetic chemicals, pesticides, or natural carbon substances released by plant roots and microbes. Some carbon compounds in soils are chemically identifiable, such as amino acids, carbohydrates, and fats. The word “carbon” does not describe the incredible complexity of soil carbon compounds because the element carbon has the ability to form over ten million different compounds, making it the most versatile and the most common element in all soil organic matter. As millions of carbon compounds exist, then simply stating that “carbon” is important to soil is an extreme oversimplification that does not impart any information regarding its chemical or physical form in natural environments.



Graphite is carbon. It is one of the softest materials known, that's why it is used for lubricants and pencil leads. Diamonds are composed of about 99.5% carbon, the balance being nitrogen and boron, are the hardest natural material known. Both substances are relatively pure forms of carbon. The fact that a substance can exist as two or more structurally different elements is called allotropy, which is a common occurrence in nature, and is dealt with extensively in chemistry text books. For example, there are 33 allotropes of elemental sulfur (S). Obviously, graphite and diamonds are not bioavailable and not the "carbon" that is used in fertilizers.

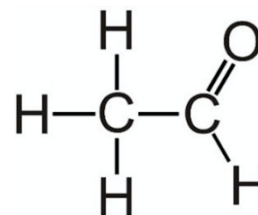
Carbon in diamonds, carbon dioxide (CO_2), and the carbon in carbonates (CO_3^{2-}), such as the calcium carbonate (CaCO_3) found in limestone, is referred to as *inorganic* carbon because it is not closely associated with hydrogen atoms and are not chemically or physically the same as the carbon configurations generated by living organisms (biogenic carbon). Although a typical soil analysis does not include inorganic carbon, it is "carbon", nonetheless. Therefore, applying calcium carbonate in the form of limestone is applying "carbon".

The "carbon" claimed to be in soil inputs must be organic carbon. The simplest organic carbon compound is methane, which is made up of only carbon and hydrogen, with a chemical formula of CH_4 . It combines with oxygen easily, burning or exploding upon oxidation. Natural gas, swamp gas and the gas coming off of garbage landfills is primarily methane. Adding swamp gas to a soil would be adding "carbon". Again, this simple organic carbon compound is not a desirable carbon referred to when someone is referring to "carbon". But, without a universally agreed on definition, methane fits the role.



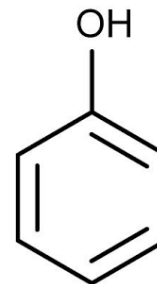
Complex Carbons

Carbon has some remarkable characteristics that have been manipulated by biological systems to their advantage. The carbon atom has the unusual ability to combine with itself, forming either long or short chains of single, double, and triple carbon-to-carbon bonds. The structure of acetaldehyde on the right is an example of that versatility. Acetaldehyde is the "garbage can" odor of rotting garbage. It's "carbon".



Various hydrogen and oxygen compounds can attach to the carbon chains or carbon rings in an infinite number of combinations. It's analogous to using bricks to build a structure, then placing functional components into the bricks, such as doors and windows. The organic chemistry term is *functional groups*.

The example on the right is a six-member carbon ring with a hydroxyl (-OH) functional group attached; carboic acid. In more complex organic chemistry, each intersection of a line indicates a carbon atom for the sake of simplicity. Single lines represent single carbon-carbon bonds and double lines indicate carbon-carbon double bonds. Carbon rings also have the ability to attach to each other or they can form extremely complex ring-ring combinations attached to long complex carbon chains. By the way, carboic acid is corrosive and flammable, used primarily for manufacturing plastics, epoxies, and herbicides. It is 90% "carbon".



Synthetic compounds are not the same as natural substances

Although some carbon compounds have identical chemical formulas, the way they are arranged will cause them to have completely different chemical properties. They are called *isomers*. Just as houses made of the same material and doors and windows can be arranged in all sorts of configurations, functional groups on organic carbons can be arranged many different ways also; twisted, turned, flip flopped, or have left and a right-handed configuration, just like the way your hands are mirror images of each other. Your hands are, for the most part, identical, however your

left-hand functions in a different manner than your right, and you can't put a left-hand glove on your right hand. This is an example of stereoisomerism.

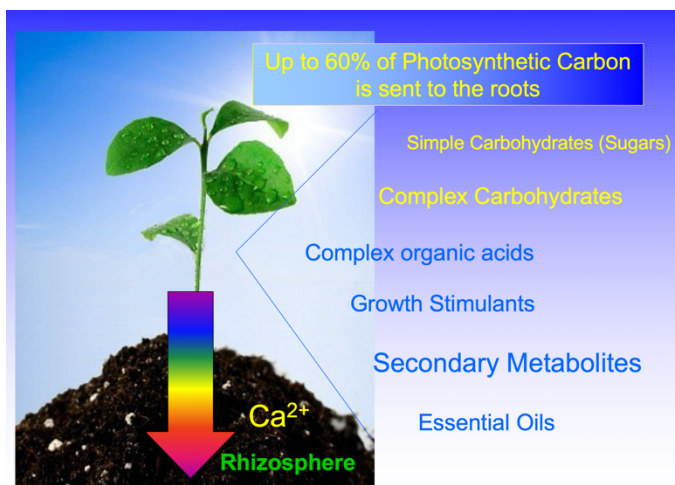
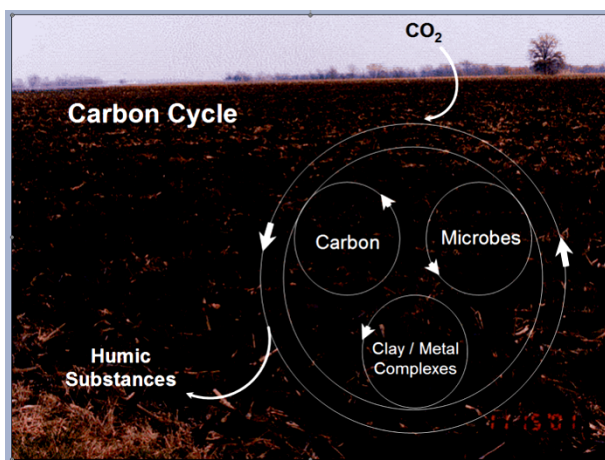
Right-handed and left-handed versions of identical organic carbon compounds react differently in living organisms, performing entirely different functions. This is similar to the way letters are arranged in words; both "star" and "rats" are made of identical letters. As a general rule, human-made (synthetic) organic compounds do not have the same biological activity as natural substances despite the fact that they have the identical chemical formula and, in many cases, are named the same as natural products.

Scientists who work with stereoisomers, however, designate the difference between these molecules by using the suffix *D* or *L*, indicating whether the isomer is *dextrorotary* or *levorotary*, i.e., the left or right version of the isomer. Soil bacteria utilize and synthesize the *D* version of many amino acids as well as the *L* versions, using them for cell wall integrity and signaling. The primary sources of *D*-amino acids for bacteria and plants are the soils where bacteria are constantly recycling amino acids, plant rhizophagy, and seawater.

Complex Carbons in the Carbon Cycle

All of the carbon in soils is part of the Earth and atmosphere Carbon Cycle. The Carbon Cycle starts with carbon dioxide (CO_2), ends with the most complex carbons on Earth. With all the twisting and turning in concert with the ability to form limitless carbon structures, the complexity of organic carbon compounds can be mind boggling.

The cycling of carbon in natural soil systems starts out simple. Plants sequester carbon dioxide (CO_2) from the atmosphere, combine it with hydrogen (H) through photosynthesis making a vast array of organic carbon-based sugars, starches, acids, fats, waxes, lignins, etc.



A substantial portion of the organic acids and complex sugars are routinely excreted by plant roots to feed the microbial soil system (microbiome). The primary beneficiaries of this soil/microbe/plant exudate system are bacteria, who in turn feed the plant with bioavailable minerals, plant growth stimulants, provide disease protection to the plant, and become food for fungi and other living soil organisms.

Many of the complex carbon compounds excreted by plant roots are called *secondary metabolites*, meaning they are plant products that are secondary to primary growth, but very important for stimulating soil microorganisms, who in turn release many beneficial compounds that support plant health and ward off diseases.

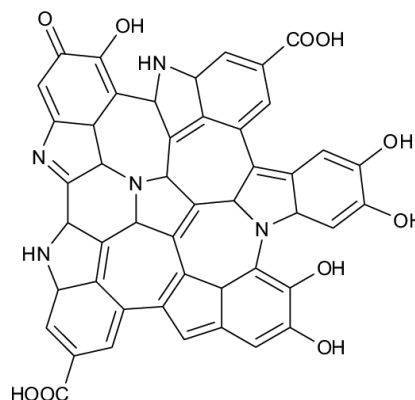
To give you an idea of just how important this function is, plants commit anywhere from 40 to 60% of all the carbon sequestered from the atmosphere to the production of root exudates released into the soil system. Over 12,000 compounds have been identified, and there may be as many as 100,000! These carbon-based exudates range from simple sugars to extremely complex metabolites.

Upon the death of plants, some parts of the plants decay rapidly in soils while others (waxes, fats, lignins) are much slower to decay, and will eventually contribute to the more stable carbons that support healthy soils. The fungi in the soil that thrived by eating the bacteria, leave behind an extremely complex, therefore stable, dark colored class of carbon compounds called melanins.

When the bacteria and fungi die off, their residues commingle with the remains of plant roots and shoots. That creates an extremely complex combination of slow and fast decaying biomatter mixed with all of the enzymes and substances released into soils by living plants and microbes.

The slow decay process of the more complex brown carbons results in a complete chemical and physical change in the original materials. When the completely decayed materials from plants and microbes are allowed to commingle over time, the result is an even more complex super-mixture that is no longer physically or chemically recognizable, usually black in color, and can no longer be easily separated into its original chemical components.

The process of first breaking down plant and microbial matter into complex carbons that recombine over time into something entirely different is called *humification*. Because of their extreme complexity and lack of an obvious structure, the final black products of humification have never been well defined chemically; they just look like black dirt. They are called *humic substances*; highly stable and extremely complex carbon compounds.



Compost

Composting starts a very complex process that is dominated primarily by the microbial decay of hydrocarbons. The less complex carbon compounds found in plant tissues, such as carbohydrates, are broken down rapidly; while the more complex carbons, such as lignins, will take a much longer time to decompose, and may not totally decompose in the compost pile. As the pile matures, the odor and color of the composting materials changes. Composting materials tend to get darker and darker as the carbon compounds are converted to humus, which is a complex mixture of partially and fully decomposed organic matter.

The conversion of biomatter to humus (humification) that takes place in composting systems is similar to the process that occurs in soil systems. Although composting provides some humic substances, there are biochemical differences in the humic substances produced in compost compared to humic substances found in soils, lakes, rivers and streams probably because of the major differences between the conditions in soils compared to compost piles.

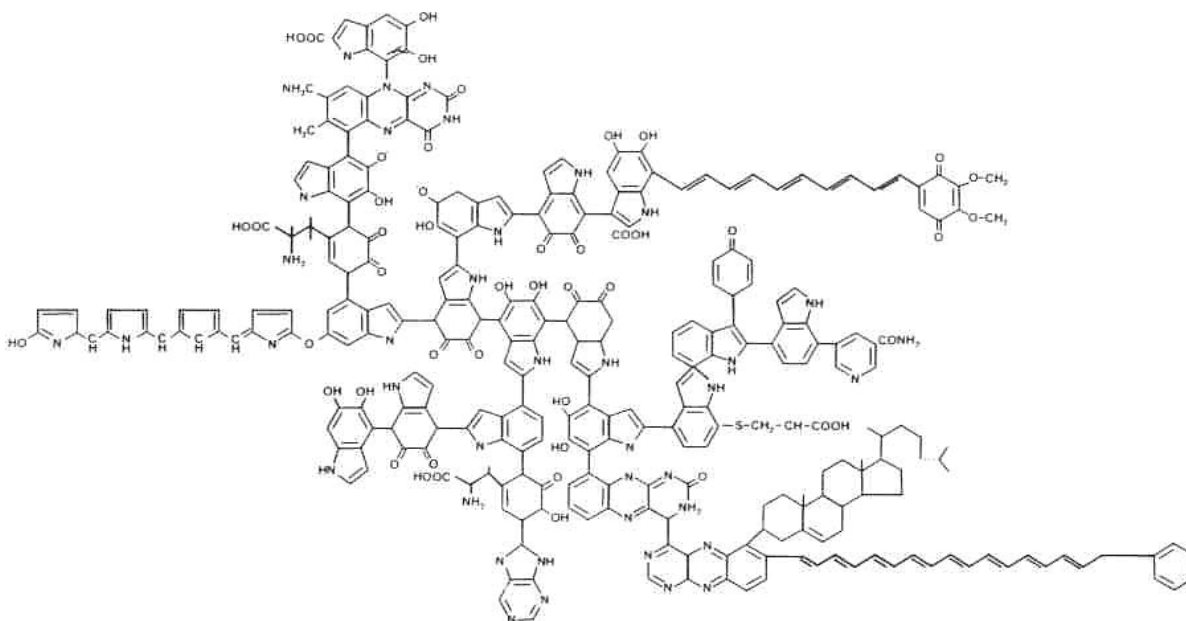
The soil humification process occurs in an environment of incredibly complex chemical, physical and biological interactions that is not duplicated in an above-ground compost pile. A compost pile is not exposed to the same metal components, enzymes, pH, trace elements, earthworm interactions, and the complex interactions of plant exudates with microbes that are found in soil ecosystems.

There are two major differences; time and temperature. Composting is rapid and hot, whereas the humic substances in soils are developed over long lengths of time at much lower temperatures. Depending on soil conditions, it can take years, decades, or more, for nature to create a completely humified material in soils. The end results of both processes, humic substances, are very similar with only some minor chemical differences, but those differences may be crucial.

The humic substances that develop from various source materials have slightly different chemical profiles. Municipal sludge, animal manure, straw, paper waste, vermicompost, etc. provide humified materials of different chemical and microbial makeup. As the humic substances derived from these various sources have a lot in common chemically, they all work very well when

applied to soils. No matter which source of raw material is used to make compost, the humified remains tend to increase the nutrient holding capacity (CEC), metal complexation (chelation), water retention, and biological activity of the treated soils. Over time, the different humic substances from the various amendments “mature” in the soil systems to become completely humified materials, if good biological regenerative practices are used.

Mature humic substances derived from soils and geological deposits are more complex than those from compost and have more functional groups, such as more doors and windows in houses. Their functions are similar to doors and windows in that they allow nutrient cations and anions to become part of the humic structure by allowing them to move in and out of the structure, holding them or releasing them into biological systems. The more functional groups present in humic substance, the higher the nutrient holding capacity and the ability to bind toxins, for example toxic metals and pesticides.



Balancing for Carbon

To simplify the explanation of these processes, the following terms have been proposed;

- Green carbon; the simple carbon compounds left behind in the soil that are consumed immediately by bacteria; amino acids, simple carbohydrates, such as sugars,
- Brown carbon; the more complex carbons that are decomposed by fungi; waxes, fats, melanin, lignin,
- Black carbon; the dark-colored remains of plants and microbes that become less and less identifiable; humus, humic substances.

When green carbons are incorporated into the soil, they provide simple carbon compounds that are easily broken down by microbes. This energy source for microbes causes an explosion in the microbial population. The immediate benefit from green manures is the conversion of locked up soil minerals into plant available nutrients, and the microbes themselves will become plant food upon being consumed by plant roots or upon their death.

The more complex brown carbons, such as lignin and melanins, will be slowly degraded by fungi and other organisms over longer periods of time. These complex carbons will eventually turn into humus exhibiting a brown-colored tint. The more complex carbon compounds of composts provide a sustained release of nitrogen, phosphorus, micronutrients and sulfur, while providing for better soil water holding capacity, pH buffering and increasing biological activity.

All of this activity over long periods of time will eventually end up as humic substances if high inputs of soluble nitrogen are avoided. Humic substances, the black carbon materials

responsible for stabilizing nutrients and improving soil conditions over long periods of time, further increase soil cation exchange capacity, pH buffering, water holding capacity, ability to detoxify, all increasing plant nutrient uptake efficiency. Because humic substances are composed of the microbial decay products of biomatter that has recombined into a more stable form of carbon, they are resistant to any further microbial breakdown.

When combined with clays and minerals, humic substances protect microbes and their enzymes as well as keeping plant nutrients in bioavailable forms, providing ideal conditions for microbes and minerals to interact in soil systems. Human digestion presents an almost identical system of interactions among minerals, microbes and organic matter to provide both nutrition and protection from disease; collectively called the human gut microbiome.

Commercial Humic Products

The numerous humic products found in the market place today are typically derived from raw materials sourced from ancient geological deposits of humified organic matter that have matured over long periods of time. They consist of dark humic materials that remain after the natural biodegradation of biomatter that has stabilized and is resistant to further biodegradation.

The main difference between humus in compost and the dark colored materials found in geological deposits is the maturity of the humified materials in the deposits, whereas humus in compost is a mixture of both fully humified, partially humified, and non-humified materials. Although only a small fraction of compost is humic substances, they are primarily responsible for the effectiveness of compost.

In soils, mature humic substances are critical components of ecosystems, providing the conditions that are necessary to maintain balance and self-regulation within the chemical, physical, and biological realms of soil systems. The manifestation of these self-regulated systems is soil health, plant health, and production, especially in low organic matter soils.

