Soil Carbon

Eco Agri-Minerals

Introduction

The most important aspect of sustainable crop production is the conservation and building up of organic matter; soil carbon. Soil carbon is typically reported as soil organic matter on a soil analysis report. However, soil organic matter is a very broad term and soil carbon even broader; it may be small bits of stubble and roots that haven't broken down from the previous crop, microbial remains, or it may be humus, which provides the dark colored portions of soils that are similar to the complex carbon compounds found in composts.

Carbon is actually an element. Soil organic matter may consist of anything as simple as graphite, which is nearly pure carbon, or synthetic chemicals, pesticides, or natural carbon substances released by plant roots and microbes. Some carbon compounds in soils are chemically identifiable, such as nitrogen containing amino acids, carbohydrates and fats. There is also a large group of substances that have recombined into materials so complex that their chemical formulas have not been determined.

The simple usage of the word "carbon" does not describe the incredible complexity of soil carbon compounds, most of which are important to sustaining agriculture. 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. If millions of carbon compounds may exist, then simply stating that carbon is important really needs to be explained further.

Simple Carbon

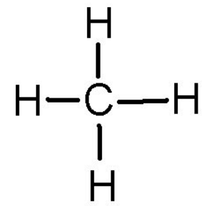
Natural carbon soil components that *are* beneficial to crop production are composed of mostly carbon, hydrogen, and oxygen assembled by living organisms into compounds (biomatter) that range from very simple to extremely complex.

The simple form of carbon called graphite, which is one of the softest natural materials, is used for lubricants and pencil leads. Diamonds are also composed almost entirely of carbon and are the hardest natural material known. Both substances have the chemical formula C. Obviously, graphite and diamonds are not the "carbon" that is used in agriculture. The fact that a substance can exist as two entirely different materials that are chemically identical will be expanded on later. The ability of an element to exist in many forms is called allotropy, which is a common occurrence and is dealt with extensively in the scientific literature and chemistry text books.

The carbon in graphite, diamonds, carbon dioxide (CO_2), or the carbon in carbonates, such as the calcium carbonate ($CaCO_3$) found in limestone, is referred to as *inorganic* carbon compounds because they are not closely associated with hydrogen atoms and are not chemically the same as the carbon configurations generated by living organisms. A soil analysis does not include inorganic carbon.

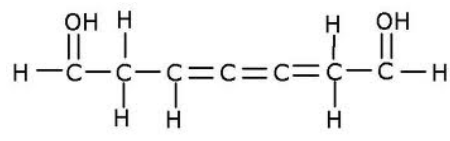
The carbon that is important to soil health and crop production is referred to as *organic carbon*. Organic carbon, which can combine with hydrogen, oxygen and nitrogen in an almost infinite number of ways, is the basis of all life as we know it. The simplest organic carbon compound is methane, which is made up of only carbon and hydrogen, but it does not contain oxygen. It combines with oxygen so easily, it will explode upon oxidation. Natural gas, swamp gas and the gas coming off of garbage landfills is primarily methane.

Again, this simple organic carbon compound is not the carbon referred to when we are referring to soil carbon. Carbon compounds from green manure crops and composts are much more complex.

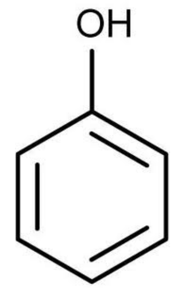


Complex Carbons

Carbon has some remarkable characteristics that have been exploited by biological systems to their advantage. For example, the carbon atom has the unusual ability to combine with itself, forming either long chains of single, double, and triple carbon to carbon bonds, or forming rings of carbon - carbon = carbon bonds. Various hydrogen and oxygen compounds can attach to the carbon chains or carbon rings in an infinite number of combinations. It's sort of like using bricks to build almost any kind of structure imaginable, then placing functional components into the bricks, such as doors and windows. In organic chemistry they are called *functional groups*.



The example on the right of a six-member carbon ring with an -OH (hydroxyl) functional group attached is called phenol or carbolic acid. In typical carbon ring drawings, each intersection of a line indicates a carbon atom. The carbon atoms are eliminated from the drawing for the sake of simplicity. Single lines represent single bonds and double lines indicate carbon double bonds. Carbon rings also have the ability to attach to each other or they can form extremely complex ring-ring combinations as we'll see later. The rings can also attach to long complex carbon chains.



The chemistry of these organic carbon substances is the basis of life.

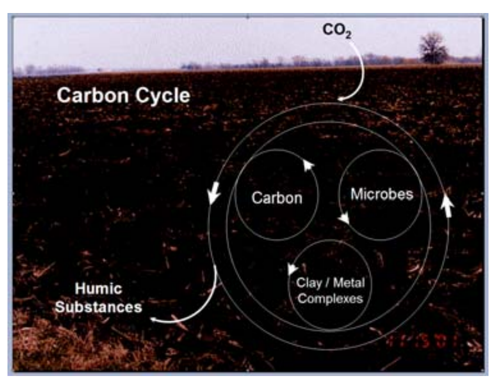
Synthetic chemicals are not the same as natural substances

Although some carbon compounds may have identical chemical formulas, the way they are configured will cause them to have completely different chemical properties. 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 configurations, just like the way your hands are mirror images of each other. Your hands are, for the most part, identical, except your left hand functions in a different manner than your right, and you can't put a left-hand glove on your right hand.

Every twisted, turned, flip flopped or right handed / left handed version of organic carbon compounds reacts differently in living organisms, or not at all. As a general rule, human-made (synthetic) organic compounds that have identical chemical formula as natural products do not have the same biological activity as natural substances. Nature has figured out how to efficiently control the flipping and flopping of carbon molecules and chemists can only try.

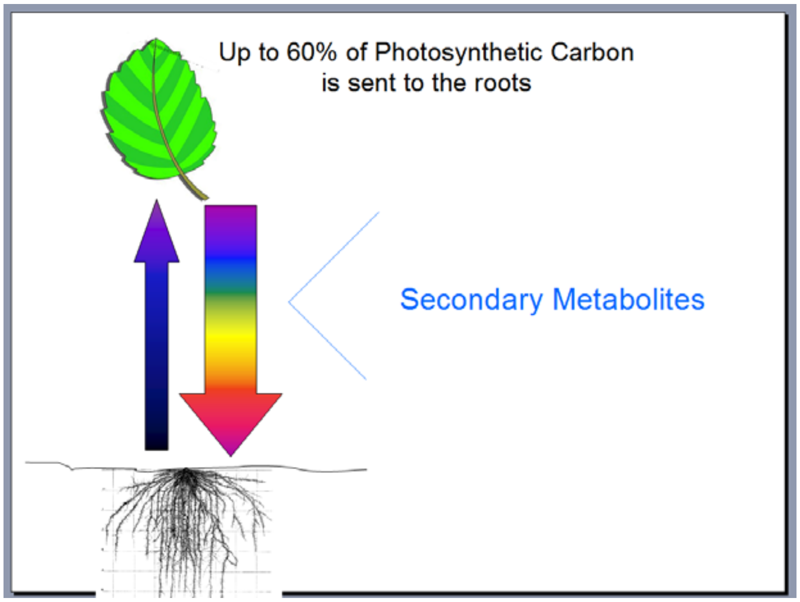
Complex Carbons in the Carbon Cycle

With all this twisting and turning in concert with the ability to form any kind of carbon structure with no limits on the kind of structures, nature must have had a plan on what to do with the millions of possible carbon compounds. As you can imagine, the complexity of organic carbon compounds can be mind boggling.



The cycling of carbon in natural soil systems starts out simple. Plants take in 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.

Organic acids and complex sugars are routinely excreted by plant roots to feed the microbial soil system. The primary beneficiaries of this soil – microbe - plant - food 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 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.

To give you and idea of just how important this function is, plants commit up to 60% of their carbon sequestration 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!

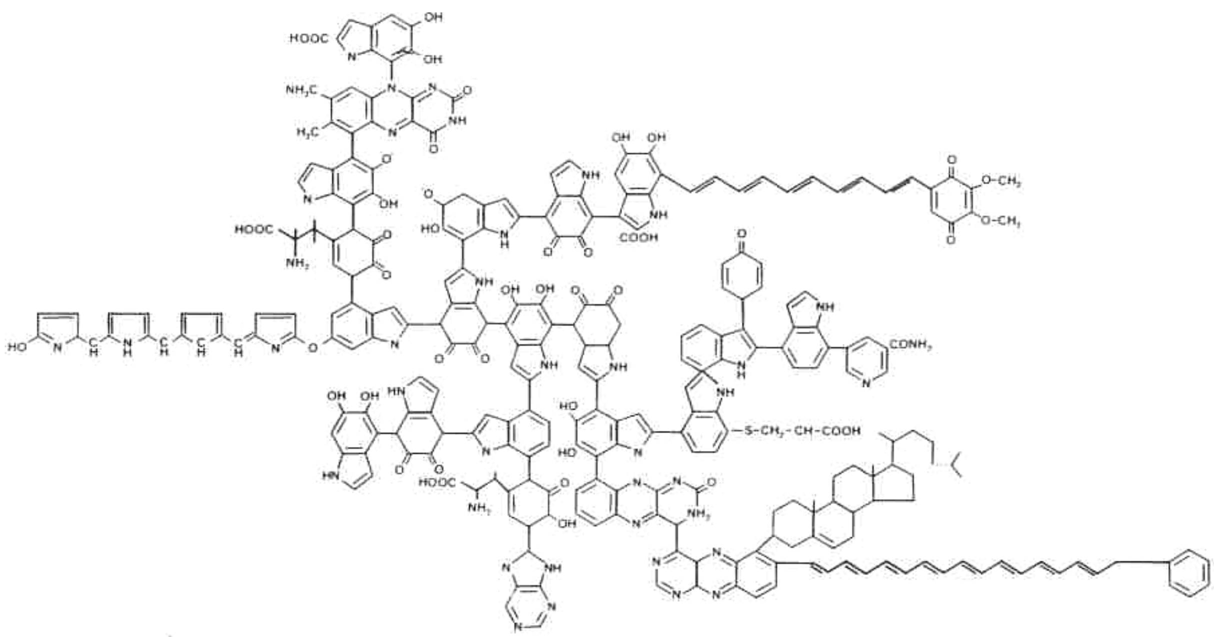
Upon the death of plants, some parts of the plants decay rapidly in soils while others (waxes, fats, lignins) are much slower to decay, and will eventually contribute to the more stable carbons found in healthy soils. The fungi in the soil that thrived by eating the bacteria, leave behind an extremely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

When the bacteria and fungi die off, their remains commingle with the remains of plant roots and shoots. That creates an extremely complex combination of slow and fast decaying chemicals and biomatter mixed up with all of the enzymes and stuff that are put into the soil by living plants and microbes. Calling this complex mixture an “alphabet soup” would be grossly understating the situation.

The less complex carbon compounds left behind in the soil are consumed immediately by bacteria and the more complex carbons are decomposed by fungi. As the physical remains of plants and microbes become less and less identifiable, the dark material that starts forming is what we commonly called *humus*.

The slow decay process of the more complex carbons (waxes, fats, lignins, melanins) 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 supermixture 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 call *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*; the most complex of all carbon compounds.



Humic Substances

Humic substances are the black materials that impart the dark color to fertile soils and compost. They are literally everywhere. They are the most common form of carbon in soils and they are responsible for maintaining the health of every ecosystem on the face of the earth. The water soluble portions of humic substances are responsible for the dark-yellow tint of some streams, rivers, and lakes. Notice the numerous times nitrogen (N) appears in the image above of a theoretical humic structure, emphasizing how important microbial action leads to stable nitrogen products. Therefore, the carbon cycle and nitrogen cycle are intimately connected, so much as to appear to be the same biological processes.

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, they 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. An almost identical system of interactions among minerals, microbes and organic matter that provides nutrients and protection from disease occurs in livestock and human digestion.

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 will not totally decompose in the compost pile. As the pile matures, the color of the composted materials tends 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 a pile of above ground compost. 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.

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 agricultural practices are used.

Mature humic substances are more complex and have more of those functional groups that I mentioned earlier, where I likened them to doors and windows in houses. Their function is 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.

Less mature humic materials have fewer functional groups, making them less effective at governing nutrient availability and providing protection from poisons. The more functional groups present in humic substance, the higher the nutrient holding capacity and the ability to bind toxins, like toxic metals and pesticides.

Balancing for Carbon

When green manures are tilled into the soil, they provide 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 their death.

The complex plant carbons from green manures, 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. Compared to fertilizers, the carbon compounds of composts provide a more 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. Humic substances, which are the black-colored materials responsible for stabilizing nutrients and improving soil conditions over longer periods of time because of their high cation exchange capacity, pH buffering, water holding capacity, ability to detoxify, and resistance to further microbial breakdown.

Commercial Humic Products

The numerous humic products found in the market place today are usually derived from the raw materials sourced from geological deposits of humified organic matter that have matured over long periods of time. Most of these deposits are associated with low rank (brown) coal. 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 humates 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 expression of these self-regulated systems is soil health, plant health, and production.

By in large, commercial humic substances of geological origin are strikingly similar to the mature humic substances found in soils, suggesting that their role in agriculture is obvious. They can be used to replace the humic substances that have been destroyed by non-sustainable practices, provide stability to any soil that is low in organic matter, or enhance biological / organic production systems. They are extremely versatile.