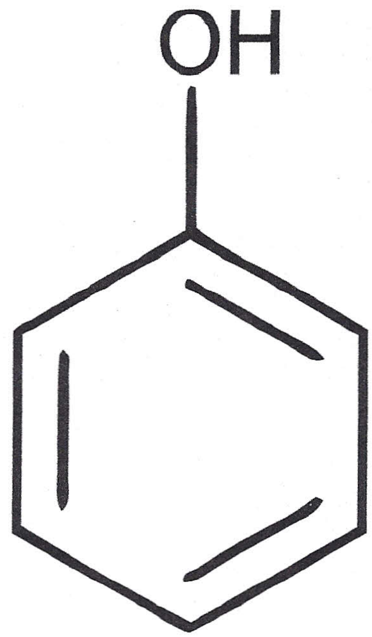
Carbon



by Lawrence Mayhew

The simple title of this article is intended to contrast the common usage of the word "carbon" with the incredibility complex carbon compounds that are important to agriculture. The element carbon has the ability to form over 10 million different compounds, making it the most versatile and the most common element in all organic matter on the face of the Earth, in living and dead matter.

When someone says you have to increase the carbon in your soils to feed microbes and build soil organic matter, etc., just what are they talking about? They should be talking about building up soil humus from the complex carbon compounds found in composts, green manure crops, microbe and worm poop, and the exudates released by plant roots into the rhizosphere.

SIMPLE CARBONS

The complex carbon compounds that are beneficial to crop production have very little chemical, physical and biological similarities with the simpler forms of carbon. One simple form of elemental carbon is graphite, which is one of the softest natural materials; it is used for lubricants and pencil leads. Diamonds are composed almost entirely of carbon and are the hardest natural material known. Obviously, these examples are not the "carbon" that is used in agriculture.

The carbon in carbon dioxide (CO_2) that plants pull from the air, or the carbon in carbonates, such as the calcium carbonate ($CaCO_3$) of limestone, are not chemically the same as the carbon found in living organisms. These simple forms of carbon are referred to as *inorganic* carbon compounds because they are not closely associated with hydrogen atoms.

The carbon that is important to soil health and crop production is referred to as *organic carbon*. Organic carbon, which can combine with hydrogen and oxygen 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. It wants oxygen so bad 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 you are advised to increase your soil carbon content. Carbon compounds from green manure crops and composts are much more complex.

COMPLEX CARBON

Carbon has some remarkable characteristics that make it very adaptable to biological systems. For example, the carbon atom has the unusual ability to combine with itself, forming either long chains of carbon — carbon bonds, or forming rings of 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 [Carbon 4] of a carbon ring with an -OH functional group attached is typical of carbon ring drawings where each intersection of a line indicates a carbon atom. The carbon atoms are eliminated from the drawing for the sake of simplicity. Carbon rings have the ability to attach to each other, forming extremely complex ring combinations.

TWISTS AND TURNS

Although some carbon compounds may have identical chemical formulas, amino acids for example, the way they are configured will cause them to have completely different chemical properties. Just as bricks, doors and windows can be arranged in all sorts of configurations, functional groups on organic carbon chains can be arranged many different ways also; twisted, turned, flip flopped, and left and a right configuration, just like your hands. Your hands are for the most part identical, but your left hand functions in a different manner than your right.

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

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, otherwise you would love studying organic chemistry, right?

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) and oxygen (O) and then make all sorts of organic carbon based sugars, starches, acids, fats, waxes, lignins, etc.

Organic acids and complex sugars are excreted through the 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 soil organisms.

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. [Carbon 1]

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 very slow decay process of the more complex carbons (waxes, fats, lignins, melanins) results in a complete chemical change (as well as physical change) in the original materials. When the completely decayed materials from plants and microbes are allowed to commingle over relatively long periods of time, the result is an even more complex supermixture that is no longer recognizable (either physically or chemically), 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, the final black products of humification have never been well defined chemically because they have no obvious structure; they just look like black dirt. They are called *humic substances*; the most complex of all compounds in the world.

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 Earth. The water-soluble portions of humic substances (dissolved organic carbons) are responsible for the dark tint of some streams, rivers, and lakes.

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 providing protection and nutrient bioavailability 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 because there are some major differences between the conditions in soils compared to compost piles.

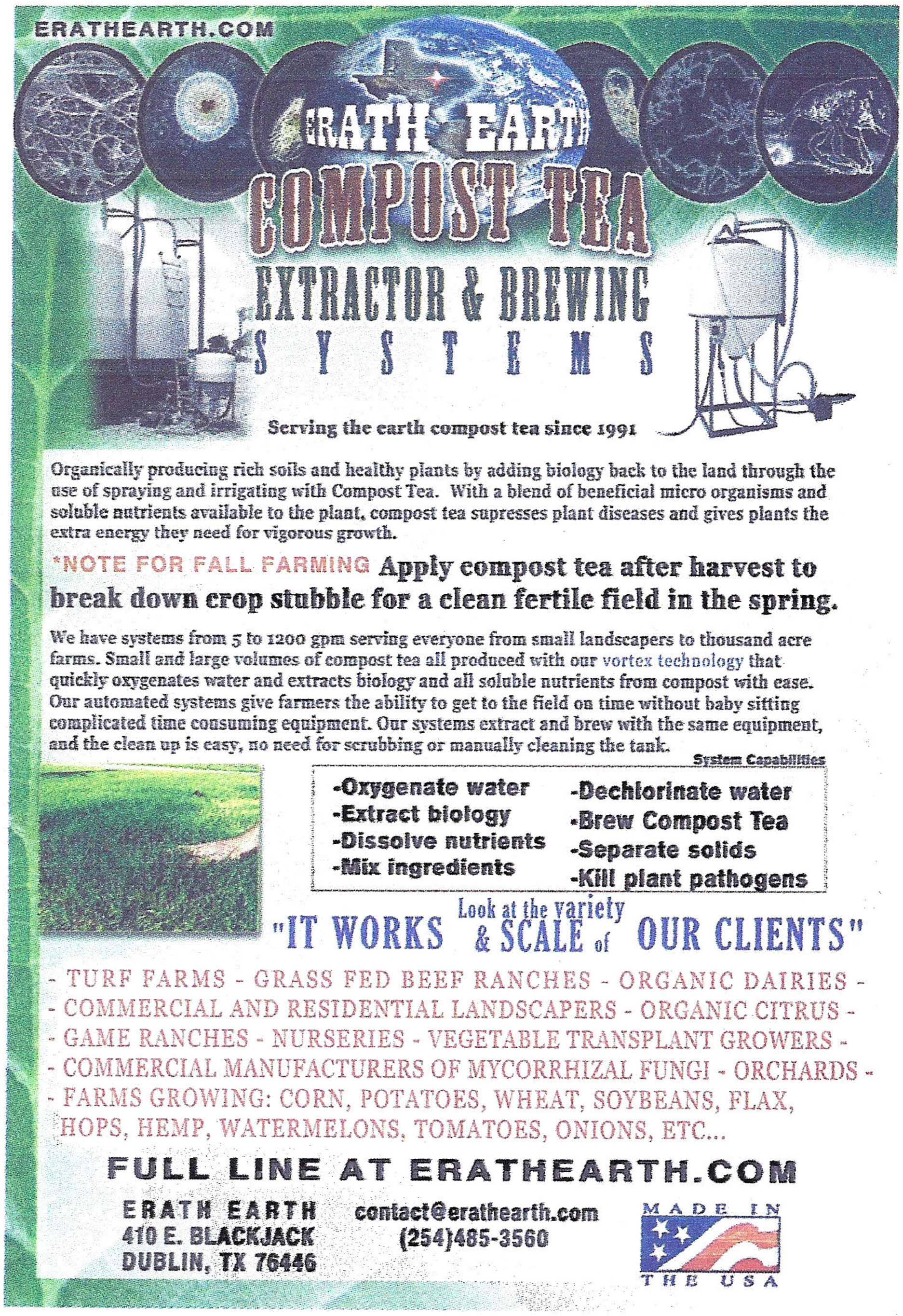
The soil humification process occurs in an environment of incredibly complex chemical, physical and biological interactions that is not duplicated in a pile of above-ground compost. A compost pile is not exposed to the same metal components, enzymes, pH, trace elements, earthworm interactions, and the 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. The good news is 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 on a humic molecule (we assume they are molecules), the higher the nutrient holding capacity and the ability to bind toxins and other nasty things, like toxic metals and pesticides.



HUMIC PRODUCTS

There are numerous humic products in the marketplace today. Typically, the raw materials used in humic products are derived from large geological deposits of humified organic matter that have matured over long periods of time. Most of these deposits consist of dark substances that remain after the natural biodegradation of biomatter, and whose distinct characteristics are their highly heterogeneous molecular makeup and relative resistance to further biodegradation.

The main difference between humus in compost and the dark colored materials found in geological deposits is the inability to chemically define the dark materials in the deposits, whereas humus is a mixture of both non-definable as well as easily defined substances, such as waxes, lignins, amino acids, polysaccharides, proteins, fats and numerous chemicals of microbial origin. Only a small fraction of well-defined compounds exist freely with humic substances.

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.

On the whole, 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.

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, or *green carbon*, 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 bugs over longer periods of time. These complex carbons will eventually turn into humus, or *brown carbon*. The brown carbon from composts provides a more sustained release of nitrogen, phosphorus, micronutrients and sulfur than fertilizers alone, 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, or *black carbon*, are responsible for extending the stabilization of nutrients and soil conditions over longer periods of time because of their extremely high cation exchange capacity, pH buffering, water holding capacity, ability to detoxify, and resistance to further microbial breakdown.

Lawrence Mayhew will be presenting at the 2010 Acres U.S.A. conference in Indianapolis, Indiana, as well as instructing a pre-conference intensive workshop, "Comprehensive Eco-Growing Systems," Dec. 6-8. For information visit *www.acresusa.com*.