

The Bio-Geo-Chemical Process of Plant Nutrition and Soil Formation: Can This Help Us Grow Healthier Oaks?

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ABSTRACT

For many decades, urban landscapers, horticulturists, farmers and agronomists have utilized the balanced fertilizer concept of N-P-K with a few minor plant nutrients thrown in from time to time. Fertilizers were formulated to stay in a soil solution for as long as possible, so that plants had a chance of utilizing them. For the objective of increasing the yield of an annual crop, fertilizers worked very well; however, they did so at a cost to the biological health of soils. Trees and specifically oak trees are obviously not an annual crop, but the same issue of soil decline can inflict maladies of poor nutrition if the soil's biological health is not managed properly! Nature's Bio-Geo-Chemical process is sabotaged by the use of the 'brute force' paradigm of modern agriculture and urban horticulture, causing chaos and death within the terrestrial biosphere, ultimately also causing the soil to lose the pipeline of Humic Acids. While the theme of this conference is oak trees, the problem of soils can be exemplified by what's happened to our food quality and nutrient density over the past few generations. There are many studies coming from all regions of the globe showing a decline in the density of vitamins and minerals found in our food. This presentation will cover the basics of soil chemistry and the mutualistic biology provided by bacteria and fungus, often called the Soil Food Web. I will show how and why Humic Acids are capable of changing a soil's chemistry and biology so that we can successfully grow a wider range of trees and plants in places they are not necessarily native to.

Keywords: anion, mycorrhizae, cation exchange, humic substances, RoundUp ready, soil food web, trophic levels

Introduction

Trees—specifically for this Conference, oak trees—are fascinating plants, because they live for many years and they grow tall, which challenges the conventional wisdom of how water and mineral nutrients are transported higher than a few feet. Water flows up into the organism, transporting soil minerals that are purified into elements, but many things must fall into place before this can happen. Nature finds a way to turn rock into soil and make the mineral elements of the rock into a nutrient that is valuable to a plant; this is called the **Bio-Geo-Chemical Process**. Many of these valuable elements are removed from the site because of the way we manage and maintain sites. When grass is mowed and leaves are raked and hauled away, or trees are harvested and removed from the site, soils are not being re-mineralized with the minerals cycled back in the form of decomposing organic debris. The problem is that neither agriculture nor urban horticulture is sustainable if we don't work with Nature's process of soil building. The situation is exemplified in agriculture where food is produced on modern farms, using modern chemicals, big tractors, soil fumigants (needed to fight soil disease), and GMO crops that are 'RoundUp Ready'—and the food being produced may not be very good for us. Many USDA affiliated officials, County Agricultural Agents and professors from agriculture colleges will argue that we cannot feed the world's bulging population without modernizing agriculture worldwide. However a scarier threat to the survival of mankind is the loss of healthy top soil, reducing our ability to produce quality food without poisoning our environment with chemicals.

For many decades, urban landscapers, horticulturists, farmers and agronomists have utilized the balanced fertilizer concept of N-P-K with a few minor plant nutrients thrown in from time to time. Fertilizers were formulated to dissolve into a soil water solution, so that plants have a chance of utilizing them. However, some of that fertilizer washes down into our ground water aquifers, into our streams, rivers and oceans—never a good situation. For the objective of increasing the yield of an annual crop, concentrated N-P-K fertilizers worked very well, but they did so at a cost to the biological health of soils. With better yields came more disease pressure on the crop, poor nutrition to the consumer, loss of soil structure, and a decline in top soil. Recalcitrant soil carbon is in decline globally; more specifically, Humic Acids and the precursor processes for making more Humic Acids are missing from most sites managed by mankind. This is very serious as Humic Acids are potentially the most important part of a healthy and productive soil, and have been described as “essential” in a recent paper published in the *Journal of Chemical Education* (Davies and Ghabbour, 2001).

While the theme of this conference is oak trees, the problem of soils can be exemplified by what has happened to our food quality and nutrient density over the past few generations. Whether a plant is a tree or a field crop, if it is failing to uptake minerals for any reason, it will not get what it needs in order to be healthy. The Kushi Institute findings on food nutrient density demonstrate this problem. The Kushi Institute analysis of nutrient data from 1975 to 1997 found that average calcium levels in 12 fresh vegetables dropped 27%; iron levels, 37%; vitamin A levels, 21%, and vitamin C levels, 30%. A similar study of British nutrient data from 1930 to 1980, published in the *British Food Journal*, found that in 20 vegetables the average calcium content had declined 19%; iron, 22%; and potassium, 14%. Yet another study concluded that one would have to eat eight oranges today to derive the same amount of Vitamin A as our grandparents would

have gotten from one. There are many more studies from all regions of the globe showing the same decline in the density of vitamins and minerals found in our food, including the food produced on organic farms.



1/ *Quercus hintoniorum* Nixon & C.H. Mull.

The Soil Food Web

Soil is the bridge between all life and the inanimate world, where the geosphere, the atmosphere, the hydrosphere and the biosphere meet, providing a fragile condition; “[w] here a thin blanket of air, a thinner film of water, and the thinnest veneer of soil combine to support a web of life, diversity and ongoing change” (Meléndrez, 2010). In recent years the industry of organic agriculture has become aware and supportive of the concept of a ‘soil food web’, which describes the flow of organic nitrogen from the smallest of microbes to a progressively larger and larger animal. In the process the excess nitrogen always leaks from the decay and consumption of the protein that was part of all those bodies of bacteria, protozoa, nematodes and other animals of soil. Each level of the process is called a **trophic level**. As we move up the levels to progressively larger and larger microbes, to multi cell animals, and finally larger animals such as earthworms, there is always an excess of nitrogen that becomes available to the vegetation growing on the site and this becomes the primary source of nitrogen in every ecotone on earth. It could also be the major source of nitrogen for our gardens, farms, mine reclamation sites, etc. Nitrogen may be the most emphasized of the big 3 major nutrients including phosphorus and potassium, called the N-P-K major nutrients, but there are many more

called the minor nutrients. Like your multiple vitamin mineral supplement A to Z formula, plants also need many elements such as iron, zinc, manganese, etc. These nutrients are present in the soil in the form of charged particles or ions, called **cations** when the charge is positive and **anions** when it is negative. All the minerals needed by a plant are expected to be provided in a natural ecosystem by decaying organic matter that is cycling. In this way, the decomposing Soil Organic Matter (SOM) is re-mineralizing the soil.

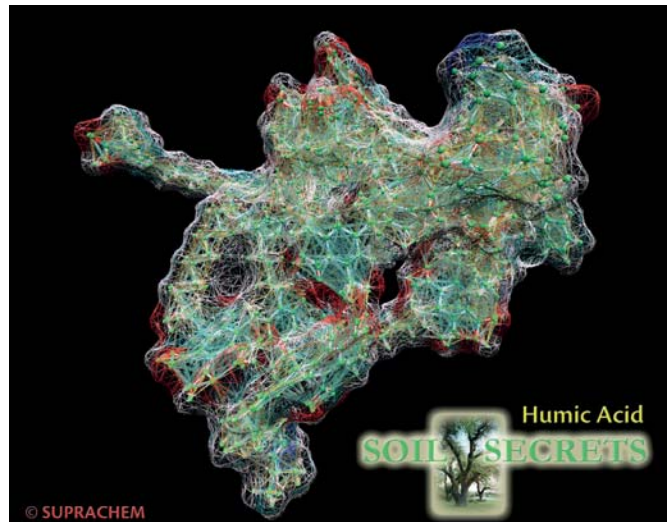
If the soil site is located where farming over many generations has been harvesting crops and consequently has shipped off many of the indigenous minerals of the site, or the soil pH is acidic, or the soil has a low cation exchange capacity, or thousands of years of high rainfall have washed away many of the plant nutrients, then it's likely that you will have a problem providing the nutrient density that your plant needs. This limiting factor is seen in the soil conditions of the managed forests of Europe, where generations of foresters have removed timber and destroyed the soil's structure, resulting in the depletion of soils! In agriculture and in urban horticulture, the question is, do you have enough minerals in organic form cycling in the soil and can your soil hold onto these mineral nutrients once they are no longer organic and have been liberated from the decaying organic matter? Agriculture and urban horticulture are haunted by disease pressure in the soil, caused by the overgrowth of soil disease microorganisms such as *Verticillium* wilt, *Phytophthora* blight, Texas root rot (cotton root rot), pink root disease, *Rhizoctonia*, and *Pythium*, a damping-off root rot. Modern agricultural fertilizers and soil fumigants have upset the balance of Nature, causing a decline in our beneficial soil microbes, particularly the mycorrhizal fungi, and stopping the competitive exclusion of disease!

For the purpose of describing the problem of sustainable soils, I'll cover two major bottlenecks in this paper. One limiting factor consists of the mutualistic mycorrhizal fungi that all oaks trees need for optimum nutritional uptake of many of the minerals that are not easily soluble in water. The other limiting factor is what I term the Carbon Connection, or the availability of carbon. Some carbon substances of the soil are simply decaying organic matter while other carbon fractions are powerful biologic chemicals that are doing many things that are critical to soil and plant health.

The Carbon Connection

To most plant professionals, landscape architects, nursery people, farmers and home owners, the concept of adding organic matter to soil as a method of improving the health of soil sounds reasonable. For most of us, the main defining characteristic of a top soil is the presence and the concentration of SOM that either accumulated over many centuries or was intentionally added. Organic matter can be in the form of actively decomposing dead things such as roots, leaves, wood or compost, or it can be in the form of complex molecular carbon-based chemicals that are not actively decomposing. It can be said that SOM is composed of a continuum of materials of varying chemical complexity with mean turnover times from days to years and even millennia (Davidson and Janssens, 2006). The discrete pools of soil carbon substances that make up the total SOM can be divided into more discrete pools that can be characterized by the turnover times they exhibit in soil (Parton et al., 1987, Jenkinson, 1990 and McCown et al., 1996). SOM pools are chemically divided into two categories, **labile carbon** which has a rapid turnover rate

and **recalcitrant carbon** which is slow to decay, lasting decades or longer. It is the accumulation of recalcitrant carbons that has the lasting benefit of building top soil! Due to the strong chemical bonds of the recalcitrant carbon substances, they are not easily consumed by the saprophytic microbes of soil, therefore they can accumulate and build a top soils' physical, chemical and biological characteristics. Labile carbon is any SOM that is in an active state of decomposition, turning rapidly



2/ Supramolecular Humic Acid Molecule.

back into CO₂ and includes dead roots, leaves, animals (large and small), along with soil amendments such as compost, manures, peat moss, worm castings, mushroom compost, etc. Within the recalcitrant carbon substances of soil may be found powerful biologic chemicals of Nature called **Supramolecular Humic Acids**, or humic acids for short. The common term **humus** refers to the scientific term **Humic substances**, another name for recalcitrant soil carbon. Humic substances may or may not contain a significant amount of Humic Acids, or the active fractions of Humic Acids called Humic acids, Fulvic acids and Humin. While soil amendment products are available that claim to contain Humic Acids, it's difficult for a manufacturer to prove that their Humic Acid product actually contains this active ingredient with the proper chemical characteristics since there is not a standardized method of analysis that commercial or university soil labs are capable of performing (Piccolo, 2002). Saying that the Humic Acids are Supramolecular is very significant because when any chemical is Supramolecular, the molecules of the chemical can find each other and self-assemble into giant clusters or chains called Supramolecular structures, where each molecule in the structure is not chemically bonded to the other molecules. It's this characteristic that really amounts to a powerful biologic chemical! In chemistry, **molecular self-assembly** is the process by which molecules adopt a defined arrangement without guidance or management from an outside source. At the 2013 IOS conference I showed a 3-D geospatial image of Humic Acids forming a Supramolecular structure and I also showed how Humic Acids, when supramolecular, attract and hold water molecules, preventing the water from easily evaporating. See next, an attached image of a Supramolecular Humic Acid molecule that was purified from a soil sample, described and characterized by the collaborative efforts of Soil Secrets LLC, SUPRACHEM Labs and the United States National Nuclear Security Administration laboratories.

In experimental studies, a variety of chemical, physical and biological fractionation procedures have been developed to characterize various pools of soil C and N and to study the distinction between labile soil carbon, recalcitrant soil carbon and Humic Acids and their impact on the carbon to nitrogen ratios (Olk and Gregorich, 2006). Recalcitrant soil carbons, also known as Humic substances, can be further described as potentially containing powerful biologic chemicals that are Supramolecular Humic Acids (Piccolo,

2002), (Meléndrez and Wood, 2011). While the general literature still concludes that there is considerable discrepancy between what is simply soil carbon, what is recalcitrant Humic carbon and what are the Humic Acids, the debate is caused by a lack of purification techniques that allow for the extraction of the Humic Acids without damaging or destroying them completely, therefore making it difficult or even impossible for typical commercial or university soil labs to perform true chemical analysis for modeling studies (Piccolo, 2002). Recently, however, Soil Secrets and a team of chemists at the National Laboratories of Sandia and Los Alamos in collaboration with the team of chemists from SUPRACHEM have developed the technique of purifying Humic Acids, for the objective of analysis, from a soil sample without changing them, providing the evidence of what the molecular description of Humic Acids really is and what benefits they can provide (Meléndrez and Wood, 2001).

Here's my laundry list of benefits provided by Supramolecular Humic Acids

1. Help the macro-aggregate formation of soil.
2. Help improve drainage, porosity and oxygen diffusion into the soil. All plants and all beneficial soil microbes need oxygen.
3. Have an extremely high cation exchange capacity allowing the chelation of plant nutrients so they won't wash away during high rainfall events.
4. Participate in microbial respiration, helping microbes to continue functioning when soils become saturated during high rainfall or irrigation events.
5. Can remove salts and sodium from soil.
6. Can accelerate the decomposition of petroleum hydrocarbons from soil, in the event of an oil spill.
7. Help to manage water in the soil and are particularly important in arid climates by helping to conserve water.
8. Help in the fluid transport of water up into a tree or taller plant by changing water into a semi water/gas state for improved uptake.
9. Help to hold plant nutrients in a water solution in the soil, so that plants can uptake the nutrient easier.
10. Stop virus replication in cells.
11. Reduce disease pressure in soil by changing the environment to one that is more supportive of beneficial microbes, causing competitive exclusion of the pathogen.
12. Help make indigenous minerals available to plants by creating a weak acid called carbonic acid, which will liberate minerals.

The Mycorrhizal Fungi Connection

The second bottleneck to providing optimum nutrition to crops or to urban landscapes is a fungus-plant relationship. Mycorrhizal fungi are best described as a partner with plants, where both fungus and plant are mutualistically benefited from the partnership. Research performed by several entities including the USDA Agricultural Research Service has proven that the 50 to 100 years of farming in the United States has taken a toll on the indigenous mycorrhizal fungi count in soil (Taheri, 2012). While many people will claim that mycorrhizal fungi are already in the soil and therefore don't need to be added, the research on this fact appears to dispute that claim. Research performed by the USDA Agricultural Research Laboratory for the upper Midwest measured how

many mycorrhizal fungi spores remained in a farm soil as compared to a native prairie soil that is not being farmed and the difference was huge. In addition, the farm soil was dominated by a different kind of fungus that was not mycorrhizal, so while the native non-cultivated site was dominated by arbuscular mycorrhizal (AM) fungi, the agricultural soil was dominated by non-mycorrhizal fungi. For example, the *Candida* yeast problem that may affect humans is a fungus that can dominate in a soil and which can cause disease pressure problems with crops. The same is true concerning urban landscapes that have a history of fertilizer use, compaction, and other practices that impair the plants' ability to maintain a relationship with mycorrhizal fungi. Mycorrhizal fungi can sequester minerals from the soil that the plant can either not reach or cannot harvest because the minerals are complexed into a chemical form that ties up the mineral preventing it from being put into solution for plant uptake. An example of this is the acidified phosphorus used in fertilizers. When acidified phosphorus comes into contact with iron in the soil, iron-phosphate is formed, a substance that will not oxidize and therefore cannot become soluble for a plant to sequester by itself. However, the hyphae tubes of mycorrhizal fungi are soil drills and they can explore the soil tenfold further than their host plant can with roots and they can make enzymes and chemical solutions that can liberate the iron and the phosphate, transporting those elements back to the host plant for feeding. The benefit of being supplied minerals and water by the mycorrhizal fungi is paid for by the plant as it will supply liquid carbon (glucose) that the mycorrhizal fungi needs for energy.

At the risk of over simplifying the many benefits of mycorrhizal fungi, here's a laundry list of benefits.

1. Nematode control, controlling harmful nematodes by eating them and their eggs for a nitrogen source. Remember the soil food web is all about nitrogen cycling.
2. Disease prevention, as mycorrhizal fungi protect plant roots from disease and also keep the host plant healthier so it can protect itself from disease.
3. Improved drought tolerance, as the mycorrhizal fungi's hyphae can sequester water from soil that the plant roots cannot reach.
4. Soil building, as the AM fungi (endotypes) in the genus *Glomus* make a glycoprotein called glomalin, a precursor chemical to recalcitrant soil carbons. This helps to glue the soil into a better macro-aggregate structure.
5. Improved water percolation into the soil, due to the improved macro-aggregate structure and the improved concentration of Humic Acids that also help soil structure and water management.
6. Improved uptake of soil minerals into the host plant, which will increase the nutrient density of that plant, therefore improving the health of the plant.
7. Improved tolerance of extreme pH conditions
8. Improved uptake of minerals that normally are tied up when the pH of soil is either too acid or too alkaline.

Finally, it has been demonstrated that in agriculture, mycorrhizal fungi can replace on the average 25% of the phosphorus we currently utilize without a decline in yield, on sites where adding phosphorus has always been needed because the indigenous phosphorus on the site is chemically tied up. However if there is plenty of phosphorus in the soil, but not available to plants, the mycorrhizal fungi can supply all the needs of the plant by harvesting what is native to the site. The key is to not wait for the native

mycorrhizal fungi to rebound once you begin a transition of appropriate mycorrhiza-friendly management techniques. Instead, it is very cost effective to inoculate your crop or your landscape with a mycorrhizal product that contains the proper species for the type of plant you are nurturing. There are plenty of good quality mycorrhizal products now on the market that provide what I call an “agriculturally applicable product” which means the product has a high spore count per pound of material and the manufacturer can show you evidence of the spore count provided by a certified 3rd party lab.

My Conclusion

I’ll hang my hat on the science and the benefits of mycorrhizal fungi and Humic Acids that are Supramolecular, because both play an active role in the Bio-Geo-Chemical process of plant nutrition and soil formation and without either the whole process is compromised. Over 90% of the Earth’s plants are dependent upon mycorrhizal fungi to successfully sequester the water and the minerals that plants need for optimum nutrition. While some plants may survive without that relationship, they may struggle, be easily infected by disease, grow poorly and yield a poor crop. Without Humic Acids and a mycorrhizal relationship, landscape plants such as trees may be prone to chlorosis, salt burn, drought, slow growth, poor health and a reduced life expectancy. Combined, Humic Acids and mycorrhizal fungi provide the environment for healthy soils, leading to the perpetuation of healthier plants.

Photographers. Title page: Béatrice Chassé (*Quercus macrocalyx* Hickel & A. Camus). Photo 1: Béatrice Chassé. Photo 2: Suprachem.

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