

Humus, Humic Acid and Humates

Foreword:

This is a very technical and complex field. Without an adequate foundation in Chemistry, Botany and Nutrition, the reading of most articles that one finds on the INTERNET is about as informative reading as how to garden in Greek. Either there is too much technical mumbo jumbo, or the information is replete with hype-- or worse, full of misinformation. The only place appropriate for that kind of BS is perhaps in fertilizer compost itself!

The average gardener, houseplant enthusiast, or farmer, should not have to be a soil scientist to comprehend how to employ basic soil-building principles. The writer certainly wasn't when he started to try to figure out what the chemists and fertilizer purveyors were attempting to put across. However, before one can convincingly re-articulate techniques in simpler terms, one truly needs to understand what he or she is talking about, first. Unfortunately, most of us were sufficiently intimidated by High School Chemistry class that, that is where it all stopped.

For those of you who would still like to try to build upon your knowledge, but one brick at a time, this article might be ticket. To the extent that it is accurate, it may save you tons of reading of the kinds of articles with which I had to grapple, in order to glean the following gems.

Montmorillonite. If you forget everything you read after this but that word, you will have picked up a gardening tip and agricultural term that will prevent or overcome a multitude of mistakes. For the best source of this natural mineral complex go to:

www.chelatedtraceminerals.com

That is not merely a self-serving opinion of my own, but was articulated by one of the Godfathers of Trace Mineral Research. He said:

The most outstanding form of Montmorillonite, is the brown source from Panaca, Nevada...The Panaca Montmorillonite is superior to all other known deposits. All other deposits of which I am aware were formed by volcanic action, which means that most of the ingredients present are in their elemental state and are not readily assimilated by animals and humans... In order for minerals to be more readily metabolized, they must first be chelated. [Melchior T. Dijkers PhD DSc, retired professor of organic-chemistry, Loyola University, scientist and research Bio-Chemist (**Faust, 1986**). Refer to www.montmorillonite.org]

So, What is Humus?

The term "humus" dates back to Roman times when the term was commonly used to designate the soil as a whole. The modern connotation has been applied exclusively to the completely decomposed organic matter of soils and composts, although it is still loosely used with reference to different fractions of this organic matter, as well as, to complexes formed by the action of chemical reagents upon a variety of organic substances. More precise terms for developing humus or its by-products can be found by consulting the paragraphs written about humic substances, organic matter, humates, humic acid and fulvic acid, inter alia.

In 1761 Wallerius first defined "humus" in terms of decomposed organic matter. However, the prevailing ideas concerning the chemical nature of humus and the mechanism of its formation at that time were still very vague. Most often it was considered as a complex formed in soils, in bogs, or in composts, from plant residues, by a special process of "humification".

The famous work of De Saussure, "Recherches Chimiques Sur La Vegetation", devotes considerable attention to humus. He reasoned that it is not a homogeneous substance, but that it consists of various readily removable complexes. Thaeer differentiated between "mild humus", formed in the presence of sufficient oxygen, and "acid humus" or peat, formed with limited admission of oxygen.

Thus, the term "humus" came into general use at a time when organic chemistry was still in its infancy. We now regard most organic and inorganic compounds as more complex substances rather than of simple in chemical composition. [*Humintech website*]

Humus is formed by the decomposing action of soil microorganisms (e.g., bacteria and fungi), which break down animal and vegetable material into elements that can be used by growing plants. According to Waksman, this decomposition may take place "under aerobic and anaerobic conditions, usually in soils, composts, peat bogs, and water basins". Technically, humus itself, should be distinguished from the by-products it forms that are active constituents of organic [fertilizer](#). Because of its low specific weight and high surface area, humus has a profound effect upon the physical properties of mineral soils with regard to improved soil structure, water intake and reservoir capacity, ability to resist erosion, and the ability to hold chemical elements in a form readily accessible to plants. [*The Columbia Encyclopedia*]

Simple Definition: [HUMUS](#) is the organic portion of the [soil](#) remaining after prolonged microbial decomposition [*National Safety Council website*].

Different kinds of soils will have different balances of microorganisms. Row crops and grass system soils will be populated with a majority of bacterial microorganisms. Bacteria choose to feed on green, succulent, fresh organic matter. A forest, orchard or vineyard will have soils dominated by fungal species. Fungi prefer woody, starchy food. [**Padgham, 2005**]

Generally speaking, humus is recognizable as a brown to black complex and possessing cellular organization in the form of plant and animal bodies. It is the major component of organic matter in the soil, making up between 65% and 80% of the total. An interesting fact is that humus also assumes an important role as a fertility component of all soils, far in excess of the percentage contribution it makes to the total soil mass. However, the most important function of humic substances within the soil is their ability to hold water, and available water is without doubt the most important component of a fertile soil. Soils that contain high concentrations of humic substances hold water for crop use during periods of drought. Growers who routinely apply humate-based fertilizers, and conscientiously integrate production practices that preserve humic substances, can frequently harvest a crop even during periods of dry weather.

Complex carbohydrates synthesized by bacteria function together with humic substances, silt, and clay to form soil aggregates. As the humic substances become intimately associated with the mineral fraction of the soil, formation of colloidal complexes of humus-clay and humus silt, occurs. These aggregates, formed by electrical processes, increase the cohesive forces that cause clay components and the very fine soil particles to become attracted to one another. Once formed, these aggregates help create a more “friable” topsoil, or “crumb structure”. Soils with good crumb structure have improved tilth, and more porous openings (open spaces). These pores allow for gaseous interchange with the atmosphere, and for greater water infiltration. Humus adds to the soil structure by coating these mineral particles and holding them together; and thus serves as a major reservoir of plant nutrients.

In summary, although humus generally makes up only a small percentage of the total soil mass, its value to the overall picture cannot be overrated. Without humus, soils would be largely unproductive and merely increasing the amount of conventional fertilizers would soon reach the point of diminishing returns. On the other hand, organic farming which actively employs humus and fosters its retention, has proven to be a cost-effective alternative to chemical treatments, besides the fact that increasing humus actually improves soils long-term while simultaneously increasing nutrition and decreasing the effect of pollutants.

Non-humic Substances

Non-humic compounds are soil organic compounds that are still identifiable as:

Sugars and Starches (carbohydrates)

Fats (lipids)

certain Acids, etc. [*UC Davis*]

non-humic substances such as carbohydrates (a major fraction of soil carbon), fats, waxes, alkanes, peptides, amino acids, proteins, lipids [Petit]

Soil Carbohydrates:

Carbohydrates constitute **5 to 25%** of the organic matter in most soils. Plant remnants contribute carbohydrates in the form of **simple sugars**, **cellulose**, and **hemicellulose**, but these are more or less decomposed by actinomycetes, bacteria, and fungi that synthesize **polysaccharides** and other **carbohydrates** of their own in turn.

Carbohydrates (CHO) are sugar-base molecules. Complex carbohydrates are chains of sugar molecules and are found in plant foods everywhere. Starch is a polymer or long string of glucose molecules... [S J Gislason]

Three major groups of carbohydrates

1. **Monosaccharides:** aldehyde and ketone derivatives of the higher polyhydric alcohols.
2. **Oligosaccharides:** a large group of polymeric carbohydrates consisting of a relatively few monosaccharide units.
3. **Polysaccharides:** contain many monomeric units (8 or more)

The carbohydrate matter in soil occurs as:

- Free sugars in the soil solution
- Complex **polysaccharides**
- Polymeric molecules of various sizes and shapes which are attached to **clay** and/or **humic colloids** very strongly

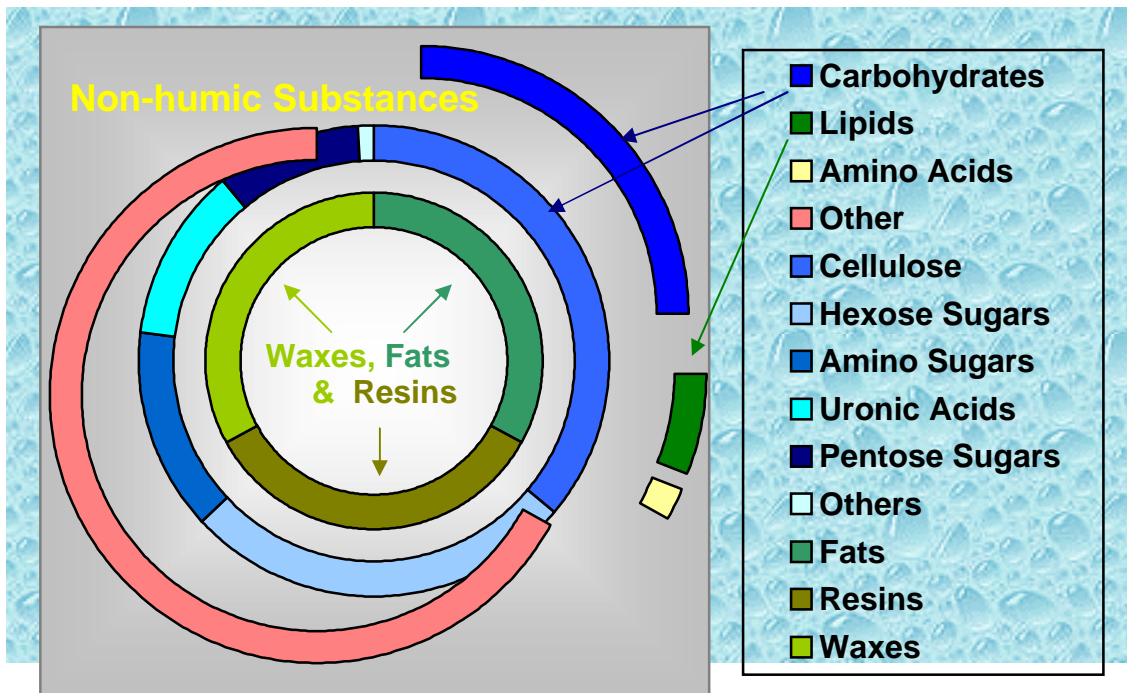
Sugar	% of Organic Matter
Amino Sugars	2-6%
Cellulose	< 15 %
Hexose sugars	4-12%
Pentose sugars	< 5
Uronic acids	1-5%
Others	trace

Soil Lipids

Rather than a specific type of compound, the class of organic compounds designated as lipids represents a convenient analytical group. **Lipids** are comprised of a diverse group of materials ranging from relatively simple compounds such as **fatty acids** to more complex substances such as **chlorophyll, fats, polynuclear hydrocarbons, resins, the sterols, terpens, and waxes**. So-called **fats, resins** and **waxes** constitute the bulk of the soil lipids. In normal aerobic soil it is believed that the presence of lipids is largely attributed to the remains of plant and microbial tissues.

From **2 to 6%** of soil humus occurs as **fats, resins, and waxes**.

Lipids are physiologically active. Some compounds act as growth hormones whereas others have a depressing effect on vegetative growth. **Waxes** and similar substances may be responsible for the water-repellent condition of certain sands.



Amino Acids

Amino acids exist in soil in several different forms, such as:

Free amino acids either in the soil solution or in soil micropores

Peptides or **proteins** or simple amino acids, bound to **clay minerals** on external surfaces and or internal surfaces.

Peptides or **proteins** or simple **amino acids**, bound to **humic colloids**

e.g., H-bonding and van der Waals' forces, or
in covalent linkage as quinoid-amino acid complexes

As mucoproteins

Muramic acid

Amino acids, constantly being decomposed by microorganisms, have only an ephemeral (short-lived) existence in **soil**. Since they are readily decompose the amounts present in the soil at any point in time represent a balance between synthesis and destruction by microorganisms.

Weather conditions, the soil's moisture status, fluctuations of organic residues, condition of the soil culture, and stage of growth and type of plants present, dramatically affect the the soil's free amino acids content. <http://www.up.wroc.pl/~weber/no.htm>

Humic Substances

Humic matter is completely decomposed organic matter and it is readily soluble in acids or bases. Humification is the biological process of converting organic matter into humic substances. [*Humintech website*]

Humic substances can be subdivided into three major fractions:

- (1) HUMIC ACIDS
- (2) FULVIC ACIDS and
- (3) HUMIN.

These sub-divisions are arbitrarily based on the solubility of each fraction in water adjusted to different acid/alkaline (pH levels) conditions. Humic substances are a colloid and coat soil particles, acting as a cushion and an interface between the non-living mineral of the soil and the living plant root. Native soil humic substances enhance plant growth both directly and indirectly.

Plants and animals can absorb elements more readily in humic form because the elements have already been assimilated and chelated by the micro-organisms which may have utilized parent organic matter eons ago. Many of the components of humus are heterogeneous, relatively large, stable organic complexes. Physically, they function to give the soil structure, porosity, water-holding capacity, cation and anion exchange. Biologically, they affect the activities of microorganisms. Chemically, they serve as an adsorption and retention complex for inorganic plant micro-nutrients, especially iron. Inorganic iron compounds are very unstable in soil and tend to become insoluble and unavailable, especially in calcareous soils. However, humate compounds can incorporate iron into chelated complexes, maintaining its availability to plants, although still in insoluble form.

Therefore, it can be said that humic substances are high molecular weight compounds that together form the hydrophilic, molecularly flexible, polyelectrolyte components of humus. The elemental analysis of humic substances reveals that they are primarily composed of carbon, oxygen, hydrogen, nitrogen, and sulfur in complex carbon chains. (Petitt) Specifically, humic matter has been shown to increase the uptake of nitrogen by plants, and to increase soil nitrogen utilization efficiency. Nutritionally, humic substances are also sources phosphorus, as well as, enhancers to the up-taking of potassium, calcium, and magnesium, benefiting micro-organisms that benefit the plants in turn. All of these effects increase the productivity of the soil. In addition, *chlorosis* in plants has been prevented, or corrected by humate application, probably the result of the ability of humate to hold soil iron in an assimilatable form. This phenomenon can be particularly effective in calcareous (alkaline) soils that are usually low in organic matter content, and deficient in available iron.

Humic substances have been shown to contain a wide variety of molecular components. Some typical components are:

- aliphatic compounds (carbon chains)
- carbonyls
- esters
- ethers
- fatty acids
- furan-ringed compounds (aromatic) including various combinations of benzene, acetal, ketal, and lactol.

- lignins
- lipids
- peroxides
- phenols
- polypeptides
- polysaccharides, and quinones

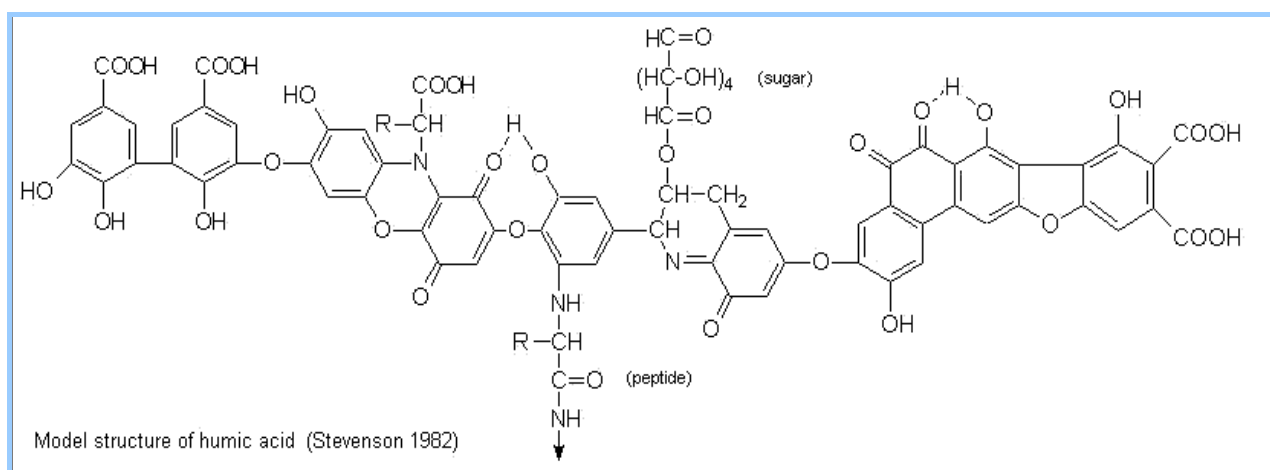
Applied pesticides substantially interact with humic substances in the soil, but the reactions are complex. Certain pesticides may be immobilized by humates and can be caused to practically disappear from the soil environment. In this case, humic substances can be very effective in removing excess pesticide from sandy soils very low in organic matter thus avoiding toxicity hazards. However, the degradation of a particular pesticide will be determined in part by the rate of release. Amazingly, a number of degraded pesticides can form new groups of compounds that complex with humates, which can then be absorbed safely by plant roots. Degradation or inactivation of other toxic substances such as nicotine, aflatoxins, antibiotics, and shallots, and most organic pesticides is also mediated by humic substances. In the microbial degradation process not all of the carbon contained within these toxins is released as CO₂. A portion of these toxic molecules, primarily the aromatic ring compounds are stabilized and integrated within the complex polymers of humic substances. Humic substances have electrically charged sites on their surfaces which function to attract and inactivate many toxic substances. Humates are even recommended nowadays with frequency by the Environmental Protection Agency for the use of for clean up of toxic waste sites. Many bioremediation companies have sprung up that apply humate-based compounds to toxic waste sites as a part of their clean-up program. Growers who farm soils low in humus should include the purchase of humic substances within their fertilizer budgets. Humic substances are extremely cost-effective, as they can be more than offset by reduced costs of other fertilizer ingredients.

In modern agriculture, commercially-available humic substances added to the soil do not directly contribute significant quantities of nutrients to plants at the rates normally applied. However, indirect effects, as catalysts as on fertilizers can be significant as revealed by studies on yield, and enhanced nutrition in plant tissues.

(1) Humic Acid (HA)

Humic acids are colloids and behave somewhat like clays, even though the nomenclature suggests that they are acids and form true salts. When the cation exchange sites on the humic molecule are filled predominantly with hydrogen ions, the material is considered to be an acid and is named accordingly. However, it has no great effect on pH because the acid is insoluble in water. When the predominant cation on the exchange sites is other than hydrogen, the material is called humate. [Senn and Klingman, 1973]

Humic acids or humus can be defined as the end product of the decomposition of organic matter by aerobic organisms. Humic acids readily form mineral salts with inorganic trace elements. An analysis of extracts of naturally-occurring humic acids may reveal the presence of over five dozen different mineralized elements present. These trace elements are bound to humic acid molecules in a form that can be readily utilized by various living organisms. As a result humic acids function as important ion exchange and metal complexing (chelating) systems.



Humic acids comprise a mixture of weak carbon chains and carbon rings. They are organic acids that are not soluble in water under acidic conditions, but are soluble in water, under basic (alkaline) conditions. When the pH is decreased below 2 in water-based solutions, humic acids solidify and fall out of solution, becoming that tiny fraction of concretions (precipitates) visible at the bottom of the test tube. On average 35% of the humic acid molecules are rings of carbon atoms (aromatic) while the remaining components (65%) are molecules in the form of carbon chains (aliphatic).

The molecular weights of humic acids range from approximately 10,000 to 100,000. Humic acid polymers readily bind clay minerals to form stable organic clay complexes. Peripheral pores in the polymer are capable of accommodating (binding) natural and synthetic organic chemicals in lattice-(clathrate)-type arrangements. [Petitt] In the absence of the clay or humic colloids, the cations may be lost either through fixation or leaching, and thereby lost to the plant root.

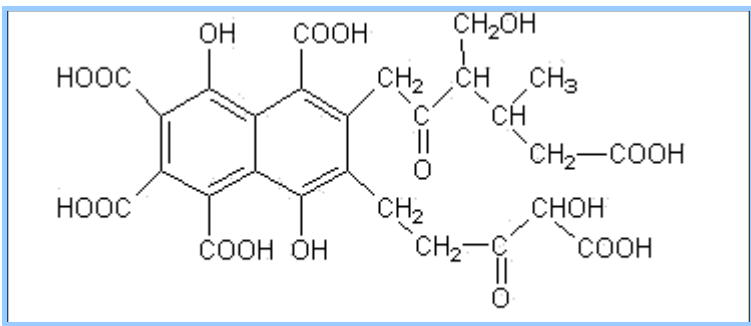
Humic acids are crucial to life on earth, but they are susceptible to depletion via oxidation, and may become deactivated by sodium or aluminum. This creates soil problems which may impact the food chain all the way up. Humic acids have been shown to stimulate seed germination of several varieties of crops. The plant characteristic that the addition of humic substances has consistently enhanced more than any other is root length, especially on sandy soils. Top growth, vigor, and trunk cross-sectional area are also increased in response to stimulation by humates, but the effect is usually more prominent in the roots. A proliferation in root growth, resulting in an increased efficiency of the root system, is a likely cause of higher plant yields seen in response to humic acid treatment.

(2) Fulvic Acid (FA)

Fulvic Acids, from "fulvus" meaning yellow. Fulvic acids are light yellow to yellow-brown in color. They are that fraction of humic substances that is soluble in water under all pH conditions. They remain in solution after removal of humic acid by acidification. [*Humintech website*]

Fulvic acid is "a water-soluble, natural organic substance of low molecular weight which is derived from humus, often found in surface water." [*Water Quality Association*]

Of the three main humic substances previously outlined, fulvic acid is perhaps the most interesting for nutritional purposes. The size of fulvic acid molecules is even smaller than humic acids, with molecular weights ranging between just 1,000 to 10,000. Because of their relatively small size, fulvic acid molecules can more readily enter plant roots, stems, and particularly, leaves. Therefore, fulvic acids are key ingredients of high quality foliar fertilizers. As they penetrate these plant parts they conduct trace minerals from plant surfaces into plant tissues. Once applied to leaves, fulvic acids transport trace minerals directly to metabolic sites within plant cells. Hence, foliar spray applications at specific plant growth stages, containing mineral chelates, can be used as a primary technique for maximizing plants' productive capacity. Nutrients that have been chelated by fulvic acid are in an ideal natural form to interact with and be absorbed by living cells.



Schematic Drawing of Fulvic Acid Molecule

When applied at relatively low concentrations they are completely non-toxic and 100% plant compatible.

Fulvic acids maintain an oxygen content twice that of humic acids. Since they have many carboxyl (COOH) and hydroxyl (COH) groups, fulvic acids are much more chemically reactive than other humic substances.

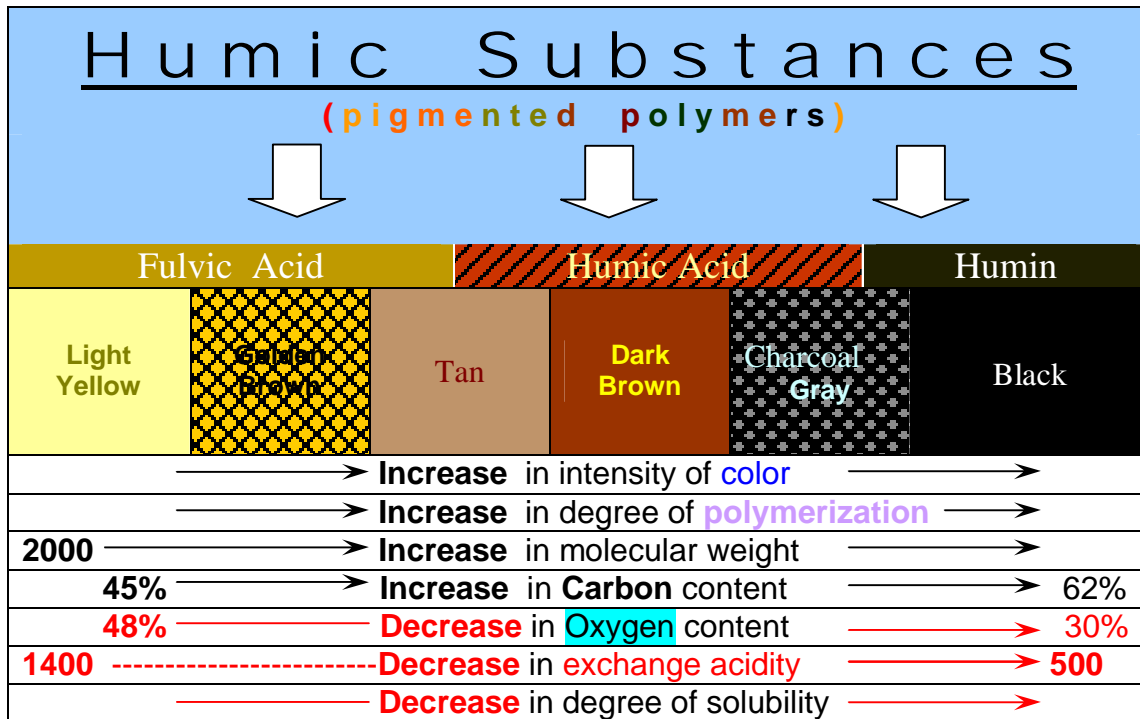
They also have a cation exchange capacity that is more than double that of humic acids. [Petitt] Fulvic acids are the most effective carbon-containing chelating compounds known. Scientists have found that fulvic acid is the element that actually makes nutrients absorbable. This gives it the ability to make a dramatic impact on all kinds of diseases and health problems that afflict the world today. Fulvic Acid is so powerful that one single fulvic acid molecule is capable of carrying 60 or more minerals and trace elements into the cells.

Scientists also tell us that fulvic acid is one of the most powerful natural electrolytes known to man. It is also one of the most powerful natural [antioxidants](#) and free radical scavengers known. Fulvic acid has the unique ability to react with both negatively and positively charged unpaired electrons and render free radicals harmless. It can either alter them into new useable compounds or eliminate them as waste. Fulvic acid likewise scavenges heavy metals and detoxifies pollutants.

It is created in extremely small amounts at a time by the action of millions of beneficial microbes, working within an adequately oxygenated soil environment. Sadly, these microbes can be wantonly destroyed when excessive amounts of nitrate fertilizers are applied to the soil, effectively wiping out the fabrication of vital fulvic acid. The hypothetical model structure of fulvic acid (Buffle's model) contains both aromatic and aliphatic structures, both extensively substituted with oxygen - containing functional groups.

(3) Humin

HUMINS are that group of humic substances that are neither soluble in high basic/alkaline ($\text{pH} > 7$) nor in low acidic ($\text{pH} < 7$) solutions. In fact, humin is not soluble in water at any pH. Humin complexes are considered the largest of the so-called organic substances, i.e., “macro” because their molecular weights (MW) range from approximately 100,000 to 10,000,000. In comparison the molecular weights of carbohydrates (complex sugars) may range anywhere from approximately 100,000 down to a mere 500. The chemical and physical properties of humins are only partially understood. [Petitt] Humins present within the soil are the most resistant to decomposition (slow to breakdown) of all the humic substances. Some of their main functions within the soil are structural, i.e., to maintain soil stability and to enhance the soil's otherwise water-holding capacity, but they also function as a cation exchange system, and improve soil content while generally improving soil fertility. Because of these important functions humin is a key component of fertile soils.



Fulvates

Fulvates are the salts more particularly of fulvic acid.

Both fulvic and humic acids are found in soil, and result from the chemical and biological degradation of dead organisms. Fulvic acids provide multiple and natural chemical reactions in the soil, instigating positive influences on the plants' metabolic processes.

Fulvic acid is especially active in dissolving minerals and metals when in solution with water. The metallic minerals simply dissolve into ionic form, and disappear into the fulvic structure becoming bio-chemically reactive and mobile. The Fulvic acid actually transforms these minerals and metal into elaborate fulvic acid molecular complexes that have vastly different characteristics from their previous metallic mineral form. Fulvic acid is nature's way of "chelating" metallic minerals, turning them into readily absorbable bio-available forms.

Humates

“Humate materials are widely distributed organic carbon-containing compounds, found in soils, fresh water, and oceans, and make up approximately 75 percent of the organic matter that exists in most mineral soils...They form complexes with phosphorus and micro elements which are easy assimilated by plants” <http://foliarfert.com/pages/humicacid.htm>
 These substances are formed from the biological and chemical breakdown of animal and plant life, and make up approximately 75 percent of the organic matter that exists in most mineral soils. Humates play a direct role in determining the production potential of a soil, and sharply increase efficiency of mineral fertilizers. According to **Professor Pettit**,

Humates are metal (mineral) salts of humic acids. “Within any humic substance there are a large number of complex humate molecules. The formation of a humate is based on the ability of the carboxyl (COOH) and hydroxyl (OH) groups (on the outside of the polymers) to dissociate (expel) the hydrogen ion... The humate composition of any one humic substance is specific for that substance. Thus, there exists a large variability in the molecular composition of different humic substances. Humates from different mineral deposits would be expected to have their own unique features.”

Soil phosphates are often immobilized through reactions with iron and aluminum, which in turn may be complexed with organic matter. Chelating agents can break the iron or aluminum bonds between the phosphate and organic matter, releasing phosphate ions into solution. This dissolution is a process which occurs in soil in the presence of naturally-occurring humic substances or plant root exudates. The addition of humates may increase the rate of this process, thereby increasing the availability of phosphorus to plants. [Obreza, Webb and Biggs, 1989]

Not all the products on the market under the name **Humates** are of a high quality. There are several different chemical structures of Humic Acid.

Organic material

Organic material might be said to be the foundation of humus. Rich in carbon remains of once-living organisms, both animal and vegetable, including kitchen waste and manures, are ingredients of compost. During the decaying process facilitated by microorganisms, organic matter in a proper environment in about a week can become good compost. However, compost is still an intermediate stage of true humus. Ultimately, compost must be integrated into the soil where it completes its decomposition and blends in with other detrital matter so completely that it no longer resembles the parent material. It must be remembered that living organisms within the resultant humus such as bacteria, nematodes, earthworms, fungi, insects and plant roots also consist of organic matter and therefore contribute to the organic content of the soil. Dead sections of roots broken off by macro-organism activity, as well as defunct microorganisms and cells from insects and worms, worm castings and excrement contribute new organic matter to the constantly developing humus in a healthy soil. All combined these ingredients make up an astonishingly low 5% of most soils' composition.

The importance of organic matter in soil is not a recent discovery. Soil fertility in early agricultural systems was based on the recycling of organic wastes, and the addition of decomposed organic materials improved plant growth. The rise in popularity and use of mineral fertilizers enabled growers to directly supply plant nutrients to the soil, and rapid growth in agricultural productivity occurred. As a consequence, the importance of soil organic matter was somewhat neglected. [Obreza, Webb and Biggs, 1989]

In the last couple of decades a resurgence or interest in organic farming has surfaced, fueled by concerns over pollution from pesticides, herbicides and other chemicals applied to the farmland. The contamination of ground water, disappointing low-nutritional value

of crop harvests and meat from livestock, disappearance of trace elements from the soils, and effects of acid rain (pH of less than 5.6) have all had their impact upon fresh legislation directed at better soil management and farming practices.

It is now widely believed that a certified organic approach is not only safer and more cost-effective, but a more much valuable one long term than the post World War II wisdom which fostered the [NKP mentality](#).

Ulmins and Ulmic Acid

Certain industrial manufacturers use mature, alkali-insoluble lignite-like coals. They typically use a degradative and oxidation extraction process to produce smaller alkali soluble humic acid solutions. The resulting oxidized mixtures from black or lignite coals are termed 'regenerated humic acids or ulmins'. These ulmins have characteristics that are similar to humic acids derived from low-grade lignites or Leonardite shale, however are quite different chemically, thus the term regenerated is a misnomer. According to P. Mark Turner, there is no evidence that these ulmins have desirable fertilizer grade properties. [*The Catalyst Product Group website*]

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Soil Health: Conservation, Cover Crops, and Nutrient Management

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Water Quality Association <http://www.aboutfulvic.info/>

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