Humus: Still a Mystery

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Note: A glossary is provided at the end to define scientific terms used throughout this article

Humus is like air in a sense. It is abundant, renewable and essential for life to exist on this planet. However, humus is so much more complex than air that even after hundreds of years of research, no one really knows exactly what it is.

The term "Humus" doesn't really describe anything specific. It's like using the word "dog" to describe a German Short Haired Pointer. Humus is sometimes defined as the end product from the decomposition of organic residues. But since it never remains in a static condition, it is hard to refer to it as an end product.

Furthermore, the composition of humus in one soil can be so structurally, chemically and visibly different from humus in another soil, it's difficult to refer to them both as the same thing.

Over the years, a lot of information has been gathered about humus: Certain components have been identified; the nature and properties are fairly well known and the factors that control its existence are pretty much accepted as common knowledge. However, to date, an indisputably accurate method of extracting humus from soil has yet to be discovered which, in of itself, severely limits the study of this material.

Attempts to define humus date back to the time of the Romans, but it wasn't until 1761 when it was first linked to the decomposition of organic matter by J. G. Wallerius. Back then it was thought that plants were able to derive nutrients directly from humus. But in 1840, Justus von Liebig discovered that plants can only assimilate soil nutrients in an inorganic form, and that plant food must be changed into mineral salts first. Liebig believed that this occurred from chemical reactions in the soil.

About 25 years later, attention was called to the role of microorganisms in the mineralization of nutrients from humus. It was in the early 1900's that most of the significant research on humus occurred. However, a lot of the information produced became somewhat obsolete at the dawn of the chemo-agricultural age in the early 1940's.

Genesis

The formation of humus begins when organic residues of plants and animals come in contact with microbial life in the soil. The carbon compounds contained in the residues, that were synthesized by the plant or animal when it was alive, are protein and energy for the various bacteria, fungi and actinomycetes involved in the decay process.

Aerobic microorganisms are the most adept at decomposing organic matter. They need an environment where there is an adequate amount of free oxygen to live and be active. The degree to which free oxygen exists in soil plays a major role in regulating the favorable or unfavorable conditions under which humus is formed. The same is true for moisture, soil temperature and the carbon-to-nitrogen ratio of the residues being decomposed.

Where no free oxygen exists (e.g. in water), decomposition of organic matter occurs by anaerobic organisms. This process is much slower than that conducted by aerobic organisms but can, in the long run, produce a greater amount of humus (e.g. muck or organic soil). Humus formed under water is slightly different than its aerobic counterpart due more to the nature of the residues from the two different environments than the process of aerobic vs. anaerobic humification. Most of the contributions of organic matter to organic soils are from water-dwelling insects and microbes that have a higher percentage of protein than the plant residues found in forests, fields, or gardens. Other components come from organic residues transported by wind and water currents to a location where they can accumulate and settle. Much of this translocated material may already be humus. Higher percentages of humus are found in soils formed anaerobically because conditions are more favorable for humus accumulation and less favorable for its destruction.

At the other extreme is an environment where there is too much oxygen. If moisture and soil temperature are also at optimum levels, organic matter can be decomposed so quickly that no accumulation of humus will occur at all (e.g. in tropical environments where high temperatures and moisture levels occur in predominantly sandy soils that naturally contain plenty of air).

Soil temperature is another important controlling factor in the formation of humus. As the temperature of a soil increases, there is a corresponding increase in microbial activity. Soils that exist in warmer regions of the earth tend to have lower native levels of humus than soils in colder areas. Figure 1 shows that at a temperature of 88 degrees F, in well aerated soil, humus can no longer accumulate.

Microbial Processing

During humification of organic matter, microbes dismantle most of the sugars, starches, proteins, cellulose and other carbon compounds to utilize them for their own metabolism. The assimilation of these nutrients from the original residues by microorganisms is the first stage in the process of creating humus. Some of the more easily dissolved components of the residues end up being used and re-used over and over, by many different varieties of organisms, and may never actually become humus. However, they provide energy and protein for the life cycles of the organisms involved in its synthesis. The more decay resistant components of the residues are not so much assimilated as they are altered by microbial processing into humic substances.

Much of the nutrient and energy assimilated into the bodies of microbes is re-used by other microbes when they die. Some is mineralized back into plant food and some is changed into biologically resistant compounds that accumulate as components of humus. As more and more members of the biomass club participate in the festivities of eating, dying and being eaten, the cycles of soil life are implemented. Plants create organic matter which feeds soil organisms which transform the nutrients from the residues back into plant food, nutrients for other organisms and humus.

The digestion of organic matter in the soil is analogous to the digestive system in animals. Nutrients derived from food ingested by an animal are diffused into its body where they are utilized for energy and production of new cells. By-products, such as urea, water, carbon dioxide and other simple compounds are given off. The undigested portion of the food is excreted as feces.

In the soil, organic matter is dissolved and absorbed by microorganisms utilizing the nutrients and energy for their own metabolism. Their activities convert most of the organically bound nutrients back into a mineral form which is usable by plants and other microbes. The undigested portion of the residues accumulate as humus. However, humus is not completely immune to decomposition. Microbes will eventually recycle all the elements in humus back to where they initially came from, even if it takes a millennium to do it.

Decay Resistance

Some of the components in organic residues are much more resistant to decay than others. Carbohydrates such as sugars and starches will decompose faster than other carbohydrates such as cellulose and hemicellulose. Fats, waxes and lignins are the most resistant to decay of all the organic components. Proteins vary in decay resistance but are generally more resistant than sugars and starches yet more easily decomposed than all the other components.

Although many of these components exist in humus (in an altered form) (see figure 2), the degree to which they exist in the organic residues plays a role in the quantitative accumulation of humus. Materials that contain a high percentage of easily decomposed components such as sugars, starches and proteins are, for the most part, assimilated back into the living biomass. Although the energy and protein provided by these residues help in the creation of humus, the ratio of the mass and weight of the residues to the measure of humus produced is relatively high (i.e. only a small amount of humus can be created).

Materials that contain a large percentage of lignins, cellulose or other biologically resistant components have less to offer plants in the way of recyclable nutrients but contribute significantly more to the formation of humus.

Different plants inherently have different ratios of these organic components, but variance also appears in the same plants at different stages of their life. Green leaves from deciduous trees, for example, have a very different analysis of proteins vs other components than their dry, fallen counterparts.

Figure 3 shows the changes that occur in rye plants from early growth to maturity. At the young, succulent stage, organic matter from this source would not contribute very much substance for the accumulation of humus, but would benefit more the immediate needs of microorganisms and plants. Whereas, near the end of its life, the rye plants would add little to the nutrient needs of plants and soil life but provide more raw materials needed for the formation of humus.

During humification, not only are the organic components altered by microbial processing, but the ratio that existed in the original residues is changed. Figure 4 illustrates how the balance of components in straw changes from decomposition. The increase of some components and decrease of others is not magical. The nutrient needs of microbes involved in the decomposition process are taken from any available sources in the soil, and reflected in the analysis change from raw material to compost. As the compost humifies further, the changes become even more pronounced (see figure 2).

Biologically resistant components such as lignins, fats and waxes are structurally and chemically changed by microbial processing. Other biologically resistant carbon compounds are created by microorganisms as by-products of their decay activities. These decay resistant compounds are what humus is made of. This is not to say that humus is immune from further decay, but its resistance to decomposition is at a level that enables it to exist for decades, if not centuries, as a soil conditioner, a habitat for microbial life, and a vast reservoir of plant and microbial nutrient.

Energy

Humus is essentially a massive storage battery containing energy that was originally derived from the sun. Researchers in England discovered that an acre (furrow slice) of soil with 4 percent organic matter contains as much energy as 20-25 tons of anthracite coal. Another researcher in Maine equated the energy in that amount of organic matter to 4000 gallons of #2 fuel oil.

This organic energy, which is stored as carbon compounds, was originally derived from the sun by autotrophic organisms such as plants that can extract carbon from atmospheric carbon dioxide. About one percent of the energy from the sun that reaches plant leaves is used to photosynthesize carbon compounds. During the plants' life, much of the energy that is absorbed from the sun is utilized for growth, foliage production, flowering, seed production, and other functions. About 10 percent of the absorbed energy, initially from the sun, is left available to a consumer, e.g. an animal that eats and digests the plant. Like the plant, the animal uses most of the energy it consumes for functions such as growth and sustenance, but can offer about 10 percent of the energy it derived from plants to the next consumer in the food chain.

Subsequent digestions through the food chain continue the rapid depletion of available energy from one trophic level to the next. The final consumers of this energy reside in the soil. In figure 5 an arbitrary quantity of energy has been used as an example to show its flow and use. In this case, the 1 million calories of energy offered by the sun is reduced to 1 calorie of available energy by the time it flows through the food chain to soil saprophytes. However, during the season when plants are active, about 20% of the carbon that they absorb from the atmosphere is exuded through the roots as photosynthesized carbon compounds and utilized by organisms living on, near or within the root surface. This phenomena provides a direct and constant flow of plant synthesized energy for many soil microorganisms.

Obviously, the level of energy available from plant residues is higher than what can be offered by the remains of herbivores, which is higher than what is available from the residues of carnivores. The various energy levels of different residues stimulate populations of different soil organisms that perform different functions in the soil. Their populations are controlled by the amount and type of residues introduced into the soil, and the production of humus is controlled by these organisms.

Carbon Cycle

Throughout this digestion and assimilation process, from the consumption of the sun's energy by the plant, to the decomposition of all residues in the soil, carbon is released back into the atmosphere as carbon dioxide. The evolution of carbon dioxide from organic matter is an integral part of the life cycle. If CO_2 did not evolve, atmospheric carbon would not be available, the earth would be buried in humus, and life could not exist.

Figure 6 examines the cycle of carbon from the atmosphere, through the food chain, and back into the atmosphere. Plants and other autotrophic organisms (producers) need carbon dioxide in the atmosphere to live. Without it, no heterotrophic organisms (consumers), which depend on the producers for energy, could exist either.

Over a one year period, and under average conditions, about 60% to 70% of the carbon in organic residues is recycled back to the atmosphere as carbon dioxide. Five to ten percent is assimilated into the biomass, and the rest resides in new humus.

Colloidal Properties

Colloidal refers to the attraction certain soil particles have for cations which are positively charged ions of soil nutrients. Whether organic (humus) or mineral (clay), the colloid is very small, and carries a negative electro-magnetic charge that can hold cation nutrients in a manner that allows plant roots access to them. This phenomenon is called *cation exchange*.

When decomposed organic matter reaches a certain level of "maturity" and can be referred to as humus, it gains colloidal properties, which react, in terms of cation exchange, almost identically to mineral colloids. However, humus can have a far greater capacity to adsorp cations than clay, especially in a soil with a near neutral pH.

In the soil scientists' quest to isolate and define humus, many terms such as humic acid, fulvic acid, humates, humins and ulmins were developed to help literalize their findings. Some of these terms have relatively complicated definitions, and are used to identify different compounds produced by various chemical extraction methods. Most are too general and ill-defined for the complexities of humus. However, it is helpful to be familiar with two of these terms, i.e. humates and humic acid, to understand the colloidal properties of humus.

When humus particles called *micelles* form, the chemical composition is predominantly carbon, hydrogen, nitrogen and oxygen (see figure 7). The hydrogen ions that reside in compounds on the surface of the micelle can be displaced by other cations such as calcium, magnesium, potassium or sodium (see figure 8). By chemical definition, any compound that contains displaceable hydrogen is an acid... hence, *humic acid*.

If the hydrogen ions are displaced with base cations such as potassium, calcium or magnesium, the new compound is considered chemically to be the salt of humic acid, or *humate*.

By weight, hydrogen accounts for only a small percentage of humic acid, but because the atoms of this element are the smallest and lightest of all elements, its numbers are overwhelmingly higher than any other. Each location of a hydrogen ion on the surface of the micelle can potentially become an exchange site for a base cation. The tremendous amount of surface area of humic particles, coupled with the high number of exchangeable H+ ions, can significantly increase the cation exchange capacity (CEC) of any given soil.

In soil conditions, where hydrogen ion activity is high (i.e. low pH), *humus* becomes saturated with adsorbed hydrogen ions, and is called *humic acid* (HA). Has have the ability to react with mineral particles in the soil, liberating base ions such as potassium, magnesium and calcium. As more and more bases are released and are adsorbed to the humic colloid, replacing H+, HA is chemically changed into *humates*.

Humates are essentially organic colloids that are saturated with base cations. A rich soil with a near neutral pH would contain a high level of humates. Whereas the same soil with a low pH would be replete with humic acids. Unfortunately, many humic substances can dissolve and leach to lower soil horizons in a low pH environment such as in a New England forest.

Soil Conditioning

Humus is an amazing soil conditioner. Only 5% humus will transform lifeless rock dust into rich loam. It has abilities to both bind sand and granulate clay.

In sandy soils, plant and microbial mucilages from humus clog up the porous environment, increasing the moisture holding capacities, and slowing down the percolation of soil water, with all the dissolved nutrients it contains. As the moisture content increases, more plants and microbes can inhabit the environment, accelerating the creation of more humus. Under ideal conditions, the advancement of humus in sand eventually will develop the most preferred type of loam for plant production.

Unfortunately, conditions to develop humus in sand are not always ideal. In tropical environments, for example, where moisture and temperature are optimum for populations of decomposition bacteria, organic matter is quickly assimilated back into the biomass. Coupled with the abundance of oxygen in porous sand, it is difficult if not impossible for humus to accumulate.

In clay soils, humus forms an alliance with clay particles. Both particles are colloidal; i.e. they have an electro-negative charge capable of attracting and holding cation nutrients. Complexes are formed in the soil between the two particles, which not only increase soil's overall CEC, but also mitigates the cohesive nature of clay, causing granulation.

Humus accumulation is naturally easier in clay soil than sand, because environmental conditions for decay bacteria are often not as ideal. Moisture levels in clay soils often reach the saturation point, leaving little room for oxygen needed by aerobic life. Soil water also acts as a buffer for temperature changes, keeping the much needed heat level for microbial activity at a minimum. In addition, evaporation of moisture from the surface has a cooling effect on the soil (just as evaporation of perspiration from the skin cools the body).

Clay can also assist to stabilize humus. Clay-humus complexes formed in soil can further inhibit bacterial decomposition, and increase the lifespan of humus to over a thousand years. Soil scientists calculate that in Allophanic soils (a volcanic clay soil), the mean residence time of humus ranges from 2000 to 5000 years.

Over time, and under the best of conditions, humus can eventually change both clays and sandy soils into media that are visible similar.

Accumulation/Destruction

In an uncultivated, natural environment, humus accumulates in accordance with the favorable or unfavorable conditions of the region. Unless global or regional conditions change, humus accumulation reaches an equilibrium with factors that destroy it, and it becomes a relatively fixed component of that environment.

In cultivated environments, humus is an important asset which, like most other assets, is easier to maintain than replace. Unfortunately, the value of humus is often not fully realized until it is severely depleted, and its benefits no longer available.

Old, stable humus is biologically resistant. Depending on environmental conditions under which it exists, humus can sit in soil for centuries, even millennia, with only minimal decomposition occurring. However slight, decay still occurs, and eventually even old humus will cycle back from where it came. The formation of new humus is critical to maintaining a stable presence of this asset in the soil.

Current agricultural and horticultural practices have little effect on old, stable humus. However, many of those methods of cultivation can destroy new humus in the formative stages, when it is more vulnerable to decay than its older counterpart.

Figure 9 shows typical response of organic matter introduced into soil. It’s important to note that even under the best of conditions, a relatively small amount of humus is created in comparison to the level of organic matter initially introduced.

If conditions exist that further accelerate the decomposition of organic matter, even less humus will eventually be created. In extremes such as tropical environments where moisture, heat and soil oxygen are abundant, a lot of carbon dioxide is evolved, but not much in the way of humus.

Aeration from the plow or rototiller is probably the most significant factor in the depletion of native humus levels of cultivated topsoil. That, coupled with mono-cultural practices and the absence of organic carbon in fertilizer materials has cause a greater than 50 percent decline in native humus levels over the years on many of the farms throughout the U.S. This represents a loss that probably, will never be recovered. Even old humus complexes that are normally very resistant to decay can be fractured by cultivation and made more vulnerable to biological processes.

Excessive applications of lime can significantly accelerate the decomposition process of humus. The low pH in acid soils inhibit the activities of bacteria. As the pH is raised by applications of lime, bacteria populations grow and a relative increase in decomposition occurs. Experiments done back in 1920 show a marked increase in CO2 evolution (a measure of organic matter decomposition) as varying amounts of lime were added to soil. (See fig. 10) A small amount of calcium can stimulate plant growth to the point where the increased amount of residues added to the soil balance the loss from greater microbial activity. However, excessive lime applications can hasten the destruction of humus at a pace greater than the plant residues can accumulate it.

Excess nitrogen applied to crops is another culprit. The effect of adding too much nitrogen to the soil is very similar to what happens when it is added to a pile of slowly composting carbonaceous organic matter such as dry leaves or saw dust. The temperature of the pile is raised immediately, large volumes of carbon dioxide are released and the whole process of decomposition is accelerated exponentially. The reaction occurs regardless of the type of nitrogen added (i.e. organic or inorganic).

Humus in the soil has more real value than money, real estate, stocks or bonds. Its value doesn't fluctuate; it doesn't become scarce in a recession; it's worth can't be depleted by inflation and it can't be stolen. It is the direct or indirect source of sustenance for all life on earth. It can sometimes be lost by environmental changes, but more often, its demise is from either the apathy or the inadvertent errors of the steward who tends it.

Humus is a renewable resource. Its presence in the soil can be maintained indefinitely. Unfortunately, many agricultural and horticultural practices are essentially mining humus. Like other mined products, such as coal, minerals and oil, the natural resource can eventually be exhausted.

Summary

The popular scientific definition of humus is "A more or less biologically stable, dark, amorphous material formed by the microbial decomposition of plant and animal residues". It is difficult to visibly differentiate humus from organic matter in other stages of decay. Compost, well rotted manures and peat are not necessarily humus. However, at some hard-to-define point, all of these organic materials will contribute immeasurably to the humus content in the soil.

It is not realistic to think that one can quantify or qualify humus production from contributions of organic matter to soil. There are too many factors that control its formation and existence in the soil environment. One can only assume that cultural practices that both minimize the depletion, and contribute to the formation of humus, will maintain the best possible level of soil humus for each individual environment.

Glossary

Actinomycetes—Decay microorganisms that have a fungus-like appearance but, like bacteria, do not contain a well defined nucleus.

Adsorption—The adherence of one material to the surface of another via electro-magnetic forces, e.g. dust to a television screen.

Aerobic—Needing oxygen to live.

Anaerobic—Needing an environment with little or no oxygen to live.

Assimilation—Digestion and diffusion of nutrients by an organism for growth and/or sustenance.

Autotrophs—organisms that can synthesize carbon compounds from atmospheric carbon dioxide utilizing energy from light or chemical reactions.

Base cation—A positively charged ion, historically belonging to the earth metal family e.g. potassium, magnesium, calcium, etc.

Biomass—The accumulative mass of all living things in a given environment.

Carbon : Nitrogen ratio—a ratio measured by weight of the number of parts carbon to each part nitrogen e.g. 10:1, 50:1, etc.

Carnivores—Organisms that consume animals or insects for sustenance.

Cation—An ion of an element or compound with a positive electro-magnetic charge.

Cation exchange capacity—The total amount of exchangeable cations that a given soil can adsorb.

Colloids—Very small soil particles with a negative electro-magnetic charge capable of attracting, holding and exchanging cations.

Faunal—Pertaining to microscopic or visible animals.

Floral—Pertaining to plants or bacteria, fungi, actinomycetes, etc.

Free oxygen—Gaseous oxygen not bound to other elements as in oxides, hydroxides or water for example.

Furrow slice—Plow depth of approximately 6 - 7 inches.

Hemicellulose—A carbohydrate resembling cellulose but more soluble; found in the cell walls of plants.

Herbivores—Organisms that consume plants for sustenance.

Heterotrophs—Organisms capable of deriving nutrient for growth and sustenance from organic compounds but incapable of synthesizing carbon compounds from atmospheric carbon dioxide.

Humification—The biological process of converting organic matter into humic substances.

Humology—The study of humus.

Lignin—A biologically resistant fibrous compound deposited in the cell walls of cellulose whose purpose is for strength and support of stems, branches, roots, etc.

Micelle—(Micro-cell) A negatively charged (colloidal) soil particle most commonly found in either a mineral form (i.e. clay) or organic form (i.e. humus).

Mineralized—The biological process of transforming organic compounds into non-organic compounds (minerals) e.g. mineralization of protein into ammonium.

Monoculture—The cultural practice of growing only one variety of crop in a specific area every season without variance.

Mucilage—compounds synthesized by plants and microbes that swell in water, taking on a gelatinous consistency, that function to maintain a moist environment.

Saprophyte—an organism that can absorb nutrient from dead organic matter.

Taxonomy—Science of classification.

Trophic levels—Levels of consumers within a food chain in relation to producers of organic nutrient such as plants e.g. producers—primary consumers—secondary consumers—tertiary consumers—decay organisms.

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