

By Kevin T. Smith, Ph.D.

Humus is a Latin word, meaning on or in the ground, but what is humus in the context of tree and landscape care? Is humus the same as soil organic matter?

With the increased emphasis on biologically-based products for sustainable landscapes and tree care, the sources and quality of humus products have greatly increased in recent years. Some experts stress the importance of humus for soil fertility, yet other experts say that humus has no nutritional value. This apparent conflict is resolved by recognizing the origin, function and fate of humus for the tree and forest system, particularly for soils in the moderate to wet temperate zones.

Humus greatly contributes to soil fertility, soil structure including aeration and water retention, and carbon storage. The physical and chemical properties of humus are derived from the biology of trees and their associates.

The term humus is used in two different ways. Many tree and landscape practitioners refer to humus in a broad sense, with the same meaning as soil organic matter. This broad definition includes living biomass, partially decomposed plant residue, and organic matter that is recalcitrant, meaning resistant to further



Figure 3: Large piles of composting chips need to be periodically turned over to maintain proper proportions of air and water.

decomposition. The partially decomposed or composted material can still be further degraded to fuel the work of soil microorganisms to fix nitrogen and to convert the form of essential elements.

Many researchers and soil chemists refer to humus in a narrow sense that only includes the recalcitrant organic matter that resists further decay. Frequently, this narrow sense is further restricted to mean nano-sized pieces of carbohydrate that are colloids, particles so small that they remain dispersed in water without settling to form a sediment. Humus colloids are superior

even to fine clay particles for storing positively charged forms (cations) of essential potassium, calcium, magnesium and others. At appropriate soil acidity, tree roots use metabolic energy to bring these elements into the plant. Although humus greatly contributes to the storage and uptake of some fertilizer elements, recalcitrant humus is not a fertilizer or nutritional source for the tree or for soil microorganisms.

Source of organic matter

Understanding humus formation begins with photosynthesis. Photosynthesis uses the energy in sunlight to split apart and recombine the atoms that make up water and carbon dioxide to form glucose sugar and oxygen. The chemical bonds in glucose retain some of that solar energy. The controlled breaking of these bonds releases energy and powers the metabolism of the tree or of microorganisms. The energy in glucose can be stored for later consumption by linking a string of glucose molecules into a polymer or chain of starch. Starch is a good storage material that packs a lot of sugar in a small volume.

Glucose can also be converted into other sugars and other organic compounds in plants. Much of the sugar goes into plant

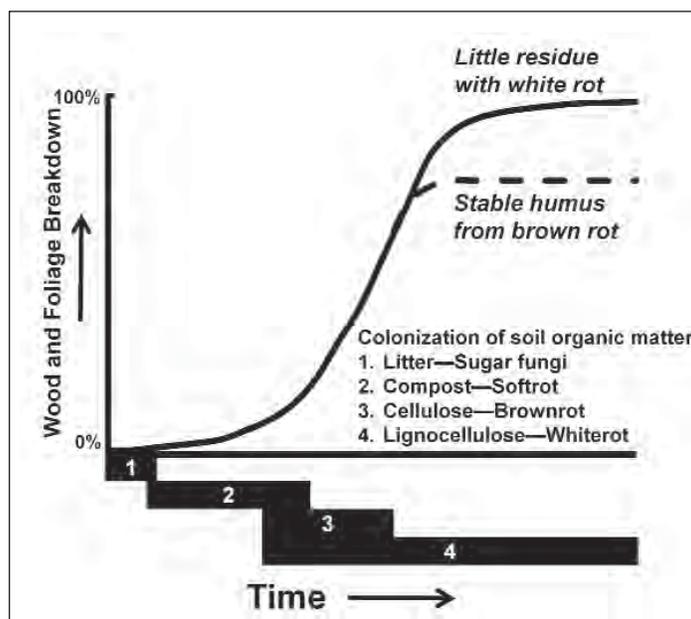


Figure 1: Conceptual timeline for the conversion of wood and foliage to humus shows overlapping colonization by different fungi.

structure. Cellulose is the most abundant structural material. Like starch, cellulose is a glucose polymer, but the special chemical bonds between the sugars in cellulose require a much higher degree of specialization to break. The long unbranched chains of the cellulose polymer are stacked into microfibrils that strongly resist compression. The cellulose microfibrils within and between cells are held together by hemicellulose and pectin. Hemicellulose is a family of short, branched polymers that contain a mix of different sugars. Pectin is a family of branched polymers of sugar acids that is also used to solidify fruit juice into jelly.

Holding together these cell wall polymers is lignin, the second most abundant carbohydrate in wood. Lignin provides bending strength and is a complex, branched polymer of short chains of carbon with interspersed phenolic rings. Phenolic rings are hard to break by most microorganisms. The orientation of the rings can block access to the carbon chains by large degradative enzymes. Although the chemical structures differ, grasses and other higher plants produce lignin, too.

Humus formation

Although the details vary by location, plant decomposition can lead to humification or humus formation. While still attached to the living tree, the surface and interior of foliage, branches and other living or dead plant parts contain bacteria, fungi and other microorganisms and small invertebrates. In healthy trees, the development of these organisms is kept within certain limits by the tree



Figure 4. Mycorrhizal roots find the composted fermentation layer of soil a rich source of critical essential elements.

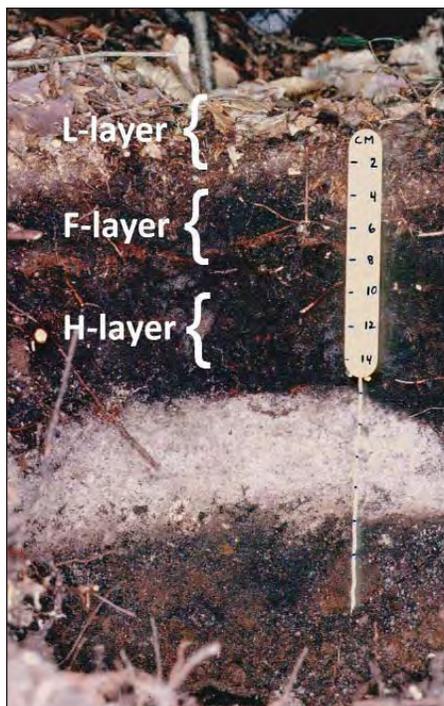


Figure 2. Organic soil layers of a typical forest soil show litter, composted organic matter, and humus.

symplast, the network of living cell contents and by protective features of living cells and tissues. Although attention gets drawn to these organisms when they cause disease or pest outbreaks, most of these organisms have little effect on the functioning of healthy trees. Some may actually be beneficial as predators for potential pests and pathogens or to simply exclude possible troublemakers through competition.

Within a short time of being shed and added to the surface layer or litter on the forest floor, the bacteria and fungi are no longer held in check by the now dead or absent symplast. The “sugar fungi” and related bacteria that had been present on the formerly living surfaces plus new colonizers from the forest floor rapidly consume the soluble sugars and nitrogen-based compounds that were in the shed litter (time period 1 in Fig. 1). The sugar fungi, usually asexual stages of Ascomycetes, do not cause a measurable change in weight of the litter as they don’t break down the cell wall materials, but they do take up soluble nutrients and leave behind a lot of high-carbon material. In natural forests, this process occurs in the litter or L-layer of the organic forest

floor (Fig. 2).

Some of the more specialized sugar fungi are also capable of breaking down the sugar acids of pectin. As the pectin is broken down, the wood matrix opens up, allowing access of both air and water into the tree tissue, exposing more surface area to colonization by invertebrates as well as fungi and bacteria. The partially degraded organic matter becomes recognizable as compost (time period 2 in Fig. 1). Given the proper range of temperature and moisture, the litter is degraded by the softrot or compost fungi and their associates. Softrot is characterized by degradation of the pectin, hemicelluloses, and the formation of cavities in cellulose. Ascomycete softrot fungi and bacteria may alter the structure, but do not actually degrade lignin.

In compost piles (Fig. 3), microbial metabolism activity can generate considerable heat. In undisturbed forest soils, this material becomes part of the fermentation or F-layer (Fig. 2). In the F-layer, the organic matter has lost some of its physical form, but the source of the material from foliage or woody branches is still recognizable. In moist, but not waterlogged environments, the F-layer can support a rich diversity of non-woody fine roots and mycorrhizae (Fig. 4).

The proper combination of physical



Figure 5. Brownrot wood decay helps form humus, even in the living tree.



Figure 6. Peat bogs are a rich source of soil organic matter yet are low in some essential elements.

structure, moisture and aeration favors the development of brownrot and whiterot wood decay, both caused by basidiomycete fungi. In brownrot, the cellulose is selectively decomposed, leaving behind a brown residue originally formed from lignin, but modified as other components are removed. These modifications of lignin increase its capacity to store positively charged fertilizer elements. This residue left behind from the brownrot wood decay process (time period 3 in Fig. 1) and related processes in herbaceous plants is humus.

Much of the organic matter in humus has not only undergone the wood decay process, but also the digestive processes of other organisms and includes the living and dead remnants of microorganism and invertebrates. The fine organic matter of humus is seen as the H-layer in natural forest soil (Fig. 2). In contrast with brownrot, all components of wood are degraded in whiterot, resulting in little or no residue (time period 4 in Fig. 2). Organic acids and other small organic fragments leached from the H-layer help store fertilizer elements in mineral soil.

Some of these soluble or colloidal pieces from humus are called humic and fulvic acids. Originally described by solubility and molecular size, humic and fulvic acids are being more rigorously defined and marketed as biological soil treatments. Their chemical structure is variable and may not be possible to determine in the intact plant. They do contain phenolic rings and short chains of carbon that tend to condense, sometimes into quite large complexes.

Humic acids can be formed independently of lignin breakdown and be extracted from certain algae and some higher plants. Determining the precise structure of humus and fulvic acids as they are in the intact plant is challenging. Environmental conditions such as pH affect the tendency of the acids to condense into large, complex structures that may not exist in the intact plant or in composted plant materials. The condensed acid polymers are beneficial, as they bind or chelate fertilizer elements in both the mineral soil and in the organic forest floor.

Conditions for humefaction

The microbial component of humefaction requires the proper combination of air and water. In sphagnum peat bogs, flooding excludes the oxygen necessary

to support much decomposition of either cellulose or lignin and organic matter accumulates, sometimes to great depths. In addition to deep layers of organic matter, tree growth in bogs is highly limited, both because of the lack of aeration for the roots and that the naturally acid environment usually has reduced amounts of essential calcium and magnesium, and high amounts of aluminum and iron that interfere with element uptake by trees (Fig. 6).

Sphagnum peat is mined from bogs in some parts of the world, both for use in horticulture and as fuel. Over time, the biological cycle of peat formation becomes the geological cycle of lignite or brown coal production. Lignite and lignite extracts are commercial sources for some humic acid soil treatments.

In the broad sense, humus as soil organic matter fuels the cycling of essential elements. In the narrow sense, humus provides much of the basis for forest fertility through the chelation of essential elements that are then available to trees and other plants. In both senses, humus provides soil with good aeration and water holding capacity essential for both urban and rural forests. Ongoing research investigates other roles of humus for tree growth and defense.

Humus is a central link between tree biology and their environment.

Kevin Smith, Ph.D., is a plant physiologist and project leader with the USDA Forest Service Northern Research Station in Durham, New Hampshire. This article was taken from his presentation, "Tree Response to Climate Change" at TCI EXPO 2009 in Baltimore. †