The Soil Life - Humus - Soil Fertility Connection

1. NPK Theory of Soil Fertility

Modern NPK theory was born in the now famous lectures that Justis von Liebig gave before the British Association for the advancement of science. He argued "the primary source whence man and animals derive the means of their growth and support is the vegetable kingdom. Plants, on the other hand, find new nutritive materials only in inorganic substances."

Simple logic holds that you could then analyze the produce of an acre and "return the nutrients" removed for a maintenance fertility program, or you could add a little more and have a "build up program".

The following table shows the nutrients contained in 100 bushels of corn, soybeans, and wheat.

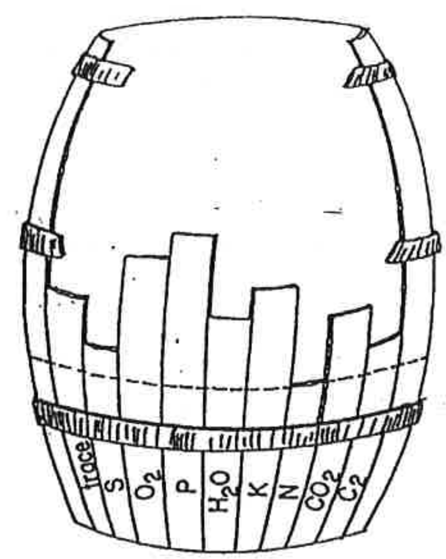
Pounds of Selected Plant Nutrients Contained in Crops

		N	P_2O_5	K_2O	Ca	Mg	S
Corn	100 bu.						
	Grain	90	36	26	11	13	10
	Stover	67	24	98	18	12	7
	Total	157	60	124	29	25	17
Soybeans	100 bu.	375	88	138	18	18	10
Wheat	100 bu.						
	Grain	125	38	38	2.5	15	8
	Straw	50	12	88	15	8	12
	Total	175	50	126	17.5	23	20

Source: National Plant Food Institute 1962

It became common practice to soil test to determine the most limiting nutrient and increase its quantity in the soil. It was believed then, in the same way that the shortest stave in a wooden barrel limits the amount a barrel can hold, the most limiting nutrient in soil limits crop yield. Maximum yield then should be obtained by putting an excess of everything in the soil, in effect lengthening all of the barrel staves.

LIEBIG: **LAW OF THE MINIMUM**



LIMITING FACTORS

YIELD LIMITING VARIABLES WE CAN CONTROL

1. Hybrid
2. Population
3. pH
4. Weed Control
5. Soil Tilth
6. Drainage
7. Tillage
8. Fertility
9. Planting Date
10. Right Equipment – Adjusted Properly
11. Pest Management
12. Crop Rotation
13. Harvest Date
14. Planting Depth
15. Fertilizer Placement and Timing
16. Soil Life – Most Important

Howard

Sir Albert Howard commented that von Liebig's views "remained those of a chemist who understood nothing about humus because he was enchanted with laboratory chemistry and dealing with only a fraction of the facts."

Albrecht

William Albrecht commented "In our attempts to comprehend how the insoluble rock can make soil which, under proper moisture, will nourish plants, we have too long believed that the nutrient inorganic elements from the soil must be water soluble. Those elements need to be viewed in their compounds, in their larger molecules and as absorbed ions to give the lowest possible ionic activity when held by colloids requiring energies to exchange them and make them more ionic."

In short, he was saying that nature deals in insoluble nutrients and serves them up on signal through a complex biological system.

Von Helmont

Jon Baptista von Helmont, a 17th century Flemish physician started getting a handle on what happens when plants grow in the soil with his "tree experiment." He was trying to measure how soil matter was displaced when plants grow. To do this, he planted a willow tree in a large earthen tub. He planted a 5 pound sprig into 200 pounds of soil. The tub was then covered except for a small hole for the tree trunk and one for watering.

Five years later, the tree weighed 164 pounds. Von Helmont reasoned if the tree had picked up the difference between 5 pounds and 164 pounds, then the soil in the tub should weigh only 41 pounds. The results proved him wrong! After oven drying the soil, he found the 200 pounds of soil had only lost 2 ounces.

2. Later observations of von Liebig

This is a translation of some later observations made in1843 by Justis von Liebig, the father of NPK agriculture.

"I had sinned against the wisdom of our creator, and received just punishment for it. I wanted to improve his handiwork, and in my blindness, I believed that in this wonderful chain of laws, which ties life to the surface of the earth and always keeps it rejuvenated, there might be a link missing that had to be replaced by me - this weak powerless nothing."

"The law, to which my research on the topsoil lead me, states, "on the outer crust of the earth, under the influence of the sun, organic life shall develop". And so, the great master and builder gave the fragments of the earth the ability to attract and hold all these elements necessary to feed plants and further serve animals, like a magnet attracts and holds iron particles, so as no piece be lost. Our master enclosed a second law unto this one, through which the plant bearing earth becomes an enormous cleansing apparatus for the water. Through this particular ability, the earth removes from the water all substances harmful to humans and animals - all products of decay and putrefaction, of perished plant and animal generations."

"What might justify my actions is the circumstance, that a man is the product of his time, and he is only able to escape the commonly accepted views if a violent pressure urges him to muster all of his strength to struggle free of these chains of error. The opinion, that plants draw their food from a solution that is formed in the soil through rainwater, was everyone's belief. It was engraved into my mind. This opinion was wrong and the source of my foolish behavior."

"When a chemist makes mistakes in rating agricultural fertilizers, don't be too critical of his errors, because he has had to base his conclusions upon facts which he can't know from his own experience, but rather, has to take from agricultural texts as true and reliable. After I learned the reason why my fertilizers weren't effective in the proper way, I was like a person that received a new life. For along with that, all processes of tillage were now explained as to their natural laws. Now that this principle is known and clear to all eyes, the only thing that remains is the astonishment of why it hadn't been discovered a long time ago. The human spirit, however, is a strange thing; "Whatever doesn't fit into the given circle of thinking, doesn't exist"."

3. Vitality Theory of Soil Fertility

The vitality theory says that soil life is the basis for soil fertility. The greater the quantity and variety of life growing and feeding in and on soil, the better its fertility.

Siegfried Lubke's definition of a fertile soil:

"A soil isn't fertile because it contains large amounts of humus or minerals or nitrogen, but because of the continuous growth of numerous and varied microbes and soil life which break down and reconstruct nutrients from organic matter supplied by plants and animals into a plant available form. The populations of soil life benefit us by making minerals plant available, building humus, building slimes and the crumb structure of the soil. A soil teaming with varied forms of life is an excellent growth environment for plant roots."

4. The Composition of Soils

The more we learn about the complex plant/soil relationship, the more we realize how primitive our knowledge is. It is not clear today how many elements are essential or exactly how they interact with soil life to influence plant life. This is a list of the components thought to be contained in the top **6-2/3** inches of soil in three different soil types. (SEE FIGURE 1 AT END)

5. The Live Portion of the Soil

A closer examination shows the live portion to be extremely complex and varied. The following is one research team's evaluation of that live portion.

Soil Life Found in a Temperate Grassland Soil
(M. Thompson & F. Troeh, *Soils and Soil Fertility,* 4th ed., 1978):

Organism	***number/acre***	***lbs./acre***
bacteria	800,000,000,000,000,000	2600
actinomycetes	20,000,000,000,000,000	1300
fungi	200,000,000,000,000	2600
algae	4,000,000,000	90
protozoa	2,000,000,000,000	90
nematodes	80,000,000	45
earthworms	40,000	445
insects & other arthropods	8,160,000	830

A. Aerobic - Anaerobic Soil Life

1. Aerobic - Soil life that requires air. The most important group to agriculture.
2. Faculative Anaerobic - Soil life that can live with or without air.
3. Obligate Anaerobic - microbes which do not require air and are suppressed by it.

B. Soil Life Populations Can Be Increased

1. They can be increased by changing system conditions that favor multiplication.
2. Soils can be inoculated with new or additional populations.

C. System Conditions That Lead to Increased Numbers and Variety of Soil Life

1. Soil Oxygen - Dissolved oxygen at 2+ ppm
2. Soil pH - 6.0-8.0 Individual species favored by higher or lower pH's
3. Soil Temperature - Above 50^{0}F - Ideal 70^{0}- 75^{0}F
4. Soil Moisture - 50-80% Field capacity
5. Carbon - Crop residues and food sources must be in contact with soil. Soils with organic matter above 2% are desirable.
6. Nitrogen
7. Phosphorus, Calcium and Other Minerals - Certain heavy metals (i.e. chromium) are detrimental to microbe populations.
8. Compost

D. Specific Populations of Soil Life have Different Functions

Each class is very specific in what it does. The bacteria, fungi and actinomycetes are rather immobile and do not move very far in the soil.

E. Relationships of Different Groups of Soil Organisms

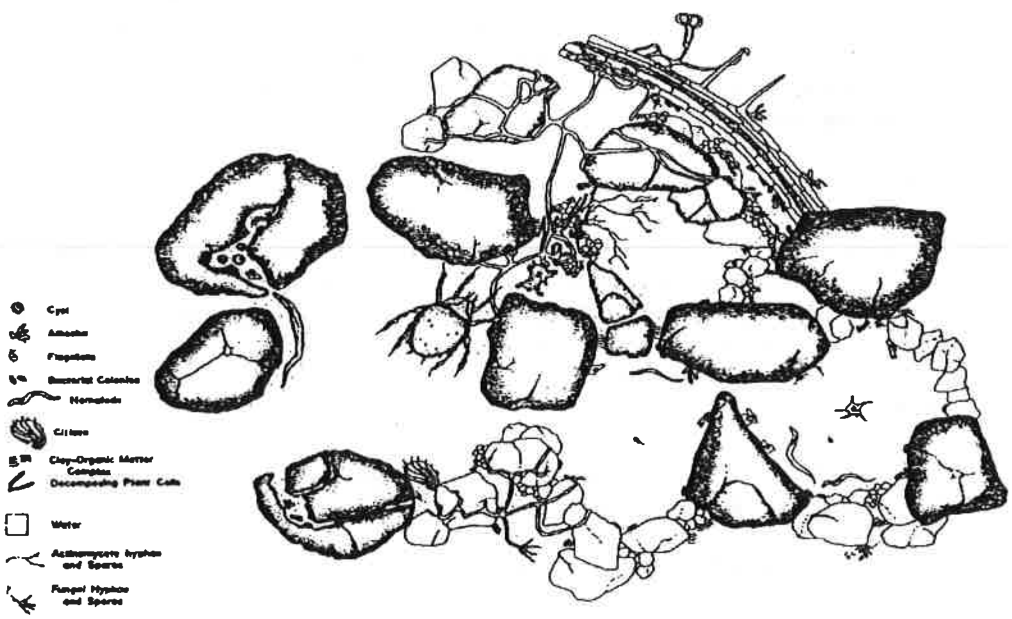


Figure 5.2. Trophic relationships among different groups of soil organisms are controlled by accessibility to their resources. This illustration represents approximately 1 cm^2 of a highly structured microzone in the surface horizon of a grassland soil. Courtesy of S. Rose and T. Elliott, personal communication.)

6. Humus

A. The Definition of Humus

There is no one good definition of humus. It has many facets – like a human being.

Some scientists have defined organic matter and humus as one in the same. This is not true!

Humus comes from organic matter as bread comes from wheat.

1. Many things happen in the process.
2. Many types of bread can be baked from the same wheat - many types of humus can be formed from the same corn stalk.
3. Humus is produced by the impact of all soil life.
4. Humus is built from a variety of ingredients. The better the quality and variety of organic matter, the better the humus.

There are different states of organic matter. It is not called humus while it is still being broken down.

B. The Influence of Humus on Soil Fertility

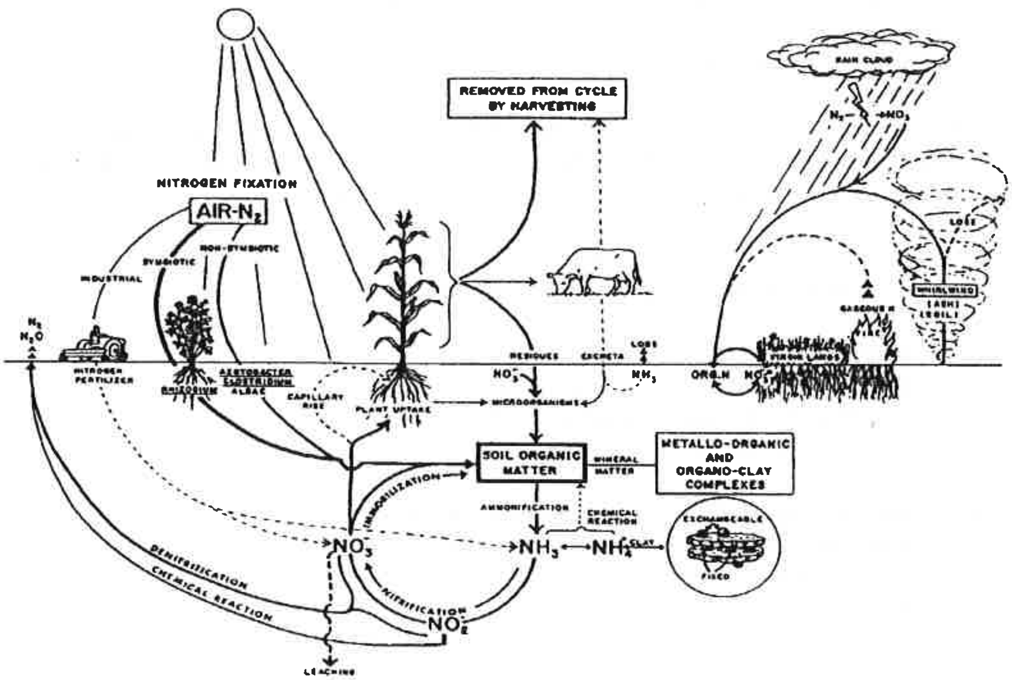
Because the humus fraction of the soil is so important and multifaceted, H.H. Koefp and others have described it as having two aspects. One aspect they call effective humus, the other they call stable humus. The influence of humus on soil fertility is summarized as follows:

	Effective humus	**Stable humus**
1. Organic soil substances	Effective humus is decomposed and nourishes the microbic population of the soil.	Stable humus is permanent and combines with the soil minerals.
2. Influence on nutrient supply	Microorganisms fix nitrogen out of the air; effective humus gives off nitrogen, phosphorus, sulfur, and other mineral substances during mineralization; effective humus mobilizes nutrients including trace elements from the soil minerals.	Stable humus contains supply of nutrients that are gradually released (old fertility). It stores available nutrients and prevents leaching.
3. Soil structure	Microbial population of the soil helps to create and stabilize soil structure.	Stable humus makes light soils more plastic and increases their water-holding capacity; makes heavy soils more porous, improves aeration and their warming up; it forms the crumbly structure of the topsoil.
4. Health and quality	Effective humus supplies plant hormones, antibiotics, and stimulates biological activity that inhibits the spread of pathogenic microorganisms.	Stable humus contains numerous active substances, stimulates biological activity; it includes a rich variety of microorganisms that inhibit the spread of pathogenic organisms.

C. The Formation of Humus

Microbes take organic matter and convert it to longer and longer carbon chains. This is done only under ground by microbes that are very immobile. Microbes need carbon sources and nitrogen sources.

1. The Nitrogen Cycle



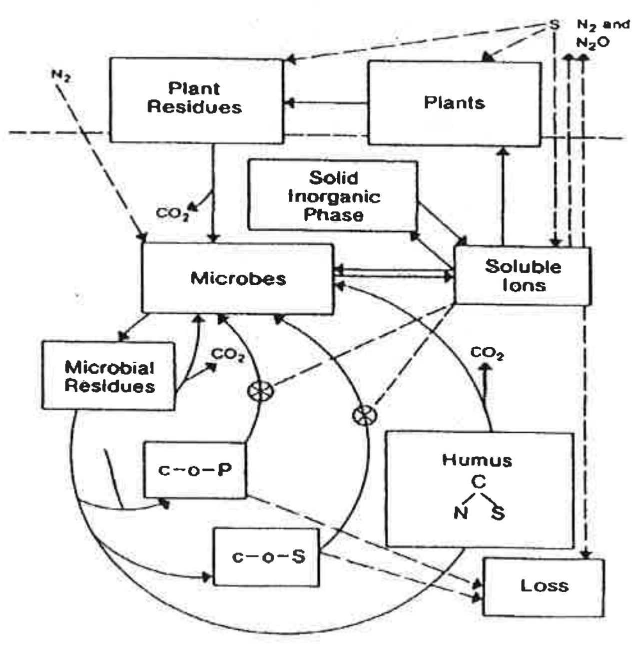
2. Phase I of Humus Formation

Numerous species of microorganisms break down protein from dead organic matter into peptones, amino acids, amines, ammonia, nitrite and nitrate.

Mineralization takes place so that from the original complex, nothing is left but the simplest compounds of the elements.

If the process went on indefinitely, only mineral matter plus $C0_2$, H_20, N_2, $N0_3$, NH_3, $S0_4$ a nd 0_2 would remain. However, it does not continue indefinitely.

3. Carbon Cycle



The Carbon Cycle

4. Phase II of Humus Formation

Other organisms take over as the second phase of humus formation. These stabilize the breakdown and build up again reversing the process

From simple chemical structures and pure elements, for instance carbon, oxygen and nitrogen, they produce sugars, carbohydrates, amino acids, and subsequently proteins and peptide chains.

7. Bits and Pieces in Conclusion

A. The organic matter or crop residue can start out with a carbon nitrogen ratio of 100:1 or 25:1 and still end up as humus very near a C:N ratio of 12:1.

1. As carbonaceous organic matter is consumed, microorganisms continue to grow by consuming their predecessors.
2. Excess nitrogen applied to the soil will require the consumption of carbon or humus from the soil.

B. Microbes eat first. It is important while planning cropping systems to remember that while microorganisms are taking nutrients they are denying them to the plants.

C. Breakdown products from fresh manure may find their way back to plants, animals or man and cause toxic effects. For example, plants having absorbed scatols and indols cause increased gas formation during digestion. Cattle only bloat on pastures that have been over spread with mineral fertilizers or fresh manure.

D. Plant roots excrete organic acids and enzymes, which in turn favor microorganisms, which in turn release more organic acids and enzymes. In a biologically active soil there is a continuous process of give and take, release and absorption, availability and taking into storage.

E. The plant root rhizosphere is the site of the soil plant interaction. It contains many more microorganisms and more or less concentration of nutrient ions than the surrounding soil.

F. All biochemical action is dependent on or related to the presence of enzymes. The variety of living organisms will determine the enzymes' presence and the intensity of biological process. (See Figure 2 at end)

G. Many aerobic microorganisms produce antibiotics that inhibit the spread of pathogens.

H. The availability of phosphate to plant roots in a biologically balanced soil system is entirely different than chemical laboratory availability. Rock phosphates come available slowly, but steadily in an organic system. Most laboratory available phosphate can be fixed as inert iron or aluminum compounds at low pH and as inert calcium compounds at high pH.

I. Water soluble potash in a soil goes easily where water moves - upward into the plant or downward away from it. Forage crops may absorb 5 to 6 times more potash than normal, being harmful to consuming livestock. Humus is the regulator to hold, to absorb, to avoid leaching or luxury consumption, yet hold the potash ready when the need arises.

J. In stable humus we find practically no free ammonia, only a limited amount of nitrate, but a large amount of organic nitrogen. This organic nitrogen is contained in the proteins, amino acids, and other compounds of the life of microorganisms in soil or compost.

K Soil tests from two fields showed nearly identical chemical analysis. Yet one field produced maximum yields, the other average to medium yields. The difference between the two lay in the soil structure and the humus condition.

L. Humus quality can be measured with chromatography.

(Figure 1.)

COMPOSITION OF SOILS

For 1 Plow Acre 6-213 Inches in Depth

Approximately *2,000,* 000 *lbs., or 1, 000 tons*

Element	Sandy Loam lbs. per acre	Silt Loam lbs. per acre	Clay loam lbs. per acre
Organic Matter	20,000	54,000	96,000
Lbs. of Nitrogen	1,340	3.618	6,342
Live Portion (Earthworms, Bacteria)			
Silicon Dioxide	1,905,000	1,570,000	1,440,000
Aluminum Oxide	22,600	190,000	240,000
Iron Oxide	17,000	60,000	80,000
Calcium Oxide	5,400	6,800	26,000
Magnesium Oxide	4,000	10,400	17,000
Potash	2,600	35,000	40,000
Phosphate	400	5,200	10,000
Sodium Oxide	4,600	26,000	24,000
Titanium Oxide	13,600	18,000	14,400
Sulfur Trioxide	600	8,500	6,000
Manganese	2,500	2,000	2,000
Zinc	100	220	320
Copper	120	60	60
Molybdenum	40	40	40
Boron	90	130	130
Cobalt	50	50	50
Clorine	50	200	200

Compiled by 1. L. Halbeisen and W. R. Franklin.

(Figure 2)

Some Soil Enzymes Found in Soil and the Reactions They Catalyze

Enzyme	Reaction catalyzed
Oxidoreductases	
Catalase	$2H_2O_2 \rightarrow 2H_2O + O_2$
Catechol oxidase (tyrosinase)	*O*-Diphenol + ½ $O_2 \rightarrow$ *O*-quione + H_2O
Dehydrogenase	$XH_2 + A \rightarrow X + AH_2$
Diphenol oxidase	*P*-Diphenol + ½ $O_2 \rightarrow$ *P*-quinone + H_2O
Glucose oxidase	Glucose + $O_2 \rightarrow$ gluconic acid + H_2O_2
Peroxidase and polyphenol oxidase	A + $H_2O_2 \rightarrow$ oxidized A + H_2O
Transferases	
Transaminase	$R_1R_2\text{-CH-N}^+H_3 + R_3R_4CO \rightarrow R_3R_4\text{-CH-N}^+H_3 + R_1R_2CO$
Hydrolases	
Acetylesterase	Acetic ester + $H_2O \rightarrow$ alcohol + acetic acid
α- and β-Amylase	Hydrolysis of β(1 → 4) glucosidic bonds
Asparaginase	Asparagine + $H_2O \rightarrow$ aspartate + NH_3
Cellulase	Hydrolysis of β (1 → 4) glucan bonds
Deamidase	Carboxylic acid amide + $H_2O \rightarrow$ carboxylic acid + NH_3
α- and β-Galactosidase	Galactoside + $H_2O \rightarrow$ ROH + galactose
α- and β-Glucosidase	Glucoside + $H_2O \rightarrow$ ROH + glucose
Lipase	Triglyceride + 3 $H_2O \rightarrow$ glycerol + 3 fatty acids
Metaphosphatase	Metaphosphate → orthophosphate
Nucleotidase	Dephosphorylation of nucleotides
Phosphatase	Phosphate ester + $H_2O \rightarrow$ ROH + phosphate
Phytase	Inositol hexaphosphate + 6 $H_2O \rightarrow$ inositol + 6-phosphate
Protease	Proteins → peptides + amino acids
Pyrophosphatase	Pyrophosphate + $H_2O \rightarrow$ 2-orthophosphate
Urease	Urea → 2 NH_3 + CO_2