Soils Simplified

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Introduction

Soils are the interface between the physical (geologic) and biological words and serve as a foundation for terrestrial life. We depend on soil to sustain our natural forests and grasslands, for crop production, litter decomposition, filtering of residues, and the recycling of nutrients. Soils function as their own ecosystem, yet are intimately and obligately tied to aboveground biotic ecosystems. Soils, in themselves, can be viewed as a living body, with the sand and silt serving as the skeletal frame; the clay and humus serving as the connective tissues, tendons, and muscle; water and dissolved solutes functioning as the lifeblood; the microbial community functioning as the digestive and respiratory systems; and finally the flux of nutrients, energy, and life through the soil represents the soul. Although soils do not have a reproductive capacity (one of our key factors in the definition of a living body), they do have the capacity to continuously regenerate themselves and are constantly growing and developing both downward and upward.

Soil Composition

From a physical perspective, soils are composed of a combination of mineral matter, air, organic matter, and water. The soil pie is the most basic way to consider the average composition of soil. Soils can be thought of as being about 50% solids and50% void space. The void space is filled by a variable amount of air or water.

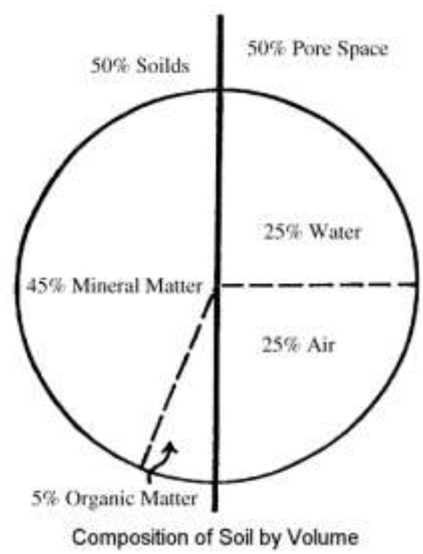

Figure 1. The soil pie

The solid fraction is made up of **mineral matter** (sand, silt, clay and coarse fragments) and **organic matter**. The organic matter includes living and dead organisms and simple and complex organic compounds. The composition of soil is described in far greater detail below.

Soil Mineral Matter

One of the first things you ever learn in an introductory soils class is **soil texture** and how to estimate it from the "feel method." The soil texture is simply the relative percentage of sand, silt and clay in a soil. The relative proportion of sand, silt, and clay are referred to in the common descriptive names such as a sandy loam, silt loam, or clay. The "tilth" of a given soil is directly related to texture and a soil with an even feel of the three separates is termed a loam.

Sand is often thought of as silica, or simply what you find on a beach. However, in soils parlance, sand is nothing more than a physical size class for a form of mineral matter. Sand is any mineral material with a diameter of 2 mm to 0.05 mm in diameter. To a microarthropod sand would appear as an enormous boulder. It is generally some sort of a spheroidal shape, but can be in any of myriad forms. Sand has no specific mineral composition and is found in the greatest abundance in soils that have undergone only minimal weathering and that have been recently deposited by glaciers, rivers, creeks or marine depositions. Given this size range, sand has a gritty feel when rubbed between your fingers and will crunch when you get it between your teeth.

Silt is the next smallest form of mineral matter in soils and is any material between 0.05 – 0.002 mm diameter. To our friend the microarthropod, silt would appear like a small stone. Again it has no specific mineral composition, but has a feel of silk or flour when rubbed between your two fingers or between your teeth.

Sand and silt are what we earlier called skeletal material of the soil because they are of such a large particle size and are basically inert.

Clay on the other hand is considered to be a colloidal material (discussed below) and is any mineral material with a particle diameter of less than 0.002 mm or 2 µm. The microarthopod considers a clay particle to be no bigger than a dust spec. This particle size makes it basically of a size similar to a bacterial cell and unobservable to the unaided eye. This small particle size and net negative charge also give it the colloid al properties that make it function like connective tissue in the soil body. The very small size and plate-like shape of clay particles mean they provide a huge amount of surface area within the soil. If you could lay out all of the surface area of a single gram of clay (roughly a teaspoon) it would cover an area the size of a football field!

Separate	diameter (mm)	surface area (m^2/g)
Sand	1.00	0.01
Clay	0.01	1,000
Sandy loam	mixed	0.1
Silt loam	mixed	10
Clay loam	mixed	300

Table 1. The surface area of a 1 g sample of sand, clay, and three soil texture types. Note that all of the surface area in the soils originates from the clay within the sample.

What is the value of high surface area? **Surface area** reflects a number of beneficial properties relating to water holding capacity, the capacity to form stable aggregates, and the capacity to support microbial life. Water arranges itself around solid mineral surfaces, thus the higher the total surface area, the greater the capacity to hold water. Higher surface area also reflects the soils ability to attract and adsorb organic compounds, a property that can be extremely valuable in the presence of invasive plant species that release allelopathic compounds, or following contamination events wherein organic compounds are concentrated in mineral soils. Soils with high surface areas form more stable aggregates than soils with low surface areas. Specific surface of a soil also represents surface on which soil microorganisms attach themselves, move, and multiply.

The data in Table 2 demonstrate the importance of clay content in determining total surface area in soils. Even in the sandy loam where sand accounts for 90% of the soil mass, this large percent of total mass accounts for less than 1% of total surface area

Table 2. Surface area, percent of mass, and percent of total surface area of various mineral size separates in a clay loam and in a sandly loam.

		Clay loam		Sandy Loam	
	Surface area (m^2/g)	Soil Mass (%)	Surface Area (%)	Soil Mass (%)	Surface Area (%)
Sand	0.07	15	0	90	0
Coarse silt	4.6	20	0	4	0
Fine silt	32	20	0	1	0
Coarse Clay	250	15	1.8	3	8
Medium Clay	792	15	5.8	2	14
Fine Clay	12,600	15	92	1	79

Soil Organic Matter

Soil organic matter represents one of the forms of connective tissue in the architecture of soil - and so much more. The organic fraction of soil perform multiple functions including: long-term storage of plant generated carbon (C); the primary food source for microorganisms; an important colloid in soil that provides water holding capacity, cation exchange capacity (negative charge complex), and source of surface that adsorbs and holds compounds that are otherwise recalcitrant (resistant to decomposition) and potentially phytotoxic.

Perhaps more important than all of these combined factors relating to soil productivity and soil quality, is the fact that land management techniques directly influence the concentration of organic matter in soil. This is not true the amount of sand, silt, clay or coarse fragments. With these factors you get what you inherited from the parent material. With the organic matter fraction, the amount and composition are directly influenced by the type of vegetation, time period it has been present, presence or absence of fire, type and intensity of tillage operation, amount and nature of organic amendments to the soil. Therefore, land management choices greatly dictate long-term soil productivity.

Black is beautiful. When we think of a fertile soil, one of the first things that come to mind is color. Dark soil colors are most often a function of soil organic matter accumulation and specifically **humus** accumulation.

Humus is incompletely decomposed organic material collectively termed humic materials (humic acid, fulvic acid and humin) which has a rich dark color. It is a microbial decomposition byproduct and is probably the single most useful "waste" product in the world. Humus has an extremely small size (smaller than clay) and the particles are charged resulting in a capacity or organize water, attract cations and serve as a source of food and energy in the soil environment.   Humus is a macromolecule, a pseudopolymer with no specific structure. A type structure of humic acid is given below. Humus accumulation in soils provides a nice simple proxy for productivity in organic or sustainably managed agricultural lands. Humus accumulation in natural ecosystems is dictated by a combination of the nature of plant litter inputs (degree of recalcitrance), moisture, and temperature. Cool temperatures and moist conditions tend to emphasize humus accumulation while warm conditions result in more rapid and complete breakdown of organic materials resulting in less being left behind as humus. Farmers and gardeners love to see black surface soils rich in humus for all the reasons described above.

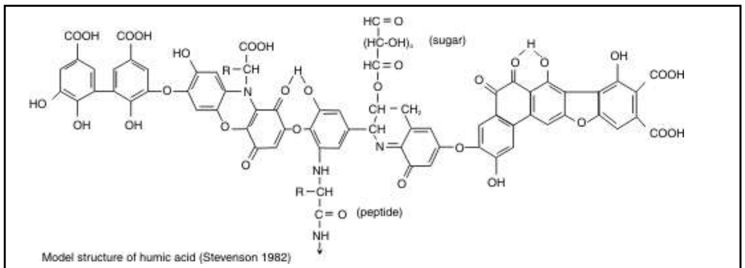

Figure 2. Type structure for humic acid.

However, soil organic matter is much, much more than just humus, it is a combination of (1) living microbial biomass; (2) fresh **organic detritus**, (3) myriad intermediate **breakdown products** (including proteins, sugars, and nucleic acids) which are collectively termed **non-humic materials**, and (4) **humic materials** such as humic acids, fulvic acids, humin and charcoal. Examples of non-humic and humic materials, their relative size and longevity in soil is given in Table 3. All three of these broad groups of organic materials are needed for a productive soil. The fresh organic detritus is immediately subject to microbial enzymatic breakdown. Complex food webs are set up around the decomposition of detritus resulting in the disintegration and decomposition of the material into breakdown products. The hyphae of saprobic fungi envelop fresh detritus, bacteria and archaea colonies explode on moist detrital surfaces and both release exocellular enzymes that initiate the decomposition of the material and release of non-humic materials into soil solution.

Non-humic materials are any organic compounds that can be isolated and described chemically. This includes proteins, any of the 22 amino acids found in soil, starch, cellulose, hemi-cellulose, complex carbohydrates, simple sugars, nucleic acids, secondary plant metabolites (phenolic, poly phenolic, and terpinoid compounds), lignin, and a host of other compounds.   We can collectively look at much of this material as metabolic carbon which is needed to maintain the microbial community and allow their soil building processes to continue.

When we think about this consortium of organic materials in soil we can think of a mixing pot filled with this variety of compound. Microbes in the soil look at this mess as organic abundance. Basically microbes need these non-humic materials for energy and nutrients. The compounds are present in both soluble and insoluble forms, adsorbed and absorbed, volatile and non-volatile. Microorganisms primarily consume these compound via adsorption, thus soluble forms are most readily available. However, the majority of organic matter in soil is not soluble, but rather is in a solid or complex and unavailable form and must undergo enzymatic decomposition prior to adsorption.

Why do we need metabolic organic materials in soil? Because most all processes in soil that are driven by microbes require energy which is provided by metabolic organic matter. Examples of such processes include N fixation by free living microbes, solubilization of inorganic, insoluble minerals, and formation of enzymes required in the degradation of organic materials. If soil organic matter were composed only of humic materials, the soil microbes would basically starve or operate at a greatly reduced capacity. Humus, though energy rich, is too recalcitrant or difficult to degrade to make it a viable or important short-term energy resource in soil.

Table 3. Soil organic matter fractions, average molecular weight, and mean residence times.

Class of compound	Average molecular weight	Turnover times
Simple sugar	90 – 140	minutes
Di and tri saccharides	180 – 420	minutes
Starch	> 1,000	minutes
Amino acids	48 – 120	minutes
Proteins	700 – 100,000	minutes to months
Complex carbohydrates	1,000 – 50,000	days to months
Cellulose	> 1,000	months
Waxes	500 -	months to years
Lignin	500 – 1400	tens of years
Fulvic acid	500 – 3,000	hundreds of years
Humic acid	>10,000	500 – 1,000 years
Charcoal	NA	3,000 – 12,000 years

The long life span of **humic materials** and charcoal in soil makes them a semi-permanent structure in soil and a long-term form of C storage. Humic materials carry a charge and function similar to colloidal mineral materials by greatly increasing water holding capacity, cation exchange capacity, and porosity (reduced bulk density) in soils. All of these factors make humic matierials highly desirable addition to mineral soils, however, as evidenced by their long turnover times they do not reflect a significant source of metabolic energy in soil.

Charcoal, the byproduct of biomass burning events and has a number of characteristics that make it similar to humic materials, however, it is formed extremely rapidly during oxygen limited combustion. Charcoal has been found in soils associated with forests, savannahs, prairie, and deserts. It is ubiquitous in soils, but its ecological and biochemical role in soil was greatly ignored scientifically until the end of the 20th Century.

Charcoal was found to be the central ingredient in the formation of the famous Terra Preta anthrosols (human amended soil ecosystems) of the Amazon. These altered forest soils (once bright red Oxisols) were repeatedly amended with large quantities of manure and charcoal, ultimately resulting in the formation of deep rich, black, agricultural soil islands in a sea of low productivity Oxisols. The synergistic effect of manure and charcoal in these soils results in unusually high productivity and biodiversity for this region (see insert).

In natural coniferous forest ecosystems charcoal may play an important role as a surrogate for humus in otherwise organic matter poor soils. In low elevation ponderosa pine ecosystems, for example, charcoal was formed on a fire return interval of 7 – 35 years, with a modest quantity added each event, but slowly accumulating over time to today account for up to 40% of the carbon in forest soils. Aromatic groups are greatly lost during the combustion process resulting in a C rich, N poor material that provides adsorbtive properties. Charcoal increases soil waterholding capacity, cation exchange capacity, and produces a dark, black color that aids in soil warming in springtime.

Addition of charcoal to productive agricultural or grassland soils has little positive effect, however, the addition of charcoal to acidic, phenol rich forest soils increases the activity of N transforming bacteria and when added with manure improves the beneficial properties of manure and has the potential to enhance the productivity of otherwise degraded soil.

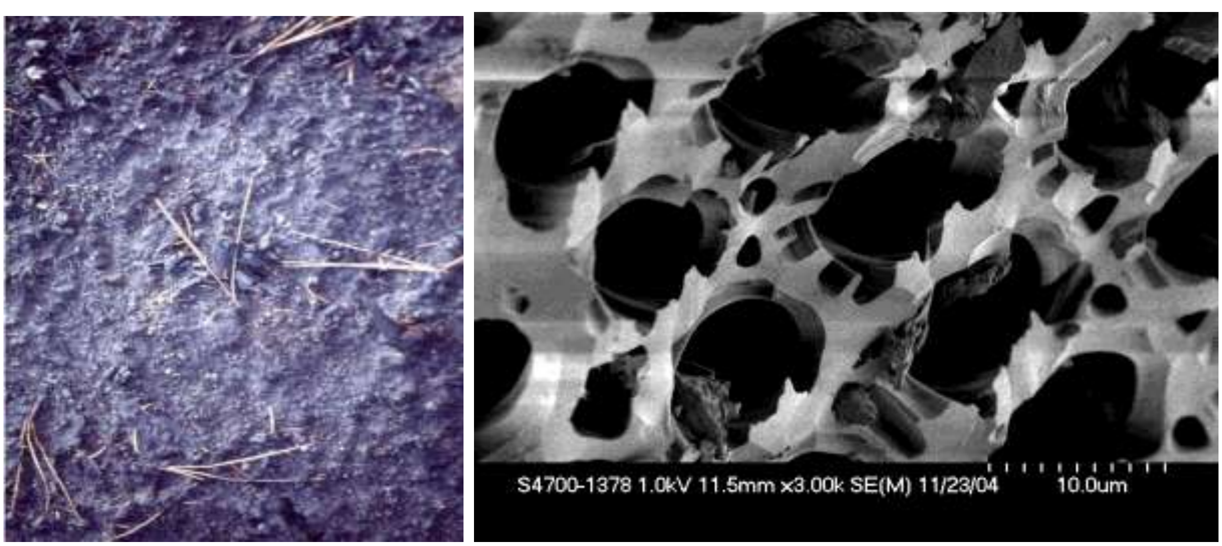

Figure 3. Charcoal on the forest floor and an electron micrograph of charcoal.

Living Organic Matter

The soil **microbial community** accounts for 100 million bacterial cells in a single gram of prairie soil (less than a teaspoon of soil) along with hundreds of meters of funal hyphae, 10, 000 protozoans, a similar number of algal propagules, and larger microarthropods, nematodes, and worms measured on a square meter basis. The diversity of microorganisms belowground is stunning, yet poorly understood.

	Ag Land	Prairie	Forest
	Organisms per gram (teaspoon) of soil		
Bacteria	100 mil. -1 bil.	100 mil. -1 bil.	100 mil. -1 bil.
Fungi	Several yards	10s – 100's of yds	1-40 miles (in conifers)
Protozoa	1000's	1000's	100,000's
Nematodes	10-20	10's – 100's	100's
	Organisms per square foot		
Arthropods	< 100	500-2000	10,000-25,000
Earthworms	5-30	10-50	10-50 (0 in conifers)

The most diverse (both functionally and in total numbers) group of organisms in soil are the bacteria and archaea. Within these kingdoms of prokaryotes exists an incredible diversity of metabolisms, functions, and growth forms. There is just not sufficient space to describe all of the important roles of prokaryotes in the soil environment. For example, only the bacteria and archaea have the capacity to fix nitrogen from the atmosphere, generating most of the total N in terrestrial ecosystems on Earth. The prokaryotes are also responsible for iron, ammonium, and sulphur oxidation as well as nitrate, iron, and sulphate reduction. These processes make nutrients available to plants and free nutrients up from unaccessible geologic forms. The fungal community in soils represents lower diversity and fewer numbers than the bacteria, but represent greater total biomass and play a role of equal and in some cases greater functional importance in the soil environment. Soil fungi are extremely important in the deocomposition of plant and animal detritus. Specialized fungi called mycorrhizae form a synergistic relationship with plant biota in which they greatly increase the capacity of plants to access nutrients and water. Fungi are also extremely important in the formation of stable aggregates in soil. Protazoans function as detritavores and grazers (Figure 6) in the soil filling out the soil food web and managing bacterial populations. The larger soil fauna function as primary, secondary and tertiary consumers creating a complex and multifaceted food web with a high degree of diversity and functional redundancy.

Plants

Soils live in obligate symbiosis with **plant life**, where in plants convert solar energy to food energy that is either used within the plant or shunted into the soil as plant litter or exudates. In the absence of this life giving transformer of solar energy, the soil would decline due to lack of energy and the plant community could not complete life cycles without sufficient nutrients and water.

As indicated above, plants and soil live in obligate symbiosis. Plants, as producers, convert solar energy into simple sugars which are then converted into amino acids, nucleic acids, secondary metabolites, storage compounds, lignin and cellulose. When the plant releases compounds into the soil via litter fall, root exudation, and plant mortaility, soil organic matter is formed. In a general sense any organic compound in soil is a portion of the total soil organic matter pool and all forms of carbon compounds have a role to play.

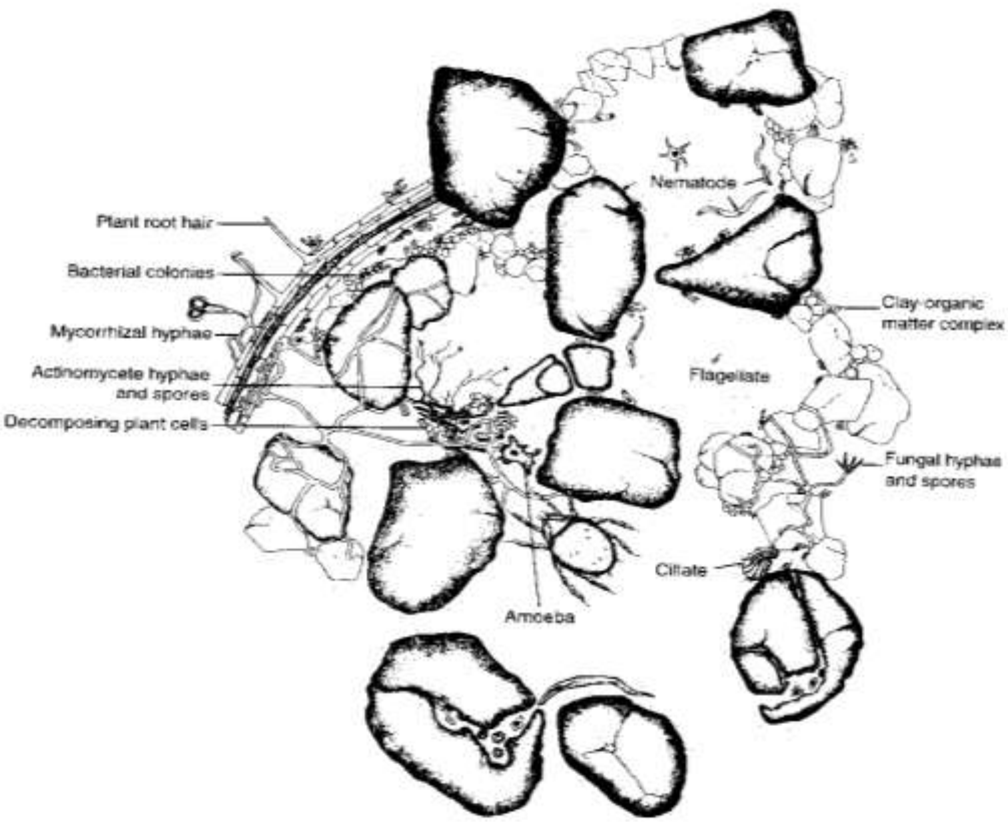

Figure 4. Diagram of the relative scale of soil particles, soil organisms and plant roots.

Soil Water and Solutes

All soils are porus and in accord have the capacity to hold water. The mineral nature of soil results in the general attraction water for soil surfaces via hydrogen bonding. Soils are generally not saturated except in the case of wetland soils or periods of intense rainfall. Therefore, under non-saturated conditions, soils hold water against gravitational pull. Plants take up water from soil via negative water potential in the atmosphere which pulls water out of soil pores, into the roots through the xylem and out the plant stomates. Plants are absolutely dependent upon soils for

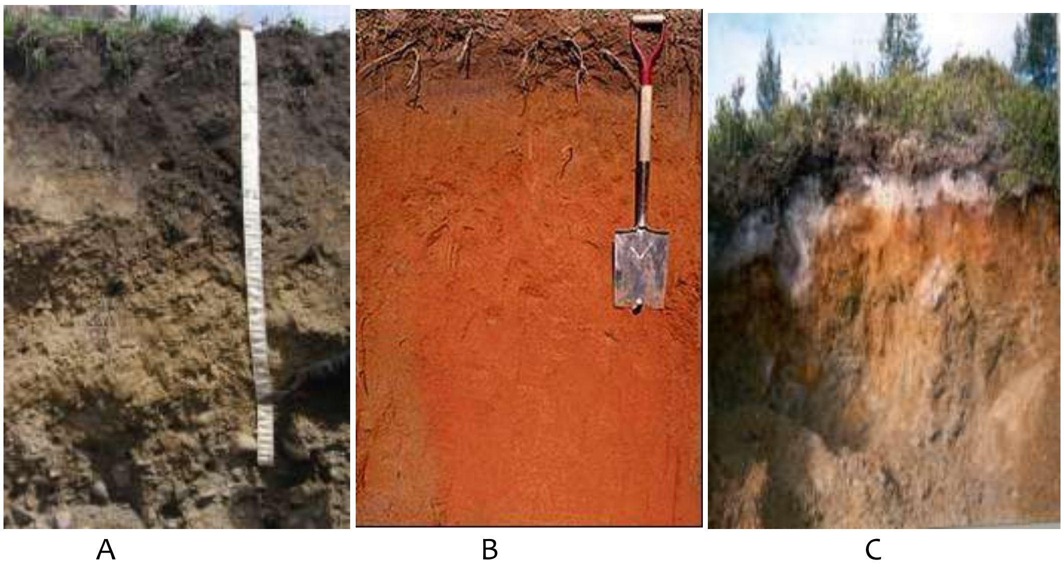

Figure 5. profiles of a temperate grassland soil (A), a tropical forest soil (B), and a boreal forest soil (C).

water uptake. A combination of small and large pores creates an ideal environment for transmitting water under conditions of heavy rainfall and holding water against evaporation and gravitational pull. Solutes in soil water include dissolved inorganic salts, dissolved organic materials and suspended matter. Plants take up nutrients via the soil solution and do so both passively and actively via ion transport pumps.

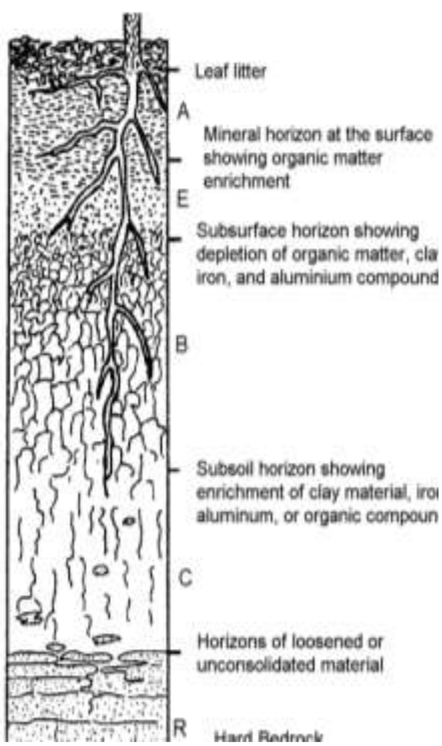

Figure 2. The soil profile.

Soil Form and Structure

Now that we understand the composition of soil, let's look at the structure of soil. The large scale perspective of soil structure is represented by the organization of the soil into **horizons**, horizontal layers of soil created by the downward movement of solutes and accumulation of organic matter over time. Although each soil has horizonation, the nature and characteristics of these horizons are completely dependent upon differences in the state and flux variables that led to the soil's genesis. Together these horizons make up what we call the **soil profile**.

Laying on top of the soil profile is the litter layer and humus layers that accumulate on the surface of some soil types (called O horizons). The surface mineral horizons are either an A or E horizon. The A horizon is a zone of melanization where organic matter has been incorporated into the mineral soil. The E horizon lacks melanization, but resides at the surface (common in desert soils or coniferous forest soils). Both A and E horizons are zones of elluvation where these upper horizons experience a net export of solutes, clays and organic matter to lower horizons. The B horizon is a zone of illuvation where the solutes, clays or humus leached from upper horizons accumulates. The C horizon is unaltered parent material and R represents bedrock.

On a more microscale, the physical architecture of the soil is represented by the redistribution of clay, silt, and organic material into **aggregates**, or little clumps. Aggregates along with the soil texture (percent of sand, silt and clay) dictate the soil's capacity for infiltration, aeration, drainage, root penetration, tuber formation, cation exchange capacity, and myriad other functions.

We measure aggregation as the percent of soil that exists in water stable clods or peds (that which won't pass through a 2mm sieve with gentle washing with water. The aggregation along with the natural porosity of the physical structure set by the individual particles creates air space. Water naturally drains readily into large pore spaces and aeration of the soil is maintained under such conditions. Poor structure results in poor drainage and ultimately limited aeration. Roots, fungi, animals and most bacteria all need air to respire, thus good aeration of the soil benefits numerous secondary factors.

Of Humus and Humility

The relationships between soils and humans

Preamble

The meaning, nature, and importance of life is not measured in tangible packets that can be judged or scrutinized, rather it is a sense, feeling, or accumulation of wisdom and experience. Soil represents the accumulation of knowledge and experience passed down by centuries of life and death of organisms as simple as the amoeba and as complex as human beings. All terrestrial organisms eventually pass through soil and become a part of soil leaving behind a legacy of enrichment for futures to come. This enrichment is embodied in humus. The humus molecule is as complex and variable as the history of organisms from which it was created. This wisdom or legacy builds on itself and creates the very soul of soil to which we are directly and indirectly connected.

A wise soils professor at the University of Wisconsin, Dr. Francis Hole, used to refer to himself as "Francis Hole, TNS" which meant "temporarily not soil", a title he felt was more important and meaningful than the title of PhD. We are, after all, very temporary living on the surface of the Earth in our familiar physical form. After our active life on the surface, we are converted back into humus or partially charred and begin a new life within the soil where our remains will be cycled and recycled for thousands of years.

Whether we acknowledge it or not, we are intimately connected to the soil. Most every mineral nutrient in our bodies came from soil -- our skeletons are built from Ca and P derived from soil. Most all of our sustenance originated from plants that derived most all of their nutrients and water from soil. Our houses are built in and on the soil. We drive on it, walk on it, play on it, die on it and are buried in it. So it is a mystery why we as humans pay so little attention to soil. As a species, we have abused soil to generate our food, our security, our shelters, and our income. Contrary to our cultural disregard to soils, it is interesting to note that most all religions refer to humans originating from clay or soil, and when our vessel of clay is no longer functional, to soil it will return. In spite of this ancient, deep, and constant connection with soil, we continue to ignore our dependence on soil, simply viewing it as an expendable non-entity on which we grow crops.

> *We know more of the celestial bodies in the sky than we do of the soil under our feet.*
> ~ Leonardo da Vinci

Over the past two millennia humans have 'toiled in the Garden of Eden' attempting to produce sustenance from the Earth in localized units or farms to avoid solely roaming in search of natural products. In the process of working with soil and learning from soil, humans have both enhanced their relationship with soil and, in far too many cases, sowed the seeds of their own destruction through the abuse of soil. Time and time again lessons learned went un-heeded, often as a result of arrogance, and abused lands were abandoned in the face of poor yields and famine. In these instances, humans moved on while their legacy was recorded in the scorched or scarred Earth left behind, the soul lost from the soil and the landscape abandoned. In other cases where the climate and landscapes were more favorable or forgiving, humans managed to learn from mistakes and built upon their knowledge to either save or even deepen the wisdom in the soil. These legacies remain on the landscape as well, but are threatened by arrogance once again with industrialized society not heeding the lessons of the past nor the wisdom of the soil and moving forward in a over-consumptive, energy wasteful, unsustainable approach.

In hubris and ignorance, we have failed to support our end of the symbiotic relationship we have with soil. Some of the effects on the soil are clear and acute while and others more subtle and chronic. Either way, if we don't take care of the soil, how can it take care of us?

The White Bread Diet

Land management that deprives soil of energy and recycling of nutrients results in the long term decline in soil condition. This has been observed in many times in many cultures. In the United States, soil quality has declined dramatically following 100 years of row crop production with an increasing emphasis on synthetic inputs and less of a holistic approach to soil management. By conducting row crop production with a monoculture of continuous corn or a two crop rotation of corn and soybeans, producers inadvertently placed their soils on the "white bread diet."

Rather than a biodiversity of native grasses and forbes, Great Plains agroecosystems provided soils with the roots of scant row crop that were only present for a short portion of the year and which only covered a fraction of the soil surface. Fields were clean tilled in the fall and left to mineralize away organic C without the continual enriching input of root exudates and annual input of dead root and shoot tissue. Row crops are only growing extensively for 2 to 3 months a year, and the richest portion of the plant is harvested and exported from the site eliminating the recycling of most nutrients and greatly reducing the total C input into the system. Soils wind up with a diet of cellulose, deposited primarily at the end of the growing season in one dump following harvest.

To make up for the export of nutrients off site, a vitamin pill of synthetic nutrients (primarily N, P, and K) were applied annually, however, alkaline metals and trace nutrients were completely overlooked and energy inputs are not even considered.

As soils became more acidic as a result of ammonia fertilizer applications and the poor diet of cellulose, antacid was prescribed in the form of calcium carbonate (agricultural lime). Although the symptom of acidity or acid reflux was overcome, the holistic view of the greater problem was completely discounted.

Problems or symptoms were treated while the health of the soil continued to decline. The color changed from a rich ebony to a pale ochre, the granular structured surface changed to a plugged and compacted surface that did not readily accept rain and experienced a shortness of breath. The soul of the soil was eroding away with little or no replenishment. Herbicides, fungicides, and insecticides were applied much like antibiotics and medicines to address illness caused by poor health. Conservation tillage approaches were later employed to stop the hemorrhaging of organic matter and surface soil to drainage ditches. No-till was paraded out as a savior of soil, prescribed to protect against erosion, but addicted the system to herbicides and increased energy inputs. The soils began to gain back some fat in the form of organic matter, but the vigorous, athletic nature of the soil was lost.

Reversing the effects of years of poor management is not impossible, but will take patience and care. The five year transition from conventional to organic productivity is partially a function of the depletion of organic N in soils. Mineralization of organic N at a rate commensurate with uptake rates requires that several years of organic N pools be mineralizing at once contributing to a whole. This concept is described in detail in later chapters.

Accumulating sufficient diversity of organic matter to reduce pathogen titers in soil will require several years of applications of fresh and composted organic materials. A diverse assemblage of soil organisms will grow over time with these applications and will ultimately provide protection against epiphytotics.

Tillage in agroecosystems is a disturbance required to incorporate high energy replenishing foods for microbes (manures and green manures). Although damaging to soil structure and energy consumptive, it can be likened to natural disturbance cycles such as fire and represents a necessary input to an athletic oxygenated soil. Alternative tillage systems that leave residues at the surface and cause less overall disturbance while allowing for incorporation of fresh and composted organic inputs are being developed and will need to be further improved with time.

Natural ecosystems will need to be emulated to ensure that the health of the soils comes first rather than a focus on simple high yield farming. The soul of the healthy soil is built from diverse inputs and the input of a diversity of contributors. The wisdom of this soul is greatest when provided by the greatest number of individuals.

Our Bodies Our Soil

How does soil management influence human health and longevity? Although modern medicine and science has not made any direct link between soil health and human health, several attributes are simply intuitive.

The decline of human health

A few potential examples are given below, but we may actually have little or no idea of what types of human deficiencies are being induced by over exploitation of our soils, over-filtration of our drinking water, and poor eating habits in the form of fast foods and empty calories.

Human nutrient deficiencies in under developed countries are extremely common, obviously most common where hunger or famine is prevalent. Deficiencies in developed nations are not only an unacceptable outcome of laziness, greed, and ignorance. Laziness because agricultural crops are primarily produced by industrial scale farms that simply fertilize for maximum yields with little or no consideration of product quality; greed, because industrial agriculture, fast food companies, and pharmaceutical companies stand to gain the greatest profit from doing the least; ignorance, because the average consumer doesn't consider the content of what they are eating much less where it came from and how it was produced.

The decline of soil health

When the **native prairies** were originally turned, all nutrients were present in great abundance, recycled year in and out with the only export coming with occasional fire, erosion, or migratory events. At the same time, imports rarely came at the hand of these same processes. Trace elements and microbes introduced via dust deposition.

With **modern agricultural practice** came the removal of grains or fruits from the field and export to a local distant from the actual farmstead. Nutrients taken up by crops and concentrated in the grain were lost from the soil forever. Initially this would have been overlooked as the native fertility of the soils could supply the basic needs of the crops, however, within 10 years significant deficiencies would appear and productivity would drop dramatically. This could be offset by manure additions and planting of leguminous rotation crops, however, simple mass balance accounting would demonstrate that the amount of nutrients exported in grains could not be supplied by manures produced from animals raised on crops grown on the same farm as the grains were grown.

At the same time that agriculture was exploding across the Great Plains in the late 1800s, a **waste management crisis** was unfolding in large urban areas. Human waste management was being centralized in urban locales and dilution via dumping in lakes, rivers and marine environments was leading to disease, anoxia in water bodies, and eutrophication of lakes and rivers. Nutrients were being exported on a one way ticket to our lakes and oceans while soils suffered from nutrient and organic matter depletion.

It was not until 1945 that mandatory waste treatment was required by federal law in large urban centers in the US. At this stage it was simply a matter of "primary treatment" where solids are separated from liquid and the latter dumped, still untreated, into water bodies. In the 1960s "secondary treatment" of wastes to remove dissolved organics and reduce pathogen loading was added as mandatory, greatly reducing the immediate threat that our own waste posed to our health and welfare.

From the correction of this crisis came the recognition of a less dire, but perhaps more insidious problem: **Long term soil depletion** and mineral deficiencies and imbalances that are not readily recognized with modern medicine.

This problem was exacerbated by the shift in agriculture starting in the 1960s away from the integrated farm (livestock and crops grown together) to an **industrial agriculture** model where grain crops were grown separate from livestock on enormous tracks of land. This meant that the livestock that were once fed grain from the local farm and produce manure to be reapplied on the farm were now being separated. Grain was delivered to large confined animal feedlots from large distances, but manure remained on the feedlot piled and slowing eroding away to forces of wind and water. Break even hauling distances for manure in the 1990s were estimated at 12 miles. That means that it was cheaper for farmers to buy synthetic fertilizers than pick up free manure from feedlots if they were over 12 miles away.

This crazy situation, combined with the rampant erosion losses of the 1930s to 1960s, has led to whole-scale depletion of soil nutrients, carbon, and productivity. The reaction by the agricultural industry was to simply indicate that all nutrients could be readily supplied by **synthetic fertilizers** and productivity improved with **pesticides** and **tillage operations**. Unfortunately, these great minds in industry and the federal government () failed to consider the long term effects of soil carbon depletion, trace mineral losses, and increased demand on synthetic fertilizers.

What does increased fertilizer use mean for the greater populous and for the sustainability of our agricultural systems? It really means two things: (1) Increased pollution of lake and marine ecosystems; (2) Continued degradation of one of our most precious natural resources, soil.

First you need to consider that there is basically no **nitrogen** in the geologic strata, so historically most all of our soil N came from biological N fixation via legumes, cyanobacteria, and actinohrizal bacteria (see Chapter X). Nitrogen fertilizers today are generated from the Haber-Bosch process, by which huge amounts of natural gas are used to convert N_2 gas (that which makes up 78% of our atmosphere) to NH_3 after which it can be converted into various forms of N fertilizer. Well all of this will be discussed in more detail below, so lets call it good for now, and just realize that all of this N being put into soil and the environment is being formed de-novo meaning that it would not exist in a bioavailable form in the terrestrial or aquatic world otherwise! In otherwords, we are pulling a safe and nonreactive, nonavailable form of N out of the sky and pumping it directly into energy and ecosystem N cycle at rate in excess of biological fixation while biological fixation continues. This is one of the leading causes of "nitrogen saturation" of terrestrial and aquatic ecosystems. And, importantly, application of synthetic nitrogen fertilizers is the single greatest energy sink on the farm today. The amount of energy required to produce and deliver enough N to fertilize a 1000 acre conventional Midwestern corn grain farm annually is roughly equivalent to 2,47,000,000 BTu or about 18,000 gallons of diesel fuel or 2,421,600 cu feet of natural gas (based on 130 pounds N fertilizer per acre, 19,000 Btu/pound of fertilizer). That is on an annual basis!

Now what about **phosphorus** (P) and **potassium** (K)? Well these are actually present in the geologic strata, so if you are lucky you have a fair amount of K in the mineral soil. And on relatively young soils composed of glacial till derived from sialic minerals, this is often true. However, on mature, leached soils or immature soils composed of quartzite or an equivalent low K rock, then K may well be required in large amounts. Phosphorus is often the next limiting nutrient and the one required in the next largest quantity after N. Although also present in the geologic strata, it is limited by its low solubility under both acidic and alkaline conditions. We will discuss this in greater detail later, so let's just jump right to the point here. The average Midwestern corn field, right or wrong, currently consumes about 30 lb P/a and 25 kg K/a annually. Both of these nutrients are generally mined out of the Earth, meaning that they originate from a finite supply that will ultimately be exhausted. (The finite nature of P has become extremely evident. If there were space here, I would discuss the issue of "peak phosphorus", but that will have to wait for another time.) Furthermore, these nutrients are being pulled from a buried, unreactive, unavailable source and being put right into the active nutrient cycles. While this isn't a huge problem with K, the addition of P to water bodies leads to eutrophication of lakes and streams and aids in the formation of dead zones in marine environments.

So what about all of the other nutrients? Soil fertility is to be discussed in chapter Z, but it is important to understand the background on why a holistic approach to soil fertility is absolutely necessary to achieve a sustainable agricultural system.

The macro nutrients **Ca and Mg** are rarely limiting in modern agricultural production in the US as a result of the high levels of these nutrients in our immature soils and the fact that agricultural lime, which often contains both of these nutrients is applied regularly to bring the pH of acidic, mature soils back into a desirable range.

Sulfur rains down on our agricultural fields nationwide as a result of fossil fuel burning which puts SO_2 into the atmosphere ultimately becoming sulfuric acid in rain water deposition on soil. Sulfur is only limited in leached systems that are not down wind of any major emission source.

The **trace nutrients** B, Cl, Cu, Fe, Mn, Mo, Ni, and Zn are all present in the geologic strata and may be more or less limiting by geographic area, leaching conditions, export rates, and deposition rates. There are other minerals required in our bodies, or in those of livestock, that may also be depleted over time or deposited in excess including Se, Co, and F. It is probably safe to say, that just because there is enough of these minerals for plant growth, does not necessarily mean that they are in sufficient supply for our bodily needs. Mineral deficiencies by region are much less common now as a result of our globalized food distribution system, but it is possible that we are all being deprived of nutrient inputs at a rate that might otherwise offset the occurrence of various diseases.

Reversing the Trend

In the 1980s the concept of **sustainable agriculture** arrived at the door of the common person. For the first time people were recognizing that land degradation and food quality were more than a function of just erosion and conservation tillage. **Organic agriculture** was, for the first time, considered something more than a fringe bunch of hippies that left the commune to live off the land on their own. The nation's land grant schools were developing programs in sustainable or alternative agriculture. This rapid change and promise continued into the early 1990s when high tech agriculture, molecular biology (transgenic crops), and vertical integration of the agricultural industry seemed to change the pace at which progress was being made. Agricultural schools started downsizing and changing their names to more modern, fundable titles that focused on environmental sciences rather than agriculture. With so few students returning to rural communities or to the farm after college, the enrollment in agricultural schools was faltering.

The seeds for sustainable agriculture and sustainability in general were; however, effectively sown in the 80s and early 90s and our awareness of the issues has continued to grow, slowly, but it is growing. Education and awareness are at the heart of solving the intricate and insidious problem of agricultural industry and soil degradation.

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