SOILS -- An Overview

from remarks by Demetrio P. ZOURARAKIS

Introduction and Definitions

Modern agriculture is undergoing a shift in paradigm, from a mechanistic, reductionist, rationalistic view to one which is more holistic. The systematic, holistic view is not new. These two paradigms have been coexisting for a long time. The methods of organic agriculture have been known for many years. It is not as though we are creating a new theory which explains everything. The knowledge is already there and it works. We are now faced with the question, that given our current circumstances can we be sustainable? Can we return to sustainable use of our natural resources? This is significant when we consider the importance of a healthy, readily available food supply.

As we learn the importance of viewing the plant environment of our planet, and in this case our gardens and farms, as a complete system, we begin to realize that this system extends below the surface to the soil environment.

What are soils? Are they merely layers of dirt? Of course not. Soils are natural bodies, each with a unique form and structure, which is the result of the combination of climate, plants, animals, parent rock materials, groundwater and age. They support plants, both physically and nutritionally, occupy large portions of the Earth's surface and are three dimensional bodies having shape, area, breadth, width and depth. Soils are independent entities, but can be classified to simplify our study of them. Like biological organisms, soils are born, mature and eventually die. For example, in the Tropics we would observe blocks of iron oxide or bauxite, which were soil at some point. The rest is gone.

What is the value of soil science? Soil science is a tool which can help explain why a particular soil is in a particular location. It can describe the properties of specific soils and can predict their behavior. This can help determine what, if anything, needs to be done to modify that behavior. Whatever our motives for wanting to understand the nature of soil - whether we want to conserve and protect it as the skin of the planet, as a viable natural system inherently deserving of respect, or for future generations -- or for the extraction of profit or to provide food and nourishment for the population -- soil science can offer some very beneficial insights.

In the study of soil, as with any natural system, interconnected with other systems, incorporated into the larger whole of this web of life, it becomes important to specify the boundaries of observation. Soil science considers a range from the basic horizon to the parent material as its field of study.

Genesis and Evolution of Soils

As was mentioned in the introduction, soils are born, mature and die. Knowing the origins of a soil can help us predict its behavior and how its going to react.

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Soil Forming Factors

Parent Material -- The formation of soil occurs in stages, which may grade distinctly from one into another. These stages include accumulation of unconsolidated rock fragments (parent material), which may be deposited by the movement of glaciers, wind gravity or water. The parent material determines the distinct geology and mineralogy of the region. It may also in some situations be accumulated in place from the natural weathering of hard rocks. Many of a soil's characteristics are determined by its parent material. The second stage is the accumulation of horizons (layers of soil). This results from the dominance of one or more process over another producing individual layers which differ from those above or below them.

Topography -- Topography includes the surface features of an area, the relief, rivers, lakes, etc.

Organisms (Including humankind) -- Organisms do a lot for soil formation. All soils begin with rock. Soil formation is going from rotten rock to soil. It is a very complex process of mineral weathering and organic matter creation. In the earliest stages of weathering lichens will stick to rock (not grass or trees, but lichens, something which can deal with rock). At the end of the process is humankind. This organism can create or destroy soils and accelerate the development of soil forming factors.

Climate -- This includes rainfall and temperature. Because water is a milieu of chemical reactions and is also a chemical reactant (part of the reaction), the more water the faster a soil develops. In the West, (e.g. Arizona) there is little soil development because those soils are very young. These aridisols (dry soils) are kept young because there is not sufficient water to make them develop. Temperature is also a significant factor in the aging of soils. In Alaska, there is also very young soil, which is frozen all year round. The rate of reaction is significantly slowed down by the cold so the soils do not age.

Time -- Many books do not include time as a soil forming factor, because it is actually an illusion. In soil development, if the climate is hot and humid (e.g. the Tropics) the soils will age quickly. Time seems to flow differently in cold, damp environments where soils age very slowly.

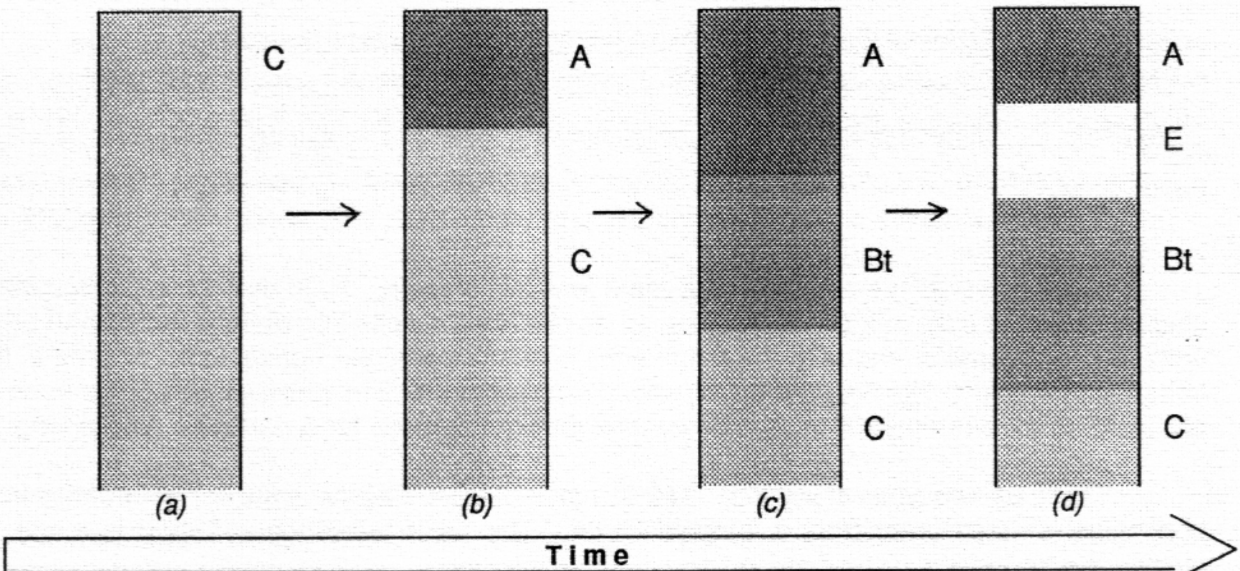
Morphology

Horizon -- An horizon is a layer of soil. These layers occur more or less parallel to the surface and each differs from the one above or below it by one or more properties. These properties include: texture, structure, consistency, porosity or reaction, and color. The boundary between these horizons and the underlying layer of rock usually occurs at 1 - 6 feet in depth. Soil horizons develop through the soil processes.

Soil Processes include: transformations, translocations, additions, and losses of organic matter, soluble salts, clays, carbonates, sesquioxides and silica. Gains are typically from additions of organic matter, oxygen or water. In some areas there can be a continuous addition of minerals through depositions from groundwater. Losses occur through percolation down to other horizons or from surface runoff. Translocations occur through the continual movement of materials dissolved in solution and deposited when water is evaporated or taken up by plants. Transformations occur from materials reacting with other materials or water within soil.

Profiles -- The soil profile refers to the sequence of horizons. Layers occur one on top of another like cake. The horizons in a profile are designated by A,E, D, B, C, and O. An O horizon is the organic layer which is composed of loose leaves and decomposing organic debris, such as in a woods or pasture. The A horizon is a mineral layer, and is the typical topsoil. E horizons are not common here and are extreme cases of A, gray sandy, bleached and leached. These two layers lose clays to the rain. The clays migrate to the B horizon, which is the reddish layer we commonly call "clay". The red color is not the clay itself, but is the iron oxide that moves with the migrating clay. Roots are very happy in the A horizon, not so much is B. A has coarse textures and large pores so organisms and roots can breathe easily and water moves out pretty quickly. The E horizon is usually too acidic for healthy root growth. The C layer is the parent material -- rotten rock. (See Figure 1).

Figure 1: STAGES OF SOIL DEVELOPMENT



(a) Parent Material	(b) Young Soil Entisol	(c) Mature Soil Mollisol	(d) Old Soil Alfisol
Original material before soil development begins	Thin solum, organic matter accumulation in A horizon, from which carbonates have been leached. Minimal weathering and eluviation.	Organic matter content is at a maximum. Has moderate clay accumulation in the B horizon and the solum is acid.	Very acid in reaction, severely weathered, and has less organic matter than mature stage. Clay accumulation in B horizon has formed a clay pan. An E horizon exists.

Taxonomy (Classification) -- Soils are classified according to their physical and chemical properties There are six categories in the current classification system: order, suborder, great group, sub group, family and subgroup.

Table 1. SOIL ORDERS

Order	General Nature
Alfisols	Gray to brown surface horizons, medium to high base supply, with horizons of clay accumulation: usually moist, but may be dry during the summer.
Aridisols	Pedogenic *(soil formatory)* horizons, low in inorganic matter, and usually dry.
Entisols	Without pedogenic horizons
Histosols	Organic soils (peats and mucks)
Inceptisols	Usually moist, with pedogenic horizons of alteration of parent materials, but not of illuviation *(accumulation in an underlying soil layer of materials[collids, soluble salts, etc] that have been leached out of an upper layer.)*
Mollisols	Nearly black, organic-rich surfce horizons and high base supply.
Oxisols	Residual accumulations of inactive clays, free oxides, kaolin, and quartz; mostly tropical.
Spodosols	Accumulations of amorphous materials in subsurface horizons.
Ultisols	Usually moist, with horizons of clay accumulation and a low supply of bases.
Vertisols	High content of swelling clays and wide deep cracks during some seasons.

(Lapedes, 1978:768)

Maps and Surveys -- Soil surveys serve several purposes: 1. to determine the important characteristics of soils in a particular area, 2. to classify the soils into defined series and other units, 3. to determine and map the boundaries between particular horizons, 4. to predict the behavior of a soil and its adaptability to various crops, construction activities, etc. The surveys are used as tools in determining the best management practices for a particular plot of land.

There are two types of soil map. The common detailed map plots the soil boundaries from observations made throughout a surveyed area. The reconnaissance soil map is made by plotting the boundaries from observations made at intervals.

Soil Properties -- Here we address the question "How do soils behave?" Soils have physical, biological, and chemical properties.

Physical properties, which are the most difficult to change, include: 1. primary particles, like sand, silt and clay. This is the texture of a soil. These primary particles combine to form secondary particles. 2. aggregates -- These are tiny clods and form the structure of the soil.

Texture can't be changed easily. One would have to cart in sand and clay. Structure, on the other hand, can be changed. Structure is where the large pores are, where the roots get in and breathe and suck up the nutrients and water. That's where the microorganisms live, in the channels on the walls. Resulting from the texture and structure of a soil is porosity (porousness) and bulk density (compaction). These two factors affect four properties: water, air, temperature and resistance to root penetration. These four properties are affected by the physical characteristics through compaction, which alters the hydrolytic conductivity (how fast water moves into a soil).

Note: In the 1970s the theory of macropore flow (big hole theory) was developed. It was discovered that no-tillage creates earthworm holes and root holes that remain. The channels stay there and water and in a rainfall event chemicals move very quickly into the groundwater.

Another physical characteristic is the color, which tells a lot about a soil -- not only radiation variance (Does it heat up fast or slowly?) but whether or not it is eroded, and the particular horizon. A horizons are typically darker than B. O, which is the layer of organic matter is very dark and E is light when compared to an A.

Biological properties refer to the micro, meso, and macro organisms which inhabit a particular soil. These include, among others, microbes, arthropods, earthworms, etc. Each individual soil has its makeup of microbes -- in particular numbers and types. Anything you do in the process of soil management will change that. For example, if you put all your cornstalks on a field as compost, some microbes will proliferate. If the soil is flooded particular populations will be affected.

Microbes are important factors in the turnover rates of the nutrient cycles. How fast is the nitrogen cycle churned? the phosphorus cycle? Soil is also affected by disease and some antagonism among the organisms. The organic matter is very much alive.

There are Chemical characteristics of a soil as well. There are three important chemical aspects of a soil: 1. pH, which is very important (Much of plant nutrition is affected by pH); 2. nutrient starters (Crops are planted in soil because it offers physical support and is the source of mineral nutrients for the plant);, and 3. toxic substances, like aluminum (which is affected by pH).

Organic Matter

The organic component of most soils is about 5 percent. The basic properties of organic matter are:

1. It serves as a nutrient storehouse. The three most important are nitrogen, phosphorus, and sulfur. Over 90 percent of the nitrogen in soil is the organic matter. It holds about 40-50% of the phosphorus and 40% of the sulfur.

2. It has biological components, which include the presence of hormones and antibiotics. There are many others that alter the metabolic and growth rates of roots and other organisms.

3. It retains water. Organic matter has a high heat capacity when it is moist.

4. It acts as insulation.

5. Organic matter will help structure by complexing with clays. This means that all the little clods (organic matter and clay) have bridges made of calcium that hold them together. When this soil is broken up, the structure is stable. To test the structure of a soil a clod can be dropped in water. If it doesn't explode or flake, it is stable. This is the goal for agriculturalists -- to have stable aggregates, so that when the rains come they aren't broken up and the soil doesn't erode downslope.

6. It acts as a buffer. Organic matter will resist changes in acidity. The organic matter and the soil itself are buffered and resist that drop in pH.

7. It chelates or sequesters heavy metals

Soils are continuously changing; organic matter is changing. When you put cornstalks and residues into the soil, only a minor fraction of that remains over the years. About 15 percent of fresh crop residue is contributed to the soil as humus. This occurs because the residues are food for something else, which is food, etc. The carbon goes as carbon dioxide. There are estimates as to how much tilling and no tilling contribute to global warming. In organic residue the carbon is lost as carbon dioxide and water. What remains is the nitrogen, phosphorus, and sulfur along with very small amounts of sodium, calcium and magnesium.

The humus is quite stable. The 5 percent remains because it mineralizes at a very slow rate. It is chemically resistant to microbial degradation. The microbes have a very difficult time breaking down the molecules because it's very complex.

Plant Nutrients

About 95 percent of soils are minerals. There is one particle size that is particularly associated with minerals. This is clay. Clay particles are very fine. Because the particles are so small compared to sand and silt it has distinct physical - chemical properties. The particles are 1/10,000 of an inch in diameter. Clay acts as a storehouse for calcium, magnesium, and potassium. These three cations stick to the clay. Crop roots pump the potassium from the soil solution, but that which comes from the clay diffuses up. Orchard trees will pull these nutrients not only from the clay but from primary minerals -- from the rocks that make up the soil. This occurs because they stay in the soil for such a long time. They have time to draw from different nutrient sources.

Nutrient Cycles

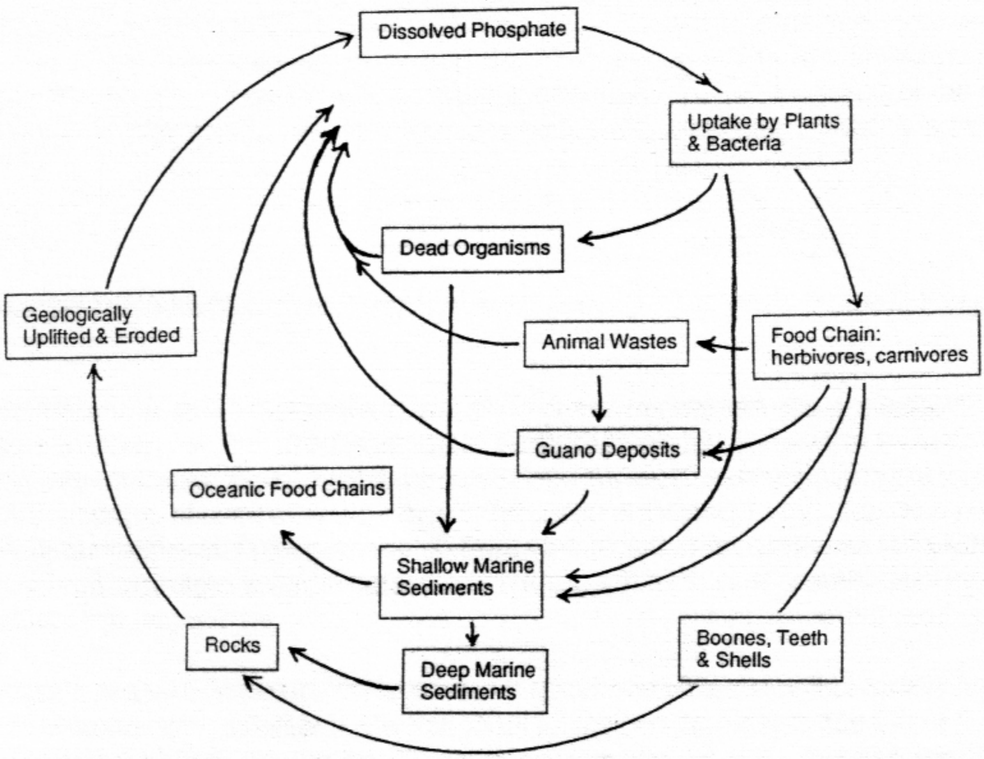
There are 16 known nutrients important to plants. Those they can draw from air and water are carbon, hydrogen, and oxygen. There is always CO_2 in the air and water. If plants shut down from lack of water it isn't nutrient deficiency, they're just droughty. Two other nutrients have a gaseous component (plants take them from the air); these are nitrogen and sulfur. The other nutrients are minerals: potassium, calcium, phosphorus, magnesium. The micronutrients are manganese, molybdium, chlorine, copper, zinc and boron.

Potassium in the soil solution is in equilibrium with clay potassium and mineral potassium, depending on the soil, parent material and the particular crop that is planted. If you have alfalfa or a tree that remains in the same spot for years, there may be time for the plant to pull nutrients from the minerals. On the other hand, a soybean crop which is there for one year may take potassium for the exchangeable pool. CEC (cation exchange capacity) is a typical clay property which is included in soil analysis. The exchangeable potassium is mostly from the clay. There is a very little that remains in the organic matter because of the organic matters charge. It can not only get micronutrients, but also heavy metals and pesticides. This clay and organic matter will absorb a lot of chemicals and contaminants.

Q. Isn't that one of the concerns about using sewage sludge? A. Yes, definitely. As a matter of fact there's a lot of vermicomposting (earthworm) work on sewage sludge, but the worms also concentrate other things --viruses, heavy metals, pesticides, and organics of all kinds. You can choose to ignore but you have to be aware that organic matter and clays will absorb things. They have a tiny particle size and many negative charges so they can absorb nitrates, sulfates, phosphates, through the clay depending on the charge. Clays can also have positive charges. They form complexes with organic matter called clayhumic compounds.

Why do we care so much about clay? When the topsoil is gone you notice that there is a lot of water retention in the clay. Plasticity of the clay is very high. If you compare the porosity and air volume of a clod of clay and a clod of topsoil which is higher? The clay is, but the pore sizes are very small and the speed which air diffuses in and water moves out is very slow. This means that roots can suffer air deficiency, unless there are cracks. Clays will crack during contraction. This is why water moves very quickly when rain begins on clay-enriched horizons. As they dry the surfaces can form crusts that impede root growth. Clay does help aggregation, meaning that aggregates are more stable moving toward higher contents of clay.

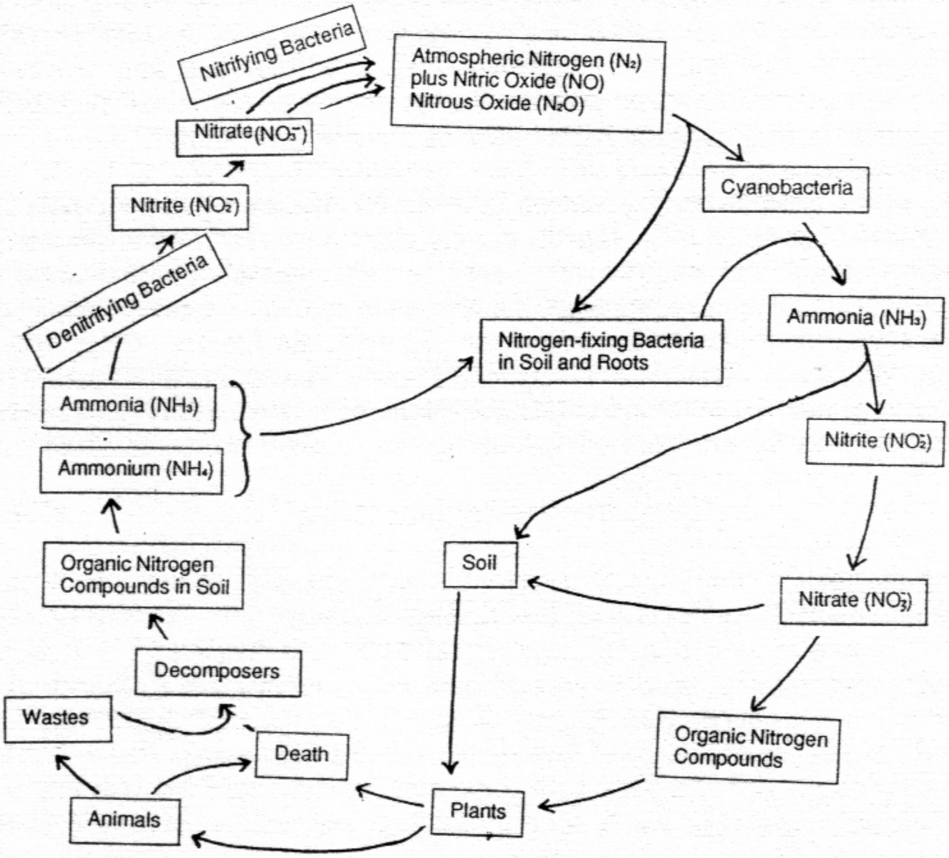
The Phosphorus Cycle



(Wessell and Hopson, 1988: 1102)

Weathering of rocks is a source of phosphorus. The nutrient is released on top of the organic layer of top soil where roots proliferate in the first couple of inches. When roots access deeper sources of phosphorus, as they go down they will grow rapidly. Soil can be characterized by the stratification of phosphorus.

The Nitrogen Cycle



(Wessel and Hopson, 1988: 1101)

We have a pile of nitrogen sitting on top of our heads. We're at the bottom of a sea of air. 70 percent of air is N_2, but we can't use it. Legumes and other nitrogen fixers can. Legumes are one of the cheapest sources of nitrogen in terms of their use of solar energy. For all the solar energy a crop gets only 1 percent is used, this is what the crop uses to combine the nitrogen and make it part of its body. Air is the primary source of nitrogen. There are many minerals which are very unavailable. They eventually get incorporated into the organic matter and plants take them up from there.

Q. What about adding urea to the soil, as a source of nitrogen? A. Urea is a saline compound. Adding it to the soil creates an ecological feedback which tells the microorganisms that their job is no longer needed. This inhibits mineralization. Even natural urea is saline. It does exist in soils with plant and animal residues, but it is in very small quantities.

Typically, inorganic fertilizers send a feedback signal to stop a particular cycle. There is a great number of regulatory mechanisms that drive cycles and chemical signals that go through membranes and tell organisms essentially "shut down this enzyme, there's too much". With the addition of inorganic fertilizers there is the possibility that microorganisms are being killed. The question becomes, do we fix the soil? or do we fix the crop? Do we fix neither or both? Every time you touch the physical properties of soil you change the chemical and biological properties. It is a web, everything is combined. These are management considerations.

Management of Soil Based Ecosystems

Soil management is to a large extent concerned with fertility, the end goal being productivity. How do we define productivity? We prefer to define it in terms of quality and quantity -- not quantity alone. This productivity is the result of three things 1. soil fertility -- the presence of all the nutrients that a plant needs for healthy development 2. the right climate in terms of water, temperature, radiation, light, and diseases, and 3. management -- Crops are not self-sustained or self-management. This includes everything the grower does from seed selection to harvest. For example: consider the rainforest or dune soils. These soils are really productive, but you have to be careful about management because the nutrients are being cycled at such a rapid rate, they are sitting in the biomass. If you carry out the biomass you get rid of the thin layer of fertile soil. This might sound like an extreme example, but it illustrates that productivity has to be defined in terms of the particular system that you're dealing with.

In this time of changing management practices, the soil uses and our land capability have been subject to change. There are many ways to alter the productivity of soil; soil can be changed by amending it with minerals, organic matter, adjusting crops to the soil instead of the soil to the crops. There are many things which can be done to change the environment, like the microclimate. The humidity can be changed, diseases eradicated. The surface of the soil can be changed with mulches The point in any management is to take a systems approach.

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