The Brookside Farms Laboratory Ass'n.

—first in the field of coordinated—

"Soil - Plant - Animal Nutrition Research"

New Knoxville, Ohio

Section 1 — Course of Instruction — Soils Department — Lesson 1

THE MIRACLE OF THE SOIL

Soil consists principally of rock particles that have become broken down into smaller and smaller particles through processes of continuous disintegration and decomposition under the climatic forces of rainfall, varied temperature, wind and running water. The collection of these mineral-yielding rock particles, mixed with clay as a foundation, together with the decomposing remains of vegetable and animal life (humus), forms the basis of our productive soil.

The function of soil is to provide a secure anchorage for plants, and to provide all of the essential nutrient elements necessary to promote and to sustain plant and microbial life.

From the productive soil, there comes forth the only known form of chemically-created, self-accumulating, self-supporting energy in the form of the living green plants. Plant life alone has the ability to accumulate and store chemical energy, which becomes the basic energy-food supply for the sustenance of all other forms of life.

By far the main elemental substance of plants, carbon, comes from carbon dioxide, which plants breathe in through their leaves from the air. The plants draw in water through their roots from the soil and circulate it upward through their structure. Much of the water so taken evaporates while keeping the leaves' interior surfaces moist for gaseous exchange with the atmosphere. The green coloring material of the leaves is a variety of chlorophyll, a very complex substance, each molecule of which is organized around one atom of magnesium.

This chlorophyll, which suggests corpuscles of "plant blood", has the remarkable ability of securing radiant energy from the sun and bringing about a chemical reaction between carbon dioxide and water to form a simple sugar called Glucose ($C_6H_{12}O_6$). This is formed by the union of two duplicate chemical units, each consisting of three carbons and one phosphorus, uniting through the two phosphorus elements which drop out to form the six-carbon glucose. This simple sugar is in turn converted by the plant - in whole or in part - into starch and cellulose which form both the reserve plant food for cellular metabolism and the anatomical structure of the plant. It is a remarkable fact that we owe all of our food, fuel, and clothing to this wonderful chemical reaction.

Besides carbon dioxide, water, phosphorus, and magnesium the living plant depends for its growth upon a number of other inorganic (mineral) food elements which must be present in the soil in such form that they can be absorbed through the roots of the plant and then circulated within the plant juices. Some of these elements are built directly into the plant structure as materials of construction while others, serving as tools, are catalysts that play an essential part in the chemical processes which promote the growth and development of the plant. In making our chemical analyses of plants, the former are plentiful - possibly quantitatively correlated with the soil's supply - and are readily measured with accuracy. The latter may have come - and gone - in only such small amounts which are called "trace elements".

Thus is seen the intricate pattern of life as it develops, - first through a process of chemicalization whereby carbon dioxide from the air and mineral nutrient elements from the soil are activated by energy from the sun and are thereby converted and stored as tissue-building and energy compounds in plants, then their subsequent conversion to a still higher form to become the tissue, blood, bone, sinew, and the special adornments of animal and human life.

The principle of life, whether microbe, plant or animal, is an eternal force of perfect, self-expressing, self-creating, self-supporting energy. Each form of life is limited to its own peculiar life cycle involving germination or conception, growth, reproduction, maturity and death. Barring accident, the only factor that can limit or prevent any form of life from completing its life cycle is starvation. Starvation may be caused from lack of sunshine and water, or it may be due to the absence of an otherwise adequate nutrient supply of a single one, or a combination, of the vital elements essential to plant and animal life.

When the pioneers first settled on our virgin soil, they found it firmly sewed to the earth by roots of trees and grass. When they cut down the forests and tore up the sod, this soil started down hill and has been going down ever since. This is because many of the essential plant food elements are not present in our soils in sufficient quantities to support annual crops indefinitely. Each harvested crop removes large quantities of these vital elements from the soil and, unless these elements are properly restored, soil depletion is the inevitable result.

It is high time that we give consideration to conserving and restoring the vital elements to our soil. The mineral resources of our soil may be compared to a bank account which dinimishes with each withdrawal until finally we will be faced by "overdraft".

SOIL AND PLANT RELATIONSHIPS

In all soil management, the important consideration is the relationship between the soil and the plants that grow on it. Most of these points of relationship have to do with the needs of the plant for water, oxygen, and nutrients (plant food), hence we speak of "soil and plant nutrition".

The soil as a whole is a mixture of solids, liquids and gases (air). By far the greater part of the solid portion (approximately 90 to 98%) of the soil is represented by the inorganic (mineral) matter derived from the decomposition of rock. The solid rock and mineral particles range in size from stones and gravel, through sand and silt to clay. The texture or "feel" of the soil is determined by the proportion of particles of these different sizes.

BUT NO SOIL CAN BE A TRUE SOIL WITHOUT ORGANIC MATTER. WHILE THE ORGANIC MATTER MAY REPRESENT AS LITTLE AS 1% OF THE TOTAL SOLID MATTER OF A SANDY SOIL TO AS MUCH AS 8 TO 10% OF THE SOLID MATTER OF A RICH SILT LOAM SOIL, ITS PRESENCE IN THE SOIL IS ESSENTIAL TO MAINTAIN PROPER MICROBIAL ACTIVITY. THIS ACTIVITY IS THE FORERUNNER AND ASSOCIATE OF THE ROOT ACTIVITIES OF PLANT GROWH. MICROBES ALWAYS EAT AT THE FIRST SITTING.

The living microscopic organisms that swarm in the soil, both fungi and bacteria, are the agencies that break down raw organic material into humus, and this again into simpler elements. They do this in the process of getting food for themselves and building up their own bodies. They in turn die by uncounted billions to further add to the soil's organic matter. Through this bacterial action, a favorable oxygen supply is maintained in the soil, and the productive capacity of the soil is, therefore, enhanced proportionately to the amount of organic matter supplied.

In general the fertility of virgin soils is associated with the continuous supply of organic matter which they receive from native vegetation, which is usually in balance with other factors. Since agricultural crops are generally removed instead of being left to decay, not enough raw material is added to the soil each year to maintain a natural balance. One result is a serious loss of nitrogen which is stored largely in the organic matter and released by decay. Another result is a serious change in the structure of the soil itself, which becomes less freely divided and compact as the amount of organic matter is decreased. Like nitrogen, the phosphorus and the sulfur are also stored in, and released by, decay of soil organic matter.

The first soil management problem, therefore, for any farmer to consider is that of maintaining the organic matter supply in his soil. Not only does the amount of organic matter decide the fertility level of his soil, but it also modifies the texture and structure of the soil itself. It is also important in regulating the "aliveness" of the soil through microbial action and regulates the water-holding capacity of the soil as well.

Return to the soil as much organic matter as you can in the way of manure, stalks, straw, stubble, etc. and practice green manuring wherever and whenever possible is the first recommended management practice.

ASIDE FROM THE GENERALLY IMPORTANT CONDITIONS CENTERED ABOUT THE SOIL ORGANIC MATTER, THERE ARE EIGHT PLANT FACTORS, NAMELY, (1) SEED, (2) LIGHT, (3) HEAT, (4) SOIL MOISTURE, (5) SOIL STRUCTURE, (6) SOIL AIR, (7) SOIL FERTILITY AND (8) ABSENCE OF HAZARDOUS SOIL CONDITIONS. THE FIRST THREE ARE MATTERS NOT SIGNIFICANTLY RELATED TO THE SOIL, BUT THE OTHERS CAN BE SIGNIFICANTLY MODIFIED BY SOIL MANAGEMENT PRACTICES.

AN ADEQUATE WATER SUPPLY

The moisture content of the soil is an important factor controlling failure or success in crop production. This means that all dry farming operations center around the water supply. If ten inches of rainfall are required for any crop, nine inches may mean total failure, twelve inches — or two inches over the minimum — may mean a normal crop, while fourteen — or four inches over the minimum — may give twice as much yield as twelve inches.

In "dry farming" the precipitation (rain and snow) is the sole source of water supply and the proper conservation of this valuable asset becomes of prime importance. The water-supplying capacity of the soil is governed largely by the texture and structure of the soil itself and the depth to the underlying water table. The seasonal total water supply by precipitation is a meteorological matter dependent upon the climatic conditions.

SOIL WATER

Soil water occurs in three forms, designated as hygroscopic, gravitational and capillary.

A. Hygroscopic soil water is that water which is chemically bound in the soil constituents and is not available to plants. It represents that approximate 10% moisture still present in the soil after it has been air-dried.

B. Gravitational water is that water which normally drains downward out of the pore spaces of the soil after a rain. If drainage is poor, it is this water which causes such soil to be soggy and unproductive.

C. Capillary water is the water which rises in the soil from the lower soil levels, possibly from the water table, much in the same way as kerosene rises in the wick to feed the flame of a kerosene lamp. It moves in any direction according to concentrations of water in the soil, hence moves toward the roots when they are lowering the concentration of water next to them. It is this water upon which plants must depend, principally, for their supply of moisture.

SOIL STRUCTURE MODIFIES SOIL TEXTURE AND SOIL CAPILLARITY

Because plants depend upon the capillary water in the soil as the principal source of moisture supply, it is important that the factors of soil structure and texture which contribute to the efficiency of the capillary action of the soil be developed and serve to the most efficient degree.

Medium textured loam and silt loam soils, because of their faster rate of movement of moisture downward during rainfall and later from lower depths to the root zone and the fact that they can bring up moisture from greater depths than either sand or clay soils, provide the best conditions of available, but not excessive, soil moisture for best results.

Low organic matter content and poor soil texture and structure are the limiting factors that reduce the efficiency of a soil's capillary capacity. The presence of a "plow sole compaction", dividing the subsoil and the top soil strata, is probably the most frequent obstruction found in soils to impede the normal movement of capillary water. This compaction layer, usually about one inch in thickness, is caused by the downward pressure of the plow when a soil is turned at the same depth year after year.

When such a compaction layer exists (usually found in the heavier, tight clay soils) the water from rains will soak into the ground only to the depth of this layer, with the remainder running off to be erosive. Because the surplus of water in such a soil cannot readily leach downward through the compaction layer, it leaves the soil soggy and un-aerated. At the same time in dry weather such a soil restricts the capillary water rising through this "compaction layer" and causes severe drought for the plants.

To correct a soil where the plow sole compaction layer (found in 50% of all samples tested) has become a limiting factor toward proper and efficient capillary action of a soil, several management practices may be employed to correct this condition, among them, subsoiling and the use of deep-rooted crops.

Any device whereby the compaction layer is broken up, permitting the gravitational water to move downward after a rain and permitting the capillary water to rise freely into the root zone in dry weather will make a great improvement in the soil's productive capacity. Many subsoiling devices are on the market and, when used intelligently, will represent an excellent investment. The use of a Graham-Hoeme Plow, just deep enough to break the compaction layer, has indicated doubling of crop yields in many cases. Subsoiling should be done when the ground is relatively dry. If done when the soil is wet, it often runs together again, producing little - if any - effect.

The use of such deep-rooted crops as sweet clover and alfalfa in the rotation will generally improve a soil's capillary capacity. This is because of their deep-rooted characteristics, often penetrating downward in the subsoil as much as three to ten feet. As their large and sturdy roots decay, the organic matter represented in these roots will serve as wicks for the capillary rise of water in the soil. Brome grass, which develops a very large and fibrous root system, sometimes penetrates as much as four feet and it, too, develops much organic matter in the soil and improves the soil structure as well.

Because water represents the most important mineral compound, physically and chemically, in the nutritional requirements of plants and animals, the provision of an ample water supply is of the greatest importance to a successful farming enterprise. Because of the very valuable services rendered by the U. S. Soil Conservation Service in assisting farmers with proper soil and water Conservation practices, we heartily recommend that you apply to your local County Soil Conservation Office for their services in assisting you in this most important engineering service.

THERE MUST BE ADEQUATE AERATION TO PERMIT THE DEVELOPMENT OF A GOOD ROOT SYSTEM AND AN ACTIVE MICROBIAL FLORA GIVEN TO OXIDATION OF MAINLY CARBON FOR ITS ENERGY.

Soil aeration is dependent largely upon the "tilth", that is, good structure, of the soil. The sizes and shapes of these structural groups, sometimes referred to as granules, and their resistance to breaking down in water make what is called the structure of the soil. Adequate areation and extensive root development come about because of good soil structure.

Sandy soils show little, if any, granulation due to the coarseness of their component particles. With soils containing a substantial percentage of clay, working them when wet results in destruction of the granular structure. Excessive tramping by livestock under like conditions is likely to have a similar effect. Sand soils are excessively aerated; clay soils are insufficiently so.

Alternate freezing and thawing, or wetting and drying, and penetration of the soil mass by plant roots are natural forces which favor the formation of soil particles or aggregates. Such aggregation is most highly developed in soils near neutrality in their reaction; both strongly acid and strongly alkaline soils tend to "run together" and lose their structural character. Tillage also tends to break down the structure of many soils.

Associated with both texture and structure is pore space, or porosity. These spaces may be large in the case of coarse, sandy soils or those with well developed granulation in silt loams. In heavy soils containing mostly finer clay particles, the pore spaces may be too small for plant roots or soil water to penetrate readily. Good farm soils have 40 to 60% of their bulk occupied with pore space, which may be filled with either water or air, neither of which can truly be said to be more important than the other.

Here, as in all other soil relationships, a satisfactory balance is important for productivity. Too much water slows the release of soil nitrogen, depletes mineral nutrients and otherwise hinders proper plant growth. Too much air speeds nitrogen release beyond the capacity of plants to utilize it and much of it is lost. The stored water in an over-aerated soil evaporates into the atmosphere and is lost to plants. Aeration, the exchange of soil air with atmosphere, capillary efficiency of water, microbial activities and other dynamics, by which the living soil is made productive, are improved by the good granular structure or good tilth of the soil. For this the decaying organic matter is a requisite.

THERE MUST BE A SUPPLY OF PLANT NUTRIENTS SUFFICIENT FOR PROFITABLE YIELDS.

Here proper soil management, guided by chemical tests, may be profoundly effective in ascertaining the true status of soil nutrients and in the practice of supplying them in such amounts as will correct the specific deficiencies to provide a balanced diet for crops of higher requirements and physiological complexities synthesizing products of higher nutritional values as feeds and foods.

Among the soil's deficiencies that affect productiveness, there is first that of organic matter in the broader nutritional values and activities of its unknown compounds serving directly and indirectly in plant nutrition. Then there are calcium (and magnesium), the alkaline earths, according to which soils are classified into the two major groups, the pedocals and the pedalfers, as partially and highly developed soils respectively according to varied geoclimatic settings. Ecologically these also represent producers or non-producers, respectively, of protein-rich, nitrogen-fixing leguminous vegetation by which soils have been built up in organic matter or are less so.

In soils with the organic matter in ample supply, the negative nutrient elements, or anions, namely nitrogen, sulfur and phosphorus, are usually better supplied and made more available by decay of that organic matter.

The positive nutrient elements, namely calcium, magnesium, potassium and sodium are held by the clay surface adsorption and retention within the different chemical structures of the different clays in varied geo-climatic settings. Those retained nutrient cations are, nevertheless, exchangeable to the plant roots for other cations, among which hydrogen is the most active one.

The trace elements, namely manganese, iron, copper, and zinc as cations and boron and molybdenum as anions, and possibly others, may fit also into the above behaviors as deficiencies via the organic matter or the clay.

Management of these nutrient essentials as elements or as compounds is the major control via the soil of crop production in respect to both quantity and quality in nutritional values to man and his livestock.

THE SOIL MUST BE FREE FROM UNFAVORABLE CHEMICAL CONDITIONS, SUCH AS EXCESSIVE ACIDITY OR ALKALINITY, HARMFUL CONCENTRATIONS OF SALTS OR EXCESS OF CERTAIN ELEMENTS OR COMPOUNDS THAT CREATE UNBALANCED CONDITIONS FOR PLANTS.

Equally important as the organic matter supply, the water supply, the efficiency of soil aeration and the adequacy of nutrient elements in a soil there is the proper chemical balance of the soil. A soil that is over-saturated with the cationic elements, such as lime (100% Base Saturation at pH 7.00 and over) so that there is no active hydrogen in the soil, is undesirable as most plant nutrients function best when the soil is slightly acid, showing about 10% hydrogen saturation. In the complete absence of hydrogen, the availability to plants for such elements as phosphorus, manganese, iron, copper, zinc, boron and possibly others is severely restricted.

Similarly, when the hydrogen saturation in a soil exceeds 20% of its Total Exchange Capacity, it represents just that much inactive or un-used nutritive capacity. Besides, the excessive hydrogen saturation may severely restrict the proper growth of many crops because of the increased acid condition and thereby increased nutrient deficiencies that it promotes in the soil. The degree of acidity or alkalinity of a soil may be determined by its pH value and for best balance for the majority of crops grown a pH range between 6.0 and 6.5 has been found to be the most efficient. That pH is the result of proper balance of nutrient cations, among which the cation hydrogen from the soil is not included.

Similarly, when soils with poor leaching qualities such as the tight clay soils, or soils with a heavy plow sole compaction layer become over-saturated with such acid salts as sulphates and chlorides (which accumulate from heavy fertilized applications) the root development of many plants in such soils becomes severely affected.

The matter of a balanced chemical condition for your soils is, therefore, carefully studied and reported together with recommendations for their correction in your soils report.