

Organic Matter - the energy of life in the soil

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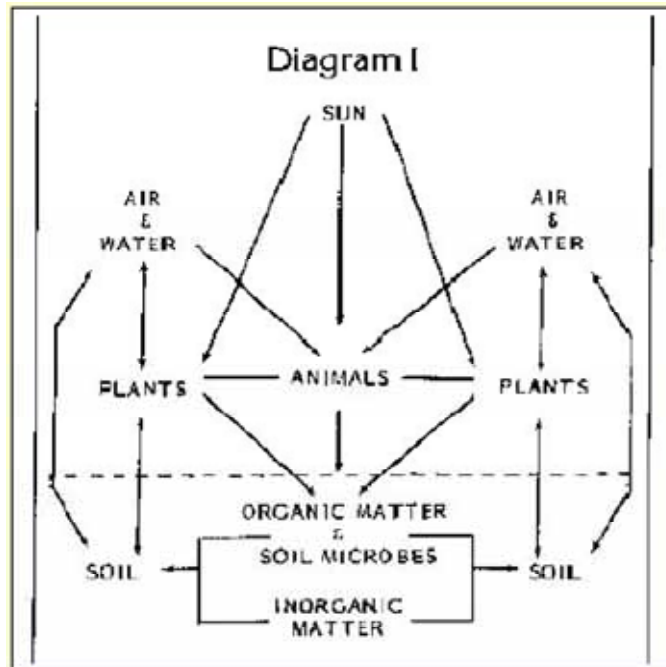
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The seeds of every great civilization have been sown in the soil. So have the seeds of their destruction-- and our industrial civilization is no exception. In many regions today's farmers are faced with soil erosion rates higher than the Dust Bowl era of the 1930's. Our survival depends on a new understanding of soils, a task which must be shared by all of us whether we cultivate a farm, a tiny patch of urban earth, or no land at all. In this essay I review the sources of sustained fertility, discuss techniques for fertility management, and describe my own experiences in managing a mixed orchard and vegetable farm in Eastern Washington.

SOIL ORGANIC MATTER

The key to soil fertility is neither an idea nor a philosophy. The key is soil organic matter, a physical substance we can see, smell, and touch. In soil organic matter we find both the why and the how of soil regeneration, both the light and the roadmap that can lead us towards an abundant future rather than the last chapter in a history book. Like all living organisms, soils need food and energy to grow and function. Organic matter in the soil is a primary source of that food and energy .



What exactly is soil organic matter? It may be plant tissue, animal tissue, or microorganisms. In an average soil with 6% organic matter, about 85 to 90% of the organic matter is in non-living plant and animal residues, 5% to 10% is in living roots, and the rest is comprised of both dead and living microorganisms including bacteria, fungi, and molds. The common factor is always the same. The material either still is or used to be part of a vibrant, living organism. The majority of the plant and animal tissues that comprise soil organic matter are no longer part of a functioning

organism, but they still carry much of the energy of life within their structure. As the organisms decompose from an organic (or living) to an inorganic (or non-living) state, the energy of life is slowly released. This whisper of life determines whether a soil will pulse with the force of creation or lie cold, hard, and inanimate. In the planetary cycle of life, soil organic matter is as important as water, sun, air, and plants.

LIFE IN THE SOIL

Because soils play such an active role in the life cycle, it is important to think of them as alive. A quick review of the major life processes is therefore in order. Animals get energy from the foods they eat. Their bodies break down complex plant and animal tissues first through the process of digestion, and then through the process of respiration. Digestion is made possible by enzymes which transform complex, insoluble organic matter into soluble forms. These soluble forms can be either assimilated into cells or respired. Respiration, like birth and death, is common to all living organisms. In respiration oxygen reacts with the components of sugar to form water and carbon dioxide. Of primary importance is the fact that this reaction releases energy. Respiration is how plants and animals get the energy to maintain all life processes. But where does the energy come from in the first place? The energy to sustain our bodies comes from the sun through the process of photosynthesis.

In the presence of sunlight and chlorophyll, plants combine water and carbon dioxide through photosynthesis to form sugar. Chemically speaking, this process is exactly the opposite of respiration. The main ingredients are the same, but photosynthesis stores energy while respiration releases it. The sugar that results from photosynthesis is later used by plants in the bio-chemical synthesis of more complex foods like carbohydrates and proteins. These foods are synthesized by plants with elements from the soil and the air. But the ingredients do not become food until they are combined with the energy of the sun. Only plants can perform the miracle that transforms the energy of the sun into plant tissue. Animals cannot create any basic foods. While both animals and plants respire (break down food to get energy), only plants can photosynthesize (capture energy and create food).

SOIL BUILDING

The process of soil building may be compared in some ways to the building of animal tissue. Like plants and animals, soils also "are what they eat" (or what we feed them), and without food they literally grow weak from malnutrition or starve to death. In soils, organic and inorganic matter are both decomposed through a digestive process made possible by soil microorganisms. The microorganisms produce enzymes which digest organic matter and release a wide variety of elemental minerals such as calcium, phosphorus, sulphur, and nitrogen in soluble forms. The end products of the decomposition of organic matter are exactly the raw materials plants need to synthesize food. Even more significant, however, is the fact that this process releases energy originally received from the sun.

The energy released from organic matter is important because it feeds the billions of microorganisms contained in each teaspoonful of living soil. These organisms are such an integral factor in soil processes that they can be best regarded as an "organ" of the soil rather than as separate entities. This further emphasizes that healthy soils should be thought of as not only fertile, but alive. The energy flow now becomes more clear. Plants transform the sun's energy into food, and organic matter is the vehicle which transfers this energy to soils. Soil microorganisms live off some of this energy, but they also release more of it for reuse-- first by plants and then by animals. In the process, soil is continually regenerated by plants in order to sustain plant life. The system is self-supporting. If there is a weakness, it is the presence of the human animal that takes more than it gives and constantly tries to improve the efficiency and productivity of an already highly organized, productive, yet seemingly effortless natural system.

INORGANIC SOIL CYCLE

The inorganic soil cycle starts with the rock and parent material of soils.

oxidation. Many bacteria are also critical to the mineralization of plant and animal tissue, and to the release of carbon dioxide. It has been proven that the layer of air above a soil high in organic matter has a richer concentration of carbon dioxide than the air over a soil low in organic matter. Plants require the carbon dioxide for photosynthesis, so the organic matter content of soils can actually affect the rate of photosynthesis of plants. Actinomycetes are similar to bacteria. They are especially important to the decay process and in the formation of various antibiotics. The many antibiotics, hormones, and enzymes produced by soil microbes are important examples of natural products not available in a bag of synthetic fertilizer. Each has a specific purpose, but antibiotics in general inhibit the spread of pathogenic microorganisms in soils.

Without organic matter as a source of carbon, nitrogen, sulphur, and energy, most species of soil microorganisms all but disappear from the soil. At concentrations of up to 1,000 pounds per acre-foot, the bodies of these constantly dying, recycled organisms can account for as much as 3% of the actual soil organic matter. Like other living organisms, soil microorganisms require oxygen, moisture, warmth, and a source of food. The loss of any one component can cause alterations in the entire soil system. For instance, if oxygen is not present in soil, desirable microbial activities don't simply stop, they proceed in a very undesirable fashion. In anaerobic conditions (without oxygen), different kinds of microbes take over and begin a process of putrefaction and fermentation rather than decay. The result of putrefaction may include noxious gases and products toxic to plants such as hydrogen sulfide, methane, various alcohols, and more highly concentrated organic acids. Under the proper conditions a series of reductions occurs in the organic soil cycle that can be generally described as follows. Fungi often initiate the first stage as organic matter is decomposed into nonhumic substances like proteins, carbohydrates, lignins, fats, waxes, resins, pigments, and tannins. As soil microbes consume portions of these nonhumic substances for food and energy, further decomposition yields simpler compounds. The final products of decomposition are humic acids and humic bases. From this stage on the reactions are primarily chemical rather than biological. In chemistry, an acid plus a base yields a salt. Salts can be dissolved in water or in the soil solution. When salts dissolve, the positive and negative charges bonding the individual elements are broken, and the charged (or ionized) elements are freed in solution. These ionized elements and more complex organic compounds are the nutrients that plants are able to remove from the soil solution and utilize. The primary humic salts derived from soil organic matter include various nitrate, sulphate, and phosphate forms of salt. Soil organic matter thus serves as the source for nearly all plant nitrogen and sulphur, plus about one-third of all phosphorus. The salts that result from both the organic and inorganic soil cycles are not particularly stable. Like synthetic fertilizers, they are in a highly soluble form. Once in the soil these salts dissolve after contacting moisture, and elemental nutrients become immediately available. If plants cannot utilize them at once, one of two things is likely to happen. The ionized particles are either leached out of the soil (especially by rain or irrigation), or they precipitate or solidify into forms unavailable to plants. Precipitation occurs especially when the soil solution has reached the saturation point and cannot dissolve any more salts (i.e. over-fertilization). This is why overfertilization with highly water soluble materials can be harmful to plants. Just like animals, plants need a steady diet of balanced nutrients. When too rich a diet is provided they get sick.

This also explains why the majority of highly water soluble fertilizers applied to soils are simply wasted. Plants cannot possibly get all the nitrogen they need for the year from a quick shot in the spring or fall. More than half the synthetic fertilizer applied by American farmers leaches into water tables and streams, or feeds weeds and grasses rather than the intended crop. Some natural fertilizers, such as highly water-soluble Chilean nitrate of soda, also fall into this category.

HUMUS AS A NUTRIENT RESERVOIR

The storage capacity of soil is in its humus, the stable portion left behind after initial decomposition has altered organic matter beyond recognition as plant or animal tissue. Humus involves both states B and C in **Diagram III**. Both are always present in soils with organic matter and stage B is always decomposing into stage C. About two-thirds of most kinds of organic matter (especially green manure crops) decompose within a matter of weeks into water, carbon dioxide, energy, and other by-products. The remaining one-third constitutes the more stable humus which may remain in soils for years, with more resistant forms such as lignin remaining

for over 100 years. It is humus that may hold large quantities of water, nitrogen, sulphur, and phosphorus in reserve in soils, releasing them gradually over many years. Stable humus is considered more or less permanent, and may combine with many soil minerals. With sufficient organic matter added to soils each year, only minimal amounts of nitrogen, sulphur, and phosphorus fertilizers may ever be needed, depending of course on the particular crop and soil. Part of the storage capacity of humus is due to its ability to act as an organic colloid in the soil. A colloid is a collection of particles too small to remain in suspension and too large to be dissolved. All the particles in the colloid have an electrical charge and they may attract other charged particles like sulphates or nitrates, or ionized elements like calcium, binding them in storage until some further action weakens the bond and releases them in the soil solution. Most soil colloids are composed of clay particles. Organic colloids can be increased through addition of organic matter. Organic colloids have greater Cation Exchange Capacity (ability to store positively charged nutrients) than clay colloids, up to 100 times as much per equal weight. When soil organic matter drops below 2%, the organic soil cycle in Diagram III can function only minimally. The inorganic cycle also suffers. Even as minerals are made available through the inorganic cycle, if organic matter is low they are more liable to be leached from the soil or bonded in unavailable compounds before plants can use them. The result is that plants have to work harder to find nutrients and farmers have to invest more time and dollars in crop production.

THE LOSS OF SOIL FERTILITY

Without an active organic soil cycle soils are unable to regenerate themselves. Under the very best of conditions it takes about 30 years for nature to create an inch of topsoil. That's 150 years to build the minimum 5 inches necessary for most agriculture. Yet in half the cropland in America, topsoil is being lost faster than it can possibly be replaced. In some areas, like the Palouse wheat district of Washington and Idaho, it is being lost at a rate 5 to 10 times faster. This translates into the staggering equivalent of 20 pounds of lost topsoil for every pound of wheat produced. Loss of soil is one thing. Loss of soil fertility (or life potential) is more difficult to measure. Lifeless soils may still serve as a medium for plant growth, but without the spark of life provided by organic matter to fuel basic soil and life processes, food crops must be fed

artificially with synthetic fertilizers to maintain any semblance of health. The vital presence of soil organic matter determines whether a commercial farming operation will be at least partially self-sustaining or totally dependent on the importation of nutrients to maintain plant growth. If farmers rely heavily on synthetic fertilizers without also supplying adequate amounts of organic matter, soil microbes die and disappear. The more lifeless the soil becomes, the more the farmer is required to import synthetic fertilizer. These imported nutrient sources are sometimes necessary in commercial crop production, but agricultural systems with non-functional soils are subject to rapid decline and failure if fertilizers become unavailable even for a single season, or if they are supplied in the wrong amount. The difference between the natural and artificial systems may seem slight at first, and many consider synthetic fertilizers a perfectly sound substitute, but consider the difference between a natural lake containing fish and a large aquarium in which fish are raised. One system is self-supporting. The other depends on artificial energy sources-- imported food for the fish and a pump to circulate and clean the water. Both work, but the second system is more expensive to maintain and more subject to failure by something as simple as a loss of electricity.

THE PRESENT CRISIS

Farmers are in the midst of crisis, but if you eat three meals a day it's your crisis too. Our modern agricultural system is weak in many ways because of its dependence on non-agricultural factors. For instance, food is still grown in soil, but the major nutrients come from fertilizer factories rather than from the soil. The most common synthetic fertilizer is nitrogen, which depends on the natural gas industry for production. This was once a cheap source of nitrogen, about 5 cents per pound. Now that natural gas is being deregulated, the present price of nitrogen (about 15 cents per pound) should skyrocket. At the present time the energy equivalent of 100 million barrels of oil are used each year to produce synthetic nitrogen. In a sense we have chosen to ignore a cheap and inexhaustible supply of nitrogen from decaying plant material, opting instead for dependence on fossil fuels. The March/April, 1982 edition of High Technology magazine quoted Richard Rortvedt of the USDA as saying that crops can't get enough nitrogen

from decaying plant material left by the rotation of nitrogen-fixing crops such as soybeans. "Rotation is an aid but not a replacement for commercial fertilizers," he said. As with many USDA policies, the statement is backwards. Commercial fertilizers should be an aid but not a replacement for crop rotations and the maintenance of soil organic matter. In contrast, Robert Rodale has said, "Farms and farmers should be (natural) energy collectors." If we visualize plant communities as natural "factories" manufacturing food with the free and powerful energy of sunlight and the mineral and biological resources of soil, we can understand Rodale's statement. Too many modern farmers are forcing higher production mainly by increasing their energy input with imported sources of artificial energy. Unfortunately, the artificial energy sources are finite and non-renewable. Meanwhile the soil system is being taxed beyond its limit. Soils are exhausted until only artificial energy "fixes" can keep them going. The fertilizer industry could be described as a highly profitable network of agricultural drug dealers whose profit motive seems to justify exploitation of biological communities. There is no harmony, no mutual benefit, no pleasure or reward, and no sustainability in this system. The benefit of temporarily increased food production is truly insignificant in light of the systematic destruction of North America's best farmland. Since we depend on that farmland for survival, the continuance of our present philosophy can only ensure our eventual self-destruction.

Yet the fertilizer syndrome describes only one of many weaknesses in our agricultural system. The "heart" of modern agriculture is actually in the hands of the banking and lending institutions rather than in the cycle of life on this planet. Credit is the life blood, and "credit attacks" are now a major cause of death for both family and large corporate farms. The legs of our agriculture are in the transportation system, which is subject to fuel shortages and strikes. The muscle is in the manufacturing industry where heavy equipment is turned out in increasing size at incredibly increasing cost. The machinery makes agriculture dependent on the steel industry, the rubber industry, the automotive industry, and the synthetic plastics industry. And finally, we find that agriculture's loudest voice in North America is unfortunately the mass media advertisers who care more about selling food than about growing it or maintaining farmland. From the perspective of soil organic matter, modern agriculture will soon find itself without a foot to stand on, for the feet of agriculture are the soils themselves. Without organic matter in their soils farmers are walking on air, suspended by strings controlled by the natural gas and fertilizer industries. In time of crisis there can be no path of retreat. The only escape lies through a doorway American farmers have spent the last 40 years bricking up in the form of lifeless, compacted soils.

THE TURNING POINT

After a time of decay comes the turning point. The powerful light that has been banished returns.
I Ching

As farmers and gardeners we have the ability to respond to the crisis in agriculture and effect change. This responsibility begins on our own little piece of ground, wherever there is room to tuck a seed in the soil and nurture it. It begins with soil organic matter. Most soils in arid regions of the western United States are naturally low in organic matter. Content usually varies between .5 and 1.5%, and they are termed mineral soils for this reason. They are often light colored, sandy loams. Generally the higher the organic matter, the darker the soil. The low organic matter content in the soils of the Intermountain West is simply a result of the arid, semi-desert climate which supports relatively little natural plant growth compared, for example, with a temperate zone forest or a rainforest. Minimum plant growth means minimum organic matter, which is why cropped soils should never be left bare for long periods. To insure sufficient soil organic matter levels, plants must be growing and dying simultaneously and continuously. When our western soils are cropped, the existing organic matter may be depleted within a matter of years. Such soils are nearly always deficient in nitrogen, perhaps sulphur, and possibly phosphorus. But because our soils are young (geologically speaking) and were formed through glacial and volcanic action, they are generally high in minerals, especially potassium, and often in trace elements like magnesium. The amount of these major and minor elements will vary considerably from one location to the next. Continued cropping of soils will also deplete their mineral content. Total depletion never occurs because the mineral portion of the soil always has a high reserve in the natural rocks. The reserve, however, may not be readily available. The decomposition of rock occurs only slowly, and the benefits are minimal when organic matter is neither present to aid in

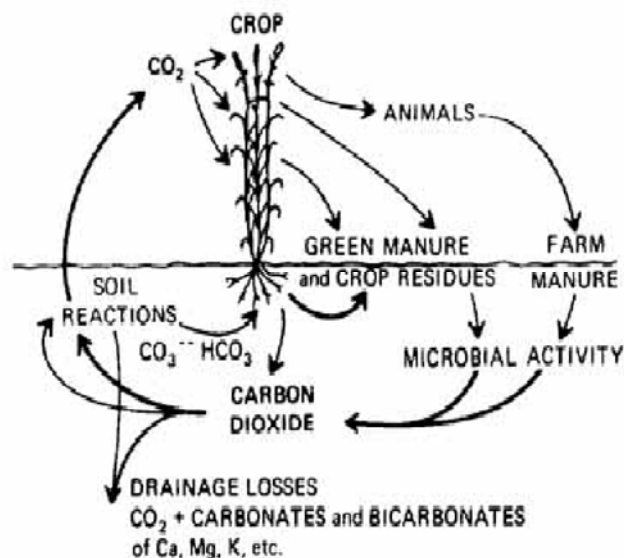
decomposition nor to store the final product. Organic matter is not difficult to accumulate and maintain in soils as long as rainfall can be supplemented with at least some irrigation. The less water available, the harder the chore. (Maritime farmers and gardeners may actually have to worry about their soils remaining too wet. Organic matter cannot decay properly in wet, compacted soils that exclude oxygen.) A minimum content of 2 to 3% organic matter is necessary before soils can begin to benefit from it. An increase to 5% will often double the cation exchange capacity of the soil. A "cation" is a positively charged particle (i.e. an ion of calcium or potassium), and cation exchange capacity (CEC) is the ability of soils to store positively charged ions. As CEC increases, some soil testing companies will actually report your soil has changed from a sandy loam to a loam. In reality, you cannot change a soil type but, by increasing soil organic matter, you can make it function as if it were a different soil.

TECHNIQUES FOR INCREASING ORGANIC MATTER

Green manures-- crops which are turned back into the soil for increased organic matter-- are an excellent means of building fertility. In my own orchard in north central Washington I raised the soil organic matter level from .8 to 5% in just three years by growing two annual green manure crops of buckwheat and one annual crop of winter rye. Part of the rapid increase is also attributable to the incorporation into the soil of the many years accumulation of surface thatch beneath the trees. Buckwheat, which has been an important part of my green manure program, is a broad-leafed member of the dock family. Like most broad-leafed annuals it loves heat and is very sensitive to frost. The plants will begin flowering only 40 to 60 days after seeding, at which point they should be turned into the soil and reseeded in 2 to 4 weeks. Soil moisture and warmth are required for the proper decay of plant residues even when green and lush. If reseeded too early, the young buckwheat plants will compete with the microorganisms for nutrients (especially nitrogen) involved in the decay process. Microorganisms always eat first. Plants get the leftovers. Buckwheat is deep rooted and, if irrigated, will grow quickly on even the poorest of soils. Its roots penetrate hardpans and, like alfalfa, buckwheat is good at bringing calcium, potassium, and phosphorus up into the topsoil. Four buckwheat crops in two years doubled the available calcium and significantly raised the level of potassium and other nutrients in my topsoil. The one disadvantage of buckwheat is that land must be taken out of production for part of the season. Unlike buckwheat, winter rye is a crop that can be seeded in late fall and then turned under the following spring while it is still lush and green, before main crops are planted. Winter wheat or even spring barley may also be used in this manner. Annual ryegrass is an excellent green manure for use in orchards in early spring or late fall. When spring planted, it can be mowed through the summer to stimulate growth, left as a cover over winter, and then turned under early next spring. (Note, however, that in some areas of the country annual ryegrass is also considered a noxious weed because it goes to seed before removal of the cash crop it infests. This is especially true of grain and seed crops.) With the exception of buckwheat, the crops I have mentioned are very hardy. Other good green manures include legumes (nitrogen fixers) like alfalfa, clover, peas, and soybeans. The alfalfas and clovers are best suited to semi-permanent pastures since they require the first year just to get established. Annuals like soybeans and field peas are best for quick crops. It is critical to incorporate green manures into the soil while they are still lush and green. If they pass the flowering stage and begin to produce seed, if the grain begins to head out, or if the plant begins to turn brown, dry, and brittle, then the carbon to nitrogen ratio is too high to be an effective green manure. Such crops have up to 80 times as much carbon as nitrogen and will actually steal nitrogen from soils while they decompose. Corn, for example, provides a great deal of organic matter, but its carbon content is so high it needs the addition of a nitrogen fertilizer or manure as it is turned into the soil to insure decay. Soil organic matter may also be increased by the time honored methods of hauling manures, composts, leaves, etc. The hauling method is time consuming and energy expensive, often requiring a truck, a loader, and a spreader to handle large acreages. The method is ideal for gardeners and small truck farmers, but it is less practical for many commercial growers whose soils have the capability to provide their own organic matter when properly managed. A new method being experimented with is the concept of living mulch. In this approach, green manures are actually grown at the same time as cash crops, thus serving as a mulch and later as organic matter. The key is to use low growing, mat-forming plants such as white clover. If they are seeded 4 to 6 weeks after the cash crop they won't reach the stage of most rapid growth until the cash crop is already maturing. Competition is therefore minimal, yet weeds are controlled without the cultivation which leaves bare the majority of soil in row crop production. A final method for increasing soil organic matter is to rotate land between annual crops and 2 or 3 years of semi-

permanent pasture seeded with a mixture of grasses and legumes. Seeding a sod cover, in fact, is the best way to increase the soil's organic matter content because sod provides a root system that is much more dense than annual crops, and because plant roots rather than tops always provide the bulk of organic matter. The bulky mass of sod also means decomposition will take longer. (Some grasses also encourage nematode problems, however, so sods must always be incorporated into soils well in advance of the seeding of annual crops.) Between the rows of trees in my own orchard I have planted vegetables in a 5 year rotation that includes 2 years of a grass and clover sod followed by 3 years of annual crops. Each vegetable is also followed by a green manure to maintain organic matter. An early season crop may actually be followed by both a late summer and an overwintering green manure. This ensures that more raw material is being added to the soil than is being annually harvested. The strips between the tree rows and the cropped middles are left in a grass and clover sod that is mowed regularly and incorporated into the soil every 3 to 5 years. From the air one would see a grid pattern of alternating strips of trees, sod, and vegetables. This system obviously requires management but it also works wonders, proving that maximum production potential and maintenance of organic matter levels are not incompatible goals.

The Carbon Cycle



Carbon, regardless of the various other elements that may be present, is the characteristic and omnipresent constituent of all organic matter. As a consequence, its movements during the microbial digestion of plant tissue are extremely significant. Most of the energy acquired by the fauna and flora within the soil comes from the oxidation of carbon and, as a result, its oxide is evolved

continuously and in large amounts. The various changes that this element undergoes within and without the soil are called the carbon cycle and are shown graphically (above).

In all soil, higher plants furnish most of the various carbonaceous materials for microbial dissolution. As these are digested, carbon dioxide is given off. This is the main soil source of this gas, although small amounts are excreted by plant roots and are brought down in rain water. The carbon dioxide of the soil, evolved both in summer and winter, escapes in large degree to the atmosphere, where it may be used by plants and thus completes the cycle.

A lesser amount of carbon dioxide, and this is just as important a feature as the atmospheric loss, reacts in the soil, producing carbonic acid, and the carbonates and bicarbonates of calcium, potassium, magnesium, and other elements. These salts are readily soluble and may be lost in drainage or be used by higher plants. Thus, not only are Ca, Mg, and K ions present to the absorbing surfaces of microorganisms and higher plants, but CO_3 and HCO_3 ions are made available as well. Small amounts of carbon may, therefore, enter plants in this way. Most of the carbon, however, is acquired by photosynthesis.

SUMMARY

Soil systems are complex, and the unavailability of any one nutrient necessary for plant growth can cause failure of a food crop. Still, we can state a general rule that the energy and dollars farmers spend to raise crops are inversely proportional to their soil's organic matter content. There is an upper limit (somewhere) but, particularly for most western soils in arid regions, it can be said that as soil organic matter goes down, energy expenditures go up. The mere presence of organic matter alone cannot guarantee that any of the many "desirable events" necessary to make nutrients available will take place, especially in commercially cropped soils. That depends on the cultural practices and timing of a skillful caretaker of the soil. But in the absence of sufficient soil organic matter many of these events cannot possibly take place. A potentially good farmer without sufficient soil organic matter is a little like a bird without wings. No amount of determined struggling can free the grower from the inevitable laws of nature. Food is energy, the same stuff that both we and the stars are made of. Just as we must continue to feed ourselves, we must remember to feed the soil.