Soil Organic Matter
The Key to Soil Fertility and Health

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When farmers gather, talk revolves around fertilizers, weed control techniques, and new crop varieties. Tractor model numbers roll off tongues like honeyed barbed wire, the subtle oneupmanship of horsepower. Assertively they compare yields and markets. However, lurking in the background, shrouded in mystery and ignorance, dwells a dark stranger. Mention soil science and the crowd quickly loses interest. Few farmers would willingly admit that the soil beneath their feet is a mysterious and intimidating substance, that chemistry was something they once eagerly forgot and microbiology is a word they'd rather not have to define. To most, the soil is an antagonist that must be brought under control, an inanimate material to be tilled, fertilized, drained, irrigated, and otherwise molded to suit the farmer's needs. Sustainable farmers need to understand the soil instead as a living dynamic system; they must treat soil as a partner, not as an adversary.

Dr. Fred Magdoff, professor of soil science at the University of Vermont, brings a fresh perspective to agricultural productivity. He challenges his listeners to reorganize their thoughts and priorities concerning crop growth and soil management. Magdoff considers organic matter as truly the key to soil fertility and health. Soil quality is the result of complex chemical and microbiological interactions made possible by healthy and active organic matter. Not many farmers know the percentage of organic matter in their soil and fewer still credit it as a major factor in crop productivity, as a potent protection against pathogens, and as absolutely essential to the maintenance of good soil structure. This is not a new concept. An agricultural bulletin published nearly 100 years ago stated that "worn out" soils with reduced productivity result from organic matter loss, a perception that has been largely neglected by scientists and farmers in recent times.

Soil organic matter usually ranges from 1-6% of the soil volume weight. Soil that is farmed with little concern to increasing organic content can quickly lose much of this important component, thereby greatly reducing potential productivity. To understand the important role of organic matter in soil, Magdoff stresses that we must first identify the material correctly. Organic matter comes in three basic forms - the living, the dead, and the very dead:

First, there is the 'living' organic matter which includes the live plant roots, microbes, earthworms, nematodes and other tiny animals. Soil can contain an amazingly diverse population of different species of living organisms. Too often people assume that nematodes and microbes are harmful. There are probably well over 100,000 species of nematodes alone. Most of these nematode species are beneficial, helping to recycle nutrients from decaying organic matter, serving as food for larger organisms, and keeping the populations of pathogenic microbes in check. Only a relatively small number species of nematodes are parasitic on plants. Earthworms are invaluable to soil structure as they burrow through the soil, providing channels for water movement and root growth and releasing nutrients in a more available form for crop growth.

Second, there is the 'dead' organic matter. This is the active particulate organic material, fragments of decaying stems, roots, fungal hyphae, dead animals and microbes. In a healthy soil, this component is quite a mixture, coming from many different sources. Active organic material provides nutrition for a diverse population of fungi, bacteria, plants and other organisms.

Third, there is the 'very dead' organic matter. As amusing as this concept may seem, it is important to differentiate between the actively decomposing organic matter, the second group, and the well decomposed humus, this third group. Humus particles are very small and dark. They are relatively stable over a long period of time. Humus is not major direct source of available plant nutrients, as it continues to break down very slowly. However, because humus carries a high cation exchange capacity, it helps hold essential nutrients for plant root absorption. Humus also is important in maintaining healthy soil aggregation. Well decomposed humus may account for between 60-80% of the total soil organic matter.

Soil organic matter in its three forms has a profound effect on almost everything that goes on in the soil and on the soil's ability to grow healthy plants. Some of these effects are:

1. Soil organic matter, especially that which is actively decomposing, is a tremendous source of nutrients for growing plants. As dead plants, animals and other soil organisms decompose, many of the mineral ions that had once composed their structure are released. Organic matter will also chelate certain elements, such as zinc, and then hold those elements in an stable available form for plant root absorption.

Once mineral ions are released, a second critical role of organic matter comes into play. Free ions not held securely by electrical attraction to soil particles will often be removed by leaching and erosion. Many essential ions, such as potassium and calcium, carry a positive charge. Humus, actively decomposing organic matter and clay particles usually carry a negative charge. Electrical attraction between cations and particles results, holding the cations securely in the plant rooting zone and available for plant absorption. The ability to hold and release positively charged cations is known as the 'cation exchange capacity' or the CEC of the soil. In soils low in clay, such as sands and sandy loams, much of the soil's CEC is due to negatively charged organic particles.

2. Soil organic matter increases biological diversity in the soil. Beneath our feet, almost entirely unseen and still poorly understood, there is a thriving complex food web of many different types of organisms in the soil. From the most humble bacteria to the more sophisticated earthworm, each member of the web plays a critical role. A diverse population of organisms establish competitive barriers that hold the population of any one species in check, preventing that species from increasing greatly in number. This can provide a very high level of biological control against the growth of most pest populations.

The surface of most plant roots are colonized by a layer of beneficial fungi called mycorrhizae. Mycorrhizae are very important for plant root water and mineral absorption by greatly increasing the effective rhizosphere (rooting zone) area. Availability of phosphorus is largely dependent on mycorrhizal and other microbial activity that converts phosphorus to a form that the plant roots can absorb. The mycorrhizal layer also presents an effective barrier around root tissue that pathogenic fungi and bacteria often can not penetrate. By feeding all these organisms a varied diet of different types of organic materials, biological diversity will be enhanced and crop growth will improve.

In a healthy soil high in organic matter, earthworms will be plentiful. Worm channels and old root channels will increase water infiltration and facilitate new root growth.

3. Soil organic matter improves soil tilth or structure. In a healthy soil, mineral and organic particles will form clumps or 'aggregates'. These aggregates fit together in such a way that provides channels for root growth and water infiltration. Good aggregate stability also resists the formation of compacted layers and crusted surfaces. When a damaged soil gets wet, small silt or clay soil particles can flow together, creating layers that are impermeable to water and roots. When rain causes surface aggregates to break down a crust may form and seedlings may have difficulty emerging, water may not be able to infiltrate the soil, and erosion by water run-off may rob the soil. Mycorrhizae on plant roots secrete a mucus-like substance called glomalin which helps to form aggregates and increases aggregate stability.

4. Soil organic matter can stimulate plant rooting. There are certain chemicals produced by soil microorganisms that have hormonal-type effects on plant roots. These chemicals are similar chemically to plant hormones and have comparable growth stimulant effects. Many such materials are derived from humic acid, a product of decomposition. This concept, that has been advanced by alternative agriculture proponents for years, is now being supported by recent scientific research.

Research at the University of Maryland has also shown that increasing soil organic matter can increase crop yield. An experiment showed that corn increased in yield about 80 bu/acre for every 1% increase in soil organic matter.

5.Soil organic matter stabilizes the chemical composition of soil. A soil rich in organic matter is well buffered and therefore resists rapid chemical changes, especially changes in pH. This can be both an advantage and a disadvantage. A high organic soil will require more lime to cause the same pH change, but once a favorable pH is achieved, it will change less rapidly. Organic matter can also sequester harmful materials in forms that are not damaging to plants. Aluminum toxicity is much less of a problem in low pH soils that are also high in organic matter, and if toxic chemicals enter the system, they will be more rapidly decomposed by the mixed population of microorganisms.

6. Soil organic matter also darkens the soil, which can help to warm the soil earlier in the spring.

7. Soil organic matter plays a critical role in the natural cycling of chemical elements. Organic matter can hold and store excess carbon, and therefore it is not released into the atmosphere as carbon dioxide, a potent 'greenhouse gas'. The amount of carbon in soils is three times that of the earth's atmosphere. The top 6 inches of a field with 1% organic matter will store more carbon that would be found in the entire atmosphere above that field. As the atmosphere becomes increasingly contaminated with greenhouse gases, it may become ecologically important to store as much carbon as possible in soil.

The vast majority of nitrogen in the environment is in the form of nitrogen gas, a substance that plants can not absorb. Nitrogen gas is made available to plants only by a relatively small number of soil bacteria. The normal cycling of nitrogen in a soil relies on a healthy microbial population capable of converting nitrogen gas into ionic forms that plant roots will absorb. The cycling of most other nutrients relies on a mixed soil microbial population, the soil chemical composition and a high enough CEC to hold ions until needed by plant roots.

Magdoff stresses that while all these beneficial effects are possible by increasing soil organic matter, the diversity in the different types of microorganisms and the variety of the different types of organic matter are also of critical importance. Feeding the soil a variety of organic materials promotes biological diversity. Interactions between plants, soils, weeds, and insects and other organisms are complex and largely not well understood. Recent research on ecological pest control has shown some pretty amazing results concerning the effect of soil health and pest populations. Dr. Joe Lewis of the USDA Agricultural Research Service Station in Tifton, GA demonstrated that when an insect feeds on some plants, the plant is stimulated by the insect saliva to produce specific volatile compounds. These chemicals serve as attractants for predators of that particular type of insect. Soil conditions seem to have a profound influence the amount of volatile chemicals that a plant will produce. If the plant is not healthy, especially if the plant is growing without optimal nitrogen, fewer volatile compounds will be produced. Dr. Larry Phalen at Ohio State University experimented by growing sweet corn in the greenhouse in soils from organic growers and soils from conventional growers. High populations of European corn borer moths were released onto the plants. Phalen was able to document that the moths preferred to lay eggs on corn growing in conventional soils. While it is not clear exactly what components in organic soil are providing such protective effects, it is probable that organic matter quality and level are critical.

Soil organic matter management presents a dilemma. Organic matter must decompose in order to provide maximum benefits in nutrient release, biological stimulation, and improved soil structure. However, organic matter is also lost through decomposition. When organic matter is added to a soil, about 80% is eventually lost through decomposition while about 20% will end up in the stable humus portion. Because of this, if farmers want to increase the stable humus portion of the top 6 inches of the soil by 1%, they must add about 100,000 lb of undecomposed organic matter. While the primary value of soil organic matter lies in this dynamic nature, it does present major challenges.

Management of soil organic matter can be viewed as a bank account, where gain and loss must be balanced in order to remain relatively constant. Organic matter can be gained through additions of different types of plant residues, additions of manure and compost, and through varied crop rotations. The different types of organic amendments to soil have distinct effects on soil quality, soil tilth, and soil microbial populations. Organic matter can be lost through erosion and as well as by CO_2 loss as soil organisms feed on organic residues. Accelerated decomposition and various types of tillage results in organic matter loss. Soil organic matter will increase only when gains are greater than losses. Because of this, it is essential that soil organic matter be managed carefully and creatively.

Increasing soil organic matter can be best accomplished by the following practices:

1. Use of cover crops. Cover crops reduce soil erosion, increase biodiversity, increase the organic matter level, and improve soil aggregation. Cover crops also continuously provide a living host for mycorrhizal fungi and other microbes, effectively inoculating the next crop with a healthy population. It is no surprise that crops grown after a cover crop show higher levels of mycorrhizae. Certain species of cover crops can specifically suppress certain types of nematodes and other pathogens. It is important to look for niches where cover crops would fit into the crop rotation.

When a cover crop is tilled in the spring when plants are young and succulent, the biomass will quickly decompose. This rapidly releases many nutrients into the soil. The disadvantage of this accelerated decomposition is that very little of the material remains as stable humus in the soil. Decomposition of older cover crop material can briefly tie up essential nutrients, especially nitrogen, and this may result in temporary nutrient deficiencies. Cover crops should be used for short term soil organic matter improvement, in conjunction with other materials and practices that can supply more stable decomposed material.

2. Additions of compost and manures. Compost is organic matter that has gone through the decomposition process. It may be derived from animal or plant wastes. When compost is added to a soil, most of the organic matter is already in the form of humus. A high percentage of compost can then be incorporated into the well stabilized "very dead" or humus portion of the soil organic matter, increasing soil nutrient holding capacity and improving soil tilth.

The degree of compost maturity can affect its ability to suppress pathogens. Composts that are too mature can show lower pathogen suppressive ability, partly because they do not provide adequate nutrition to the competitive organisms needed to hold pathogen populations in check. Uncomposted manure can be a valuable source of organic matter and nutrients, but will rapidly undergo decomposition in the soil, having a similar effect to freshly tilled cover crops.

3. Crop rotations. Research has repeatedly shown that crop rotation alone increases yield. Often there is at least a 10% increase in yield when a crop is grown after a different crop rather than after itself. Other research showed that cropping corn silage continuously for five years without manure return resulted in a 20% depletion of soil organic matter and yield depression. Long-term varied crop rotations add a combination of different plant residues, enhance biodiversity, produce better habitat for beneficial organisms, and decrease erosion.

Important factors to consider when planning crop rotations would include alternating deep rooted perennials with shallow rooted annuals, heavy feeding crops with light feeding crops, and row crops with sod-forming forage crops. High residue annual crops add back a considerable amount of organic matter. It is important to consider how much crop residue remains after harvest. Corn grown for silage has a very different effect on soil organic matter than does corn grown for grain. When silage is removed, most of the organic matter and nutrients are taken off the field, and if they are not returned in the form of manure, this will rapidly deplete the soil.

4. Reducing tillage. Most tillage operations cause organic matter loss and destroy aggregation. This can lead to compaction and erosion. By reducing the frequency and amount of tillage, organic matter level usually increases due to improved biological activity. Reduced tillage can also result in better water and root infiltration, improved

soil tilth, less erosion, and a higher level of plant nutrients. There are reduced tillage systems that can be used in sustainable agriculture conditions. Using no-till with a living or dead mulch has been successful under some conditions. Steve Groff, a farmer in Pennsylvania, plants tomato transplants directly into a mulch of hairy vetch that has been killed by rolling and chopping. The dead mulch provides good weed and erosion control for the rest of the season while adding a considerable amount of organic matter to the soil.

It is important to note that reduced tillage does not work in all soils. Cool wet soils are not generally adapted to such systems. If an organic farmer intends to rely on tillage and cultivation for primary weed control, reduced tillage may limit cultivation options. It may be a good idea to rotate periodically with different tillage systems. Under any condition, it is important to combine reduced tillage with other good management practices such as cover crops and good crop rotation.

The tremendous importance of soil organic matter may be easy to overlook, but loss of productivity is not. Conventional farming, with its heavy use of synthetic fertilizers, monoculture, pesticides that kill microbial life, few cover crops and a general disregard for soil organic matter, has already destroyed a large amount of the soil's original organic matter. Heavy use of outside inputs has so far masked the impact of this on productivity. Eventually, such practices may deplete soil organic matter beyond the point where chemical inputs alone can maintain high yields. If sustainable farmers wish to maximize their yields and maintain the long term health of their farms, it is essential to deliberately incorporate approaches to increase organic matter level and diversity into each year's operations.

Dr. Fred Magdoff has included many of these concepts in his book, Building Soils for Better Crops - Organic Matter Management. This is available for $10 (includes postage) by contacting Dr. John Nelson, Northeast Region SARE Program, Hills Building, University of Vermont, Burlington, VT 05405. The first edition of the book is currently available. An updated version, with more information on ecological soil management, will be available during the winter of 1999-2000.