3. Organic Matter and Promotion of Healthy Biological Activity

Organic matter in soil

For practical purposes, soil organic matter (OM) can be divided into three basic categories: raw organic matter, active humus, and stable humus. Each has its own particular characteristics that are important in the understanding of how soils work and release nutrients to plants. Soil analysis uses a concentrated acid digestion to determine total soil organic carbon; this is measuring any raw residue included with the sample (although most is screened out during processing), plus the active and stable humus. The soil OM is a rough measure of the quantity, not the quality of the organic matter. Some laboratories offer such techniques as bioassays or chromatography to assess quality of soil OM; these offer some exciting possibilities.

The carbon cycle is the system through which organic matter moves from atmospheric CO_2 to organic form and back again. Raw organic matter is crop residue, stubble, leaves & prunings, forest debris, or applied manures, organic mulches and wastes. Carbon occurs in organic form in carbohydrates (sugars, starches, cellulose), lignins (rigid or woody components), and proteins (N containing amino acids). The main characteristic of raw organic matter is that the nutrients contained in them are not available for higher (crop) plant use until they have decomposed. Soil animals, fungi, bacteria, actinomycetes, yeasts, algae, nematodes, and other organisms use the large carbon compounds and minerals for food. Stevenson (1986) estimates the mass of bacteria and fungi to be about 1700 and 2500 pounds per acre respectively. As soil organisms feed, they release minerals in a series of digestive stages that differ according to the materials, the biota in the system, and the conditions. Decomposition does, however, undergo the following general reaction:

$$\text{Organic matter} + O_2 \gg CO_2 + \text{Humus} + \text{minerals}$$

$$\text{Humus} + O_2 \gg CO_2 + H_2O + \text{minerals}$$

Active humus is made up of compounds, organisms, and materials resulting from the initial stabilizing decomposition. The decomposition process releases plant nutrients such as N,P, S, micronutrients, and polymeric compounds such as humic & fulvic acids, which are soil colloids that contribute to CEC and bind soil particles into aggregates. High amounts of active humus in soils result in very good soil structure.

After active humus decomposes, stable humus is formed. This is composed of the materials that undergo further breakdown very slowly. This component is not considered in the nutrient cycle for any given season. For example, according to Stevenson (1986), turnover of nitrogen from active humus is about five times that for stable humus. The ultimate result of decomposition and mineralization is carbon dioxide and inorganic minerals.

The rate at which the carbon cycle proceeds is regulated by temperature, moisture, oxygen, and ultimately, the carbon/nitrogen ratio in the organic matter. A pile of sawdust, high in carbon with a C/N ratio of 90 will sit for years with little decomposition. A pile of chicken manure with a C/N ratio of 5 can heat up and ignite. Mixed together to a C/N ratio of 25 there will be efficient breakdown. This is one of the main principles used by the compost industry. As Albrecht noted, native soils high in proteinaceous (high N) vegetation achieve rapid OM turnover while high carbon/low nitrogen forest soils accumulate organic matter.

Stevenson (1986, p. 58) outlined four agricultural practices that may accelerate decomposition and mineralization of soil organic matter: cultivation, irrigation, liming, and green manuring. I have added two additional important practices: nitrogen fertilization and microbial inoculation.

Cultivation - Improves aeration and moisture, thereby increasing microbial activity and the release of organic compounds to soluble forms.

Irrigation - Improves the moisture status of the soil, with enhancement in the activities of microorganisms.

Liming - Increases the activities of earthworms and other faunal organisms; encourages actinomycetes, which may be more effective decomposers than bacteria and fungi; facilitates the precipitation of metallic cations that are effective in stabilizing humic substances.

Green manuring - Greatly increases the numbers of microorganisms and thereby the rate of oxidation of organic matter.

I would add the following:

Nitrogen fertilization - Narrows the C/N ratio of soil, increasing microbial activity and OM breakdown.

Microbial inoculation - Supplies decomposing and nitrogen fixing microbes; maintains adequate populations.

The practices that contribute most to the long term lowering of organic matter levels are cultivation, irrigation, and nitrogen fertilization. Stevenson reviewed the losses of soil OM due to cropping (pp. 55-60). Most agricultural soils have reached an equilibrium of OM levels lower than native soils as a result of these practices. However, soils are complex, for example: although irrigation decreases OM level by increasing respiration and bio-activity each time the soil is wetted, irrigation can also be used to grow vegetation and increase soil biomass. Soil aeration is essential for good OM breakdown, and the BCSR approach pays particular attention to this aspect.

The Case for Inoculation

All the soil textbooks discuss the chemical changes occurring during the nitrogen cycle, the forms of N taken up by plants (nitrate and ammonium), and the need for optimum conditions for these conversions (50-60 temperature, 6-7.5 pH). Farmers make important assumptions that these conditions exist following fertilizer application, and that bacteria which convert applied N fertilizers are present, just waiting to be "fed". Actually, conditions in the root zone of trees and vines are not best for these conversions. Most orchards and vineyards use herbicide strip sprays for weed free conditions under the trees or vines. Many use drip or micro spray irrigation, and a common practice is the application of fertilizers through the watering system. Peterson and Stevens (1994) include several studies in Tree Fruit Nutrition showing that the weed free area below the canopy (where the water, roots, and fertilizer are concentrated) will show the most rapid pH drops. In one example pH fell from 5.7 to 4.0 over a three year period in apples fertilized through the drip system. Young tree vigor declined "possibly as a consequence of acidification of the soil immediately beneath the emitters" (p.192-194). In another example the pH of a cherry orchard soil varied from 7.3 under the grass sod outside the drip line to 5.1 under the tree (p. 154). Kirchhof, Jayawardane, Blackwell, and Murray (1995) observed that grapevine roots have trouble growing in low pH subsoil layers due to (a) poor root growth from excess aluminum, hydrogen, manganese and other metals, (b) deficiencies of calcium, magnesium, phosphorous, iron, and molybdenum, and (c) reduced water availability during drying cycles due to poor soil physical properties. Albrecht, of course would have emphasized that the acidity is the symptom of calcium (and magnesium) deficiency, not the cause of the problem. Several points back up Albrecht's view; roots need calcium to initiate new growth and the soil structural properties desired require the addition of calcium salts. Addition of sodium carbonate or potassium hydroxide, or any other alkaline salt without calcium would raise pH but not necessarily accomplish the objectives.

All the mineral nitrogen fertilizers commonly used, with the exception of calcium nitrate, acidify the soil zone to which they are applied. Amounts of limestone needed to counteract this acidity range from 1 pound for every pound of 16-20-0 fertilizer applied to 1.5 pound for every pound of ammonia. Acidification strips off base cations (Ca, Mg, K, Na) from the soil colloid, leaving fewer nutrients, and soil structure becomes worse. Potter, Bridges and Gordon (1985) found this also affects populations of earthworms and other organic matter decomposers, decreasing earthworms by as much as 66%. Clearly, the average 50% inefficiency of N fertilizers is related to the poor chemical and biological conditions inherent in concentrated applications of the concentrated mineral forms of N. The organisms responsible for N transformations and organic matter breakdown are often missing in agricultural soils. Methods of 'seeding ' our soils with beneficial microbes should help prevent nitrogen loss.

The use of composted organic matter, preferably inoculated with a diverse population of decomposers and N transforming microbes, is the optimum situation for returning productivity to soils. The presence of microbes with their food and environment makes it the superior choice. A common misconception exists about the use of compost: it must supply all the nutrients needed by the crop, or else it fails as a fertilizer. Actually, compost will supply maintenance amounts of nutrients for most tree fruits and vines at the 2-3 ton/acre rate commonly used in northern California. Compost is also used as a tool to achieve best efficiency of applied N, P, K or other nutrients. High demand crops such as corn, cotton or nuts need more N than can be economically applied via compost. Very low amounts of nitrogen applied to a soil following compost results in optimum efficiency of applied nutrients due to the microbial activity inherent in such a situation. The additional N from chemical fertilization can stimulate the soil biota. The more numerous and diverse the microbial population, the lower the potential for N loss. Bishop and Godfrey (1983) discussed nitrogen transformations during composting. They demonstrated the presence of N fixing organisms, and stressed the importance of C/N ratio and aeration.

Various microbial products are available to augment the soil population; they are too numerous to review. These products, categorized as "Biotics" under CDFA regulations consist of organisms, enzymes, or by-products of organisms. The species, strains and concentration of ingredients must be identified. Efficacy data (usually from California trials) must be submitted and approved prior to sales in the state. Only four such products were registered by 1996 (CDFA 1996). The costs of efficacy studies prevent many products from being registered and tried by farmers. In addition, if any claims are made for disease prevention, resistance, or suppression the material must be registered as a pesticide with both the Federal and State Environmental Protection Agencies. Although the development of such products requires millions of dollars of research and documentation, many new biotics are being produced.

Types of inoculants

"The ability of a few bacteria, actinomycetes and blue-green algae to fix molecular N_2 can be regarded as being second in importance only to photosynthesis for the maintenance of life on this earth" (Stevenson, 1986, p. 117). Modern farming practices and the use of concentrated minerals as fertilizers lower organic matter content and microbial populations of farm soils. Reinoculation with soil life forms will help with nutrient efficiency. Weil and Kroontje (1984, p. 293) emphasized that NO_3 availability changes as pH changes, "not because the solubility of nitrates is affected, but because the activity of nitrifying micro-organisms is affected." Such studies point out the importance of biological activity in nitrogen management.

The most widely recognized inoculants are the nodule forming bacteria used when planting legumes to insure nitrogen fixing organisms are present. Best results from inoculation occur when: (a) no similar nodulating N fixers are in the soil, and (b) available N levels in the soil are low (Huber, 1984). We learned this latter point when we recommended legume cover crops for pear orchards. Several growers achieved excellent stands of clovers, but could find no nodules, and thus no nitrogen fixing activity, on the roots.The growers were still applying spring nitrogen, and thus wasted either clover seed or some of the applied nitrogen. Nodulating bacteria are also very sensitive to temperature, moisture, and pH. Albrecht (1975) stresses the importance of calcium for nodulating bacteria and N fixing. Under optimum conditions legume cover crops and their symbiotic partners can fix from 150-250 pounds per acre of nitrogen (Stevenson, 1986). As little as 15 pounds per acre can be realized; 50 pounds per acre is generally used as an average.

Free-living bacteria reside in the organic matter of the soil, and do not form root nodules, although some do form symbiotic associations with plants by living on the roots. According to Stevenson (1986), most soil scientists believe N_2 fixation by free living bacteria is low, from 5-20 pounds per acre per year. Other researchers have reported that there is as much as 200 pounds per acre. These organisms can often make significant contributions (p. 123-124):

1) Over 100 species of N_2 fixing bacteria have been discovered; their combined contribution could be appreciable.
2) Gains in soil N in legume-free grass sods suggest extensive fixation in the rhizosphere of crop plants.
3) Crops can be grown continuously on the same land for several years without N fertilizers.

Sibbett, Peacock and Day (1996) studied walnuts for five years in which five N amounts from 0-300 pounds per acre per year were applied. Although the highest N rates often resulted in the highest yields, the differences were insignificant and would not pay for the additional nitrogen. The five year average yields from 0 and 300 pounds per acre N varied less than 10%. Quality and other attributes were not studied. The prevalence of walnut blight in the various fertilizer regimes was not indicated. Such disease and quality considerations add complexity to studies, but often show important trends between N use and other problems. The source of nitrogen in the fertilizer blocks with no added N was attributed to organic matter fixation and the possible presence of nitrates in irrigation water. This demonstrates the importance of considering organic matter and fixation from non-legumes in nitrogen management.

Blue green algae, now called, cyanobacteria, occupy practically every environmental situation where sunlight is available for photosynthesis. They can synthesize all their cellular material from CO_2, atmospheric N, water, and mineral salts. Since they fix N only in the presence of sunlight, they are limited to aquatic systems and the surface of soils, especially in humid areas. In rice they are the principal source of N for over 1 million hectares in China (Stevenson, 1986). They undoubtedly contribute some N from river or pond irrigation water; however their average annual contribution to crop land is estimated to be only 25 pounds per acre. Applications of limestone in northern California often result in a temporary bloom of algae on the soil surface or areas where limestone has been spilled. Cyanobacteria may contribute more N than estimated. At least one microbial inoculant is sold which is primarily from this group.

Actinomycetes are microbes between bacteria and fungi in structure, and are common in local soils because they are decomposers of the woody components, cellulose and lignin, in organic matter. A few have been reported to fix nitrogen (Stevenson), however their main role is most likely release of N and minerals from organic matter and production of antibiotics that can deter root disease organisms.

Walking through our local oak-madrone forests & grasslands, noticing the lack of legumes, I often wondered: what is the source of the nitrogen for the annual biomass production? Free-living N fixers obviously play a greater role in production than science acknowledges. The conditions needed for optimum N_2 fixation by free-living microbes are: adequate organic matter residues and mineral nutrients, low levels of available N, near-neutral pH, and suitable moisture. In a typical vineyard or orchard with irrigation and fertilization, often only one of these optimum conditions exists in the root zone - suitable moisture.

After providing optimum conditions for soil bio-activity (which produces yield and quality benefits), inoculation of soil with beneficial microbes will further the progress towards less fertilizer applied with optimum uptake. Microbes called plant-growth promoting rhizobacteria (PGPR), which colonize plant roots, have been used in the Soviet Union on millions of acres since 1958 according to Suslow, Kloepper, Schroth and Burr (1979). They performed tests in California on vegetables and row crops that showed increased vigor and yields of 5-144% due to increased nutrient delivery, production of plant growth hormones, or replacing other, harmful organisms. They concluded "the application of beneficial bacteria to seed to increase yields and reduce pesticide use is an attractive and likely prospect; the benefits could be considerable" (p. 17). Which particular microbial product will produce the best results depends on the individual crop and soil situation. Petrik Laboratories (1996) formulates several products from over 30 species. These are recommended for many purposes, including root stimulation, soil inoculation and remediation, and organic matter digestion. Other companies are producing bacteria, fungae, and other microbial products and mixtures for plant stimulation, biological control of pathogens, and soil remediation. Projects involving successful treatment of 200,000 tons of petroleum-tainted soils using aerobic composting are described in BioCycle (1995). Microbes are even being genetically engineered to perform their functions more efficiently.

Several products for tree fruits and vines show promise. Mycorrhizal fungi can improve P uptake and growth of grapevines following fumigation (Katz, 1996). Root rot of vines has been controlled with cultural controls which favor the Trichoderma fungus (Dutt, Olsen & Stroehlein, 1986). Crown rot of apple is managed with cultural controls (better drainage) and a bacteria (Enterobacter) with or without a fungicide (Levesque, Holley & Utkhedes, 1993).

Using compost extracts to inoculate crops with diverse microbial populations for pest or disease control shows promise, but will be hampered by pesticide registration requirements, quality control considerations (especially human pathogens), and the difficulty of maintaining microbe levels on the plant surface environment. All inoculations will be more effective if combined with BCSR to insure good soil structure, aeration and nutrition.

Organic matter amendments

The use of manures for fertilization probably followed closely behind the domestication of animals in agricultural development. Other organic wastes have also been used as soil amendments. They are an inevitable part of human, animal, and agricultural life. Manure and organic waste generally contain all the major and micronutrients in varying amounts. Other benefits of their use are maintenance of organic matter (OM) and enhancement of soil bio-activity. The disadvantages of raw organic amendments are many. Organic wastes are bulky, and have relatively low concentrations of nutrients. They can contain nitrates, soluble salts, heavy metals, and human and plant pathogens, and often have odors and other nuisances associated with them.

The release of nutrients from raw organic matter is termed a "decay series", expressed as the percentage of nutrients mineralized following a single application. Approximately 50% of the nitrogen is available during the first season, 10-25% the next year, 10% the year after, etc. Some manures take up to 10 years to completely mineralize. Organic matter breakdown and nitrogen transformations require the same conditions as N fertilizers for best assimilation - good aeration, and optimum moisture and mineral balance.

Storage of manure can result in loss of as much as 90% of the N and much of the potassium (K) within three weeks, due to leaching, freezing, volatilization