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 at high temperatures, and ammonia formation (Plaster, 1992). Similar losses could occur with grape pomace, fruit and vegetable waste, and most raw organic wastes. They are extremely unstable, often noxious, and require decomposition prior to use by plants. Plaster (p. 323) concludes that "the best way to handle manure is to spread it immediately on unfrozen ground and then plow it into the soil." This solves the problem of the odors and nuisances, and helps prevent nutrient losses. It buries pathogens, which kills some but inoculates crop soil with others. The soluble salts, nitrates and heavy metals are still potential problems, and the bulky nature of raw organic wastes limits hauling to distant agricultural sites.

Composting of agricultural wastes solves many of the serious problems with raw organic wastes, and results in an agronomically superior fertilizer. This is becoming common; "never before have so many farmers, researchers, advisors, federal and state agencies recognized the importance of agricultural composting" (Kashmanian, 1995). Many agencies, such as the California Department of Agriculture (1996) define composting as the biological decomposition of organic matter accomplished by a controlled process of aerobic or anaerobic decay. In scientific circles, composting is aerobic digestion and anaerobic digestion is known as "moldering." I have initiated, managed, and provided consulting services for composting facilities for over 15 years, and I have never seen an anaerobic facility produce any product that was stable. It always requires subsequent aerobic treatment. I define compost as aerobically decomposed (or digested) organic matter. Every compost facility has some machine, chamber or method designed for aeration of the raw material. The composting is a rapid digestive process which utilizes water, air, organic matter balanced to optimum C/N ratio, and sometimes microbial inoculants. The waste is reduced in volume by 50-75%, and nutrients are stabilized in organic form.

The process enriches the finished product with microbes which will continue the mineralization.

Aerobic composting produces a valuable amendment teeming with beneficial microbes. Vallini, Bianchin, Pera and Bertildi (1984), in a review of composting of a variety of mixtures of industrial and agricultural wastes (tomatoes, olive husks, cork, sewage sludge, vegetable tannery waste) reported on the microbial populations of the finished composts. Reduction of pathogens was 1000 times, and the resultant microbes included high levels of aerobic bacteria, actinomycetes, ammonia producers, N fixers, and various fungi. Total aerobic bacteria ranged from 10^9-10^{13} cells per gram. The vegetable tannery sludge had the most potential for pollution, and aerobic composting became the best management strategy (p. 46):

> In this way a polluting substance, biologically toxic due to its strong concentration of tannins and polyphenols, and extremely harmful to crops, can be transformed quickly and cheaply into an agriculturally useful product, hygienically safe for the environment.

Biological activity in soils is increased by compost additions. Workneh, van Bruggen, Drinkwater and Shennan (1994) compared 9 farms using compost and green manures with 9 conventional operations using only inorganic fertilizers. The farms adding organic matter had higher levels of bio-activity with lower incidence and severity of two main tomato diseases, associated with lower nitrate contents, better soil structure, and more balanced fertility. Sivapalan, Morgan and Franz (1993) found similar results comparing conventional farms with those receiving compost: increased microbial populations, and higher numbers of species with growth promoting or disease suppressive activity.

A very important attribute of composted organic matter is slow release of nutrients, especially nitrogen. Maynard (1994) compared compost applications with inorganic N-P-K fertilizer over three years and five different row crops. Total nitrogen applied in the compost plots was 3-5 times that of N-P-K plots, yet nitrate N levels in groundwater below plots showed 50% more in the N-P-K plots. Chicken manure compost performed as well as inorganic fertilizers in intensive cropping systems for tomatoes, eggplant, peppers, broccoli, and cauliflower.

A very important characteristic of compost is the absence of plant and animal pathogens. The U.S. Environmental Protection Agency definition distinguishes compost from fresh (raw) organic matter only when it has been through the thermophyllic stage and achieved sanitization (Biocycle, 1987). During this stage the aerobic systems commonly reach 150^{o} F, which is credited with pathogen elimination. Throughout the composting process are a series of stages where certain microbial groups dominate; the later stages feed on the organisms and compounds from the earlier stages. Pathogen reduction is also achieved from competition for nutrients and direct predation by other organisms. Golueke (1983) listed heat, competition, antibiosis, destruction of nutrients, and time as the agents and mechanisms bringing about the destruction of pathogenic organisms.

The antibiosis that occurs during composting offers some interesting prospects. Early in the process crop wastes are teaming with decomposers, often the same organisms which cause diseases on the farm. Later antagonistic microbes take over, resulting in compost full of biocontrol agents. This property of composting systems was reported by Hoitink and Kuter (1985, p. 191) at Ohio Agricultural Research and Development Center, who predicted "Composts may become a food base for biocontrol agents used in the agriculture of the future". These researchers developed a nursery mix suppressive to common root rots in the industry. Other researchers found similar results with root rot and damping off (Burkham, 1990). Logsdon (1995) provides a review of current research, citing successes with disease control in vegetables, soybeans, peppers, tomatoes, vegetables, alfalfa, and beans. One large project in Brazil composted the bagasse from sugar cane from 150,000 acres, applying the compost to fields in a five year rotation. Resultant yield increases were 15%, with partial credit going to disease suppression.

Several applications of this concept could have importance locally. An organism commonly found in compost is Trichoderma, a fungus which is an antagonist of several soil pathogens. Baker and Cook (1974) called this organism the main biological agent in suppression of Armillaria, locally known as oak root fungus. This fungus infects vineyards and orchards in the area; methyl bromide fumigation is sometimes used to combat or prevent this disease. Compost may be valuable in management of this disease. There are two comprehensive reviews on the use of compost in place of fumigants: in nurseries (Quarles & Grossman, 1995) and in forest nurseries (Quarles, 1997). Other references reported vineyard response to nematode problems from various organic amendments, including compost (Pryor, 1980). In the early 1980's while working for New Era Farm Service, I wrote and circulated a flyer to customers suggesting an alternative program to soil fumigation. The basis for the program was balanced soil cations, compost application, sub-soiling, and cover cropping. At that time I was unable to convince any farmers to try the program, however our agronomists in the San Joaquin Valley commonly used the program to manage nematodes in vineyards. Recently, University of California scientists have tested materials such as compost, green manures, clover teas, and fertilizer combinations on several crops for nematode control. Several materials and techniques produced good results in grapes and cotton (McKenry, 1996).

Foliar application of compost extracts has been tested for disease control. The goal is to inoculate above ground plant surfaces with beneficial microbes which compete for food or suppress plant pathogens. Weltzein (1988) reported successful results in grapes, potatoes, sugar beets and barley. Tranker and Brinton (1997) found three-day extracts of moderately mature compost controlled powdery mildew on grapes as well as pesticides. They did find, however, that control on actual bunches was not as effective as on leaves. This may limit its usefulness. Presently, one pesticide is available which is a parasite of powdery mildew. It is alternated with sulfur or other pesticides for control.

Nutrients in compost

Nutrient content of compost varies much more than fertilizers produced by controlled chemical processes. Due to the stabilization of C/N ratios, maximum nitrogen content of compost is about 1.75% N. Although analyses occasionally show higher N, this is measuring free ammonia which will volatilize as the material is spread in the field. Aerobic composting is a biological process, and is thus subject to natural limitations. Mineral contents vary with raw materials, unless additional plant nutrients are added during the process. To guarantee nutrients, fertilizer companies must be within 5% of the stated percentage. This means a compost with 1.6% N must be within .08% N content to comply with CDFA regulations. Urea, at 46% N can be off by 2.3% and still comply. This gives the compost industry a disadvantage versus mineral fertilizers.

Compost can compete economically with commercial fertilizer. A well formulated agricultural compost will have an N-P-K (nitrogen - phosphorus - – potassium) analysis of 1.5 - 1.5 - 1.5 with 1-2% calcium. Magnesium, sulfur, sodium and other elements are present in lower amounts, and micronutrients are measured in parts per million. Commercial fertilizers are thus called "high" analysis materials while composts are considered "low" analysis. Commercial fertilizers are applied at rates from 50-300 pounds per acre while composts are used at 2,000 - 6,000 pounds per acre. Compost requires special equipment to apply, increasing its overall cost. On the other hand, its use does offer all of the advantages previously discussed. Many believe that these advantages more than pay for the increased application costs. Table 4 shows how agricultural compost compares with mineral N-P-K fertilizer in cost, nutrient content, and dollars per pound of major nutrients:

Table 4

Comparison of Nutrients in Mineral Fertilizer vs. Agricultural Compost

Material	# N-P-K per ton	Cost/ton	Other Nutrients	$/# nutrients
Triple 15	300-300-300	$342	S, Ca	$0.38
Compost	30-30-30	$30	S, Ca, Mg, micros, 0 M	$0.33

(personal communications with Mendocino County dealers, 11/97)

Compost use in California.

According to Ralph Jurgens (personal communication, 1997) New Era Farm Service produces and distributes from 100,000-120,000 tons annually in the San Joaquin Valley. This is applied at 1 - 3 tons/acre to approximately 50,000 acres of crop land. Several smaller compost facilities exist in northern California. Sonoma Compost in Petaluma distributes about 20,000 tons/year. In Napa County, Upper Valley Disposal sells 6,000 tons/year, and in Mendocino County, Cold Creek Compost produces 8,000 tons/year. No commercial producers are presently operating in Lake County, and Contra Costa County is within trucking distance of several producers. Estimated total annual use in Napa, Sonoma, Lake, and Mendocino counties is 34,000 tons per year (personal communications, September, 1997).

Organic Fertilizers

Pelletized or soluble organic fertilizers are increasing in popularity. The same basic principles apply: C/N ratios must be adequate for breakdown and the materials must digest in the soil before releasing most of the nutrients. Chicken manure, cottonseed meal, blood meal, and other relatively high nitrogen organic materials are pelletized and used as commercial fertilizers. Soluble blood meal, fish emulsions, and other organic materials can be applied through irrigation systems. The cost of such materials is often 2 - 5 times per unit that of inorganic N-P-K. A comparison of two commonly used, soluble high N materials is interesting.

Urea, the most commonly used nitrogen source, is 46% N with up to 2% biuret, a toxic compound formed during manufacture. Soil bacteria eventually convert urea to ammonia or nitrate; it is subject to 75% loss under the worst conditions. Although it is one of the cheapest N fertilizers, special coatings, bacterial or chemical inhibitors are sometimes added to increase its efficiency, which adds to the cost. Urea requires 1 pound of limestone for every 1 pound of urea to counteract acidity.

A water soluble, hydrolyzed fish protein product which has an analysis of 12 - 0.2 - 1 N-P-K is being used by organic growers in California. The product contains 20 amino acids, 25 fatty acids, 10 vitamins, and low amounts of nine minerals.While most of these constituents are not considered available to plants, they are food for decomposers and any soil microbes who come in contact with the material. Several times I have seen measurable responses in trees and vines to applications of 10 pounds/acre of hydrolyzed fish protein. This would amount to 1.2 pounds/acre of actual N, most of which must be digested to be available to plants. The stimulating effect of organic fertilizers on soil has been tudied by many researchers, including Leclerc, Cauwell, Lairon

Hummel, Jellum and Privett (1997). These studies generally demonstrated increased microbial activity, slower N release, and reduced soluble N leaching when organics were compared to mineral N forms.

Hauck, in the epilogue to Nitrogen in Crop Production (1984, p. 785), discussed the possibilities of improving N efficiency:

> Whether soil organic matter can be manipulated to keep more N in readily mineralizable forms is not known. Since about 25% of applied N typically is stored temporarily in the soil organic matter complex, a relatively small change in the sequence of immobilization - mineralization may benefit plant growth. Research on the chemistry and microecology of soil organic matter requires attention at several levels of integration.

The many possibilities for inoculation of soils and plant root zones will require such research by both institutions and private industry. By combining balanced fertility, lower and more frequent amounts of nutrients, and stimulating biological diversity the problems associated with fertilization can be minimized.

Cover Crops

The use of cover crops is increasing after falling into disuse during the 1950-1980's. Many benefits occur with the use and manipulation of the vegetation on the orchard or vineyard floor. Northern California soils are formed under forest or woodlands; they tend to accumulate organic matter. Grazing and tillage both deplete organic matter. The longer these practices are done, the more depletion occurs. Most agricultural land is in a steady state of low organic matter relative to native vegetation. Cover crops help maintain and replace this OM.

Tillage chops organic matter into small pieces, allowing more rapid breakdown by microbes and weather. The soil is subjected to increased leaching during the winter, which aggravates calcium deficiencies, lowers pH, and makes clay soils tighter with poor drainage and aeration. Our natural tendency towards soil acidity is aggravated by excess tillage.

Mowing the cover increases organic matter in orchards and vineyards. The accumulation gets better every year with adequate rainfall. Planting cover crops or proper culture of native cover provides many benefits with some disadvantages; these are summarized in Appendix E. Cover crops improve soil structure, increase nutrient availability, increase soil microbial activity and above ground diversity, decrease erosion, and modify microclimates.

One aspect of cover cropping which is usually not considered is the nutrient requirements of the vegetation. Legumes are often planted for their nitrogen contribution with little regard for their nutrient needs. Grasses can be used to tie up nitrogen and control excess vigor by competing with trees or vines for nutrients. Table 5 shows nutrient needs of several common cover crops.

Table 5

Nutrient Removal of Harvested Cover Crops in pounds/ton

Crop	N	P_2O_5	K_2O	Ca
Cowpeas	62	12	42	27
Red clover	56	13	45	24
Sweet clover	44	11	44	29
Vetch	55	15	45	24
Brome grass	40	12	44	9
Bermuda grass	50	12	40	8
Fescue	40	16	48	9
Timothy	36	14	54	8

Note. From A & L Agricultural Laboratories. Agronomy handbook: soil and plant analysis. p. 121. Adapted with permission from the author.

Considering that a free growing cover crop would remove an average of 4 tons/ac of biomass, the following figures are worth consideration (Table 6):

Table 6

Average Nutrient Removal for Clovers & Grasses, in pounds/ton

Crop	N	P_2O_5	K_2O	Ca
Legumes	216	52	176	104
Grasses	166	54	186	34

Since cover crops are rarely left to grow through the season, these figures are larger than the actual amounts of nutrients tied up during growth. However, it does show the relative importance of the different nutrients. Calcium and potassium are required in large amounts for legumes (which fix their own N). Nitrogen and potassium are more important for grasses. While these nutrients are ultimately returned when cover crops decay, either temporary or chronic tieups of marginal nutrients can occur. If calcium, phosphorous, potassium, or any nutrient is in short supply, trees and vines will be competing with the cover crop for essential food. If a healthy, N fixing legume cover is desired, abundant calcium and potassium are needed, and the best results occur if optimum BCSR conditions are in place.

The condition and makeup of the cover crop is a reflection of its culture and management. Excessive N applications prevent legumes from fixing nitrogen despite luxurious growth. Research in Australia found that under low calcium conditions grasses and other weeds can soon invade and take over clovers - and that legumes responded to calcium amendments regardless of pH (Woodruff, 1972). Undesirable plant species in the cover crop are best addressed by examining every aspect of soil and culture - whichever species are growing are best suited to the current conditions. Often, applying limestone to make conditions conducive for legumes results in native clovers invading orchard and vineyard sites. Addition of needed potash, phosphate, or other minerals often results in dramatic changes in the cover crops - usually away from weedy species towards desirable covers. This has happened often enough that I rarely recommend seeding cover crops until the mineral content of the soil has been balanced, and the tillage program has been minimized.

Seeding specific cover crops for the purpose for augmentation of natural enemies of pests is a relatively new and rapidly expanding practice. Research on the farm and in trials is showing the promise of this pest management technique.