ORGANIC SOIL AMENDMENTS AND FERTILIZERS

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Publication 21505

Acknowledgments

This publication is a result of the efforts of many individuals. The authors would like to thank Barbara Wetzel (UC SAREP), Marianne Post (UC Davis, Repro Graphics) and Jim Coats (UC DANR) for their assistance in designing and producing the publication. We also appreciate the talents of Arleen Chin (Visual Media, UC Davis) and Marianne Post in creating the graphics, and VonZetta Gant (UC DANR) for designing the cover. Lastly, we acknowledge the important input and guidance of the following reviewers:

Jill S. Auburn, UC Sustainable Agriculture Research and Education Program
William Dost, Forest Products Laboratory (UC Berkeley)
Deborah Giraud, UC Cooperative Extension (Humboldt County)
Lyra Halprin, UC Sustainable Agriculture Research and Education Program
Louise Jackson, Department of Vegetable Crops (UC Davis)
William C. Liebhardt, UC Sustainable Agriculture Research and Education Program
Jeff Main, farmer (Yolo County)
Glenn McGourty, UC Cooperative Extension (Mendocino County)
Dennis Pittenger, Department of Botany and Plant Sciences (UC Riverside)
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Bruce Wyatt, UC Cooperative Extension (Sonoma County)

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Introduction

Amendments and fertilizers are materials added to the soil to enhance soil quality and promote plant growth. *Organic* soil amendments and fertilizers are used for these same purposes, and are materials specifically derived from living organisms. This sense of the word "organic" is the primary one used in this publication. The term can also refer to a particular type of farming or farm product. As defined by California state law, food can be labeled organic if it has been produced without synthetically compounded fertilizers, pesticides, or growth regulators. Many of the products described in this publication also fit this legal definition and, in fact, are used widely on organic farms in California.

In the not-so-distant past, organic materials were applied routinely to farms in California to improve soils and maintain crop productivity. Since the 1940s and 50s, however, the farming picture has changed dramatically. One major difference is the introduction and increased use of petroleum-based fertilizers. The causes for this shift include (1) the separation of livestock and crop production, (2) an increase in farm size, (3) relatively low petroleum prices, and (4) advances in industrial technology and in the development of fertilizer products. The result has been to relegate many residues and by-products, which yesterday's farmers would have considered valuable, to the category of "wastes."

Farmers are renewing their interest in organic soil amendments for a number of reasons:

- problems with poor soil quality (compaction, crusting, water infiltration), and a desire to improve soil tilth by increasing organic matter
- strict standards for growing "organic" produce that disallow the use of petroleum-based (synthetic) fertilizers
- ready access to a source of quality organic material ("waste product")
- increasing costs of synthetic fertilizers
- a desire to promote recycling and reduce dependence on synthetic fertilizers.

The aim of this handbook is to provide farmers and agricultural advisers with practical information about the management and availability of organic materials in California. We begin in Chapter 1 with a discussion of soil organic matter: What role does it play in crop production? How does it relate to the quality and fertility of soil? What factors influence soil organic matter levels? In Chapter 2, we offer some general guidelines for evaluating organic amendments and fertilizers and deciding which to use. Chapter 3 includes details on various organic materials currently available in California. The list of materials in this chapter is not exhaustive. Some products are not included simply because the information about their composition and efficacy is inadequate. Gypsum and liming materials are covered separately in other publications.

The information presented in this publication will help you choose the organic amendments or fertilizers that best fit your particular situation. Specific materials are listed in the index, and a glossary at the end of the handbook defines some of the important terms and concepts.

"Amendment" or "Fertilizer"?

Whether a material is considered a soil amendment or a fertilizer is usually determined by its effect on plant growth. Fertilizers affect plant growth directly by improving the supply of available nutrients in the soil. Amendments, on the other hand, influence plant growth indirectly via improvements in the soil's physical condition (e.g., soil tilth, water infiltration). The distinction between these two concepts is clear when you compare materials such as ammonium nitrate (a fertilizer) and gypsum (an amendment). It is more difficult to distinguish between amendments and fertilizers when evaluating natural or organic products. Animal manure, for example, easily falls into either category depending on your reasons for applying it: manure can be a source of readily available nutrients, but it can also supply significant quantities of organic matter, which improves soil aeration and water retention. California State Fertilizing Materials Law eliminates some of the confusion by defining specific quality standards and characteristics for the production and sale of these materials. The legal terms related to soil amendments and fertilizers are included in the Glossary.

1. Soil Organic Matter

What Is Soil Organic Matter?

Soil organic matter (SOM) is the fraction of soil that originates from living organisms. At any given time, SOM consists of the living soil organisms and a non-living fraction derived from plant and animal residues in various stages of decay. Soil organic matter is not a static component of the soil; it is in a state of flux due to the continuous activity of decomposers, the diverse group of soil organisms relying on organic residues for energy and nutrients (fig. 1.1).

Organic residues are a complex mixture of readily decomposable and resistant molecules made up largely of carbon (50-55%) and nitrogen (7-8%). It is useful to think of SOM as composed of several pools that differ in decomposition rate. The accessibility of these various SOM fractions to decomposition determines their ultimate fate in the soil (fig. 1.2).

Determining Factors

Organic Residues and Decomposition Rate

In natural undisturbed ecosystems, the addition of organic matter is balanced by decomposition, and the various fractions of SOM are in a state of dynamic equilibrium. SOM levels remain fairly constant as new organic matter is added and decomposed. The quantity of organic matter in a natural soil is determined by factors that affect decomposition rate, such as temperature, moisture, soil texture, and organic matter input from plants. Typically, when soil is brought into agricultural production, the organic matter content declines until it reaches a new equilibrium (Campbell and Souster, 1982). This decline in SOM is thought to result mainly from cultivation, which disrupts soil aggregates and makes more SOM susceptible to decomposition (Buyanovsky et al., 1987; Kay, 1990). Most agricultural soils in California are fairly low in SOM, containing 0.3 to 2 percent organic matter. A few soils such as the Venice series in the Delta contain more organic matter, but their distribution is very limited (table 1.1).

Crop Production Practices and SOM

Agricultural practices, including the method, frequency, and depth of tillage, type and amount of organic residue additions, crop rotation, and irrigation, affect SOM levels (table 1.2). The equilibrium level of SOM in an agricultural system is determined by the combined effects of all these factors which either accelerate or restrict the decomposition rate or alter the amount of plant material produced.

Table 1.1. Soil Organic Matter Content and Texture of Selected California Soils.

Soil Series	% SOM	Texture
Yolo	0.7-1.2	silty loam
Capay	1-2	silty clay
Jacktone	2-5	clay
Redding	1.7-2.6	clayey loam
Holland	1.2	sandy loam
Delhi	0.5	loamy sand

Source: Soil Conservation Service. Soil Survey of Yolo County, 1972; Soil Survey of Sutter County, 1988.

In California, irrigation during the warm season affects SOM levels in two opposing ways. On one hand, water can increase SOM by increasing the total quantity of plant material produced on the land. On the other, the combination of moist soil and high temperatures during the growing season creates favorable conditions for rapid decomposition of organic matter. The net effect of these two forces is unclear because of the scarcity of long-term research.

Production practices can also determine the *composition* of SOM. For example, studies in the Midwest suggest that tillage not only reduces the total SOM, but also changes its composition by reducing the amount of SOM in the "slow fraction" while having little or no effect on the SOM in the "stable fraction" (Balesdent et al., 1988).

How Does Organic Matter Improve the Soil?

The difficulty in consistently demonstrating the specific benefits of organic matter in soils stems from its diverse nature, with fractions that have distinct effects on soil properties. Similar quantities of total organic matter in two agricultural soils could easily have different roles because of differing composition. The potential benefits of SOM depend on the *type* of organic matter rather than the absolute amount (Kay, 1990; Roberson et al., 1991).

Organic matter provides a number of benefits to the soil:

- increased biological activity— supplies nutrients, energy, and habitat for beneficial soil organisms

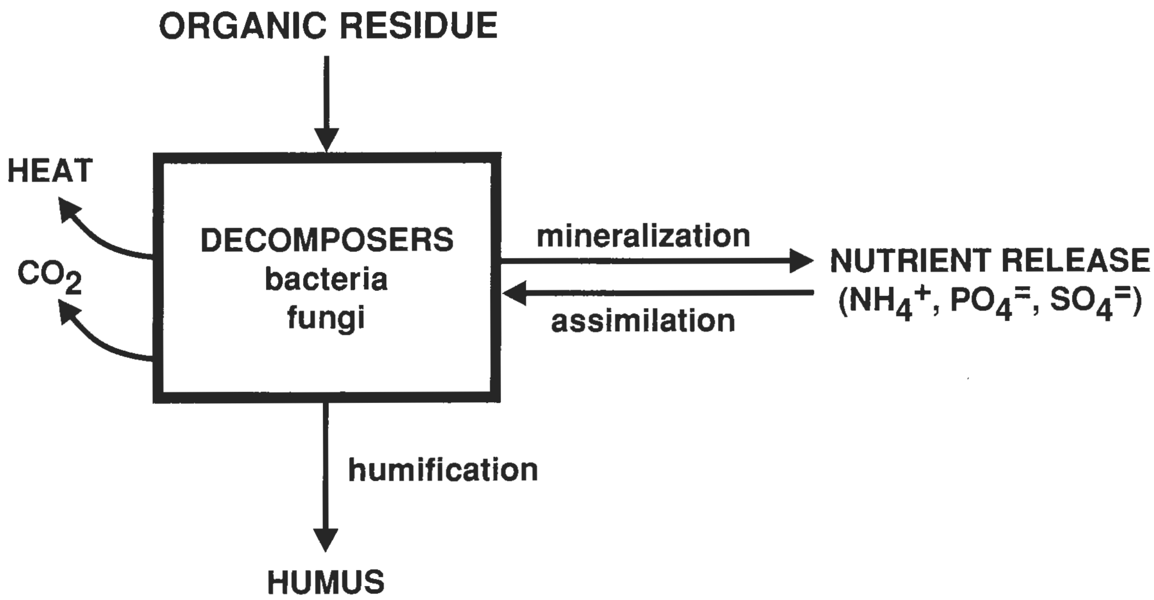

Fig. 1.1. Decomposition of organic residues.

Fig. 1.2. Organic matter pools and turnover rates. The "metabolic" components of plant residues (sugars, proteins, etc.) are quickly assimilated and broken down by soil organisms, whereas "structural" components such as cell walls (cellulose, lignin) are more resistant to decomposition. A portion of these more stable components of plant residue are modified to become humus (fractions B & C). SOM is commonly divided into three fractions with varying turnover times: (A) active SOM, turnover time 2-3 years (newly added OM, living organisms and associated structures); (B) slow SOM, 20-40 years (organic components derived from plants and soil organisms that are resistant to decomposition, physically protected organic compounds); and (C) passive (or stable) SOM, 500-1,000 years (extremely recalcitrant molecules, some physically protected humus). Figure from Parton et al. (1987).

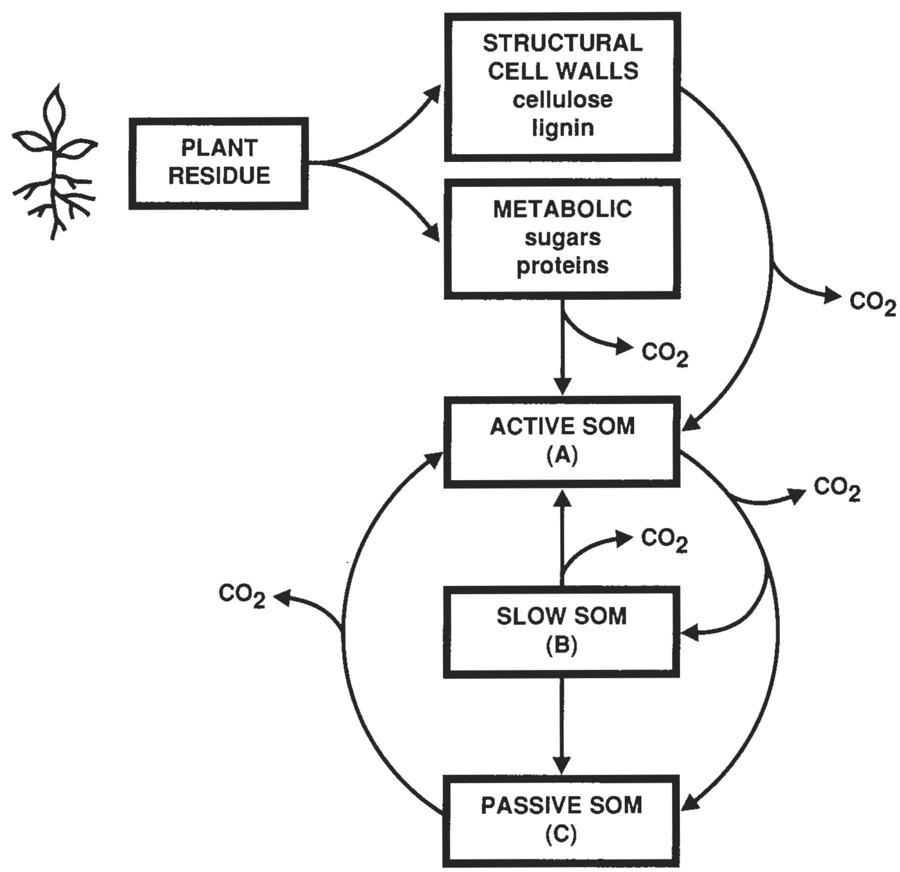

Table 1.2. Management Activities Influencing SOM Levels.

Activity	Effect on Soil Organic Matter
Tillage	Increases the decomposition of SOM
Irrigation	Increases availability of water during periods of warm temperatures; creates conditions favorable for rapid decomposition; increases the total yield of plant biomass.
Addition of organic residues	Incorporation of organic residues tends to raise the equilibrium OM level. This includes: cash crop residues, green manures, and imported organic residues such as animal manures and composts.
Composition of organic residues	Residues rich in nitrogen decompose more rapidly than those with less nitrogen. The proportion of resistant components (i.e., lignin, hemicellulose) also affects decomposition.
Crop rotation	Crops can have a significant effect on SOM levels via amount of residues returned to soil. Crops with extensive root systems and a high C/N ratio increase SOM; perennials can increase SOM through decreased tillage.

- nutrient reservoir—decomposition of SOM releases nutrients, particularly nitrogen, phosphorus, and sulfur, which can be taken up by plants
- retention of nutrients in available form — because humus molecules have many negative charges, they can interact with positively charged ions such as K^+, Ca^{++}, Mg^{++}, and H^+, and hold them temporarily in a form that is readily available to plants
- aggregate formation—SOM increases the aggregation of soil by several mechanisms resulting in a desirable, crumb-like structure
- increased porosity—increases in aggregation tend to improve the pore structure of the soil; changes in soil physical characteristics such as pore structure can alter water retention properties, and the water infiltration rate in soil.

These benefits stem from the presence of the nonliving organic residues as well as the activities of soil organisms. To help clarify the roles of these components, we need to discuss the distinct functions of SOM in soil biology, fertility, and physical structure. These processes, however, are all interrelated: The soil is a biological system that functions as an integrated whole.

Biological Effects of Soil Organic Matter

A diverse array of organisms populates the soil, including bacteria, fungi, algae, and many different types of invertebrates. By far the most predominant functional group is the decomposers (bacteria, fungi, actinomycetes), accounting for 95 percent of the living

Mechanisms of Disease Suppression

A number of researchers have shown that soil microbes can help control plant diseases, particularly root pathogens (reviewed in Cook, 1984; Cook and Baker, 1983). Because the addition of organic matter does not affect all types of microbes uniformly, the composition of the microbial population can be altered and even manipulated intentionally by the addition of various types of organic matter. Sometimes the favored microbes are antagonistic to pathogenic microbes, and the addition of organic matter results in suppression of a plant disease. Often, the antagonistic microbe releases a chemical that is toxic to the pathogen. In other instances it is simply a case of nutrient competition: The antagonist out-competes the pathogen for a limited nutrient needed for growth.

Pathogens can sometimes be suppressed by disking in a green manure. Decomposition of the green manure in the soil stimulates germination of the dormant spores of the pathogen. However, since the host plant is not around, the germinated spores have no additional food source and are attacked by other microbes. Finally, since decomposers serve as food for predatory soil organisms, any increase in their numbers will stimulate increases in the predators that can prey on pathogenic organisms.

biomass by weight. The other 5 percent is composed largely of organisms that feed on the decomposers, including protozoans, nematodes, mites and insects.

Regular additions of "food" in the form of fresh or decaying organic matter will result in an increase in the numbers of decomposers in the soil. The nature of this population expansion depends on many factors, including (1) the type of organic matter added, (2) the numbers of spores (or eggs) present in the soil, (3) physical conditions (temperature, oxygen concentration, moisture content, soil type), and (4) ecological interactions such as competition and predation.

As in any community of organisms, species interactions are complex and may favor or inhibit the activity of plant pests, particularly soilborne pathogens. Population dynamics of pathogenic soil organisms are governed by many of the same principles that regulate herbivore/predator numbers in insect populations. A soil populated by a diverse, active soil fauna will probably be less likely to favor the uncontrolled spread of a pathogenic microbe (Cook, 1984).

Besides disease suppression, soil organisms perform many other roles. Some free-living microbes fix atmospheric nitrogen. Microbes colonizing the root surface may actually stimulate plant growth by secreting hormones. Passage of SOM through the guts of worms and arthropods increases the availability of some nutrients, and the burrowing activity of these organisms aerates the soil and redistributes nutrients. We are only beginning to appreciate the numerous and varied roles of soil microbes and fauna in agricultural systems (fig. 1.3).

How Does the C/N Ratio Affect the Decomposition Rate and Release of Mineral Nitrogen?

Microbes require both carbon and nitrogen to grow and multiply. In most soil environments, carbon rather than nitrogen is limiting, so the addition of high-carbon residue stimulates microbial growth and increases the demand for nitrogen. The carbon-to-nitrogen ratio (C/N ratio) is very important in determining both the rate and the outcome of decomposition. Whether nitrogen is immobilized (taken up by microorganisms) or accumulates in the soil as NH_4^+ or NO_3^- depends on the microbes' requirement for nitrogen.

The C/N ratio of decomposers is usually between 5:1 and 15:1. If the residue has a C/N ratio greater than about 25:1, microbes will be limited by nitrogen availability and nitrogen will be retained, making it unavailable to plants. In that case, microbes compete directly with the plants for inorganic nitrogen. In contrast, residues with a low C/N ratio (less than 25:1) can be decomposed rapidly: nitrogen is in excess and will be released by the microbes in forms available to plants (NH_4^+ and NO_3^-).

The decomposition rate is also affected by lignin content. Residues high in lignin decompose slowly, even in the presence of excess nitrogen, because lignin is chemically resistant to decomposition. In such a case, carbon (actually the energy in the carbon bonds) limits microbial growth.

SOM and Soil Fertility

Soil organic matter serves as a reservoir of plant nutrients. These "organic" nutrients are bound to carbon, oxygen, and hydrogen to form large molecules in the non-living SOM. In most agricultural soils, even the low-organic-matter soils of California, the total amount of organic nitrogen in the SOM greatly exceeds the small amount that is present in the mineral form (also referred to as inorganic nitrogen: NO_3^- and NH_4^+ are the most abundant forms). This nitrogen is not available to plants as long as it is in an organic form, but neither can it be leached away. As organic matter decomposes in the soil, it releases nutritionally significant amounts of all plant nutrients in the mineral form needed by plants. In this way, SOM can function as a slow-release fertilizer providing a steady supply of inorganic nitrogen, phosphorus, and other nutrients.

The more humified SOM has many negative ionic charges that interact with positively charged ions in the soil solution, such as K^+, Ca^{++}, Mg^{++}, NH_4^+, and H^+, and hold them temporarily in a form that is available to plants. This tremendous cation exchange capacity (CEC) is particularly important in sandy soils where low CEC and leaching of mobile nutrients can be a problem. Another benefit of CEC is that it increases the pH buffering capacity of the soil. In addition, some of these negatively charged groups act as chelating agents for micronutrients such as iron, manganese, zinc, and copper. As chelating agents, they hold these micronutrients in a form available to plants.

SOM and Soil Tilth

Organic residues alter physical soil properties through both direct effects relating to increased organic matter levels and indirect effects brought about by soil organisms. Direct effects are easier to demonstrate (provided enough organic matter is added) since they relate

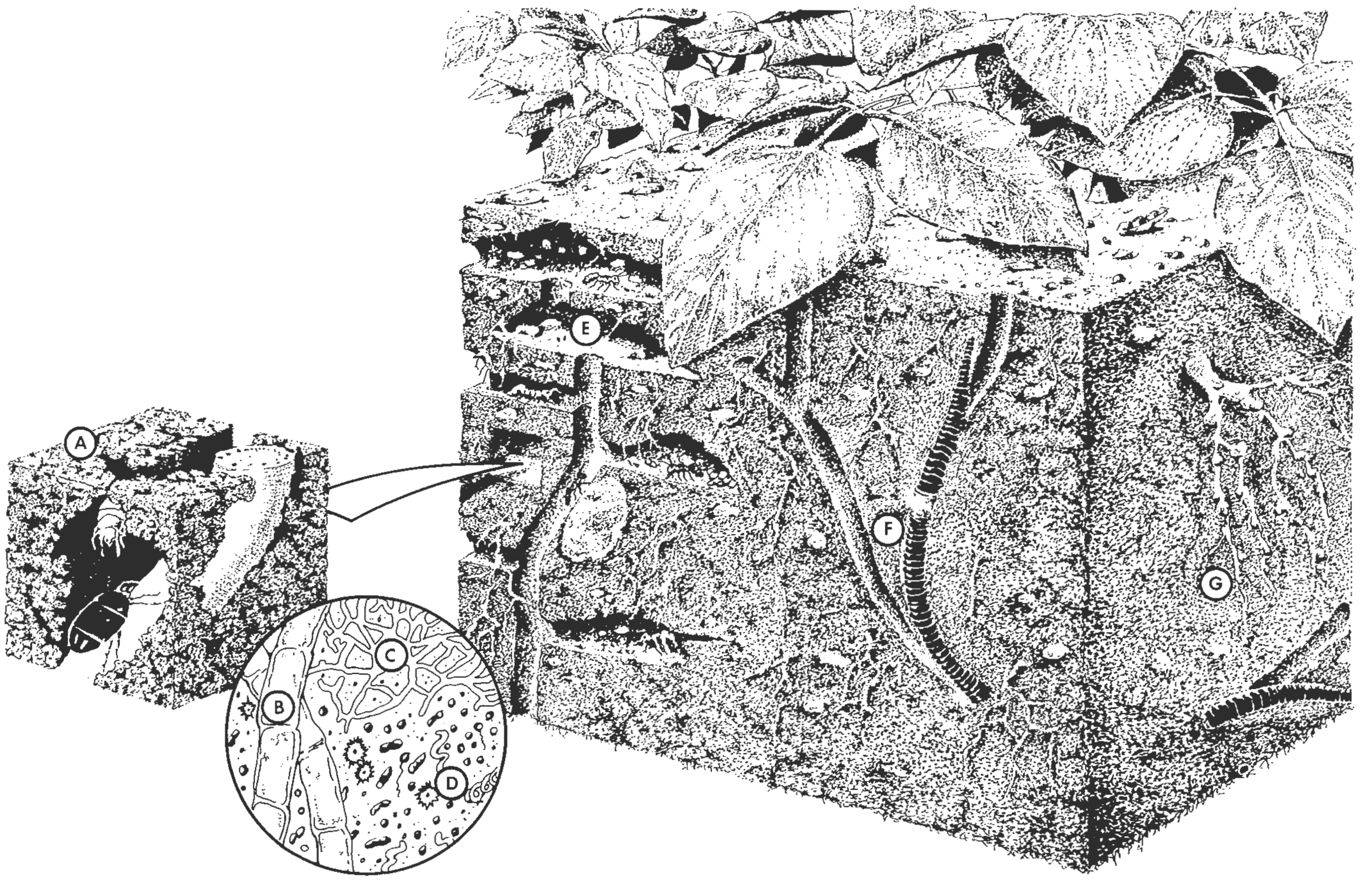

Fig. 1.3 Soil Biology. A diverse population of living organisms contributes to healthy soil. Some soil-dwelling organisms feed on living plant tissue and create serious pest problems for farmers. Many organisms, however, have a positive effect as they break down organic matter and cycle nutrients within the cropping system. A large number of soil-inhabiting nematodes (not shown) feed on decaying organic matter and its associated microorganisms, or are predators of other small soil animals. Soil arthropods such as mites and collembola (A) feed on decaying organic matter, fungal hyphae and spores, microorganisms, insect eggs and/or animal remains. Soil microorganisms including fungi (B), actinomycetes (C), and bacteria (D), decompose organic matter, thereby releasing more nutrients. Microorganisms also produce substances that help soil particles adhere to one another. Fungal mycorrhizae play an important role in transferring nutrients from the soil to plant roots. Ant excavation (E) and earthworm burrowing (F) result in a natural mixing of the soil. Earthworms are also involved in nutrient cycling. Rhizobium *bacteria (G) living in association with the roots of legumes are able to fix atmospheric nitrogen and convert it into a form useful to plants.*

Adapted from ***Sustainable Agriculture,*** *J. P. Reganold et al.* Scientific American *262(6):112-120.* *Redrawn by Marianne Post.*

to the obvious physical differences between organic residues and the mineral components of soil (sand, silt, and clay). A soil's water holding capacity, for example, can be increased simply because organic particles can hold much more water than mineral particles.

Many of the improvements in soil structure that occur from organic matter additions are the result of aggregate formation. In fact, increased aggregate stability is one of the earliest structural changes to take place when organic residues are added to soils (Kay, 1990; Roberson, 1991).

As shown in figure 1.4, there are several mechanisms for forming soil aggregates. Microbes produce a gelatinous matrix that adheres to soil particles and results in aggregate formation, while fungal hyphae hold soil particles together in the same way plant roots do. These forms of aggregation are relatively short-lived since the aggregates are held together by polysaccharides, which are easily decomposed by microbes (Oades, 1984). Longer-term aggregates are formed during decomposition as clay particles adhere to humic acids forming organo-mineral complexes. These aggregates tend to be more resistant to disruption but are smaller.

Increased aggregation can alter the pore structure, affecting water retention properties and soil aeration. Water holding capacity of soils increases as pore volume increases. In soils with a high clay content, improved aggregation can play a significant role in increasing the productive capacity of the soil. Water infiltration rate can also increase in well-aggregated soils.

Soil fauna also affect soil structure. The burrowing tunnels and castings of earthworms improve soil pore structure and aeration. While earthworms are important in no-till systems, much less is known about their contribution in heavily cultivated systems. Tillage is extremely disruptive to earthworms and tends to drastically reduce their numbers (Werner, 1990).

In California, several experiments have shown that organic residues from winter annual cover crops can improve soil tilth. Roberson et al. (1991) found that improved aggregation and hydraulic conductivity correlated with higher microbial activity and soil carbohydrate content after two to three years of cover cropping in walnut orchards. In an experiment with tomatoes and corn, cover crops increased aggregation, microbial activity, and water infiltration, and reduced soil crust strength (Groody, 1990; Roberson et al., 1992).

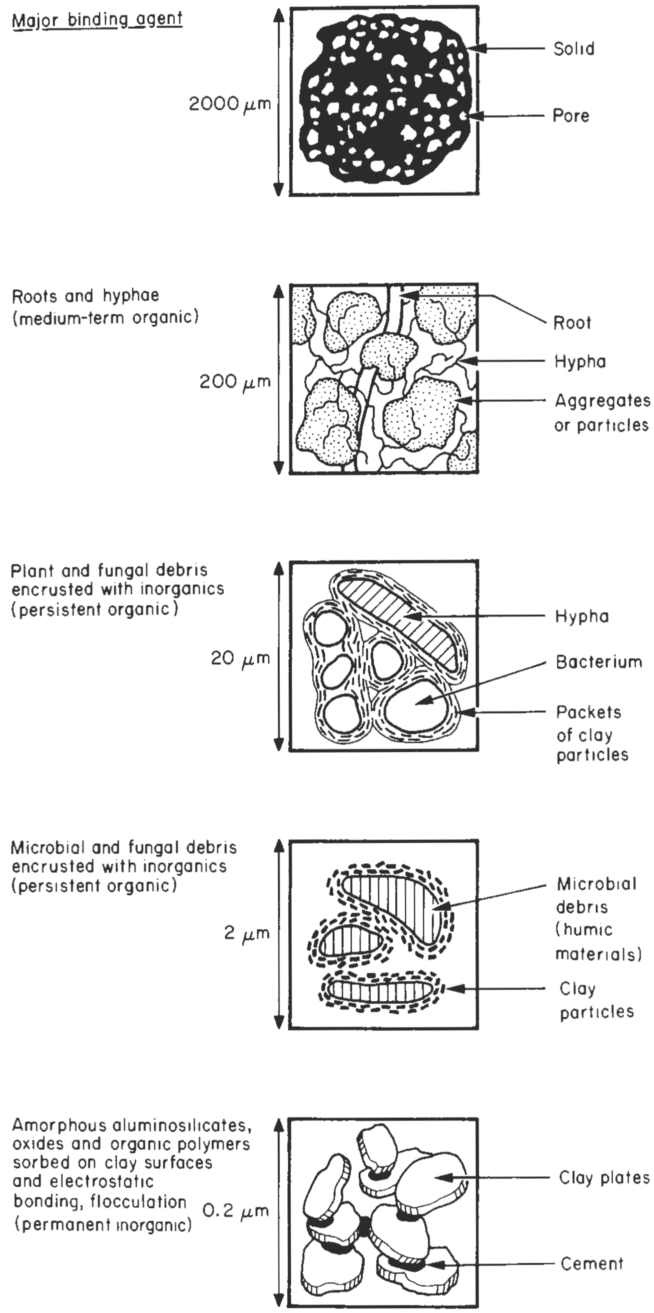

Fig. 1.4. Model of aggregate organization showing major binding agents (2,000 μm = 2 mm).

From ***Organic Matter and Water Stable Aggregates,*** *J. M. Tisdall and J. M. Oades.* Journal of Soil Science *33:141-163.*

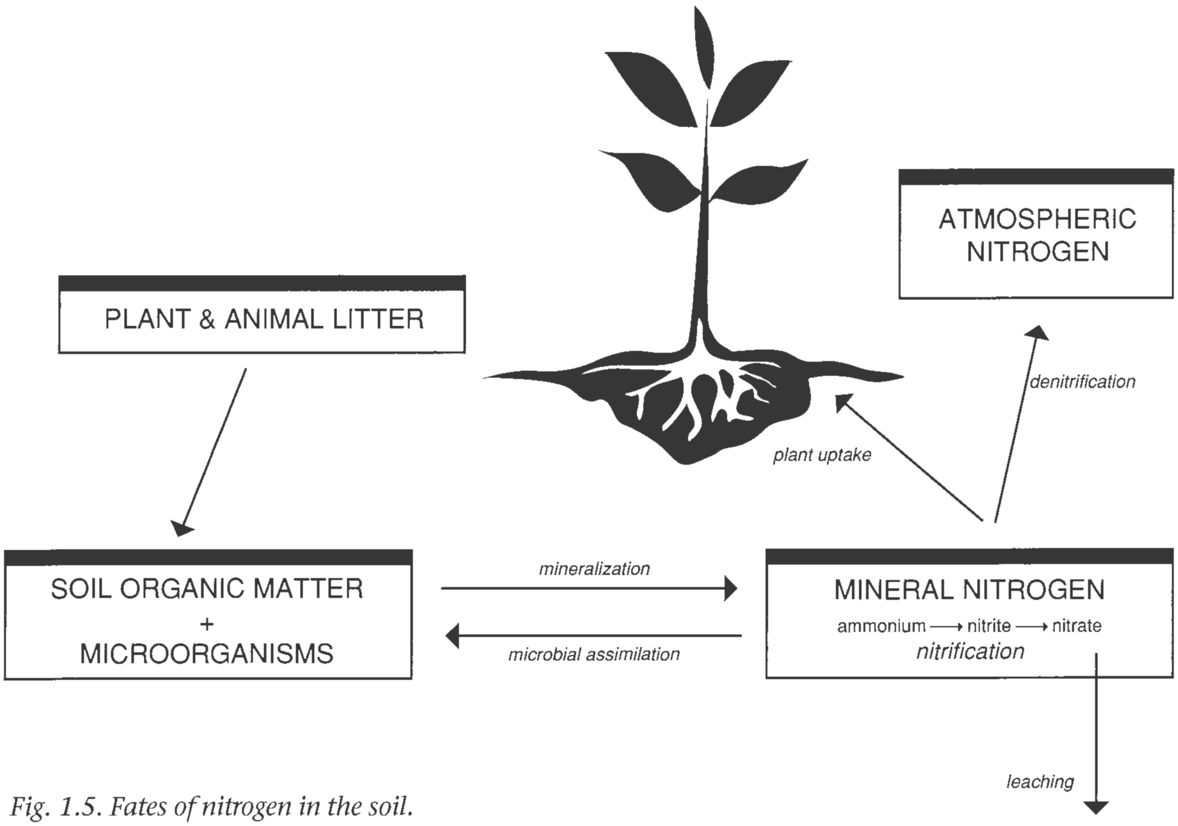

Fig. 1.5. Fates of nitrogen in the soil.

Nitrogen Cycling

Incorporating organic residues and green manures as sources of nutrients fundamentally changes the structure of agricultural ecosystems, particularly in areas where soils are low in organic matter. Instead of adding mineral forms of nitrogen or a simple organic compound such as urea, nitrogen is added as a complex mixture of readily metabolized and recalcitrant organic compounds. Rather than diminishing the role of decomposers, the use of organic residues requires the integration of soil microbial populations into the cropping system to convert nutrients into a form plants can absorb. Consequently, the decomposers play a central role in making nutrients available to plants (particularly nitrogen, and to some extent phosphorus and sulfur). Figure 1.5 shows the possible fates of nitrogen in the soil.

During mineralization, nitrogen is released from complex organic molecules as ammonium (NH_4^+). Ammonium can then be taken up by the microbes (immobilization) or oxidized by a group of organisms called nitrifyers, producing nitrite (NO_2^-) and then nitrate (NO_3^-), a process called nitrification. Plants can take up both NH_4^+ and NO_3^-. If large amounts of NH_4^+ are present — after heavy applications of raw manure, for instance — nitrogen can be lost as NH_3 gas. More commonly, nitrogen is lost through leaching of NO_3^- since it is negatively charged and not held by the cation exchange sites. In microsites of low oxygen concentrations, which can occur with over-irrigation, NO_3^- can be reduced to N_2 (denitrification) and lost to the atmosphere. Some NH_4^+ is fixed by mineral complexes in the soil, making it unavailable to both microorganisms and plants, although this NH_4^+ can be released by wetting and drying cycles. NH_4^+ can also be bonded to SOM and become part of the stable humus.

The biologically driven transformations of nitrogen are integrated with the cycling of other nutrients required by the microbes and dependent on carbon turnover. Microbial demand for NO_3^- and NH_4^+ is linked to the availability of high-energy carbon substrates: When residues containing high carbon are present, more nitrogen will be immobilized as the microbial biomass expands. Carbon is also required for denitrification.

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2. Evaluating Organic Materials

Determining the true agronomic value of an organic amendment is a complex matter, requiring analysis of both nutrient benefits and improvements in soil quality. The dollar value of the nutrients in organic materials is relatively simple to calculate, based on the nutrients' availability (N, P, K, etc.) and the current price of inorganic fertilizers.

Assigning an economic value to non-nutrient effects is much more difficult, so it is common practice to ignore these benefits altogether. This approach may seem reasonable over the short term because improvements in soil quality are relatively small compared to the nutrient effects. Over the long term, however, the non-nutrient benefits can lead to significant improvements in yield and in the efficiency of the production system.

Multi-year studies on the effects of livestock waste, for example, have shown that manure can increase crop yield beyond the level that could be attributed solely to its nutrient content. This phenomenon is most likely a result of the additional organic matter contained in the manure. As explained in Chapter 1, this organic matter may improve soil tilth, increase water holding capacity in some soils, and indirectly enhance nutrient cycling or disease suppression. Each of these parameters has a positive effect on crop yield.

Organic vs. Inorganic

Synthetic inorganic fertilizers are more concentrated and are generally less expensive per unit of nutrient than organic fertilizers. In addition, most synthetics are water soluble and are manufactured with a high degree of quality control, resulting in greater consistency in nutrient content and a more predictable rate of release into the soil. These qualities have the potential to promote precise and efficient management of nutrients in the field. Often, this potential is not achieved. The very solubility that makes synthetic fertilizers so useful can lead to inefficient use and groundwater contamination when the fertilizer is applied at the wrong time or at excessive rates. Synthetic slow-release fertilizers provide one approach to solving the problem of poor efficiency, but because of high cost, their use is generally restricted to high-value crops like strawberries or ornamentals.

Although organic fertilizers generally are less concentrated than synthetic fertilizers, the nutrients added (particularly nitrogen), are held in a non-leachable form and released slowly into the soil. Because of this characteristic, organic materials such as manure and cover crops can be looked at as a special type of slow-release fertilizer, adding to the fertility of the soil with less risk of losing the nutrients through leaching.

A recent field experiment at UC Davis comparing cover crops and synthetic fertilizers supports this hypothesis. Cover-cropped plots supplied amounts of nitrogen comparable to those of plots treated with synthetic fertilizer, levels sufficient to produce good yields of processing tomatoes. The added benefit from using cover crops was that there was no movement of nitrate below the root zone during the rainy season. (Shennan and Griffin, unpublished)

Other Considerations

A major problem with synthetic fertilizers containing ammonium, especially ammonium sulfate, is that they will acidify soils with continued use. Soil acidification can lead to poor soil structure and reduce the availability of other nutrients.

There are drawbacks to consider with organic fertilizers, too. Manure, for example, may contain weed seeds or soluble salts. Other materials that are high in carbon may have the potential to tie up nitrogen during decomposition. The cost of purchasing organic fertilizers can be high, and will vary according to the degree of processing, the distance to transport the material, and method of application.

Soil Amendments and Fertilizers: Making Good Choices

Deciding which organic material to use and how much to apply can be a difficult and confusing task. To help guide your decisions, remember the following seven points.

1. Begin with your current production system and think in terms of the overall quality of your soil, and the needs of the plants. Assess the nutrient status of the soil as well as its physical characteristics and tilth. Remember, the nutrient status of the current year relates directly to previous years' fertility: It does not reset itself to zero at the beginning of each growing season. Make sure you account for carryover from fertilizer, manure, and incorporation of crop residue. Use your own powers of observation in the field in conjunction with laboratory analyses.

2. The nutrient status of your soil can be evaluated either by direct soil sampling and testing, or by analysis of leaf or petiole tissue of the growing crop. Both methods have their merits in different situations (see University of California Division of Agriculture and Natural Resources Bulletin #1879, *Soil and Plant Tissue Testing in California*). In California, these tests must be carried out by the grower or through a private laboratory. Contact your farm advisor for reputable labs in your area. Specific nutrient requirements of a crop may be hard to pin down, and recommendations tend to change as new data become available. Your farm advisor has access to the most up-to-date and applicable research, and is a good source for this information.

3. The composition and quality of organic amendments and fertilizers is highly variable. Also, standards for characterizing and labeling do not exist for most organic materials. Therefore, if you are applying an organic material as a fertilizer, it is important to get accurate information about its nutrient composition. Some companies may provide analyses of their products free of charge. However, to have the most accurate records on nutrient inputs, each load or shipment of material applied to the soil should be analyzed separately by an independent testing facility.

4. Organic fertilizers are usually more expensive per unit nutrient to purchase, transport, store, and apply than synthetic chemical fertilizers. When evaluating the costs and benefits of various materials, however, consider that organic materials have two additional benefits. First, they can supply organic matter, which maintains soil tilth and friability. Second, organic amendments provide "fuel" for microorganisms, thereby promoting cycling of nutrients within the production system, and in some cases, suppressing harmful pathogens. It is difficult to assign a dollar value to these non-nutrient benefits.

5. Some organic materials (e.g., sewage sludge), may contain compounds or organisms that are potentially harmful to plants or humans. Use these materials with caution.

6. Keep accurate records. Monitor crop response over the course of the growing season, and make adjustments in application rates as necessary.

7. One organic material alone usually will not solve problems of soil tilth and fertility. The best approach is to develop an integrated program of soil management that combines appropriate levels of tillage with a variety of inputs including cover crops, mineral supplements, gypsum or lime, organic amendments, and/or foliar sprays.

3. Types of Organic Amendments and Fertilizers

Animal Manures

Given the size of California's livestock industry, it should not be surprising that livestock manure is one of the most common organic materials used by farmers, both as a direct addition to soil and as a constituent of compost. The state's livestock produce about 14 million tons of solid waste (dry basis) annually.

The amounts of manure produced annually by the more important livestock species are shown in table 3.1, but not all of this manure is collected and used for fertilizer. Some is disposed of on marginal soils (not as fertilizer for a crop). Manure may also be discarded in landfills.

The total quantity actually collected and applied to farmland is not known, but a 1988 survey of dairy producers in California found that 80 percent of the solid manure from that industry is applied to farmland statewide (Meadows and Butler, UC Davis Department of Agricultural Economics). Fifty-four percent of the solid manure was applied to the farm of origin; about 19 percent was sold off-farm, and another 18 percent was hauled away at the dairy farmer's expense. About 90 percent of the liquid waste was applied to the farm of origin. It seems likely that 8 to 10 million tons of livestock manure are collected and applied to land each year — about one ton per acre of irrigated farmland if it were uniformly distributed.

Table 3.1. Livestock Waste Production in California.

Sources	Solids per Year Dry Weight
	Tons
Dairy, milk cows	2,900,000
Dairy, non-milking	1,800,000
Beef, non-feedlot	3,800,000
Beef, feedlot	540,000
Broilers	281,000
Layers	330,000
Breeder hens	37,000
Turkeys	330,000
Turkey breeder hens	17,000
Horses	2,000,000
Sheep	280,000
Hogs	38,000

Source: Pettygrove, Fairbank, and Oster, 1992. [Adapted from 1989 California Livestock Statistics, California Agricultural Statistics Service.]

Types of Manure in California

Dairy cattle. The physical and chemical properties of cow manure depend in part on the method used to collect and dispose of waste in the dairy. In the drier areas of the state (southern California and the southern San Joaquin Valley) cows are kept in dirt-floor corrals where the manure plus accumulated urine is periodically scooped and stacked.

In the central and northern parts of the San Joaquin Valley, where water is less expensive and winters are wetter, cows are kept in freestall barns that are washed out daily. The wastewater flows into a settling basin or passes through a mechanical separator where coarse material is removed. The wastewater — still carrying a large amount of suspended and dissolved organic matter — passes into a lagoon. When it is necessary to empty the lagoon, this water is mixed with fresh water and used to irrigate adjacent cropland.

So dairy manure is produced in three forms: corral scrapings, separator solids, and lagoon wastewater. Only the first form is commercially available to any extent. In the southern San Joaquin Valley, solid dairy waste is a common constituent of commercial compost. Dairy manure in southern California is often dried and screened, and sold as "steer manure" in retail nurseries or is used as a component of "topsoil" landscaping material.

Beef cattle. Most of the beef cattle manure is deposited on rangeland and pasture in California, but some is collected at large feedlots and made available to farmers directly or used by commercial compost makers.

Poultry. The most important poultry manures in California are broiler litter, egg layer manure, and turkey litter. Most of the broilers in California are reared in houses with rice hulls or wood shavings as litter. Commonly, five broods per year are raised. After each brood,

Table 3.2 Plant Nutrient Content (Dry Basis) of Selected Manures and Composts.

Description	Total N	Ammonium N	P_2O_5	K_2O	S
	lbs per ton				
Non-composted poultry					
Turkey/rice hull litter	35	4	53	37	6
Fresh broiler/rice hull	78	6	51	53	9
Fresh layer	79	8	125	67	16
Aged layer	43	9	164	79	14
Non-composted dairy/steer					
Fresh dairy separator solids	43	1	17	12	10
Fresh dairy corral scrapings	47	2	26	141	12
Aged dairy separator solids	41	1	13	8	9
Aged steer corral scrapings	26	5	31	66	8
Composts					
Broiler/rice hull compost	38	2	86	50	11
Dairy	27	1	27	57	9
Dairy/gin trash	31	1	22	57	14
Dairy/steer	33	0	17	51	9
Dairy/poultry	34	2	39	66	10
Gin trash	47	0	18	75	29

All materials collected from commercial sources in California during 1990. Ammonium run on KCl extract of undried samples. All other analyses run on dried, ground samples.

Source: Pettygrove, unpublished laboratory analyses.

the house may be cleaned down to the bare dirt, but in some cases, some litter is left. Therefore, a stack of manure cleaned out of broiler houses may contain materials varying in age from a few weeks to a year or more. Variations in the age of the material, and the type and amount of litter in the manure, result in variations in its nutrient content. Turkeys are reared similarly in pens spread with rice hulls or wood shavings.

Egg layers are reared in cages in multi-layered "high-rises" or in low-rise buildings. In high-rises, the manure drops to the ground and collects and dries for as long as one year. Low-rise houses are usually scraped out more often. Layer manure in some operations is collected as a slurry in holding tanks.

Unscreened poultry manure contains feathers, uneaten feed, broken eggs, and parts of bird carcasses. When the birds go through a molt, the feather content will seem quite high. Feathers are mostly protein and will not harm the soil, but may blow around during hauling and spreading. Some egg layer manure is treated with boron-containing compounds for fly control and may be toxic to plants. Because poultry excrete liquid and solid wastes together, poultry manure is higher in nitrogen than manure of other farm animals. It usually has a ready market. Some producers carefully process their manure to enhance its value as a fertilizer or organic amendment by drying and screening it. Both for fly control and to minimize the loss of ammonia, it is recommended that poultry manure be dried quickly by spreading it in a thin layer.

Horse. In spite of the large quantity of horse manure produced in California, very little of it is commercially available. Horse manure is often mixed with a high proportion of litter material such as straw, wood shavings, or rice hulls. In some areas, horse bedding with manure is mixed with other components and composted to make landscape "topsoil."

Nitrogen Fertilizer Value of Livestock Manure and Composts

Table 3.2 shows that manures and composts are good potential sources of the major plant nutrients, depending on the type of manure and the quality of handling and storage. Nitrogen is of particular interest to farmers because it is usually the limiting factor in crop growth. In fact, manure is the most widely used and cheapest source of nitrogen in California aside from chemical fertilizers. Most of this nitrogen is in an organic form and must be converted, or "mineralized," by soil microorganisms to inorganic forms of nitrogen (ammonium and nitrate) before it can be taken up by plants.

Much research has gone into determining the rate of mineralization of nitrogen in manures, and the factors that influence it. Researchers have not yet been able to provide an accurate formula or practical laboratory test that would permit a farmer to know the availability of the nitrogen in such materials. However, we have learned enough to allow us to offer some suggestions about manure management and provide examples of the nitrogen availability in several materials.

Nitrogen Management Principles with Manure

The availability of nitrogen declines as manures age or are composted. As manures are exposed to wetting, drying, rainfall, and microbial activity, the inorganic forms of nitrogen are lost by leaching and volatilization, and the more readily decomposed organic nitrogen compounds are converted to more stable forms. Composting is a process in which microorganisms rework the organic matter, usually at high temperatures (120° to 150°F). Part of the nitrogen is lost as ammonia and part of the remaining nitrogen is stabilized in humus-like compounds that are less-readily mineralized.

The effect of composting on total nitrogen content and nitrogen availability is not well understood. Some compost suppliers report that composting in a proper manner actually increases nitrogen concentration because during composting, carbon is lost more quickly than nitrogen. In general, composts and manures containing less than 1.5 percent nitrogen (dry basis) will supply little or no nitrogen to crops during the first few weeks after application. This is due to immobilization, a temporary tie-up of nitrogen that occurs when materials with a high C/N ratio are added to soil.

Poultry manure nitrogen (non-composted) is more quickly available than nitrogen in manure from cows, horses, and sheep. This characteristic is mainly a result of the presence in poultry manure of uric acid, which is rapidly available. Additionally, roughage in cattle and horse diets results in manure that is less readily decomposed due to the presence of lignin and cellulose. However, poultry manure nitrogen is more subject to losses for the same reasons. Breakdown of uric acid nitrogen in poultry manure sometimes results in high ammonium concentrations, as high as 50 percent of the total nitrogen in the manure. Like the ammonium contained in synthetic fertilizers, this ammonium can be lost by volatilization or quickly converted to nitrate, which in turn is subject to leaching and denitrification (gaseous loss under saturated soil conditions).

Presence of bedding or litter lowers nitrogen content by dilution, but its effect on availability of nitrogen is not known. Little information is available on the effect of the

Table 3.3. Nitrogen Losses from Animal Manure as Affected by Method of Handling and Storage.

Handling & Storage Method	Nitrogen Loss %[a]
Solid systems	
Daily scrape & haul	15-35
Manure pack	20-40
Open lot	40-60
Deep pit (poultry)	15-35
Liquid systems	
Anaerobic deep pit	15-30
Above ground storage	15-30
Earthen storage pit	20-40
Lagoon	70-80

[a] Based on composition of manure applied to the land vs. composition of freshly excreted manure, adjusted for dilution effects of the various systems.

Source: Sutton et al., 1983.

Table 3.4. Nitrogen Losses from Animal Manure to the Air as Affected by Method of Application.

Method of Application	Type of Manure	Nitrogen Loss %[a]
Broadcast **without** incorporation	solid	15-30
	liquid	10-25
Broadcast **with** incorporation	solid	1-5
	liquid	1-5
Injection (knifing)	liquid	0-2
Irrigation	liquid	30-40

[a] Percent of total nitrogen in manure applied which was lost **within 3 days** after application; wind and temperature effects may increase losses.

Source: Sutton et al., 1983.

amount and type of litter or bedding material on nitrogen release from manures and composts. The most common bedding materials are wood shavings, rice hulls, and straw. These are generally so low in nitrogen content (1% or less) that they do not provide much nitrogen to plant nutrition. By providing an energy source for soil microbes, they may even temporarily (for a few weeks) tie up or immobilize inorganic nitrogen that is already present in the soil or that is released during the mineralization of organic nitrogen in the manure. Immobilization would be particularly critical with straw bedding. Straw is high in carbon and breaks down very rapidly under the right conditions.

In contrast, wood shavings and rice hulls decompose more slowly because they have both a high carbon and high lignin content. Slower decomposition means that microbes will not be competing so heavily with plants for nitrogen. Manure mixed with these types of bedding materials may be more acceptable as soil amendments (Mackay et al., 1989).

Although litter mixes with manure and readily absorbs urine, we do not know how these added components affect the breakdown of the bedding material or the rate of nitrogen mineralization from the manure. Remember, when a laboratory determines the nitrogen content of broiler litter or droppings from a horse barn, the analysis is for the manure plus bedding. It may not accurately reflect the availability of nitrogen in the manure.

Moist manure, when exposed to the air, undergoes significant loss of nitrogen as volatile ammonia. Fifty percent or more of the nitrogen in excreted manure and urine is lost from corrals, lagoons, manure piles, compost windrows, and fields or orchards after spreading. If manure can be dried quickly by spreading in a thin layer, nitrogen loss will be reduced during storage. Nitrogen losses after spreading can be significantly reduced by incorporating manure — even shallow incorporation is adequate — within a few hours of spreading. Ammonia losses in the first few days after surface spreading of fresh manure can amount to 15 percent or more of the nitrogen present per day (see tables 3.3 and 3.4). Nitrogen losses will be especially severe if liquid manure is spread on warm windy days when evaporative potential is high.

Nitrogen Availability during the First Year

Generally, during the first year after manures or composts are applied to cropland and incorporated, somewhere between 20 and 90 percent of the organic nitrogen is converted to ammonium, which in turn is converted to nitrate. For dairy and beef feedlot solid manure, 20 to 50 percent of the organic nitrogen will be mineralized (converted to available forms) during the first year for manure with an initial nitrogen content in excess of 1.5 percent. For non-composted poultry manures with or without litter, reported mineralization rates range from 30 to 90 percent in the first year. The wide range is probably the result of the very high decomposition rate and the possibility of large rapid losses of nitrogen as volatile ammonia. An example of mineralization rates experimentally determined in a greenhouse study is shown in table 3.5. This experiment involved composts and manures of different ages that were collected from commercial California livestock operations.

Table 3.5. Available Nitrogen from Animal Manures.

Manure Type	Total N % of Dry Wt.	Available N % of Total N	Available N lbs/ton Dry Wt.
Chicken	4.6	65	60
Comp. chicken	1.7	35	12
Pig	3.9	47	37
Beef	2.6	40	21
Sheep	2.3	36	17
Dairy[a]	2.9	30	17
Dairy	2.0	24	10
Composted dairy[b]	2.0	21	8
Composted dairy	1.9	14	5
Composted dairy	2.1	6	2

[a] Two samples
[b] Three samples

Source: Castellanos and Pratt, 1981.

Nitrogen Availability over Longer Time Periods

After the initial period of decomposition, nitrogen is released from the residual material at lower rates during the second and third years, finally reaching a release rate of about 5 to 6 percent per year. This rate is only slightly higher than the mineralization of nitrogen from the soil organic matter of unamended soils. However, this residual nitrogen can become important when regular additions of manure are made. For organic farmers who use manure or compost to fertilize crops, the build-up in organic matter means that over time, the rates of manure required to fertilize crops can be reduced. It is not possible to predict over a period of years what the exact residual nitrogen release will be. This amount must be determined by careful monitoring of crop performance and use of soil and plant tissue analysis. If the residual release is not taken into account, overfertilization and pollution of groundwater can result.

Phosphorus and Potassium

Animal manures and composts are also excellent sources of plant-usable phosphorus and potassium (see table 3.2). Manure contains from 10 to 90 lbs P_2O_5 per wet ton. In neutral or acidic soil, phosphorus in manure is worth 70 to 90 percent of phosphorus in superphosphate fertilizers. In calcareous (high-pH) soils, manure phosphorus is worth 100 percent or more of phosphorus in superphosphate fertilizers. This is because inorganic phosphate tends to undergo precipitation reactions and become unavailable to plants in high-pH soil. Also, availability of phosphorus in manure is relatively insensitive to cool soil temperatures down to 60° to 65°F. The potassium in manure is in a readily available form.

Salts and Weed Seeds in Livestock Manures

Salts in animal manures can accumulate to undesirable levels in the soil when excessive amounts are applied or irrigation and precipitation are inadequate to leach the accumulated salts from the root zone. Manures from animals that have had free access to salt will contain higher levels of salt. Dairy manures often contain 2.5 to 5.0 percent potassium and one quarter as much sodium (potassium and sodium contribute to the overall amount of salt in the material). Manure from beef cattle that have had ready access to salt may contain twice as much sodium as potassium. Where such manure is applied, extra irrigation water is required for leaching. As an example, if 10 tons of manure containing 7.5 percent salt are applied per acre, one extra inch of irrigation water is required. Composting does not reduce the salt level unless the compost is leached.

Manure that has not been composted, or that has been only partially composted, can also contain viable weed seeds. The type and number of weed seeds depends on the source and quality of the feed.

Sources of Information (Animal Manures)

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Compost

Compost is any mixture of decomposed organic matter. It is the result of a dynamic, biological process involving a mixed population of microorganisms. Nearly all organic wastes can be used to make compost, so the final product and its quality are variable, depending on (1) the nature of the composting process, (2) the composition of the starting material, and (3) the maturity of the compost.

Quality Factors

Type of composting. Organic matter can go through two very different decomposition processes: aerobic decomposition (oxygen present) or anaerobic (oxygen absent). Aerobic decomposition is the most desirable. During aerobic composting the unstable organic compounds present in the raw materials are broken down by bacteria, fungi, and invertebrate decomposers, resulting in the production of carbon dioxide, water, ammonia, and heat. Large molecules such as hemicellulose and lignin are broken down to form humus, the dark-colored, amorphous material remaining after decomposition is completed. Finished compost can contain up to 60 percent humus.

Anaerobic decomposition (also called fermentation) results in the production of organic acids and other compounds which are toxic to plants. Consequently, the use of anaerobically produced composts should be avoided because they can actually inhibit plant growth.

Composition of starting material. The most important characteristics of organic residues that affect the rate and outcome of composting are nitrogen and lignin contents. This fact has been demonstrated in experiments such as the one summarized in table 3.6. Plant materials of differing C/N ratios and lignin contents were composted for 180 days under the same conditions. Decomposition occurred much more rapidly in young grass, the plant material with the lowest C/N ratio (highest nitrogen content). At the end of 180 days, compost from the young grass had the lowest C/N ratio and the highest humus content. However, more than half of the nitrogen was lost during decomposition. In the straw, essentially all the nitrogen was retained, and the C/N ratio decreased dramatically as carbon was lost through respiration. The compost formed from the straw still had a high C/N ratio; if it were added to soil, nitrogen would likely be immobilized. Since straw decomposed more slowly than young grass, it also had a lower level of humus at the end of 180 days. (For more information about the effects of carbon, nitrogen, and lignin on the decomposition process see the section on **Wood-Derived Materials,** page 30.)

Crop residues generally have a high C/N ratio and consequently decompose very slowly. If residue with a large amount of nitrogen relative to carbon (a low C/N ratio) is used as the starting material, the composting process will be faster, but much of the nitrogen will be lost as ammonia during decomposition. The optimum C/N ratio for conservation of nitrogen and rapid decomposition ranges from 25:1 to 30:1. To obtain the optimum ratio, it is common to combine animal manures with plant wastes such as straw or cotton gin trash.

Maturity of compost. As composting proceeds, an increasing proportion of the organic residues will be acted upon by decomposers, resulting in stabilization and modification of the raw organic matter. Generally, more mature compost has a lower C/N ratio, higher humus content, and a higher cation exchange capacity than unfinished compost from the same starting material.

Table 3.6. The Effect of Nitrogen and Lignin Content of the Starting Material on Compost Characteristics.

	Before Composting			After 180 Days' Composting		
Material	% N	C/N	lignin	% N lost	C/N	Humus Formation
Young grass	3.7	12	low	55	9	highest
Mature grass	1.5	29	medium	15	15	intermediate
Straw + N[a]	1.5	29	high	7	36	low
Straw	0.5	85	high	0	48	lowest

[a] Nitrogen was added at the beginning of composting in the form of ammonium phosphate to give C/N equal to the mature grass.

Source: Hammouda and Adams, 1987.

Thermophilic composting

Provided there is adequate water and oxygen, metabolic activity in the compost pile with C/N ratios in the optimum range proceeds quickly enough to generate intense heat. These temperatures, which can be as high as 140° to 160°F, kill the microbes that cannot tolerate high temperatures and select for those that require hot temperatures in order to live and reproduce (thermophilic microbes). The heat generated during the decomposition process is usually sufficient to kill most pathogens and weed seeds. There has recently been a great deal of interest in microbial "starters" that are purported to stimulate the activity of decomposers and enhance the composting process. A variety of materials are being marketed as compost starters, but there are very few impartial studies to support their efficacy.

Vermicompost

Sometimes, earthworms or manure worms are used to facilitate the decomposition process. When worms are used, the compost never reaches temperatures hot enough to kill pathogens and weed seeds, so the finished product can contain viable spores and seeds. Instead, decomposition is carried out by the microbes that live in the earthworm gut as well as free-living decomposers. There is some evidence that passage of organic matter through the digestive system of the earthworm increases the proportion of phosphorus that is available to plants.

Spent Mushroom Compost

Spent mushroom compost is the material that remains after mushrooms have been harvested. Mushroom growers use a mixture of animal manures and straw to produce a compost appropriate for mushroom culture. These raw materials are put through a fast, thermophilic composting which kills many of the soil organisms that could compete with the mushroom fungus. Growers use gypsum to line the containers of compost during mushroom production, so spent mushroom compost is generally low in nitrogen and high in calcium.

Compost Nutrient Values

Table 3.7 contains several sample compost analyses. Composts are usually used as soil conditioners because of their high humus content, and as sources of micronutrients, but some composts can also supply adequate macronutrients. A high-nitrogen compost (1.5% or more) could supply sufficient nitrogen, depending on the nitrogen demand of the crop and the residual nitrogen content of the soil (Buchanan and Gliessman, 1991).

Low-nitrogen composts would have to be applied at such high rates that they are not economically feasible as a nitrogen source. Compared to manures, composts are relatively expensive (in California compost can cost three times as much as local manure), so you should be clear about your reasons for purchasing it. When purchasing commercial compost you will usually be able to obtain a chemical analysis of the product, which you can use to assess the value of the compost for your particular situation.

Table 3.7. Nutrient Composition of Finished Composts.

Starting Material	N	P	K	H_2O
	%			
Thermophilic composts				
Dairy manure + cotton gin trash	2.1	0.4	1.3	21.8
Steer manure + bedding	1.9	0.9	2.7	20.2
Vermicomposts				
Horse manure	3.4	0.25	0.77	—
Cow + sheep manure	1.5	0.07	1.41	—
Municipal waste	1.0	0.21	1.02	—

Sources: Laboratory analyses of composts available in California. Also, Hervas et al. 1989.

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Comparison of Compost Versus Manure

Compost and manure each have advantages and disadvantages. The choice of one material over another should depend on which benefits are most important at a particular time, a complete analysis of the product being sold, and your ability to store, handle, and apply the material properly. Some of the key attributes to consider are included in the following chart.

Attribute/Effect	Comparison
N content	Highly variable for both.
N stability	Nitrogen in composts is in a more stable form, so there is a decreased likelihood of losing N from the system; manures tend to contain more readily available N.
Humus content	Composts generally have a higher humus content.
Activation of microbes	Manure contains raw organic matter, which is a source of energy and nutrients for microbes. Decomposition and humus production continue after manure is incorporated, resulting in a release of N.
Pathogens/weed seeds	If compost is produced using the thermophilic process, most pathogens and weed seeds are killed during composting. Spores and seeds are usually still viable after passing through animal's gut.
Cost	Compost is more expensive.
Planting date	Manures: may need to wait 2 to 6 weeks after application incorporation. Composts: plant immediately.
Soil structure	Both manure and compost can improve soil tilth, but the timing and mechanisms may differ; a direct comparison has not been made.

Concentrated Animal By-Products

Compared to bulk organic amendments like manure or crop residue, concentrated animal by-products have a high concentration of nutrients (table 3.8). Because they contain only a small amount of organic carbon, these amendments behave similarly to synthetic fertilizers when incorporated into the soil, particularly in terms of nutrient release rates. Unlike synthetic fertilizers, however, they contain at least trace amounts of most of the other plant nutrients in addition to nitrogen, phosphorus, and potassium.

Blood meal, bone meal, hoof and horn meal, and feather meal are all useful as sources of quick nitrogen. Bone meal is a slow-release fertilizer and is used mainly as a source of phosphorus. It can also be steam-processed, which increases the availability of the phosphorus. Blood meal and bone meal are also available in a mixture that gives a more balanced ratio of nitrogen to phosphorus. This mixture has the added advantage that its nutrients are in both fast- and slow-release forms. These concentrated materials may be used occasionally in commercial organic farming operations, but for the most part their cost is prohibitive. Blood meal, for example, costs about $400 per ton, compared to $20 per ton for manure.

Table 3.8. Nutrient Contents of Concentrated Organic Residues.

Material	% N	% P	% K	Nutrient Release
Blood meal	10-14	1.0-1.5	0.6-0.8	fast
Bone meal	2-4	22-24	0	slow
Hoof and horn meal	10-14	1.0-2.0	0	fairly fast

Source: FAO, *1984 Fertilizer and Plant Nutrition Guide.* Bulletin #9. 176 pp.

Sources of Information (Concentrated Animal By-Products)

Food and Agriculture Organization. 1984. *Fertilizer and Plant Nutrition Guide* (Bulletin #9). FAO Fertilizer and Plant Nutrition Service, Land and Water Development Division, Rome.

Sewage Sludge

Sludge is a by-product of the treatment of domestic waste water and sewage. With the right facilities and technology, sewage sludge can be composted and processed into a valuable resource for amending soils. The main purpose for applying sludge is to improve or sustain soil organic matter levels. Many plant nutrients are present in sewage sludge, and numerous studies have shown plant response to sewage sludge applications (both in the greenhouse and in the field). However, continuous application usually is not recommended since it may lead to accumulation of potential pollutants.

Sludges vary greatly in their chemical, biological, and physical properties, depending on the source of sewage, the treatment system used, the process of digestion (aerobic or anaerobic), the extent to which the material is digested, and how the material is handled between processing and application to the soil. Table 3.9 gives the range of nutrient values found in sewage sludge from different parts of the United States. The variability of nutrient values emphasizes the importance of analyzing each batch or shipment of sludge in order to determine appropriate application rates.

The fate of nitrogen in composted sludge after incorporation into the soil depends on the relative amounts of nitrate-N and ammonium-N. A fifteen-year study conducted on two soils at the UC Moreno Field Station near Riverside showed that total biomass production on sludge-treated soils was equal to or better than that using chemical fertilizers, and that the organic solids added along with the sludge caused a decrease in soil bulk density and an increase in soil water holding capacity and hydraulic conductivity. On the negative side, parasite eggs could be detected as long as three months after sludge application, and plants grown on sludge-treated soils generally contained high amounts of cadmium and zinc (Chang et al., 1991).

Public acceptance of using sewage sludge to amend soils has been mixed, largely because of potentially harmful side-effects that may occur in areas of concentrated use. They include:

- the presence of pathogenic organisms (mainly bacteria, protozoa, and viruses)
- toxic levels of heavy metals (zinc, copper, lead, nickel, and cadmium)
- nitrate accumulation and leaching to groundwater
- accumulation of potentially toxic organic compounds such as polychlorinated biphenyls (PCBs) in soil
- excess salts

Several municipalities in California process and market composted sewage sludge. A range of products is available, but the most popular materials are those that have been well-cured, dried, and screened. This process results in a fairly uniform, friable, easy-to-handle material. Because of concerns over potential pollutants and toxic compounds, sewage sludge is used mainly in landscape and ornamental situations; application to food crops, particularly fresh vegetables, is generally not recommended.

Liquid digested sludge and de-watered slurry are more difficult and expensive to handle. These materials are used mostly for land reclamation, in forest production, and on golf courses.

Table 3.9 . Range of Nutrient Concentrations for *Selected* Elements in Sewage Sludge.

Element	Min.	Max.	Median
	Concentration (%)		
Organic C	6.5	48.0	30.4
Total N	<0.1	17.6	3.3
NH_4–N	<0.1	6.7	1.0
NO_3–N	<0.1	0.5	<0.1
P	<0.1	14.3	2.3
K	0.02	2.6	0.3
S	0.6	1.5	1.1
Ca	0.10	25.0	3.9
Mg	0.03	2.0	0.4
	Concentration (ppm)		
Zn	101	27,800	1,740
Cu	84	10,400	850
Ni	2	3,515	82
Cr	10	99,000	890
Cd	3	3,410	16
Pb	13	19,730	500

Source: Dowdy et al., 1976.

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Green Manures

Green manures are crops that are incorporated into the soil while they are still green and succulent in order to improve the soil and to supply nitrogen to the associated cash crop. The ratio of carbon to nitrogen is sufficiently low at this stage of plant development to allow rapid decomposition of the plant matter, resulting in the net release of nitrogen. The most commonly grown green manures are winter and summer annuals (either grasses or legumes), depending on the location, climate, and specific requirements of the cash crop being grown.

If the primary reason for growing a green manure is to provide nitrogen, then some type of legume should be planted. A properly managed legume cover crop can fix up to 150 or 200 pounds of nitrogen per acre in 3 to 6 months. Legumes are somewhat self-regulating in that if the nitrogen fertility of the soil is high, they will take up nitrogen from the soil rather than fix atmospheric nitrogen. This characteristic can be particularly important during the rainy season when the legumes hold the nitrogen and prevent its loss through leaching. Under low-nitrogen conditions, legumes fix nitrogen from the atmosphere (N_2) into an organic form with the help of nitrogen-fixing bacteria that form nodules in the roots.

The cost of the nitrogen provided by legumes varies depending on cultural practices (i.e., soil preparation, nutrient levels, irrigation) and the cost of seed. The expense can range anywhere from $0.10 per pound of nitrogen under optimal growing conditions and using seed produced on the farm, to $0.80 or $0.90 per pound of nitrogen where seed has to be purchased and other production inputs are high. Another major cost that needs to be considered, however, is the lost opportunity cost if the green manure occupies land when a cash crop could be grown.

When the green manure is disked into the soil, the organic compounds are broken down by soil microbes, and nutrients are made available to the crop. The decomposition of this plant matter, as it is converted to humus and becomes part of the stable organic matter, also has beneficial effects on soil structure (see Chapter 1, *Soil Organic Matter*). Research in this area has shown that grasses are better at increasing overall soil organic matter levels than are legumes. This effect is related to the high lignin content of grasses (essentially all lignin is converted to humus) as well as their more fibrous root systems. If the goal is to improve soil tilth or cation exchange capacity, then a green manure crop of oats, barley, rye, or Sudangrass may be the best choice.

Farmers who are looking for improvements in both fertility and tilth often grow mixes of grasses and legumes to exploit the advantages of each. Again, this is partially a self-regulating system. Ideally, under low-nitrogen conditions, the legumes will out-compete the grasses and a significant amount of nitrogen will be fixed. If nitrogen fertility is high, the grasses will dominate the stand. In reality, the situation is more complex because the ratio of grasses to legumes in the stand depends on other environmental and management-related considerations (e.g., temperature, rainfall, original seeding densities, pest pressures). For complete information about selecting, planting, and managing green manure crops, check the publications listed under *Sources of Information*.

Sources of Information (Green Manures)

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Bugg, R. L., and P. R. Miller. 1991. Grasses/legumes: Dream team. *Sustainable Agriculture News* 3(4):1-4. UC Sustainable Agriculture Research & Education Program, Davis, CA.

Miller, P. R., W. L. Graves, W. A. Williams, and B. A. Madson. 1989. *Covercrops for California Agriculture.* University of California, Division of Agriculture and Natural Resources, Oakland, CA. Leaflet 21471.

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Harvest and Processing Residue

Crop Residue

Crop residue remaining after harvest accounts for a large portion of the organic matter added to California soils. Corn, for example, can leave 2 to 3 tons of residue per acre after harvest (see table 3.10). Beneath the soil surface, decaying plant roots form another important component of the soil organic matter pool, though the amounts are much more difficult to quantify than surface residue. Surface and sub-surface residues of nonlegumes have low nutrient values and therefore do not contribute directly to soil fertility. Instead, they enhance soil tilth by increasing the quantity of soil organic matter.

The amount of nutrients contributed by leguminous residue depends on the crop and the stage at which it is incorporated. The residue of grain legumes (e.g., beans, soybeans) that have been harvested for seed contains only about 1 to 2 percent nitrogen. The nitrogen contribution of a forage legume like alfalfa will be much greater, particularly if the final regrowth is incorporated into the soil rather than harvested as hay. Depending on climate and management-related factors, alfalfa residue may contain from 3 to 5 percent nitrogen, and contribute as much as 150 pounds of nitrogen per acre.

Residues with High C/N Ratio

Harvest and processing residues with high C/N ratios, such as rice hulls, straw from grain, and nut husks and shells, will be relatively slow to break down compared to green manures and fruit and vegetable processing wastes. High-carbon materials generally have low nutrient values, but may enhance soil tilth through addition of organic matter. Immobilization of nitrogen is a potential problem with materials that have a C/N ratio greater than 30:1 and that readily decompose (table 3.11).

Rice hulls are of particular interest in California because of the large quantity generated by the state's rice industry. About 20 pounds of rice hulls are produced during the milling of every 100 pounds of dry paddy rice. Most rice hulls produced in California are used as bedding material for livestock and poultry or as landscape mulch, but soil incorporation has also been researched as another method of disposal.

As indicated in table 3.11, rice hulls have no real fertilizer value; they are nutrient-poor and decompose very slowly in soil. They can, however, be effective at improving the soil's physical condition. One laboratory study showed that the addition of rice hulls reduced bulk density and increased porosity in soils, thus improving overall water infiltration rates. Depending on soil type, appreciable physical improvement was obtained with rice hull additions of 25 to 50 percent (by volume). Field studies in California also showed significant improvements in orchard soils amended with rice hulls.

Because rice hulls decompose very slowly, much more slowly than wheat straw for example, nitrogen immobilization does not present a problem. It is important to note, however, that some crops may be sensitive to other chemical constituents in rice hulls (e.g., chloride). This sensitivity can lead to reduced yields where soils have been amended heavily with rice hulls. The high cost of transporting rice hulls and the uncertainty about their long-term effects on soil and crop productivity limit their widespread use on commercial-scale operations.

Table 3.10. Estimated Addition of Organic Matter From Various Crop Residues.

Crop	Yield (lb/a)	Organic Matter Added (lb/a) Roots	Tops	Total
Corn	7,054	2,200	4,100	6,300
Soybeans	2,418	1,000	2,200	3,200
Wheat	3,400	1,700	3,100	4,800
Dry bean	1,500	500	1,400	1,900
Alfalfa	6,000	3,400	800	4,200

Source: Donahue et al., 1983.

Table 3.11. Typical Analyses of Residues with High C/N Ratios.

Material	N	P	K	C/N
	%			
Rice hulls	0.3	0.03	0.7	120
Rice straw	0.8	0.2	1.5	46
Wheat straw	0.5	0.2	0.9	78
Oat straw	0.6	0.2	1.5	70
Barley straw	0.7	0.3	1.4	58
Corn stover	0.9	0.3	1.4	42

Source: Parnes, 1990; Wildman & Brandon, 1968.

Fruit and Vegetable Processing Wastes

A number of fruit and vegetable commodities grown in California are associated with processing industries that generate waste products with potential as soil amendments. Both solid wastes (pomace and culls) and the liquid effluent from canneries are applied to soils.

Solid waste. Fruit skin, pulp, culls, and seeds are the main constituents of the organic residue from cannery, winery and freezing operations in California. Nutrient values for a few fruit residues are listed in table 3.12. In general, processing residues have a relatively low fertilizer value, although some plant response may be expected with large additions of higher-quality materials. Increased soil organic matter and long-term soil reclamation are usually the key reasons for using processing wastes as soil amendments.

Most cannery wastes have a relatively low C/N ratio, which means that the materials will decay rapidly in warm, moist soils. In general, if raw material is applied during the hot summer months, you can expect most of the waste to decay during the first year. This rapid decay is a result of intense microbial activity in the soil, which could, in turn, improve soil structure and nutrient cycling for a short period. It may be desirable, however, to digest or compost the pomace before applying it to soils. Not only does this concentrate and stabilize the nutrients contained in the waste, but it simplifies handling and spreading of the material as well.

Grape pomace, for example, is occasionally used in its pure form, either fresh or aged. More commonly, it is composted with manure and cotton gin trash to produce a high-grade soil amendment and fertilizer. Some grape seeds may survive the high temperatures generated during composting and become weeds in the field to which the compost is applied. Mixing the pomace with other materials, however, usually disperses any remaining viable seeds sufficiently to prevent any significant problem.

Several criteria determine the feasibility of recycling processing waste in soil:

- availability and accessibility of processing by-products
- a dependable hauler with appropriate equipment
- a farmer with land and expertise for spreading and incorporating the residue
- regulatory approval (discharge waivers, permits, etc.)

Table 3.12. Approximate Nutrient Values of Selected Processing By-Products.

	Nutrient					
	% Dry Wt.			ppm Dry Wt.		
Material	N	P	S	K	Ca	Na
Tomato pomace[a]	1.8	0.3	0.2	125	20	14
Pear waste[a]	1.4	0.2	0.4	121	32	24
Peach waste[a]	0.6	0.1	0.1	105	16	7
	% Fresh Wt.					
	N	P	K			
Grape pomace[b]	0.9	0.3	1.0			

Sources: [a] Reed, A.D. et al., 1973.
[b] Jacob, H.E. Fertilizing value of pomace. *The Grape Grower.* December, 1947.

Otherwise, economic factors are likely to favor using processing wastes for livestock feed. A recent survey of California fruit and vegetable processors indicates that about 92 percent of the organic, residual waste (not including effluent wastewater) is recycled. Of this 92 percent, about half is used as livestock feed and half as a soil amendment.

Processing effluent. After screening and filtering out the solid portion of cannery waste, the resulting liquid effluent may also be used for agricultural purposes. The three main methods for disposing of processing wastewater on land are irrigation of crops, infiltration/percolation, and overland flow. These are discussed in detail in the University of California Division of Agricultural Sciences Leaflet No. 21252, *Land Application Systems for the Utilization of Fruit and Vegetable Processing Effluent.*

Oilseed meals

Cottonseed meal is the most readily accessible of the oilseed meal fertilizers. It averages about 6 percent nitrogen, 2 percent phosphorus, and 2 percent potassium. Oilseed meals are generally a good, but expensive source of slow-release nitrogen.

Sources of Information (Harvest and Processing Residue)

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Marine Products

Marine-derived organic materials are a relatively minor class of soil amendments and fertilizers, in terms of amounts used. Research and field experience indicate that these materials can improve soil structure, enhance soil microbial activity, and promote plant growth. Current costs for processing and distribution, however, limit their use on a very wide scale, particularly for medium- to large-scale farmers in California's inland valleys. Four of the most common materials are described below along with chitin, a relatively new product.

Fish Waste

Each pound of fish sold in U.S. supermarkets results in another pound of high-nitrogen waste that is discarded in the process of cleaning and packaging. This waste by-product is usually converted through a drying process into regular fish meal, which is used as a high-quality, high-value feed for poultry and livestock. As long as fish waste commands a high market value for conversion to feedstuffs, it is unlikely that it will be directed to fertilizer production on any large scale. In local situations, however, where a demand has been created, less costly methods of drying and composting can be used to produce a fertilizer-grade fish meal. This product tests out at about 10 to 12 percent nitrogen, 3 to 4 percent phosphorus, and 3 to 4 percent potassium. Dried, composted fish meal is generally applied at rates of 200 to 300 pounds per acre. Exact rates should be determined through soil analysis and crop nutrient requirements.

Spray-dried fish protein is another type of fish meal prepared through a specialized low-temperature drying process. The resulting very fine powder is readily digested by bacteria and converted into nitrogen forms available to plants. Research with turfgrass at the UC Hopland Field Station showed that it provided good turf color for up to ten weeks when applied at the rate of 10 pounds per 1,000 square feet during cool weather. Under similar conditions, other organic fertilizers failed to provide usable nitrogen (nitrates), probably because of low soil temperatures and low biological activity. Spray-dried fish protein can also be injected into drip systems for "fertigation." Research from the Hopland Field Station demonstrated that fish protein could be used successfully up to 75 ppm nitrogen (Glenn McGourty, University of California, personal communication).

Liquid fish fertilizer is another fish waste product that may be practical in some situations. This material is manufactured through a steam cooking process of hydrolysis, which extracts most of the nutrients in a liquid form.

Fish Emulsion

Fish emulsion is a secondary by-product of the fish meal industry. After removal of the solids (which become fish meal) and the oils (which go to oil products manufacturers), the remaining wastewater is usually evaporated to about 50 percent solids, making a thick, viscous end product that is bottled and sold as "fish emulsion." Since the oil has been removed, the term "emulsion" is not really accurate. "Fish solubles" would be a more appropriate name for these non-oil and non-solid portions of the fish.

The fish emulsion sold in gardening sections and in nurseries usually contains about 5 percent nitrogen, 1 percent phosphate, and 1 percent potash. The high cost and low nutrient value of this fertilizer, combined with handling and application problems, make it impractical for use in most commercial-scale farming operations. Fish emulsion is practical as a foliar-applied fertilizer for high-value crops, including ornamental greenhouse plants. It can rapidly "green up" foliage when used for foliar feeding.

Shellfish Waste

On average, the processing of shellfish generates from 50 to 60 percent solid waste. This waste consists primarily of exoskeleton material, and ranges from 25 to 40 percent protein, 15 to 25 percent chitin, and 40 to 50 percent calcium carbonate. Shellfish waste has a much lower protein value than fish waste and is therefore not a desirable source of animal feedstuff. It is a more likely candidate for use as a fertilizer source and shows relative fertilizer values of approximately 6 percent nitrogen, 2 percent phosphorus, and 1 percent potassium. In California, fertilizer is manufactured from shellfish waste by a few small, locally based companies. Availability is still quite limited relative to other more popular fertilizer sources.

Kelp/Seaweed

Though seaweed is a well-researched marine fertilizer material, there is still a great deal of skepticism about its use in agriculture. Studies conducted at various locations have established three basic benefits from soil and foliar applications of seaweed products (Senn and Kingman, 1978; Temple et al., 1989a and 1989b).

- *Supplies some plant nutrients.* Seaweed products are particularly good sources of micronutrients (trace elements) and chelating agents, which promote the availability of micronutrients. Nutrient amounts are shown in table 3.13. Nutrient analyses of seaweed materials indicate that they should be used as fertilizer supplements, *not* as fertilizer substitutes.

- *Enhances plant growth.* Many seaweed products contain active quantities of plant growth regulators. Of particular interest are those known as cytokinins, which regulate cell division and cell wall formation and also delay the process of senescence.
- *Improves soil tilth.* The colloids (gels and alginates) found in seaweed are reported to temporarily increase soil aggregation, promoting a more crumb-like structure.

The benefits of seaweed depend largely on the particular product used, method of application, and crop and soil conditions. The following list shows a variety of seaweed materials, but little research has been conducted on the efficacy of these products in the field.

1. *Wet seaweed from beaches.* Washing off salt and composting improve its usefulness.

2. *Dry seaweed meal.* Seaweed is dehydrated and ground into meal. May be applied straight or mixed with other fertilizers. Typical straight application rates range from 300 to 500 pounds per acre depending on crops, soils, climate, and quality of the meal.

3. *Liquid seaweed concentrate.* Wet seaweed is treated and cooked under pressure to extract nutrients and other compounds. Used mainly as a foliar spray, seaweed concentrate is diluted anywhere from 1:50 to 1:100 parts water.

4. *Seaweed powder.* Seaweed is liquefied, then processed into soluble powder. Seaweed powder is generally reconstituted into a liquid form and then diluted at a ratio similar to that of liquid concentrate for foliar feeding.

5. *Seaweed and fish blend.* Either in liquefied or dry meal form, this product is formulated to combine the benefits of both materials.

Table 3.13. Typical Analyses of Marine-Derived Fertilizer Materials.

Material	N	P	K
	—% dry weight—		
Fish emulsion[a]	5-6	1-2	1-2
Fish meal[a]	10-12	3-4	3-4
Shellfish meal[b]	6	2	1
Kelp/seaweed[c]			
dry meal			
(sample 1)	1.2	0.38	3.25
(sample 2)	0.87	0.08	2.09
powder			
(sample 1)	1.0	0.07	2.2
(sample 2)	0.9	0.09	2.4

Sources: [a] Fryer and Simmons, 1977.
[b] Swanson, et al., 1980.
[c] Fryer and Simmons, 1977; Senn and Kingman, 1978.

Chitin

Chitin is a by-product of the shellfish industry, and is derived mainly from the pulverized shells of crabs and lobsters. While it usually contains about 3 percent nitrogen, it is really too expensive to be used as a nitrogen source. Nonetheless, chitin may be useful in some cropping systems because, in addition to providing nitrogen, it also can be used as a biological control agent.

Recent studies have shown that chitin added to soil suppresses root-knot and other plant-parasitic nematodes. Its mode of action has two components. First, ammonia released during decomposition of chitin inhibits the infective stage of the nematode. Second, as the population of chitin-decomposing microorganisms increases, they also begin to attack nematode eggs (chitin is present in the "shell" of nematode eggs). Strict field testing requirements have kept chitin-based products off the market in California. It has been approved for use in other states. One problem with chitin is that the ammonia produced during its decomposition is phytotoxic to some crop species. Also, urea is added to some chitin products during manufacturing, which could be a limitation to organic farmers in some states (Spiegel et al., 1986, 1987, 1988).

Sources of Information (Marine Products)

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Wood-Derived Materials and Peat

Sawdust and Bark

The timber industry in California and other parts of the United States generates large quantities of sawdust and bark residue. The "slash" remaining after timber harvest makes a significant contribution to the sustained fertility of forest ecosystems. For agricultural purposes, however, the by-products have little nutrient value to speak of. Sawdust and bark are useful for supplying organic matter and improving soil tilth, and are particularly important soil amendments for greenhouse, nursery, home, and landscape use. The two major considerations when incorporating wood by-products into soil are tie-up of soil nitrogen and potential toxic effects.

Composition. Sawdust and pulverized bark are similar in their composition and behavior in the soil. Table 3.14 compares the average nutrient content of sawdust to dry wheat straw and alfalfa hay.

Behavior in the soil. Sawdust and bark have very high C/N ratios (200:1 to 300:1) and will therefore tie up soil nitrogen as they decompose. If sufficient nitrogen were not available, the temporary nitrogen deficit would depress the growth of crops planted in amended soil. Therefore, researchers have generally recommended that supplemental nitrogen be added to crops grown in soil amended with raw wood products. More recent studies show that the high lignin (a type of carbon compound) content of sawdust and bark causes these materials to break down very slowly even where sufficient nitrogen is present. In a worst-case situation, supplemental nitrogen could be required for several *years* on soil where raw materials have been incorporated. With increasing costs of nitrogen fertilizers and the potential for nitrate contamination of groundwater, the value of incorporating raw wood products and supplemental nitrogen should be carefully weighed.

Table 3.14. Nutrient Composition of Sawdust Compared to Wheat Straw and Alfalfa Hay.

Dry Material	N	P_2O_5	K_2O	CaO	MgO
			lbs/Ton		
Sawdust	4	2	4	6	0.5
Wheat straw	10	3	12	4	1.2
Alfalfa hay	48	10	28	28	7.0

Source: Allison, 1951.

A better strategy would be to compost the sawdust or bark before applying it to the soil. This process partially decomposes the material, reducing the carbon-to-nitrogen ratio of the material and minimizing the risk of nitrogen tie-up. Many products available on the market have been pre-composted, but it is not always clear to what degree. In all situations, plants should be monitored closely for signs of nitrogen deficiency when wood-derived materials are used.

If raw product is used, it should be incorporated far enough in advance of planting to allow for sufficient decomposition to prevent tie-up of soil nitrogen. The specific lead-time required is difficult to determine. Where sawdust has been added at or close to planting, it would be preferable to add nitrogen in stages as decomposition proceeds and as crop requirements dictate, rather than in one large application. Processors sometimes add nitrogen or other ingredients to the sawdust or bark before packaging, so it is important to check the label or ask the supplier to find out whether the material has been modified in any way.

Another factor affecting decomposition of sawdust and bark is the type of wood. Hardwoods are generally less satisfactory than softwoods in amending soils: their initial nitrogen demand is higher because they decompose more quickly, and they do not do as much to promote soil tilth (Bill Dost, UC Berkeley Forest Products Laboratory, personal communication)

Although several compounds found in bark or sawdust are potentially harmful to certain plants, toxicity is not generally considered to be a problem. Research information indicates there are only a few tree species to avoid. One study of 28 different tree species, for example, showed that California incense cedar wood and white pine bark adversely affected the growth of garden peas (Allison, 1965). Other reports have identified by-products of walnut (i.e., black walnut) and redwood as injurious to various crops when incorporated into the soil, particularly if the bark or sawdust came from green newly milled trees.

Wood Ash

Wood ash is available as a soil amendment in some parts of California, and may benefit soils because of the potassium and minor nutrients it contains. Ashes contain roughly 5 to 7 percent potassium, 25 to 50 percent calcium compounds and 1.5 to 2 percent phosphorus. Optimum rates of application are usually between 5 and 10 pounds per 100 square feet incorporated into freshly tilled soil. To prevent problems with salinity and alkalinity, application rates should be limited to 5 pounds per

100 square feet. Contact between freshly spread ashes and germinating seeds or new plant roots should be avoided, as it may cause burning of plant tissue.

Other Uses of Wood-Derived Materials

Sawdust and bark are excellent materials for surface mulching in landscapes and home gardens. Used for this purpose, they behave very differently than when incorporated into the soil as an amendment. With minimal soil contact, breakdown is very slow and nitrogen tie-up is generally not a problem. Wood mulches can help control weeds and conserve soil moisture. Mulches can also reduce soil temperature, enhance soil structure and water infiltration rates, and stimulate earthworm activity. Other agricultural uses of sawdust and bark are as bedding for livestock and poultry and as a bulking agent in the composting of other waste materials.

Peat

Peat is an accumulation of organic material resulting from the incomplete decomposition of plant residue by microorganisms, usually in saturated conditions where oxygen is limiting. The climate and topography in the northern latitudes of Canada and Europe have been particularly conducive to peat formation. This is where most of the world's peat soils are found and where most horticultural peat products are manufactured. The peat moss found at most nurseries, for example, originates in old lake beds or poorly drained hollows (termed "raised bogs") of Northern Canada. Rainfall and temperature patterns there are conducive to the growth of *Sphagnum* and other moss genera. The product available at local nurseries is the partially humified surface layer of moss which has been harvested and processed into a soil amendment.

There are many different types of peats, depending on environmental conditions, mineral content of the soil or rain water, and plant species present. Most peat, however, does the following:

- decomposes very slowly
- improves soil aeration
- increases cation-exchange capacity
- increases soil water holding capacity
- adds organic matter, but not much
- adds some nitrogen

Depending on the source material, peat may also acidify soil slightly. Peat derived from moss is acidic with a pH in the range of 3 to 5. Fibrous peat, derived from reeds and sedges, is more desirable in this regard because it is more neutral (pH 5-7).

The nitrogen content of peat ranges from 0.5 to 3 percent dry weight basis depending on the type of peat and the degree of decomposition. Seldom does more than 5 percent of the total nitrogen occur in mineral forms available for plant uptake. Most peat mosses have a fairly wide C/N ratio, so supplemental nitrogen is almost always needed when applying peat moss. For example, peat is a key component of many container and greenhouse soil mixes, but soil formulations always carry recommendations for additional organic fertilizers in order to supply the nitrogen needs of the plant. High dollar costs and low relative value to the soil compared to other amendments limit the use of peat in large-scale commercial agriculture.

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Soil Organic Matter and Its Role in Crop Production. F.E. Allison. 1973. Developments in Soil Science No. 3. Elsevier Scientific Publishing Co., New York, NY. 637 pp.

Soil Organic Matter: Biological and Ecological Effects. Robert L. Tate III. 1987. John Wiley & Sons, New York, NY. 291 pp.

Glossary

Technical Terms

Actinomycetes. A group of organisms with characteristics intermediate between the simple bacteria and the true fungi.

Aerobic. Occurring in the presence of oxygen.

Aggregate. A group of both mineral and organic soil particles that are held together and behave as a unit; the crumb structure of soils is composed of aggregates.

Anaerobic. Occurring in the absence of oxygen.

Bulk density. The ratio of the mass of water-free soil to its bulk volume. The lower the bulk density of a soil, the larger its pore space.

Carbohydrates. A group of organic molecules including simple sugars (glucose, sucrose) and complex polymers such as hemicellulose and cellulose, which consist of carbon, oxygen, and hydrogen atoms bound together. Soil organic matter ranges from 5 to 25 percent carbohydrates.

Cation exchange capacity (CEC). The total amount of cations a soil can hold temporarily by interactions with negatively charged sites in the soil.

Cellulose. A large polysaccharide molecule composed of linked glucose molecules. Cellulose is the major constituent of plant cell walls and is the most abundant organic molecule on earth.

Chelating agent. An organic compound that forms a ring structure in which an ion with multiple charges is held between two or more atoms. Chelated nutrients such as Fe^{++} and Cu^{++} are available to plants.

Decomposers. A group of organisms relying on dead organic matter for nourishment; mainly bacteria and fungi.

Denitrification. The conversion of nitrate to nitrous oxide and elemental nitrogen (N_2) by denitrifyers.

Dynamic equilibrium. The equilibrium achieved by many biological processes where a steady state is maintained through processes of loss and renewal. For example, a population can be in a state of dynamic equilibrium when the birth rate equals the mortality rate.

Humification. The conversion of plant and animal residues to humic and fulvic acids, the components of humus. This process occurs in several stages and is mediated by soil microbes.

Humus. The highly acidic, high-molecular-weight compounds formed from organic residues, which are responsible for the dark coloration of soils rich in organic matter. The predominant forms of humus are humic and fulvic acids.

Immobilization. The uptake of nitrogen (or other nutrients) by microorganisms; microbial assimilation.

Lignin. A constituent of the cell walls of all plants, most abundant in woody species (trees). The structure is difficult to characterize because lignin is linked to cellulose and other large molecules in the cell wall. Generally, it is composed of branched chains of aromatic alcohols (carbon rings).

Mineralization. The conversion of nitrogen (or other nutrients found in organic matter) from the organic form to the inorganic form such as ammonium (NH_4^+) or nitrate (NO_3^-).

Mycorrhizae. Literally "fungus root." The symbiotic association between specific fungi and higher plants.

Nitrification. The conversion of ammonium to nitrate by a specialized group of bacteria called nitrifyers; requires the presence of carbon as an energy source.

pH. A quantitative scale (0 to 14) used to indicate acidity ($pH < 7$) and alkalinity ($pH > 7$).

Symbiosis. The intimate, mutually beneficial relationship between two organisms of different kinds, such as between leguminous plants and nitrogen-fixing bacteria.

Turnover rate. The time required for the molecules making up a pool of substrate to be completely used and replenished. For example, if the turnover rate for organic matter is 500 years under equilibrium conditions, it takes 500 years for the organic matter in that soil to be entirely replaced through the continuous processes of decomposition and renewal from additions of plant matter.

Legal Definitions

The California Department of Food and Agriculture (CDFA) regulates the manufacturing, labeling, and marketing of amendments and fertilizers in the state. The following definitions related to this publication are taken from *Fertilizing Materials Laws and Regulations*. For more detailed information, contact the Division of Feed, Fertilizer, and Livestock Drugs, CDFA, Sacramento, CA 95814.

Agricultural mineral. Any substance with nitrogen (N), available phosphoric acid (P_2O_5), or soluble potash (K_2O), singly or in combination, in amounts less than 5 percent, which is distributed for farm use, or any substance only containing recognized essential secondary nutrients or micronutrients in amounts equal to or greater than the minimum amount specified by regulations, and distributed in this state as a source of these nutrients for the purpose of promoting plant growth. This category includes, but is not limited to: gypsum, liming materials, manure, wood fly ash, and sewage sludge not qualifying as commercial fertilizer.

Auxiliary soil and plant substance. Any chemical or biological substance or mixture of substances distributed in this state to be applied to soil, plants, or seeds for soil corrective purposes; or which is intended to improve germination, growth, yield, product quality, reproduction, flavor, or other desirable characteristics of plants; or which is intended to produce any chemical, biochemical, biological, or physical change in soil. Does not include commercial fertilizers, agricultural minerals, soil amendments, or manures. This category includes all of the following:

- synthetic polyelectrolytes
- lignin or humus preparations
- wetting agents to promote water penetration
- bacterial inoculants
- microbial products
- soil binding agents
- biotics

Biotics. All materials for which claims are made relating to organisms, enzymes, or organism by-products.

Commercial fertilizer. Any substance which contains 5 percent or more of nitrogen (N), available phosphoric acid (P_2O_5), or soluble potash (K_2O), singly or collectively, which is distributed in this state for promoting or stimulating plant growth. "Commercial fertilizer" includes both agricultural and "specialty fertilizers" (see definition).

Compost. A biologically stable material derived from the composting process. Composting is the biological decomposition of organic matter which inhibits pathogens, viable weed seeds, and odors. Composting may be accomplished by mixing, and piling in a way as to promote aerobic or anaerobic decay, or both.

Fertilizing material. Any commercial fertilizer, agricultural mineral, auxiliary soil and plant substance, or packaged soil amendment.

Fish emulsion. Fertilizing material from which the guaranteed nutrients are derived primarily from fish, which contains a minimum of 40 percent total solids from fish, and which may contain additional sources of nitrogen, available phosphoric acid, and soluble potash for standardization purposes or stabilization purposes, or for both purposes, that shall be included in the required guaranteed analysis and derivation statement.

Manure. Any substance composed primarily of animal excrement, plant remains, or mixtures of those substances.

Natural organic fertilizer. Materials derived from either plant or animal products containing one or more nutrients other than carbon, hydrogen, and oxygen, which are essential for plant growth, which may be subjected to biological degradation processes under normal conditions of aging, rainfall, sun-curing, air drying, composting, rotting, enzymatic or anaerobic/aerobic bacterial action, or any combination of these, which shall not be mixed with synthetic materials or changed in any physical or chemical manner from their initial state except by physical manipulations such as drying, cooking, chopping, grinding, shredding, or pelleting.

Packaged soil amendment. Any substance distributed for the purpose of promoting plant growth or improving the quality of crops by conditioning soil solely through physical means. This category includes all of the following:

- hay
- straw
- peat moss
- leaf mold
- sand
- wood products

- any product or mixture of products intended for use as a potting medium planting mix, or soilless growing media
- manures sold without guarantees for plant nutrients
- any other substance or product which is intended for use solely because of its physical properties.

Specialty fertilizer. Any packaged commercial fertilizer labeled for home gardens, lawns, shrubbery, flowers, and other similar noncommercial uses. These products may contain less than 5 percent nitrogen, available phosphoric acid, or soluble potash, singly or collectively, detectable by chemical methods.

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