Organic Matter Management in Forest Nurseries: Theory and Practice

BY

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Nursery Technology Cooperative

The original document "Organic Amendments in Forest Nursery Management in the Pacific Northwest", by Susan G. Blumenthal and Donald E. Boyer, was produced in response to Wind River Nursery Manager Stuart Slayton's suggestions, and through the encouragement and administrative support of Asa (Bud) Twombly, Silviculturist, Division of Timber Management, USFS, Portland, OR.

Reduced dependency on the use of pesticides in forest nurseries, as well as the current fluctuation in availability and cost of typically preferred organic amendments, has caused a greater need for alternatives in selecting suitable products. As in the original document, this revised edition attempts to offer the nursery managers additional choices.

If an adequate area is available, nursery managers should consider the possibilities of creating their own source of organic materials for incorporation into the nursery soil management program rather than relying on a volatile market product. Also, more municipalities are switching over to composted sewage treatment facilities thereby providing another source of material for nursery use.

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A cooperative publication between the Nursery Technology Cooperative (Oregon State University) and the USDA Forest Service, State and Private Forestry.

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Introduction

The topic of organic matter in forest nursery soils has remained dormant for a long time as evidenced by the paucity of literature on this topic for the past 25 years. In that time nursery production in the United States, Canada, New Zealand, South Africa, Brazil, and Venezuela has increased exponentially. Organic matter content in soil has always been a concern, yet there has been limited focus on this topic within academic research circles from the applied perspective.

A large part of the reason for this lack of research on organic matter has been a perceived need to study more pressing concerns such as seedling morphological and physiological quality. The interaction of soil microbiology with soil organic matter was not a concern so long as there were powerful chemicals like methyl bromide. The "magic bullet" effect of methyl bromide made the explosion in seedling production levels possible because there was little need to be concerned with controlling diseases, nematodes, insects, and weed seed.

Rodriquez-Kabana and Morgan-Jones (1987) made an important point that "recent removal of key nematicides (DBCP,EDB) from use in several industrialized countries through regulatory action has spurred research on "unconventional" nematode management methods." The very same statement can be modified to include herbicides, fungicides, sterilants, or chemicals in general. Regulatory measures are making it necessary to rethink all forest nursery cultural practices which impact the environment. The mandated termination of methyl bromide in the United States by the year 2000 has made it critical to find alternatives. "Unconventional" methods include poorly studied technologies and practices such as microwave sterilization of soil, steam sterilization of soil over large fields, and natural chemicals from decomposing organic amendments to retard or kill soil borne pests and disease.

Using organic matter in soil to control nematodes and pathogens is by no means well understood. Organic matter exists in many forms and within those forms it varies considerably. Certainly, the increased use of methyl bromide came about because organic additions from cover crops, some organic amendments, and fertilizers actually led to increased disease, nematode, and insect problems.

The role of organic matter in soil must be better understood in order to successfully integrate it with the other forest nursery management cultural practices. The scope of the power of organic matter will be limited within the agricultural soil environment where fertilizers, irrigation, weed control, and soil cultivation are necessary practices if target seedlings (Rose et al. 1990) are to be produced. Soil organic matter is one component of the nursery soil system and must be considered along with other confounding factors such as soil drainage, timing and amounts of fertilizer, fallow and cover crop schedules, and tillage practices. The overall management objective is to produce quality seedlings for outplanting through improved tilth, soil structure, and microbial populations. Soil organic matter is also an important component in any integrated pest management program.

Addition of organic material is justified when management practices are made easier or more effective, or when those benefits are reflected in better quality or quantity of production. In recent times organic matter chemistry in soils has taken a new meaning with the reduction of pesticide use in nurseries, especially methyl bromide which is suspected of being an ozone depleting compound. With the potential loss of methyl bromide the nursery industry is faced with no chemicals that work as well. Soil organic amendments represent a potential way to improve fungi and bacteria populations which can combat some seedling pathogens, nematodes, and insects when used in combination with select herbicides and cultural practices as part of an integrated pest management program (USDA, 1993).

This paper provides a general reference for the addition of organic amendments to forest nursery soils. The effects of organic matter on physical, biological, and chemical properties of soil are discussed. The characteristics, benefits, and side effects of the more commonly used organic amendments are reviewed in addition to the need for supplemental fertilizer. Information on various techniques for composting and practices of green manuring are given. No attempt is made to evaluate cost effectiveness of various organic amendments because organic materials vary widely in availability and cost.

Many of the terms used in this paper are defined in the Glossary. In addition, Appendix A gives examples of the calculations needed for figuring the amount of additional nitrogen to be added to mulch or incorporated amendments.

Measuring Organic Matter

An understanding of how organic matter is determined in soil is critical to understanding how to interpret the results. There are three common methods for measuring organic matter content in soil (Horneck et al. 1989). (1) The Walkley-Black method determines the amount of carbon using potassium dichromate and sulfuric acid. This method usually recovers 60% to 80% of the total carbon in a sample. Note that organic matter can have carbon contents from 48% to 58%. (2) The carbon analyzer method combusts the sample and measures the carbon in the gas. (3) The loss-on-ignition method where the sample is heated to 105°C, weighed, then ashed at 400°C, and weighed again. Then, the sample is put into a 550°C muffle furnace. The organic matter content is calculated as the difference between the 105°C and 550°C measurements.

These three methods are not likely to give similar organic matter contents on the same sample within the same laboratory. The problem is in the assumptions that are made. The Walkley-Black method measures carbon well, but the method assumes all organic matter types have the same levels of carbon. The loss-on-ignition method is not a direct method because it measures loss after drying. The carbon analyzer may be the best method, but few laboratories can afford the $30,000+ for the instrument. It is accepted that loss-on-ignition is probably the better method to use when the sample is high in organic matter.

Methods for determining organic matter content are known to vary from laboratory to laboratory across the United States. Other sources of variation exist among laboratories using identical methods due to differences in equipment and subtle differences in how the samples are handled. For this reason it is highly adviseable to investigate what the soils analysis laboratory methods are. Some laboratories will no longer use the Walkley-Black method because it uses potassium dichromate which is expensive, hazardous to handle and costly to dispose of safely. Many labs now use the loss-on-ignition method.

To get the best information to monitor soil organic matter, it is recommended to choose a laboratory which is capable of giving reliable and consistent results with "blind" samples (i.e. samples that are duplicates and unknown to be duplicates by the laboratory) that are sent in with yearly soil samples. Collect a large soil sample (~2000g), completely homogenize it by repeated mixing, divide the sample into four lots, and submit as if they were four different samples from different areas. If the sample analyses are not reasonably close to one another, it would be adviseable to discuss the discrepancies with the laboratory. Once it has been determined that a laboratory gives consistent results, it is a good idea to remain with that laboratory.

The dilemma of how to use and interpret results from more than one laboratory is not uncommon. This is not difficult, but it can be expensive and time consuming. One method is to collect a range of soil samples, split them, and send half of each sample to each of the laboratories. Upon getting the samples back, it is then a simple matter to generate a regression equation to determine differences, if any, between laboratories. A good coefficient of determination (R^2) would be .85 or better. It is a good idea to consult a statistician with a soils background. Comparing the data from samples measured years ago with data from samples measured today should be done with some caution. The methods, the quality of the chemicals, and the technology have changed dramatically over the last two decades.

Organic Matter in Soil

The presence of organic matter has long been recognized as an essential component of a highly productive soil. Since ancient times, farmers worked for good tilth in the soil; that is, the combined soil characteristics of good aeration, structure, drainage, moisture-holding capacity, buffering capacity, and nutrient availability. All these characteristics are directly affected by the amount of organic matter in the soil. The introduction, use of, and reliance on commercial fertilizers have temporarily shadowed these virtues. Increasing pressures from the population, however, have prompted reinstatement and modification of former waste management techniques. Demands for higher productivity from forest nurseries are increasing. Nursery managers must understand the role of organic matter on the total soil system, and thereby its role in plant growth, to maintain present levels of nursery production and especially to increase production of high quality trees.

Because decomposition is continual, organic material must be added and incorporated periodically. In forest nurseries, the reduction of organic material is hastened by continuous weeding and cultivation, artificial irrigation, and additions of commercial fertilizer that promote microbial activity and rapid decomposition of organic material (Wilde and Patzer 1940). In some other forms of agriculture, benefit is gained from leaving roots of crops that add organic material. But nursery production does not have this added benefit. Also, soil organic material adheres to roots and is removed with tree seedlings.

The addition of organic matter affects the physical, chemical, and biological properties of the soil. These properties are interrelated but will be discussed separately

Impacts on Physical Properties

Nursery operations including tilling, preparing seedbeds, and lifting are easier and more effective when the humus level is high. Often under intensive management, the humus level is reduced because humus decomposes and is utilized more rapidly than normal. Furthermore, when seedlings are lifted, some humus is removed with the plant and is not returned to the seedbed.

Soil Structure

Humus has a profound effect on the soil structure, the aggregation of soil particles or the way the particles fit together. Good tilth is synonymous with crumbly, granular structure. The crumbs, aggregates, or peds are held together by bonds of organic compounds and clay. Frequent additions of easily decomposable organic material provide necessary organic compounds that bind soil particles into peds (Figure 1). Aggregation by humus reduces surface crusting, enabling water to enter the soil more easily (infiltrate) and percolate downward through the soil (permeate) thus improving drainage and ease of root penetration.

Figure 1. Sawdust "clods" slowly break down into humus.

Tilth is improved by green manuring, especially in finer-textured soil. This occurs by the interaction of factors associated with improved aggregation of the fine clay particles and in a lower bulk density (Allison 1973). Sandy soil is benefited by green manuring through increased moisture-holding capacity and increased availability of nutrients. One of the chief benefits to sandy soil is an increase in cation exchange capacity. All these benefits are realized soon after the green manure crop is incorporated into the soil. Also associated are benefits in water infiltration and retention, in drainage, and in water use efficiency (Allison 1973).

Bulk Density

Nursery operations usually require long-term use of heavy machinery at times when soil moisture is high; this compacts the soil. Repeated compaction leaves many nurseries with hardpans, which restrict the root growth of young seedlings and flow of water through the soil. Addition of organic material, combined with ripping and wrenching practices, may mitigate compaction by reducing bulk density and increasing the formation of soil structure.

Water Holding Capacity

The water-holding capacity of soil is greatly increased with the addition of organic matter (Table 1). Humus acts like a sponge in the soil by absorbing water readily. Thus, additions of organic matter to coarse-textured soils can increase the amount of water stored for plant use and thereby reduce the need for irrigation. The capacity to store water is improved by water-absorbing materials such as peat moss, redwood shavings, and vermiculite and to a lesser extent by larger wood chips, fir bark, or rice hulls (Warneke and Richards 1974).

Table 1 — Relation of soils and organic matter to water–holding capacity and availability of soil water

Soils, organic matter, and their mixtures	Water–holding capacity[1]	Moisture equivalent[1]	Wilting point	Available water	
				Percent	Percent of water–holding capacity
		Percent			
Soil:					
Clay loam	44.3	20.2	7.1	13.1	30
Quartz sand	28.3	1.4	.57	.83	29
Organic matter:					
Moss peat	1,057.0	166.0	82.3	83.7	8
Reed peat	289.0	110.0	70.7	39.3	14
Mixtures:					
1 : 1, clay loam : moss peat	114.0	31.0	14.5	16.5	14
4 : 1, clay loam : moss peat	57.4	21.6	8.5	13.1	23
1 : 1, quartz sand : moss peat	89.1	12.7	5.2	7.5	8
4 : 1, quartz sand : moss peat	47.8	5.6	1.8	3.8	8

[1] The values shown represent water by weight rather than by volume.
Source: Bollen (1969).

Water Availability

Where organic amendments have fully decomposed into humus, more water is available to plants through improved aggregation. Where organic additions are not fully decomposed, infiltration and aeration are improved, but there may be slightly less available water. The exception is with coarse-textured soils (Bollen 1969). Table 1 shows little increase in available water with increased amounts of peat moss to clay soil but considerably more available with increased peat to a quartz sand.

Water relations are usually improved under summer mulches because infiltration increases and surface evaporation decreases. These relations, however, create problems in wet climates with excess moisture. By lowering evaporation in surface soil, mulch also reduces the content of soluble salt in surface soil during the summer (Roberts 1978).

Erosion

Organic matter helps reduce soil erosion by increasing the moisture-holding capacity of soil, improving infiltration, permeability, and drainage and reducing surface runoff. Also, the improved structural aggregation by humus reduces the potential for individual particles of soil to be loosened by raindrops and subsequently carried away by moving water.

Keeping the soil covered with vegetation is critical to erosion control. Green manure is often used as a cover crop for this purpose if it can be managed between crop rotations with little disturbance to the soil. Sod crops are preferable for maximum protection. In Ontario, Canada, cover crops such as rye and oats are used to prevent surface erosion by wind and water (Armson and Sadreika 1974). Mulch protects seeds or seedlings from wind and water erosion, prevents puddling and crusting of soil, and minimizes evaporation of water from surface soil (Armson and Sadreika 1974).

Temperature

Organic matter effectively insulates the soil against sudden changes in heat and cold. Mulches have been recognized to reduce the rate of heat exchanged and the total heat conducted and released from the surface of the soil (Roberts 1978). By minimizing fluctuations in temperature in the root zone of plants, mulch protects seedlings from extremes of hot and cold and reduces frost heaving. Sawdust is effectively used in Canada (van den Driessche 1969) to prevent frost heaving of young tree seedlings.

Heat capacity of a mulch refers to how much heat it will hold and depends on its water content and size of particles. For instance, peat moss holds more water than sawdust which holds more water than bark. Water is the ideal heat sink because it changes temperature very slowly. The more water an amendment holds, the more slowly it, too, will change temperature.

Insulating effects of mulch improve the distribution of roots in surface soil by improving aeration and bringing about more uniform temperatures and moisture conditions (Roberts 1978). Characteristics of the mulch such as composition, state of decomposition, size of particles, and color will determine the degree of insulation. Old mulch loses its insulating value when it becomes decomposed, wet, or compacted. Thus, the best mulch for insulation must be decay resistant.

The color of mulch material can also be important. Light colored mulches, such as most sawdust, reflect light and heat that can cause sun scald of lower leaves or needles of seedlings. Darker substances, like bark, will absorb light and heat more rapidly and also lose moisture more readily because of increased evaporation.

Aeration

Roots of plants need good aeration to absorb oxygen for growth. Soils with high bulk densities often have less pore space than those with lower bulk densities. Organic amendments tend to reduce the bulk density of soil and to increase pore space. Warneke and Richards (1974) have shown how a variety of soil amendments lowered bulk density and greatly improved permeability of soils.

The addition of polymer soil conditioners have been found to be useful in flocculating clay in soil and improving the water stability of soil aggregates. Wallace and Wallace (1990) found that plant yields increased when water-soluble polymer soil conditioners were applied together with organic matter to the soil.

The addition of organic matter to heavy soils is critical to improve aeration. Care must be taken, however, to prevent excessive additions at any one time to coarse-textured soils that may cause too much aeration and rapid drying of the soil in hot weather. Once organic materials decompose to humus, however, this is not a problem.

Impacts on Soil Chemical Properties

Humus, which is a form of organic matter, serves as a reservoir of chemical elements essential to plant growth. Most soil nitrogen and phosphorus is organic. Other nutrient elements, such as sulfur, are also associated with humus.

Macro-Nutrients

As a source of nutrients, organic matter may be generally regarded as a slow-release fertilizer. Through microbial activity, essential nutrients such as nitrogen, phosphorus, and sulfur are slowly made available to plants as the organic residue is decomposed (see "Decomposition of Organic Amendments").

Organic amendments vary widely in content and availability of nutrients to plants. Table 2 summarizes the content of selected macronutrients for a variety of organic amendments. It should be noted that nutrients contained in organic amendments are not always available to

Table 2 – Content of some macronutrients in various organic amendments

Organic material	Total N (Kjeldahl)	P	K	Ca	Mg
	Percent, dry basis				
Bark					
Douglas–fir	0.12	0.011	0.11	0.52	0.01
Ponderosa pine	.12	.003	.11	.25	.01
Redwood	.11	.011	.06	.29	.00
Red alder	.73	.153	.24	1.25	.18
Sawdust:					
Douglas–fir	.04	.006	.09	.12	01
Ponderosa pine	.04	.008	.12	.16	.02
Redwood	.07	.001	.01	.20	.02
Red alder	.37	.013	.12	.18	.04
Moss peat	[1].83	.030	.02	.50	.12
Farmyard manure[2]	1.6–2.8	1.4–2.3	0.3–0.4	—	—
Sludge:					
Sewage[3]	2.0–8.0	1.5–3.0	0.2–0.8	—	—
Mint[4]	[5]	.072	.15	—	—
Fish[6]	.04	.003	.006	—	—

— = No data.

[1] Canadian sedge peat is often 2.4 times as high in nitrogen.

[2] Aldous (1972).

[3] Hausenbuiller (1978).

[4] Data taken from laboratory test, Oregon State University, 1979.

[5] Total N unknown; nitrate N is 0.008.

[6] Dutton, Wind River Nursery. USDA Forest Service. Personal communication. 1979 and 1980.

Source: Bollen (1969), except as otherwise note

plants. Organic material must be decomposed by micro-organisms in the soil to release the nutrients into the soil solution, making them available to plants. The physical condition of the soil is a key factor in the conversion of nutrient supplies to available forms through its influence on microbial activity.

Douglas and Magdoff (1991) looked at seven types of manures, six sewage sludges, and six composted or mixed soil amendments in an attempt to evaluate possible indicies to predict nitrogen (N) availability during decomposition. They define the total amount of N that will be potentially available in a residue amended soil as

PAN = (INORG-N + MON)soil + (INORG-N + MON)residue

where PAN equals potentially available N and MON equals mineralizable organic N. Their findings show that it is possible to predict the fraction of organic N mineralized by indexing using the Walkley-Black N digest (Heese 1971).

C/N Ratio

All organic matter, whether added as an amendment or as green manure, is first broken down by microbial organisms (microbes). The microbes (bacteria, fungi, and actinomycetes) become active and multiply rapidly with sudden additions of organic material. If microbes do not find sufficient nitrogen in the amendment, they absorb their requirement from the soil, thereby competing with other microbes and plant roots. Immobilization of nitrogen occurs when much of the inorganic nitrogen is converted to organic forms by microbes which use the nutrients to build their tissues. Thus, most of the nitrogen is tied up (immobilized) temporarily in the microbial bodies, and little, if any, nitrogen is available to higher plants. The condition persists until most of the easily oxidizable form of nitrogen in their tissues is once again converted (mineralized) to inorganic states available to plants (nitrate and ammonium). Through this process the soil becomes temporarily richer in both nitrogen and humus (Figure 2).

The carbon-to-nitrogen (C/N) ratio is the limiting factor. When the amount of carbon is high in relation to nitrogen contained in the residue, such as in straw, bacteria will require a high amount of nitrogen to decompose the residue. Therefore, addition of amendments with a high C/N ratio will result in a temporary depletion of soil nitrogen if

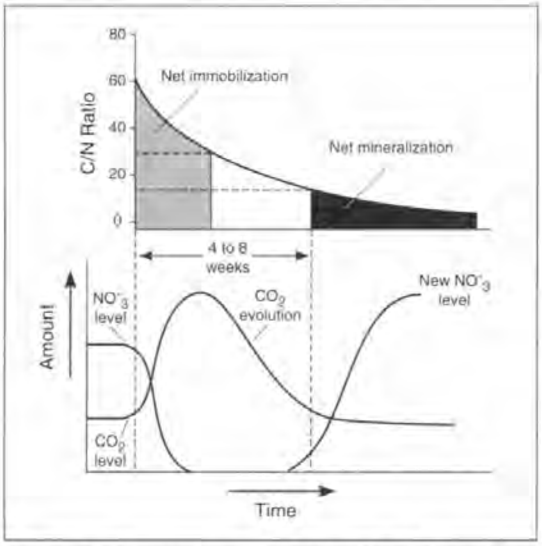

Figure 2. Changes in nitrate levels of soil during the decomposition of low-nitrogen crop residues. (From Tisdale and Nelson (1975), with permission of Macmillan Publishing Company, Inc.)

Table 3 – Analysis of cold–water solubles in various organic materials

Organic material	Acidity	Portion water soluble[1]	N (Kjeldahl)	C/N ratio
	pH	Percent, by weight		
Western redcedar:				
Bark	3.2	2.95	0.14	378:1
Wood	3.5	6.99	0.06	810:1
Redwood:				
Bark	3.2	2.35	.11	473:1
Wood	4.4	1.67	.07	753:1
Red alder:				
Bark	4.6	11.64	.72	71:1
Wood	5.8	1.43	.13	377:1
Western hemlock:				
Bark	4.1	3.95	.27	212:1
Wood	6.0	3.47	.04	1,234:1
Ponderosa pine:				
Bark	3.8	4.35	.12	422:1
Wood	4.4	2.68	.04	1,297:1
Sitka spruce:				
Bark	4.9	10.89	.41	130:1
Wood	4.1	1.27	.04	1,214:1
Douglas–fir:				
Untreated —				
Bark	3.6	5.49	.12	471:1
Wood	3.4	4.65	.04	1,268:1
Sour sawdust	2.0	12.81	.06	893:1
Moss peat	3.8	1.04	.83	58:1

[1] Total solids in 12 successive water extractions, 1:10 dilution, 24 hours each.
Source: Bollen (1969).

supplemental nitrogen is not added. Tables 3 and 4 summarize data, especially that of Bollen (1953,1969), on the C/N and other characteristics of various organic materials.

The C/N ratio of the added material determines the availability of nitrogen to the micro-organisms. For instance, if organic material high in carbon and low in nitrogen (high C/N ratio) is added to the soil, some pathogens are unable to infect their hosts because they lack sufficient nitrogen to sustain growth (Burke 1969). Powelson (1969) cited several cases in research when effective disease control occurred with the addition of residue having a high C/N ratio. Soils amended with mature, finely ground crop residues possessing a high C/N ratio controlled *F. solani* f. sp. *phaseoli*, the cause of pinto bean root rot, when applied at a rate of 10 to 12 tons per acre. Control was nullified when 120 pounds per acre of ammonium nitrate was added (Powelson 1969).

Huber et al. (1965) list a wide variety of crop residues shown to reduce bean root rot after their incorporation. These residues include sawdust, cellulose, wheat bran, sorghum, alfalfa hay, oat straw, soybean hay, bean straw, barley straw, wheat straw, corn shucks, and pine shavings. Control was attributed to the inability of *Fusarium solani* f. sp. *phaseoli* or other pathogens to compete with micro-organisms that were rapidly immobilizing soluble nitrogen. In other words, control occurred because organisms decomposing the organic residue tied up the soil nitrogen. Residues with low C/N ratios increased bean root rot. Incorporation of residues such as tomatoes, alfalfa, lettuce, bean-seed meal, green barley, barley straw, alfalfa, or soybean straw resulted in increased severity of the disease. These residues may also contain chemical compounds that encourage disease.

The hypothesis that the C/N ratio of crop residues directly influences the control of soil-borne diseases has not been clearly proven. Materials with low C/N ratios have occasionally been reported to control soil-borne diseases. There are inconsistencies in the literature, suggesting relationships other than the C/N ratio may be involved in disease control.

Huber et al. (1965) suggest that crop residues affect severity of disease through

Table 4 – Carbon–to–nitrogen ratio of farm and forest products used as mulches and soil conditions

Organic material	C/N ratio, water–free basis	Organic material	C/N ratio, water–free basis
Alfalfa hay	18:1	Cones:	
Bent grass clippings	13:1	Douglas–fir	133:1
Fiber flax, deseeded	373:1	Sitka spruce	109:1
Corn cobs	108:1	White fir	75:1
Rice hulls	72:1	Sawdust:	
Meadow hay (rush and sedge)	43:1	Douglas–fir —	
Pea vines:		Mill run, weathered 3 years	142:1
In bloom	17:1	Mill run, weathered 2 months	623:1
Mature (less pods)	29:1	Resaw, fresh	996:1
Straw:		Resaw —	
Rye	144:1	Red alder	134:1
Wheat	373:1	Western redcedar	729:1
Leaves, weathered:		Western hemlock	1,244:1
Oak	26:1	Ponderosa pine	1,064:1
Walnut	26:1	Sitka spruce	1,030:1
Douglas–fir		Lignin (Douglas–fir):	
420–year–old tree —		Scholler	881:1
Needles	58:1	Springfield	834:1
Bark	491:1	Cedar tow (western redcedar)	750:1
Sapwood	548:1	Moss peat	58:1
Heartwood	429:1	Waste sulfite liquor	
Bark —		(8.28–percent solids)	748:1
Young	304:1	Orzan A[1]	15:1
Old	293:1	Sewage sludge, digested	10:1
Cork	456:1	Cannery wastes, solid offal:	
Bast	494:1	Bean	10:1
Fines	451:1	Beet	18:1
Dust	317:1	Peach	40:1
Charcoal	305:1	Pear	63:1
Cinders	86:1	Tomato	10:1
White rot	73:1	Peptone, Difco	3:1
Red rot	49:1	Brazilian water weed	11:1

[1] Waste sulfite liquor, dehydrated ammonia base.

Source: Bollen (1953).

their effect on nitrification, which, in turn, determines the form of nitrogen available in the soil. Severity of *Fusarium* and *Rhizoctonia* was reduced by adding residues that increased the rate of nitrification. Conversely, residues inhibiting nitrification increased severity of disease, but they need to be incubated in the soil for longer periods before plant exposure.

Cation Exchange Capacity

Adding organic material to soil, particularly to sandy soils, increases the soil's ability to retain nutrients and supply them to trees. The cation exchange capacity (CEC) increases proportionally with increases

Table 5 — Cation exchange capacity (CEC) of various organic materials and nursery soils

Organic material and nursery soil	Size of mesh	CEC
		Meq/100 g
Douglas–fir:		
Bark	+5	44.8
	−10+40	39.7
	−40	60.5
Wood	−10+40	39.5
	−40+100	28.2
	−100+200	15.0
Red alder:		
Bark	−10+40	40.4
Wood	−10+40	59.0
	−100+200	7.5
Ponderosa pine wood	−10+40	13.5
Wheat straw	−10	39.4
	−60	19.4
Moss peat	−10	120.6
Nursery soils, USDA Forest Service:		
Bend, Oregon (loamy sand)		[1] 7–9
Medford, Oregon (sandy loam)		8–12
Wind River, Washington ("shotty" loam)		[1] 14–40

[1] Data on file with Donald E. Boyer.

Source: Bollen (1969), except as otherwise noted.

in organic matter. The CEC is important to plant growth by holding necessary cations such as potassium, calcium, and magnesium against loss by leaching while making them available to roots and microbes. Organic matter provides for retention of nutrient cations added to soil in the form of fertilizers. On a weight basis, the CEC of organic matter is much greater than that of clay. Leaf (1975) stated that a CEC of less than 8.0 milliequivalents per 100 grams for conifer seedlings is low and requires attention such as adding massive amounts of organic matter to correct the situation. Table 5 shows the CEC of various organic materials and nursery soils.

pH

Buffering capacity is the ability of a soil to resist change in pH. The buffering capacity will increase with an increase in clay and/or organic matter. Thus, a soil high in organic matter will not be as susceptible to sudden changes in acidity as a soil low in organic matter. This is important when considering long-term effects of various fertilizers.

Organic matter gives chemical buffering properties to the soil. This results in suppressing adverse effects of acidity or alkalinity, biocides, and to a certain extent, toxicity by heavy metals. The fact that organic matter plays a major role in adsorption of pesticides is well documented (Hance 1974, Huggenberger et al. 1973, Stevenson 1972a). The adsorption influences the rate of application, its movement through the mineral soil, phytotoxicity to species, volatility, and biodegradability. Thus, the effects of adsorption by organic matter may seem detrimental by commonly decreasing bioactivity and increasing residence time of the pesticide. On the other hand, there is the beneficial reduction of toxicity to tree seedlings. Pesticide-induced phytotoxicity is reduced proportionally by the amount of organic matter in the soil (Davey and Krause 1980). Harmful concentrations of biocides in the mineral soil can increase the mortality of seedlings, depress growth, and cause radical changes in nutrient uptake and composition of plants (Mader 1956). These changes may be accompanied by lowered resistance of seedlings to unfavorable environmental factors such as drought, frost, and insect damage. Research by Mader (1956) shows that if such toxicities from biocides are detected, incorporation of biologically active humus in the soil offers one means (perhaps the only means) to improve the growth and quality of nursery stock.

Chelation

Some of the literature suggests that organic matter plays a considerable role in tying up metals in the form of chelate complexes. Organic chelation of toxic metals such as mercury, lead, copper, zinc, and cadmium, has been recognized (Petruzellie et al. 1978, Stevenson 1972b). Metals may form a chemically bound net with organic matter and exert a protective action on soil peds.

Micronutrients

Little is known about micronutrient chemistry in nursery soils compared to macronutrients. It is known that practically every aspect of micronutrient chemistry is related to organic binding or chelation (Stevenson 1972b), but micronutrient deficiencies are difficult to show through standard soil or tissue analysis. Until the concentration of a particular micronutrient becomes deficient, tree seedlings do not manifest a weakened appearance. Therefore, the influence of micronutrients on tree seedlings remains difficult to detect (Iyer and Wilde 1974). Vector analysis (Haase and Rose 1995) is one method for examining the overall nutrient balance in plants, and hence soil. The technique allows for simultaneous comparison of plant growth, nutrient concentration and nutrient content in an integrated graphic format and aids in diagnosing deficiencies which may be visually unapparent.

Impacts on Biological Properities

Microbial Activity

Organic material is the critical energy source for both macro- and microorganisms. The initial decomposers, such as bacteria, actinomycetes, and fungi, depend on organic material to survive. The number and diversity of these first-level consumers are important to the overall balance of the microenvironment. There must be a balance between the beneficial and pathogenic microorganisms for plants to be healthy. If the humus level is low and organic material is not periodically added to a soil, the decomposer organisms will not be present in large numbers. Pathogenic micro-organisms, once introduced, will not be forced to compete in a diverse community of other micro-organisms, will have fewer natural predators, and may cause more damage than if they were present in a more stable community. Many microbiologists consider a high diversity of species indicative of high stability of the organism community (Dindal 1978).

The decomposition zone of mulch is the point of contact between the mulch and mineral soil. If the mulch is not eventually incorporated into the soil, decomposition proceeds slowly and the need for supplemental nitrogen is low. In soil amendments, only the portion that is water soluble is available for microbial decomposition. The rest, in the form of lignocellulose, is not readily available to microbes. For example, since only 5-10 percent of the bark used as mulch is water soluble, it is only that portion which is accessible for microbial attack (Bollen 1969).

Mycorrhizae

Adequate development of mycorrhizae is critical for proper growth and development of seedlings. Mycorrhizae improve the availability and absorption of nutrients, and protect delicate absorbing root tissue from attack by various soil pathogens (Marx 1973, Marx and Davey 1969, Stack and Sinclair 1975, Zak 1964). Mycorrhizae also benefit seedling growth by producing growth regulators (Slankis 1973) and protecting roots from soil phytotoxins (Zak 1971). Diversity of mycorrhizal types and their various ecological adaptability are important to tree growth (Trappe 1977) and establishment in plantations (Marx 1980). Establishment and maintenance of populations of desirable mycorrhizal fungi is directly influenced by management of soil organic matter.

Weed Resistance

As a weed control, mulch is reported to reduce hand weeding by 60-90 percent and to stimulate growth of transplants (Aldhous 1972). Mulches such as bark applied 8-10 inches thick on orchard soils should give long-term weed control for about 10 years (Bollen 1969). This practice also has the added advantages of retaining soil moisture, eliminating cultivation, and enabling year-round use of orchard equipment. Thick mulch may benefit tree nurseries with transplants; it may, however, smother smaller seedlings.

Land left barren between rotations is more susceptible to weed infestation than if covered by a green manure. Irrigation of the green manure crop, on the other hand, may encourage weed germination. Thus, the effectiveness of green manure as a weed control is unclear. Many nurseries in England (Aldhous 1972) use fallowing to reduce weeds by frequent shallow cultivation. But the detrimental effect of increased cultivation on physical and chemical characteristics of soil must be considered.

Disease Resistance

The concept that a healthy microenvironment gives rise to healthier plants is supported by evidence of tree seedlings' resistance to disease in different locations. Field plantations of young seedlings, for instance, do not exhibit the susceptibility to *Fusarium* sp. that nursery seedlings show. One possible explanation for this is that nursery soils are generally low in organic matter and have deficient microbial populations. Without adequate numbers of beneficial micro-organisms, such as mycorrhizal fungi, the nursery seedling has less chance of healthy growth than a seedling started in forest soil which, by nature of continual organic additions, has a rich, balanced microenvironment.

Evaluation of the effects of organic amendments on plant diseases is an extremely complex study of microbial ecology. Intricate interrelationships are involved between host species, mycorrhizal associations, pathogenic organisms, and presence of exudates and antibiotics associated with decomposition. Environmental factors of the rhizosphere, such as aeration, temperature, moisture and pH, greatly influence microbial interactions. Evidence of pathogenic response to organic amendments is cited for a number of crops because (1) little information is available regarding diseases of conifer seedlings and the effect of organic amendments on the diseases found in forest nurseries and (2) many disease organisms have a wide range of hosts.

Fungi, bacteria, actinomycetes, viruses, and nematodes cause a wide variety of plant disease. Lack of knowledge of the interrelationships between soil microflora contributes to frustration surrounding biological disease control. Antagonistic effects of some micro-organisms and/or associated antibiotics have been observed, although not consistently. These effects may be encouraged or suppressed with addition of organic matter. Damping-off in conifers has sometimes been reduced with bacterial inoculations. Some bacteria, actinomycetes, and fungi isolated from seedlings act antagonistically towards virulent pathogens such as *Phytophthora cactorum*, *Pythium debarynum*, and *Rhizoctonia solani* (Vaartzja and Salisbury 1965). Antagonistic effects of antibiotics produced by *Penicillium* and *Streptomyces* or other microbes have been studied. Common effects exerted by isolates tested by Vaartzja and Salisbury (1965) on other fungi (species unknown) are given in Table 6. These tests indicate inhibition without death as the most common type of antagonism in the interactions of soil fungi. Antagonism may be partially caused by competition for nutrients in addition to antibiotic effects associated with *Trichoderma* spp., *Penicillium* spp., *Streptomyces* spp., and *Bacterium* spp. Strong antagonism was also seen in a *Bacterium* spp. isolated as an associate of a nematode, further illustrating the complexity of microbial interaction in soil. Antibiotic effects from bacteria appear to be important in microbiological control of potato scab, onion pink rot, *Fusarium* and *Rhizoctonia* root rot of beans, and *Typhula* snowmold of wheat (Burke 1969).

Table 6 — Common effects of isolates of fungi on other fungi in cornmeal agar dishes

Isolate	Antagonistic effect from a distance	Stoppage of growth on contact	Lytic effects observed after contact
Aphanomyces spp.		x	
Armillaria mellea	x	x	x
Aureobasidium pullulans		x	
Bacterium sp.	x		
Basidiomycetes[1]			x
Cephalosporium spp.		x	
Cylindrocarpon spp.		x	x
Epicoccum nigrum	x	x	
Fusarium acuminatum	x	x	
Fusarium equiseti		x	
Fusarium oxsporum		x	
Fusarium oxsporum var. *redolens*	x		
Fusarium sporotrichoides	x	x	
Gliocladium spp.		x	x
Penicillium spp.	x	x	
Phoma spp.	x	x	
Phytophthora cactorum		x	
Phythium debaryanum		x	
Pythium ultimum		x	
Russula spp.		x	x
Streptomyces spp.	x		x
Suillus granulatus	x		
Thielaviopsis basicola		x	
Trichoderma spp.	x	x	
Trichoderma viride	x	x	

[1] 2 isolates.

Source: Vaartaja and Salisbury (1965).

Mutitu and Mukunya (1988) demonstrated that high levels of soil amendment with coffee hulls (2:1 w/w soil:coffee hulls) effectively controlled *Fusarium*. However, these high levels also contributed to a nitrogen deficiency. Lower amendment levels also reduced the disease significantly but not completely.

Beneficial effects of mycorrhizal associations with plants have already been discussed briefly. Zak (1964) and Marx (1973) suggested that mycorrhizal fungi protect delicate root tissue from parasitic fungi by (1) utilizing surplus carbohydrates and thus reducing attractiveness of roots to pathogens, (2) serving as a physical barrier to infection, (3) secreting antibiotics, and (4) favoring, along with the root, protective organisms in the rhizosphere. Most forest nurseries manage for the development of certain mycorrhizae that may aid seedlings in growth, nutrient uptake, protection against extremes in drought and temperatures, and/or protection against certain root pathogens. Delay in mycorrhizal formation occurs after fumigation. Sinclair (1974a) observed that potential opportunities for manipulating mycorrhizal fungi in previously fumigated soil exist during the first few weeks of seedling growth, before root systems are colonized by indigenous fungi. Nitrogen fertilizers, especially if applied in excessive amounts, can suppress the formation of mycorrhizae (Sinclair 1974b).

Nitrogen has been found to have an important effect on soil fungi (Huber et al. 1965, Smiley et al. 1970, 1972). The form of nitrogen (nitrate or ammonium) has an effect on severity of disease (Hornby and Goring 1972, Huber et al. 1965, Smiley and Cook 1973). The same form of nitrogen may have a suppressing effect on one pathogenic fungus and a stimulating effect on another. For example, the nitrate form of nitrogen has been found to decrease the severity of disease caused by *Fusarium*, *Rhizoctonia*, and *Aphanomyces*, whereas the ammonium form favors these diseases (Burke 1969, Huber et al. 1965, Smiley et al. 1970, 1972). Conversely, ammonium nitrogen reduces severity of *Verticillium* wilt of potatoes and take-all disease of wheat, but nitrate nitrogen will increase their severity.

The method and timing of nitrogen application has been shown to affect pathogenicity. Smiley and Cook (1973) found that the best control of wheat take-all disease caused by *Ophiobolus graminis* occurred when ammonium sulfate was mixed into the tilled layer rather than broadcast. Timing of the nitrogen application as a fertilizer or an amendment may affect the response of disease. Spring applications of ammonia nitrogen have resulted in increased severity of root rot of wheat, whereas spring application of nitrate nitrogen has no effect. If ammonium nitrogen is added in the early fall, when rapid soil nitrification occurs, it has no effect on the severity of disease. The effect of the specific form of nitrogen is not necessarily reflected in pathogenic population. Instead, the nitrogen form may change host resistance, activity of the pathogen, enzyme production, germination of chlamydospores (fruiting bodies of fungi) and/or other factors (Huber and Watson 1972).

Additions of organic residues or green manure will encourage saprophytic micro-organisms necessary for decomposition. The stimulated population of nonpathogenic saprophytes may compete for food, produce antibiotics, and thus may have some effect on pathogenic microbes. The organic amendment may also have a beneficial effect on the resistance of the host plant by slowly releasing nutrients available to the plant (Allison 1973). In addition, the effect of the organic material on physical and chemical soil characteristics will influence the dynamics of microbes.

Antibiosis refers to the microbial production of metabolites such as alcohols, acids, or specific antibiotics that create an unfavorable environment for other microflora (Weinhold 1969).

A long-term experiment tested cover crops of soybeans and barley that were incorporated in soil 3-5 months before potatoes were planted. The soybean cover crop and green manure completely prevented buildup of potato scab, but the barley cover crop and green manure nearly doubled the incidence of scab. The difference was attributed to an antibiotic effect of a bacterium stimulated by soybean growth (Weinhold 1969).

Bark has been used at rates of about 13 tons per acre to control *Fusarium* wilt of the Chinese yam (Hoitink 1980). Composted bark has also shown a suppressing effect on *Fusarium* wilt of chrysanthemums, whereas peat did not effect a change. Both woodshavings and urea have been found to increase the number of soil fungi. *Trichoderma* spp. were increased by additions of urea but not by woodshavings mixed with soil. *Trichoderma viride* is common in forest soil and appears antagonistic toward *Phellinus weirii* (Nelson 1972). Trappe (1971) also noted effects of alder as a biological control for *Phellinus* spp.

Wheat straw has shown a depressive effect on pathogenicity of *Rhizoctonia.* This may be because of the nitrogen starvation of the mycelium brought about by the saprophytes multiplying on the residue. The increase in $C0_2$ from increased respiration of the saprophytes may also contribute to the depressive effect on pathogens. Isolates of *Rhizoctonia* spp. are known to differ in their sensitivity to concentrations of $C0_2$ (Patrick and Toussoun 1970). The pathogenic phase of *Rhizoctonia* appears more sensitive to $C0_2$ than the resting phase (Papavizas and Davey 1962).

Several rotation and cover crops are used to control severity of disease. Corn proved more effective when used in rotation to control *Cylindrocladium scoparium* than an 8-year fallow. Corn has also been used to suppress *Verticillium* spp. in peppermint, whereas a soybean cover increased incidence of this disease because soybean is a susceptible host (Theis and Patton 1970).

Growing cover crops of flax or Sudangrass in conifer nurseries in Wisconsin has been effective in controlling root rot disease, as previously discussed. Iyer (1979) recently discovered adverse effects from using sorghum-Sudangrass mixture reflected in mortality and poor growth of seedlings. Harmful effects have not been observed in the South. An estimate of about 75-80 percent of all nurseries in the South use sorghum-Sudangrass as a cover crop. Decomposition of sorghum-Sudan hybrids may release small amounts of cyanide, which help control root pathogens. The detrimental effect of cyanide on seedlings and mycorrhizal fungi is reduced by allowing ample time for decomposition (Davey and Krause 1980). Thus, the difference in the effect of this cover crop between the northern and southern nurseries is probably the result of differences in climate (soil temperature and moisture) and subsequent decomposition.

Barley straw is considered one of the best crop amendments for reducing incidence of *Rhizoctonia* spp. (Davey and Krause 1980). There are several examples of crops that may show one effect during decomposition and another effect after rotation.

Phytotoxic compounds have been obtained from residues of barley, rye, wheat, Sudangrass, vetch, broccoli, and broadbean under natural decomposition (Toussoun 1969). Linderman (1970) observed that decomposition of barley under waterlogged conditions resulted in phytotoxic compounds in water extracts. These same phytotoxic components of the extracts (organic acids) were also found in field-decomposed barley, soybean, cowpea, and cotton. The tests implied that these aromatic acids occur in nature following decomposition of a diverse variety of plants under wet conditions.

Other tests have shown that water extracts of some plant residues were phytotoxic to seedlings of several crop plants. Among the most phytotoxic were residues from sugar beets, potatoes, alfalfa, green soybeans, peas, beans, and red clover. Other phytotoxic compounds have been found in water extracts from oat straw, timothy hay, stalks of corn and sorghum, and bromegrass (Patrick and Toussoun 1970). Green residues of plants were proven more phytotoxic than mature residues of crop plants. Obviously, many of the above crops have appeared satisfactory when used as a green manure crop or amendment as long as decomposition was allowed to occur for at least one month in a warm, well-aerated soil before sowing of subsequent crop.

Stimulation of pathogenic fungi has been observed when phytotoxins are present. This appears to be brought about by nutrients present in decomposing residues rather than by phytotoxins themselves. Toussoun (1969) suggests a two-fold effect caused by residues in stimulating the pathogen: (1) production of phytotoxins may increase exudation of host cells without causing any visible symptoms, and (2) phytotoxins may weaken host tissues, making them susceptible to attack by normally innocuous soil inhabitants.

NEMATODE RESISTANCE

Rodriquez-Kabana and Morgan-Jones (1987) re-examined the value of organic amendments in soil due to the loss of key nematicides in agriculture. They note that "the most effective amendments are those with narrow C:N ratios and high protein or amine type N content." They suggest that chitinous amendments show promise against nematodes. It is also possible to modify amendments by inoculating them with specific microbial species. Their review showed that this research area has many complex unknowns and using amendments to control nematodes and disease is difficult.

Fauna

Faunal organisms, such as earthworms, millipedes, and beetles (second- and third-level consumers) are similarly affected by soil organic matter. As predators and carriers of bacteria, molds, and actinomycetes, they also have a key role in a stable soil environment. In addition to keeping the number of micro-organisms in check, fauna are also important agents in producing good soil structure. The extensive channels they construct help loosen the soil and improve drainage and aeration. Soil fauna can flourish only in soils which have organic matter.

Decomposition of Organic Matter in Soil

The rapidity with which a given organic amendment is decomposed depends on temperature, the supply of oxygen, moisture, and available minerals, the C/N ratio of the added material, the microbial population, the age and lignin content of the added residue, and the degree of disintegration. Arshad and Frankenberger (1990) found that organic amendments contributed to the production of ethylene in the soil. Ethylene is produced by a diverse group of microorganisms and is important to many phases of plant development.

Requirements

Oxygen. Oxygen supply is essential to aerobic micro-organisms, the primary agents in decomposition. Thus, reduction in air supply will result in reduced decomposition rates.

Water. Respiration of soil microflora is generally greatest at 60-80 percent of the waterholding capacity of soil. Too much water results in less oxygen supply and may hinder processes. At low moisture levels, supplemental moisture will result in a large increase in decay, whereas similar additions at moisture levels nearer optimum will effect little change.

pH. Microbial populations are highest in soils with a neutral pH. Neutral soils, therefore, are more conducive to decomposition than acidic or alkaline soils. Since many soils in the coniferous nurseries are commonly acidic, the addition of lime could manipulate soil pH and supply calcium, accelerating initial decomposition. Lime additions, however, need to be monitored carefully to prevent an increase in pH and subsequent infection by damping-off fungi.

Temperature. Temperature is one of the most important environmental factors determining how quickly natural materials are metabolized and subsequently mineralized. There is no single optimum temperature because the composition of and optimum temperatures for microbial species vary. In the temperature range of 41°-86°F, decomposition of plant residue is usually accelerated with rising temperature. Maximum decomposition rates are reached within a range of 86°-104°F. Above 104°F, decomposition rates generally decline (Alexander 1961).

Nitrogen. Nitrogen is essential for microbial growth and therefore the breakdown of organic matter. As described earlier, if the added material is low in nitrogen, microbes will compete with higher plants for nitrogen. This may result in a nitrogen deficiency. If supplemental nitrogen is added, decomposition is stimulated. Nitrogen-rich materials, such as legumes or blood meal, are metabolized quickly and need no supplemental nitrogen. When organic amendments having a C/N ratio of greater than 20 or 30 are added to soil, supplemental nitrogen is needed. Some materials such as sawdust, however, need only to have their C/N ratio brought down below 50 to eliminate nitrogen tie-up. The decomposers of such materials will recycle nitrogen fast enough to keep up with carbon metabolism (Refer to Tables 3 and 4 for C/N ratios).

Nitrogen is required for the initial application of mulch, for a moderately thick mulch of at least 1 inch, and again after some of the more slowly decomposable constituents become available. Bollen (1969) recommends 5-10 pounds of nitrogen for each ton, dry basis, of mulch at the time of application, and 2.5-5 pounds of nitrogen per ton should be added the second year. No further additions of nitrogen should be required because it will be released from microbial bodies after their death. Irrigation must be adequate after heavy application of nitrogen to prevent salt injury to plants. Theoretical amounts of supplemental nitrogen required with application of some wood mulches are outlined in Table 7. Actual amounts can be figured using the calculations shown in Appendix A.

Adding sawdust and bark in quantity to the soil has frequently inhibited growth, but studies show that such effects are usually the result of nitrogen deficiency (Allison 1973). To calculate the amount of nitrogen required to decompose organic material, it is necessary to know the amount of nitrogen immobilized by the micro-organisms in breaking down various products. Table 8 shows the percent of nitrogen immobilized for the sawdust of various tree species and wheat straw. For instance, if 1 ton of lodgepole pine sawdust is added to an acre, the percent of nitrogen immobilized after 160 days is 0.80. Therefore, at least 16 pounds of nitrogen per acre (0.008 x 2,000 lb) would be required. Examples of calculations are in appendix A. To account for a slightly increased amount immobilized beyond 160 days, it would probably be better to add 20 pounds of nitrogen per acre. A supplement of 20-25 pounds of nitrogen per ton of incorporated dry sawdust is adequate for most woods (Allison 1965). Red alder decomposes more quickly because it contains more N than other species and may require as much as 25-30 pounds of additional nitrogen per acre. It must be emphasized that this supplemental nitrogen is designed only to meet microbial demands necessary to decompose the added material and in no way is intended to provide for the nitrogen needs of the crops that will follow.

Table 7 — Characteristics of wood mulch and theoretical amounts of supplemental nitrogen required for application of commercially prepared wood mulch[1]

Characteristic of mulch and supplemental N required	Unit	Ground bark		Sawdust (Douglas–fir)
		Douglas–fir	Hemlock	
Thickness	in/acre	1	1	1
Moisture content[2]	percent	67	80	74
Weight:				
Wet	lb/ft^3	18	21	17
	tons/acre	66	100	70
Ovendry (105-)	lb/ft^3	11	11	11
	tons/acre	20	20	18
Volume[2]	ft^3/acre	134	134	134
Supplemental N required with mulch:[3]				
Nitrogen —				
Initial application	lb/acre	100– 200	100– 200	100– 200
2d year	lb/acre	50– 100	50– 100	50– 100
Ammonium sulfate —				
Initial application	lb/acre	500–1,000	500–1,000	500–1,000
2d year	lb/acre	250– 500	250– 500	250– 500

[1] Values given have been rounded.

[2] Values are highly variable; the ones shown have been assumed.

[3] Nitrogen requirement was calculated assuming that 5–10 pounds N per ton, dry basis. was needed with initial application of wood mulch and 2.5–5 pounds N per ton was needed the 2d year (Bollen 1969).

Source: Bollen (1969).

Rate

Decomposition begins as soon as succulent green plant tissue is incorporated in a warm, moist soil. Associated with this decomposition is the release of ammonia and other macronutrients and micronutrients. This release is rapid in the first few months and continues at an ever-decreasing rate. The crop that follows is thus assured a steady release of nutrients (Allison 1973).

The quantity of lignin and cellulose in plant residue is also important in predicting rates of decomposition. Slow rates of decomposition are commonly observed with residues that are high in lignin and cellulose (Alexander 1961). Paustian et al. (1992) modeled the long-term (30-year) effects of the quantity and quality of organic amendments on soil organic matter and nutrient dynamics in a Swedish field. In those treatments not receiving organic matter the soil organic matter levels showed net losses. They also stated that lignin content showed a strong positive effect on organic matter accumulation. Adding fertilizer nitrogen increased organic matter carbon levels in all cases.

Size of particles also affects decomposition. Generally, a decrease in size will increase the decomposition rate, increase the amount of amendment that is water soluble, and hence increase the demand for nitrogen. Distribution of particles will affect the degree to which mulch will pack. For instance, if material has mostly fines with few larger pieces, it may have a tendency to seal the surface and impede infiltration.

Table 8 — Amount of nitrogen immobilized by micro–organisms decomposing sawdust and wheat straw incorporated into the soil

Type of sawdust	Nitrogen Immobilized after —				
	10 days	20 days	40 days	80 days	160 days
	Percent, dry weight				
Softwoods:					
California Incense–cedar	0.17	0.25	0.52	0.69	0.72
Redcedar	.17	.22	.17	.28	.41
Cypress	.13	.08	.17	.25	.37
Redwood	.13	.22	.21	.31	.34
Western larch	.20	.21	.44	.64	.79
Eastern hemlock	.08	.08	.20	.35	.42
Red fir	.22	.14	.36	.54	.83
White fir	.04	.00	.25	.35	.54
Douglas–fir	.07	.21	.07	.14	.30
Engelmann spruce	.15	.06	.48	.69	.74
White pine	.08	.05	.29	.48	.41
Shortleaf pine	.78	1.00	1.27	1.30	1.13
Loblolly pine	.01	.15	.31	.63	.60
Slash pine	.04	.02	.17	.46	.64
Longleaf pine	.01	.00	.15	.30	.49
Ponderosa pine	.05	.07	.19	.44	.42
Western white pine	.11	.08	.35	.61	.89
Lodgepole pine	.07	.01	.29	.61	.80
Sugar pine	.13	.15	.33	.43	.54
Average	.14	.16	.33	.50	.59
Hardwoods:					
Black oak	.86	1.17	1.21	1.20	1.05
White oak	.62	.96	1.19	1.15	1.09
Red oak	.93	1.20	1.40	1.23	1.16
Post oak	.77	1.07	1.27	1.25	1.20
Hickory	.78	1.00	1.12	1.17	1.07
Red gum	.90	1.28	1.24	1.18	1.04
Yellow–poplar	.98	1.19	1.13	1.15	1.05
Chestnut	.38	.88	1.14	1.07	1.13
Black walnut	.80	1.18	1.20	1.15	1.07
Average	.78	1.10	1.21	1.17	1.10
Average, all woods	.35	.46	.61	.72	.75
Wheat straw	1.25	1.68	1.35	1.14	—

— = No data.

Source: Allison (1965).

Timing

Application of organic elements is best made in the spring, thus allowing decomposition during warm summer months. Supplemental fertilization is made in the spring and grass or another cover crop can be planted. Soils should be kept moist but not saturated to encourage decomposition.

Microbial Activity

For centuries compost (artificial manure) has been used in China, India, and other Asiatic countries, and to a lesser extent in western countries. There are an infinite number of composting methods, but no one method is superior (Allison 1973). The basic purpose of composting is to bring about a rapid and thorough partial decomposition of organic materials with little loss of nutrients in order to produce an end product that has desirable physical and chemical properties.

Processes commonly used in composting involve piles of alternate layers of organic wastes and other materials including topsoil, peat, wood products, or other absorbing substances. Addition of animal manures speeds up decomposition and improves physical characteristics of the compost product.

Supplemental fertilizer nitrogen may be needed if organic wastes have wide or high carbon-to-nitrogen ratios. Often, animal manures can provide all or a portion of this requirement for extra nitrogen. Limestone is often mixed into the compost pile to alter the pH and to encourage microbial decomposition.

Good aeration is needed in the compost pile, especially if succulent vegetable wastes are mixed with materials having slower decomposition rates. Aerobic digestion is accomplished by mixing the pile occasionally to prevent packing into soggy anaerobic mixtures. Natural rainfall or irrigation can provide moisture that is required by microorganisms breaking down the mixture, though prolonged exposure can leach nutrients. The decay process may take 3-4 months in temperate climates but varies with materials used and climatic conditions.

Organic Amendments and Their Uses

Organic amendments may be added to the surface as a mulch or incorporated into the soil. Additions of mulch are most often incorporated into the soil at a later date. Because there are distinct differences in management practices between mulches and incorporated amendments, they are discussed separately.

The physical characteristics of soil improve after organic material is incorporated into the soil. As already described, soil usually increases aggregate stability and cation exchange capacity, and it may increase availability of various nutrients as the organic material decomposes (van den Driessche 1969).

On a large scale, such as in a forest nursery, comparable value of compost may be achieved by incorporating organic matter with appropriate amounts of supplemental nitrogen, a process sometimes called field composting. The labor and expense of large composting operations may be prohibitive. On the other hand, when disposal of objectionable wastes such as sewage sludge, garbage, canning waste and manure is a problem, composting may be justified. Cooperative agreements between forest nurseries and municipalities or industries have the high potential of lowering costs of composting and resulting in an environmentally beneficial soil amendment (Figure 3). Most recent research involving composting methods has been aimed at achieving an environmentally acceptable product from sewage sludge, garbage, and other municipal and feedlot wastes.

Figure 3. Compost of municipal sewage sludge and sawdust was added to the bed and planted with lodgepole pine. J. Herbert Stone Nursery, Medford, Oregon.

Selection and Application of an Organic Amendment

Characteristics of mulch material that should be considered are C/N ratio, size and distribution of particles, heat capacity, and reflectance. The nitrogen demand for decomposing the mulch can be estimated by considering the C/N ratio. As already mentioned, this can be misleading for a number of reasons. Only a portion of each material is water soluble or accessible for microbial attack. Also, the form of the carbon is influential. Materials having higher cellulose and lignin content will be more resistant to decomposition. Data are highly variable for volume weight of organic materials. For all these reasons precise calculations to determine need for supplemental nitrogen with mulch or incorporated organic amendments is impossible. The only resort is to proceed by careful trial and error with adequate documentation.

There is no universal optimum level of organic matter in soil. Different soils in various climates have different potentials for reaching a given level of organic matter. The level of virgin soil reaches an equilibrium that reflects the nature of the soil, climatic conditions, and kind and amount of plant cover. Under cultivation, the content of organic matter usually decreases 50-60 percent of its original level within 25 years. The decrease is likely to continue for many more years but at a slower rate. Maintenance of a suitable level of organic matter requires careful monitoring and periodic application of organic materials. For example, an optimum level of organic matter for the Wind River Nursery in Washington may be 5 percent (based on the wet combustion method of determining organic matter), whereas some Canadian nurseries may be 6 percent and some nurseries in England strive for 12 percent. Nurseries in the southern United States may be able to maintain only 1 percent with regular additions of organic material. What is important is to achieve levels commensurate with the type of soil in a certain climate.

Table 9 — Theoretical amount of supplemental nitrogen required when 1 ton of organic amendment is incorporated into the soil

Amendment	Supplemental nitrogen required
	Pounds per acre
Bark	[1,2] 10–20
Sawdust	[1,2] 10–20
Chips	10–20
Flyash	0
Sludge:	
Paper mill	0
Mint	0
Sewage	0
Leaves	10
Alfalfa or other legumes	0
Straw	[3] 25
Peat	0
Hop waste	0
Manure[4]	0

[1] For more precise calculations, use the information in table 11 and appendix A.

[2] Bollen (1969).

[3] Allison (1973). Extra N promotes more rapid decomposition in spite of a lower carbon–to–nitrogen ratio.

[4] Most clean manures not mixed with sawdust or other material.

Organic material can be incorporated using many types of equipment, such as rototiller, disk, or plow. Disking is preferred because it ensures optimal mixing while leaving some organic matter on the surface of the soil.

Incorporated organic materials may need additions of supplemental nitrogen; some general recommendations are given in Table 9. If a nursery manager is considering whether to incorporate material other than sawdust or bark, he or she should get a chemical analysis of the material. Along with cumulative properties, the manager should look at the concentrations of certain elements and give particular attention to pH and electrical conductivity. Standards have not been developed to guide the nursery manager, but some suggestions can be made. Generally, analyses should include determining the concentrations of lead, zinc, copper, nickel, and cadmium if evaluating the use of sewage sludge. Organic byproducts should be tested for pH and the usual elements (phosphorus, potassium, calcium, magnesium, and total nitrogen) and be analyzed for sodium, electrical conductivity, and cation exchange capacity. If, for some reason, the pH of the material being evaluated is less than 4.0 or greater than 8.0 or the electrical conductivity is greater than 4 millimhos per centimeter, the manager should seek assistance from a technical pool such as the soil science department at a nearby university.

Hausenbuiller (1978) has provided a generality relative to the amount of metal accumulation allowable; his generality provides a small degree of guidance. For each milliequivalent of cation exchange capacity, no more than the following amounts should be allowed to accumulate: lead 89.2 pounds per acre, zinc 44.6, copper 22.3, nickel 8.92, and cadmium 0.89.

Any material to be applied should be incorporated into the upper 10 inches of soil at least 4 months before conifer seedlings are planted. Preferably, the material should be applied before the cover crop. If analysis of the incorporated material indicates the presence of undesirable properties, a cover crop should be selected on the basis of its ability to absorb or reduce those undesirable properties. Leaching through the use of irrigation systems is also a management tool that can be used to ameliorate undesirable properties.

Types of Organic Amendments

Straw

As a Mulch. Nurseries in southern Ontario, Canada, have successfully protected fall-sown seedbeds against frost heaving by covering them with weed-free straw (Armson and Sadreika 1974). Shades made from wooden laths hold down the straw and both the straw and laths are removed from the beds when germination begins in the spring. This method of temporarily mulching during winter months may not require supplemental nitrogen. For each acre of seedbed to be mulched in Ontario, approximately 2 acres of rye are grown.

Rye straw is similarly used in other parts of the world. It is a common practice in Israel to layer rye straw 2.4-3.0 inches thick in tree nurseries, removing straw or placing it between rows when shoots appear (Koreisho and Morozov 1966). With this method, every square foot of seedling surface requires 0.216 pounds of mulch. The use of an organic fertilizer such as compost, decomposed manure, peat, or other forms is mandatory to offset nitrogen deficiency. The need for nitrogen may be due to warmer climatic conditions or leaving mulch on site.

Straw or bracken (fern) mulch is spread in tree nurseries in England 2-3 inches thick for weed control and to stimulate growth of transplants (Aldhous 1972). Under this regime, a mulch 2 inches thick requires more than 7,000 cubic feet of mulch per acre, which approximates 90 tons of mulch per acre. The moisture content or other characteristics of this mulch were not given.

Straw has been effectively used at the USFS Wind River Nursery to prevent frost heaving of shallow-rooted species such as Pacific silver fir, Engelmann spruce, western redcedar, mountain hemlock, and western hemlock.

As an Incorporated Amendment. Straw can be incorporated directly into soil with satisfactory results. If 25 pounds of nitrogen per ton of straw is added, the straw will decompose readily in the soil; this mixture usually increases crop growth satisfactorily (Allison 1973). Because of its bulkiness, straw may cause dessication of plants from air pockets in the soil. If properly chopped (or mowed), disked, and tilled, this problem should be alleviated. When straw that is used first as a mulch is incorporated into soil, faster breakdown is expected; 20-22 pounds of supplemental nitrogen per ton of straw should be sufficient in this case.

Sawdust

As a Mulch. Sawdust as mulch is applied in both fresh and composted form. The Wind River Nursery has been successful at preventing frost damage by using a one-inch thick sawdust mulch on the soil surface .

The prevention of frost heaving of 1-0 seedlings in Canadian nurseries occurs with use of sawdust mulch (van den Driessche 1969). Small quantities of sawdust are added to seedbeds in October once each rotation. Seedlings not mulched in the fall often appear greener and more vigorous in the spring. This is attributed to a demand for nitrogen because winter application of sawdust could have little effect on nitrogen nutrition of dormant seedlings. It could, however, effect nitrogen mineralization in the spring.

Sawdust is also used as a mulch for weed control, temperature regulation, moisture retention, and improved soil structure. Some English nurseries use sawdust to reduce weeding by hand. It is applied 1-2 inches thick for this purpose (Aldhous 1972). Treatments of sawdust mulch only one-fourth inch thick have shown lower maximum temperature of surface soil and a reduction in mortality of slash pine and loblolly pine (Posey and May 1954). In the study, sawdust application was made immediately after sowing and was maintained throughout the growing season. Germination was not adversely affected. Other research has shown sawdust mulches to have no effect on soil acidity (Allison 1965, Bollen and Lu 1957, Kirsch 1959), to facilitate operations such as weed control, and to reduce the rate of moisture evaporation (Kirsch 1959). Aggregate stability is also improved under sawdust mulch (van Nierop and White 1958).

Sour sawdust is produced when sawdust has been stored in piles and is moist, compacted, and in an anaerobic state; it has a toxic effect on plants because acetic acid and other volatile organic acids are present (Bollen and Lu 1970) (Figure 4). Sour sawdust is easy to detect by its acrid odor. A reaction below pH 3.5 also indicates sawdust that is not safe. Other toxic effects have been recorded from using sawdust from western redcedar (Krueger 1963), incense cedar, and Scots pine (Allison 1965). Root, bark, leaves, and possibly sawdust from the wood of black walnut are known to inhibit growth of many plants (DeBell 1980).

Used as mulch in only winter months, sawdust may not require supplemental nitrogen. If left on the ground and subsequently decomposed, adding nitrogen at the rate recommended by Bollen and Lu (1957) should be sufficient. They suggest adding 5-10 pounds of nitrogen per ton of sawdust during the first year followed by half that amount the second and third years. This rate is sufficient for most sawdusts except alder. Alder sawdust is more readily decomposed than other (Table 10) and therefore requires a higher ini-

Figure 4. Sawdust piles can become sour if left in moist and anaerobic condition.

Table 10 – Apparent decomposition of various organic amendments 50 days after being added to silty day loom soil

Material	Percent decomposed
Wheat straw	48
Sawdust:	
Red alder	40
Ponderosa pine	33
Douglas–fir	30
Western hemlock	27
Pitch	30
Bark	26
Lignin	6
Dextrose	60

Source: Bollen and Lu (1957).

tial supplement of nitrogen (Bollen and Lu 1957). The addition of 10-20 pounds of nitrogen per ton for alder sawdust followed with half this amount the second and third years should be sufficient.

When calculating the nitrogen needs of sawdust, the nursery manager can assume the weight of dry sawdust to be 10 pounds per cubic foot or 270 pounds per cubic yard. Green sawdust weighs 18-25 pounds per cubic foot, and about 500-700 pounds per cubic yard.

As an Incorporated Amendment. Fresh sawdust has stunted the growth of white spruce seedlings even though adequate supplemental nitrogen was added. Phenolic compounds are released in initial stages of decomposition. The phenolic substances have phytotoxic effects by inhibiting the germination and growth of plants. But if sawdust has been exposed to weathering, these substances are leached and are no longer harmful (Davey and Krause 1980).

Composted. Composting wood waste (bark, sawdust, chips, etc.) enhances such properties as cation exchange capacity, moisture capacity, color, texture, and stability (Bollen and Glennie 1963, Dunn and Emery 1959). Applications of composted sawdust to sandy soil produced a marked increase in the growth of both coniferous and deciduous seedlings (Davey 1953). Additions of micro-organisms that efficiently decompose cellulose can speed up decomposition of sawdust composts. Many researchers feel most nursery soils have adequate populations of efficient cellulose-destroying fungi like *Coprinus ephemerus* (Camp and Iyer 1976). Davey (1955), however, found inoculation of *Coprinus ephemerus* in a variety of sawdust composts that were treated with anhydrous ammonia, phosphoric acid, and potassium sulfate encouraged decomposition rate. Davey (1953) described a recipe to produce sawdust composts:

1. Treat fresh sawdust with 15 pounds nitrogen as anhydrous ammonia per cubic yard.
2. Add 5 pounds of 50% potassium sulfate per cubic yard and let stand 10 days.
3. Neutralize by adding 2 pounds of 85% phosphoric acid per cubic yard which is diluted with 8 gallons of water to facilitate uniform distribution and wait another 10 days.
4. Inoculate with cellulose-destroying fungi, *Coprinus ephemerus*, cultured in decayed wood.
5. Turn and water occasionally over three months after which time sawdust will have been transformed to good compost.

Bark

As a Mulch. Bark is preferred over sawdust as a mulching material because it has a slower decomposition rate, more pleasing color and texture, and it reflects less heat and light from its surface to the underside of plants (Bollen 1969). Bark also lasts longer, is less of a fire hazard than straw, and is free from weed seeds. Bark also stays in place better than either straw or sawdust.

Bollen (1969) suggests that bark be screened for use as a mulch ranging from one-half inch to fines with a majority of particles ranging from one-fiftieth to one-eighth inch (approximately #32 to 6 mesh). An excess of fines should be avoided because it stirs up dust and tends to compact, which may retard aeration and infiltration of water.

Bark is useful in preventing abrupt changes in soil temperature because of its corky nature (Aaron 1976). It is also used effectively as a weed control. Aaron (1976) reported a savings of £1,500 ($3,750) in 1973 at Surrey University (Guildford Nursery) by applying a 2-inch (50-mm) mulch to beds and borders. Weed seeds have difficulty germinating because the upper layers of bark are drier, and weeds that do grow are more easily plucked out of the bark than out of soil.

No adverse effects have been reported from adding bark to soil, either as a mulch or incorporating it, when adequate amounts of nitrogen are added. The only exceptions found in the literature are the bark of black walnut, found toxic to many plants (DeBell 1980), and that of white pine, which was found toxic to garden peas (Allison 1965). Bark tannins produced no harmful effects when added to two different forest soils (Bollen and Lu 1969).

As discussed earlier, initial addition of nitrogen does not need to be based on the total carbon content of the material because only the portion of the substance that is water soluble is readily available for attack by microbes (Bollen 1969) (Table 11, see also Table 3). With the addition of bark, only 5-10 percent is water soluble, therefore, 5-10 pounds of fertilizer nitrogen for each ton, dry basis, of mulch is needed at the time of application. To care for the more slowly decomposable constituents, about 2.5-5.0 pounds per ton should be added the second year (Table 7). No further nitrogen should be needed. To calculate how much nitrogen is required, the nursery manager needs data on bark volume weight on an ovendry (221°F) basis. Specific calculations should be done for each type of bark because variations in particle size, compaction and moisture retention make the nitrogen requirement impossible to predict otherwise.

Salty bark is bark from logs that have been stored or transported in saltwater. Salty bark of Douglas-fir logs could result in injury to salt-sensitive plants if used at the usual rate of about 40 tons per acre (Bollen and Lu 1969). The salt is readily leached by rainfall or irrigation. If ground to a 1/4- to 1/2-inch size, common for horticultural purposes and used as a mulch, it will create less hazard than if incorporated in the soil. Salty bark is not recommended for use in forest nurseries.

Table 11 — Nitrogen fertilizer requirement for optimum decomposition of crop residue

Crop residue	Nitrogen content	Nitrogen required to raise N to 2-percent concentration
	Percent	*Pounds per ton*
Alfalfa	2.40	0
Green vetch	4.50	0
Barley hay	1.20	16
Corn stalks	.90	22
Barley stubble	.60	28
Bark:		
Western hemlock	.27	[1] 35
Douglas-fir	.12	[1] 38

[1] Major constituents are resistant to decomposition. Thus, only 5 pounds per ton is required to satisfy N demand of water-soluble materials.

Source: Bollen (1969).

Figure 5. Sawdust watered just before planting the cover crop. J. Herbert Stone Nursery, Medford, Oregon.

As an Incorporated Amendment. Disking is preferred over plowing to incorporate wood products. Amounts of sawdust, bark, or wood chips to incorporate may vary according to desired organic level. Application rates range from 10-100 tons per acre. Optimal time to incorporate is before the cover crop is planted rather than before seedlings are planted (Figure 5).

For incorporating bark into soil, Bollen (1969) suggests the addition of 10-20 pounds of nitrogen per ton of bark. This is twice the amount recommended for initial application of bark mulch (although a second nitrogen feeding is also recommended). More nitrogen is needed for initial breakdown when material is incorporated because the organic material is mixed with the soil, is more accessible to micro-organisms, and offers close contact with plant roots.

Similar recommendations (10-20 pounds of nitrogen per ton of material) would also be an appropriate supplement for most wood chips.

Composted. Composted bark can be an excellent material to use as a mulch, an amendment, or growing medium. Research by Hoitink (1980) suggests that composted tree bark can be used as a biological control for some soil-borne diseases, especially those caused by fungi. Its use eliminated the need for sterilization and reduced the need for fungicides when adopted for production of containerized nursery stock. Apparently the suppressive effect was specific to bark of various tree species. Bark compost from a mixture of hardwood species suppressed *Phytophthora, Pythium,* and *Thielaviopsis* root rots; *Rhizoctonia* damping-off; crown rot; *Fusarium* wilt; and some nematode diseases on a number of plant species. Suppression of *Phytophthora* and *Pythium* root rots occurred using pine bark, but *Rhizoctonia* damping-off was unaffected. Apparently, the bark-to-peat ratio in container media also is important to suppression. Hoitink (1980) noted that if more than 50 percent of the composted hardwood bark in a bark-peat mixture is replaced with peat, root rots were experienced in nurseries and in greenhouse crops. Substitution of all or most of the peat in container media with hardwood bark, however, eliminated root rot of rhododendrons in many nurseries without the use of soil fungicides.

Sludge

Paper Mill. A mixture of paper mill sludge ("Wauna primary-secondary sludge" from Crown Zellerbach Corporation) has been used as a mulch and an amendment at the Wind River Nursery. Although studies have not shown a significant increase in growth rates, the seedlings grown in soil mulched and amended with the paper mill sludge have denser and stronger root structures than in control plots. Treated seedlings also become dormant 2-3 weeks before the controls. Use of hydromulches containing paper sludge is common in nurseries as well as roadside stabilization. Wind River Nursery has been using a hydromulch made by Weyerhaeuser Company with good results.

Paper mill sludge is a fibrous effluent of paper mills. This byproduct may undergo primary digestion, resulting in about 15-percent solids, and secondary digestion or activated process, yielding from 2- to 8-percent solids (Krzeminski 1979) up to 21-percent solids. Primary and secondary paper sludges are often mixed before they are disposed. The chemical content of paper sludges varies wildely, depending on the design of the plant, type of paper product, and the digestion process.

Paper mill sludge has been applied in a multiyear experiment at Wind River Nursery in cooperation with Crown Zellerbach Corporation. Little visible effect was noticed the first season. By the second season, however, the seedlings in sludge plots were greener in appearance and their root systems more fibrous with more feeder roots than untreated seedlings. In plots receiving heavy applications of paper mill sludge, however, nitrogen decifiencies were still evident four years later.

Because many of the organic materials available to the nursery manager as an amendment are byproducts of an industrial process, they vary considerably in their composition. Further, because different industries employ different methods of processing, there can be great differences in the composition of any single byproduct. For example, the paper industry produces sludge material that can come from (1) pulp mills, where raw timber is prepared and chipped, then reduced to fibers used to make paper, or (2) paper mills, where the fibers are chemically and mechanically treated, or (3) combinations that combine the pulp and paper processes in one facility. Primary sludge from these plants differs from secondary sludge, depending on the effectiveness of the treatment system. Most common among pulp producing techniques is the Kraft or alkaline pulping process, in which a solution of sodium sulfide and sodium hydroxide is used to dissolve the lignin and noncellulose portions of the wood. If a byproduct contains substantial amounts of sodium, for example, it can alter the reaction of the soil as well as cause the physical properties of the soil to deteriorate.

Sewage. Environmentally sound disposal of sewage waste has become a major problem for many communities. Applications on forest nurseries may not only be a viable solution to disposal but may, with proper management, benefit seedling growth.

Sewage sludge contains the solids removed from a wastewater stream. In the process, pollutants are captured so that their reentry into the environment can be managed to minimize undesirable effects. Sludge averages 3-percent solids and 97-percent water. Raw primary sludge is undigested and has undergone only primary treatment or sedimentation of the gross solids. Digested sludge has been through a secondary treatment such as waste activation, usually an anaerobic biological process (Figure 6). Mixed primary and secondary sludges are often aerobically digested.

Sludge has value as a source of macronutrients (nitrogen, phosphorus, and calcium), micronutrients (zinc, copper, manganese), and or-

Figure 6. Sludge in drying beds following digestion. Vernon Thorpe Water Quality Control Plant, City of Medford.

Table 12 — Composition of sewage sludge from 5 treatment plants, Tualatin Valley, Oregon, 1976

Component	Portland	Forest Grove	Hillsboro	Oregon City	Aloha
			Parts per million		
Cadmium (Cd)	47	18	20	23	12
Copper (Cu)	1,154	377	1,662	433	732
Lead (Pb)	1,412	147	153	567	231
Nickel (Ni)	173	69	72	110	28
Zinc (Zn)	3,250	1,730	1,808	2,267	2,800
			Percent		
Nitrogen (N)	4.58	4.80	5.85	12.10	7.10
Phosphorus (P)	1.30	1.10	1.50	2.20	2.50
Potassium (K)	.47	.41	.27	.53	.45

Source: Schotzko et al. (1977).

ganic matter (40-60 percent). Values of elements in various sludges vary widely (Table 12). Sludge can also improve physical properties of soils, such as water retention and aggregate stability.

Serious concerns about using sludge in agriculture center around three potential problems: (1) transmission of human intestinal diseases, (2) transmission and accumulation in plant or animal tissue of heavy metals, pesticide residues, and other resistant pollutants, and (3) the possibility of water pollution.

Transmission of human diseases by sludge is perhaps the least important of the three concerns. Most pathogenic organisms are drastically reduced in numbers by digestion and drying at treatment plants. Exposure in soil kills many remaining micro-organisms. The majority of illnesses associated with sewage appear to be caused by application of raw wastewater or raw sludges, contamination of private water supplies, and consumption of raw shellfish grown in sewage-polluted waters (Burge and Marsh 1978). There is no evidence of above-normal incidence of disease among sewage plant workers or for inhabitants of communities adjacent to land disposals. The presence of pathogens should not limit agricultural or forestry use of anaerobically digested sewage sludge if reasonable precautions are taken. The most thorough reduction in pathogenic organisms is achieved by composting sludge and will be discussed later.

Tests have been conducted by the University of Washington on forest soil to check survival of pathogens after application of sludge (Mayer and Edmonds 1980). Trends imply that fecal coliform bacteria associated with sewage sludge can survive for at least one year after application of sludge to forest soil, but counts are negligible after the second year. No enteroviruses (viruses originating from the intestinal tracts) or *Salmonella* spp. were present in ground water beneath sludge-treated areas.

Guidelines on sludge application in proximity to water and areas of public use are suggested in Table 13.

Table 13 – Limitations on sludge application near nonagricultural settings

Feature	Limitation
Land use	Sludge should not be applied within 500 feet of areas where population is concentrated (urban and suburban housing tracts. rural subdivisions, commercial areas, industrial parks, recreation sites, schools, etc.) if surface applied and within 300 feet if subsurface injected.
Farm residence	Sludge should not be applied within 200 feet of rural homes or gardens if surface applied and within 100 feet if sub–surface injected.
Surface water	Sludge should not be applied within 100 feet of perennial streams, ponds, lakes, or ditches unless it can be shown that closer application would not pose an environmental hazard. Sludge should not be spread within 25 feet of intermittent streams.
Ground water	Sludge should not be applied within 200 feet of private water supply wells or springs or within 500 feet of public water supply wells.
Flood hazard	Sludge should not be applied to soils where the risk of flooding is greater than 10 percent per year.

Source: Schotzko and others (1977).

Concentrations of heavy metals in some sludge may have adverse effects on plants and subsequently on the people who eat the plants. Chemical analysis of sludge can be used to determine the content of heavy metals. Sludges vary widely in their concentrations of heavy metals (Table 14). The amount and type of industrial waste contributing to the sewage system accounts for most of the disparity. If sludge is not excessively high in heavy metals, the application rate can be based on quantity needed to provide adequate nitrogen or phosphorus to plants. It is interesting to note that industrial plants in many Chinese cities are on their own sewage system, separate from the system for general use, thereby preventing heavy-metal buildup in their soils and increasing feasibility of recycling the metal.

The trace elements that seem to present the most serious threats of phytotoxicity are zinc, cadmium, copper, nickel, and lead (see Table 14). Small amounts of trace elements, such as zinc and copper, are beneficial and even considered essential for plant growth. Large quantities of sewage sludge greater than 110 tons per acre applied on acid soils may result in toxicity from heavy metals to a variety of plants. For example, Schotzko et al. (1977) observed zinc, nickel, and copper toxicity in wheat, oats, and rye.

Species and even varieties of plants vary widely in their sensitivity to heavy metals. Grasses seem more tolerant than vegetable crops. Leafy tissues accumulate more metals than grain or fruit. Older leaves often contain higher amounts of heavy metals than younger tissues. Concentrations of heavy metals tolerated by plants are shown in Tables 15 and 16. However, these data are quite general; more specific information is needed regarding adverse reaction to conifers.

Table 14 – Concentration of heavy metals in digested sludge

Element	Observed range in sludges from various locations	Portland, Oregon, sludge
	Parts per million	
Cadmium (Cd)	5– 2,000	47
Copper (Cu)	250–17,000	1,154
Lead (Pb)	100–10,000	1,412
Nickel (Ni)	25– 8,000	173
Zinc (Zn)	500–50,000	3,250

Source: Schotzko et al. (1977).

Table 15 — Total concentration of various elements typically found in soil and plants

Element	Soils		Plant	
	Range	Common	Normal	Toxic[1]
	Micrograms per gram			
Arsenic (As)	0.1– 40	6	0.1– 5	—
Boron (B)	2– 100	10	30– 75	>75
Cadmium (Cd)	.01– 7	.06	.2–0.8	–2
Chromium (Cr)	5–3,000	100	.2– 1	—
Cobalt (Co)	1– 400	8	.05–0.5	—
Copper (Cu)	2– 100	20	4– 15	> 20
Lead (Pb)	2– 200	10	.1– 10	—
Manganese (Mn)	100–4,000	850	15–100	—
Molybdenum (Mo)	.2– 5	2	1–100	—
Nickel (Ni)	10–1,000	40	1	50
Selenium (Se)	.1– 2	.5	.02– 2	50–100
Vanadium (V)	20– 500	100	.1– 10	>10
Zinc (Zn)	10– 300	50	15–200	> 200

— = No data.

[1] Toxicities listed do not apply to certain accumulator plants.

Source: Schotzko et al. (1977).

Table 16 — Amount of various soil elements tolerable to plants

Element	Range	Common	Amount tolerable (proposed)
	Parts per million		
Arsenic (As)	1– 50	2– 20	50
Boron (B)	2–100	5– 30	100
Berylium (Be)[1]	.1– 10	1– 5	10
Cadmium (Cd)[1]	.01– 1	.1– 1	5
Cobalt (Co)	1– 50	1– 10	50
Chromium (Cr)	1–100	10– 50	100
Copper (Cu)	2–100	5– 20	100
Fluorine (F)	10–500	50–250	500
Mercury (Hg)[1]	.01– 1	.1– 1	5
Molybdenum (Mo)	.2– 10	1– 5	10
Nickel (Ni)	1–100	10– 50	100
Lead (Pb)	.1– 10	.1– 5	100
Selenium (Se)	.1– 10	1– 5	10
Zinc (Zn)	10–300	10– 50	300

[1] What effect this element has on plants has not been determined.

Source: Flaig et al. (1977).

A number of factors affect uptake of heavy metals by plants. As already discussed, toxic metals are more available at increasingly more acidic levels of pH. If soil is maintained between pH 6.2 and 6.8, the availability and amount of toxic trace elements are reduced. Organic matter in soil can chelate (bind) metal cations making them less available in plants. Metals interact with soil phosphorus reducing its availability. Soils with high cation exchange capacity tend to bind heavy metals. Sludge may average pH 7 or higher and can initially raise the pH value of the soil. However, this needs to be monitored because, oxidation of organic compounds in the sludge may increase the acidity of the soil over time.

Table 17 gives guidelines for maximum application rates of digested sewage sludge for agriculture land. Slightly higher levels could be tolerated on forest soil that is not producing food crops. Some studies have suggested that domestic sludge could be applied at a rate of 4.5-8.5 tons per acre for a number of years without causing accumulations of trace elements uncommon to general soils (Schotzko et al. 1977). Heavy metals are less available in soils amended with composted sludge than with raw and undigested sludges. A soil test prior to application of sludge is advisable to determine levels of relevant trace elements already in the soil.

Application of sludge needs to be made in such a way to reduce runoff and to avoid contamination of ground water. Application should be avoided when soils are saturated. Where slope occurs, contour plowing is recommended to reduce overland flow. The criteria used in selecting sites for one study of sludge applications seem to be useful for general guidelines (Schotzko et al. 1977):

Table 17 — Maximum application rate of digested sewage sludge by element and cation exchange capacity

Element	Cation exchange capacity (CEC), meq/100 g		
	Less than 5	5–15	Over 15
	Pounds per acre		
Lead (Pb)	446	892	1,784
Zinc (Zn)	223	446	892
Copper (Cu)	112	223	446
Nickel (Ni)	45	89	178
Cadmium (Cd)[1]	4.5	8.9	18

[1] Limit per year: 1.8 pounds per acre.

Source: Schotzko et al. (1977).

1. Slope should be less than 9 percent.
2. Depth to bedrock should be greater than 60 inches.
3. Depth to seasonal high water table should be at least 24 inches, and preferably 60 inches, to avoid contamination of ground water.

Most forest nurseries would meet these criteria.

Heavy metals tend to remain near the surface of soils and do not present much problem in water contamination. Nitrates in sludge can be leached and enter ground water. Coarse-textured soils are more susceptible to leaching.

The low carbon-to-nitrogen ratio of sludge results in net mineralization of nitrogen. The nitrate form of nitrogen is susceptible to leaching. With very high application rates of sludge, nitrates contaminate ground water. One way to prevent such pollution, is to apply the sludge at such a rate that the total available nitrogen in the soil does not exceed twice the nitrogen requirement of the crop to be grown. To calculate the available nitrogen, add the (1) nitrogen mineralized from the soil, (2) inorganic nitrogen from the sludge (both NH_4 and NO_3), and (3) nitrogen released by mineralization of sludge. Some estimates indicate that organic nitrogen in sludge becomes available at a rate of 20 percent during the first growing season and at three percent for the subsequent three growing seasons (Sawhney and Norvell 1980).

Vogt et al. (1980) found the best treatment to reduce the amount of nitrate lost through leaching was to mix sludge with sawdust (1:3) and use a cover crop such as oats. If very high rates of sludge are applied (more than 10 tons per acre), the nitrate levels could be easily determined by monitoring the ground water in wells.

Presence of pesticide residue from sludge is not a serious problem now that new Federal regulations require all pesticides sold be biodegradable. Boron from detergents designed to replace phosphate-based types has been identified as a potential problem (Bengtson 1978).

Application. Immediate incorporation of sludge is advisable to minimize loss of nutrients and to reduce objectionable odors when stored. Mixing soil with sludge by deep disking or plowing decreases runoff. Deep tillage will also help reduce concentrations of trace elements in the surface. The most common methods used to initially incorporate sewage sludge is plow furrowing and subsurface injection. Handling of sludge can be difficult depending on its moisture content. Partially dewatered sludges are difficult to spread at a uniform rate of application. A variety of equipment is used for spreading and incorporating. Extra weed control may be required in the spring because weed growth accelerates in response to more available nutrients.

The desired application rate depends on trace elements present. If heavy metals are not a serious problem, then it is possible to calculate the amount of sludge needed to meet nutrient needs of selected crops. Analysis of sludge must be considered. This can be a rough estimate, assuming half of ammonium nitrogen will be lost from volatilization when sludge is applied and only half the remaining forms of ammonium are available to plants. The organic nitrogen is slowly available to plants for about 5 years after incorporation. Schotzko et al. (1977) calculated sludge requirements based on nutrient needs for a variety of crops and applied an average of 1 to 2 tons per acre each year.

Sludge and tree response. A number of studies indicate that sludge has considerable value for use in forestry. Preliminary studies from University of Washington researchers (Bledsoe and Zasoski 1980) indicate that sludge can increase tree seedling growth and favorably modify physical properties of the soil. In another study, growth of Douglas-fir was found to increase after sludge application with only slight increases of heavy metals found in foliar analysis (Zasoski et al. 1977). According to Archie (1980) two inches of sludge applied to existing stands of Douglas-fir produced "phenomenal" visual and measured responses. Such reports of growth responses are rare in literature on forest fertilization.

Commercial Sludge. Various city sewage facilities are processing solid byproducts available commercially. This paper does not attempt to review all these products. Mention needs to be made of those commonly used by some regional nurseries. Nutrient content and cost varies widely with sludge products.

In 1974 the Wind River Nursery in Washington successfully used a product from Milwaukee, WI, called "Millorganite" at rates from 1 to 2 tons per acre per year (Dutton 1977). It was applied with a small fertilizer spreader. Benefits from use of Millorganite are reportedly increased minimum shipping caliper, increased field survival, healthier looking trees, and possibly fungicidal properties. Amounts of macronutrients in Millorganite are shown in Table 18. Personnel at Wind River felt confident this sludge product was contributing to the overall health of the nursery stock.

Table 18 — Amount and concentration of compounds and elements in test samples of Millorganite[1]

Compound and element	Amount	Concentration
	lb/ton	*Percent*
Nitrogen:		
Total	120.0	6.0
Water soluble	5.6	.28
Phosphoric acid, total	91.8	4.59
Potash, total	16.0	.8
Sulphur, as $S0_3$	53.8	2.69
Magnesium, as MgO	33.6	1.68
Calcium, as CaO	31.0	1.55
Iron, as Fe_2O_3	132.6	6.63
		ppm
Copper oxide	0.86	430
Manganese oxide	.75	327
Zinc oxide	.33	163
Chromium oxide	4.4	2,190
Lead oxide	4.5	2,250
Titanium oxide	1.6	830

[1] The use of trade name is for the information and convenience of the reader. Such use does not imply endorsement by the U.S. Department of Agriculture.

Source: Dutton (1977).

Disadvantages of Millorganite include cost, slight odor, more noticeable odor when humidity is high, and the need to keep it dry (impossible to work with when wet) (Dutton 1977). Some elements such as molybdenum, boron, iodine, nickel, chlorine, arsenic, and sodium are present in trace amounts and require monitoring to ensure against toxic buildup.

The purpose of mentioning Millorganite in this paper is not to endorse the product, but to cite benefits from commercial sludge products. There are many other old and new sludge products with fertilizer value on the market, such as Akra-Solite, Humite, Nitrohumus, Nitroganic, San-Diegonite, and Fol-e-gro, to mention a few that may or may not be in current production. No information about the properties or use of other products on nursery soil was reviewed.

Fish Sludge. Fish sludge is an effluent containing water, fish excrement, and feed. It is commonly available from fish hatcheries and may have undergone sewage digestion. It can be pumped into trucks, hauled to nurseries, and sprayed onto fields. The Wind River Nursery used fish sludge in 1977 with good results. Fish sludge was obtained from the fish hatchery at Bonneville Dam and had undergone primary and secondary digestion; this includes the removal of gross solids and the effluent being subjected to a biological process. Fish sludge is sprayed on the soil before planting occurs and directly onto seedlings using a large, rain-gun impact sprinkler. There was no burn or damage to trees from spraying effluent directly onto seedlings. Application rates are 10,000 gallons per acre, per year, which supplies 100 pounds of nitrogen per acre in a solution containing 0.05-percent solids. It is believed that rates could be doubled to 20,000 gallons per acre with no adverse effects.

Table 19 — Composition of fish effluent found in a test sample from Bonneville Dam[1]

Component	Unit	Amount in sample
Total solids	percent	.35
Volatile solids	percent	60
Total nitrogen (Kjeldahl)	g/dry kg	34
Mercury (Hg)	mg/dry kg	.029
Phosphorus (P)	mg/dry kg	51
Lead (Pb)	mg/dry kg	.89
Cadmium (Cd)	mg/dry kg	.25
Zinc (Zn)	mg/dry kg	3.95
Potassium (K)		Trace

[1] Bruce Warner, sanitation engineer, U.S. Army Corps of Engineers. Portland. Oregon. Personal communication. June 1977.

Preliminary studies look promising for use of fish sludge, if the economics of hauling can be resolved. The beneficial effects may be related more to nutrient supply than to addition of soil organic matter (Table 19). Tree seedlings grown in fish sludge plots appear green and healthy. Metals and other minerals do not appear to be at a level high enough to cause adverse reactions (see Table 19).

Mint sludge. Mint sludge is one by product of industrial processing that is high in nutrients, especially nitrogen (see Table 2). Thus far, no adverse side effects have been shown with its use. Experiments incorporating mint sludge at the Wind River Nursery are encouraging, but not as impressive as applications of chicken manure. At the Bend Nursery there appears to be a residual problem with pH after incorporating mint sludge. Application of mint sludge requires adjustments in soil pH through the use of acid-forming fertilizers.

Composted sewage. Composting municipal sewage sludge appears to be the best method of disposal. Resultant sludge composts have many advantages over sewage sludge. These are described by Epstein (1977):

1. The successful composting of raw sludge would eliminate the need for expensive digesters or other means of sludge stabilization.
2. Heat produced during composting effectively destroys human pathogens.
3. The microbial decomposition of sludge during composting alleviates malodors and produces a stable, humus-like, organic material that

can be used beneficially on land as a source of plant micro- and macronutrients, and as a soil conditioner.

4. The product can be conveniently stored, and easily and uniformly spread on land.

Sewage sludge, on the other hand, is difficult to handle and produces odors when stored.

The heavy metal content of a composted sludge is lower than that of the parent sludge because of a dilution effect from the added organic waste such as wood chips, sawdust, or bark. However, heavy metals with few exceptions are not considered desireable even at low levels since they can accumlate in the soil.

A number of papers have cited successful responses of trees grown in soils with added sludge composts. An experiment using 1-year-old Douglas-fir plug seedlings grown entirely in compost made of raw sewage sludge and sawdust (1:4 by volume) at the University of Washington's Pack Forest showed that dry weights and stem diameters were not significantly different for trees grown in compost or a mixture of peat and sand (1:1). Average dry weight of seedling roots in 1978 was 0.76 grams less for trees grown in compost than for trees grown in a peat-sand mixture (significant at the 94-percent level). Stem height for composted trees averaged 3.9 inches more than trees grown in peat-sand (22.4 versus 18.5 inches). Shoot-to-root ratios averaged 2.8 for peat-sand and 3.8 for composted trees. Tilth and overall workability is better in compost than that in a mixture of peat and sand. However, it is not all positive. Rice et al. (1988) found that sewage sludge amended soil reduced aeration because of the high water content of the sludge, the application machinery caused compaction, and increased the microbial response to organic amendments.

Compost made of sludge and wood chips (1:2) supplied from the Beltsville Agricultural Research Center in Maryland to the University of Maryland have produced good results in tree nurseries. Gouin and Walker (1977) report greater stem length of seedlings of tulip and flowering dogwood in plots where screened sludge compost was added at rates of 100 tons per acre than in unamended plots. The tulip tree seedlings suffered less winter dieback when grown in soils amended with the compost. The composted sludge also increased the nutrient content (nitrogen, phosphorus, calcium, and magnesium), pH value, and water-holding capacity of the sandy nursery soil. Weeds in the form of tomato plants (from viable seed in the compost) were a problem, but application of compost to nursery beds prior to cover cropping would have alleviated the weeds.

In another experiment in a tree nursery in Maryland, an application rate of 100 tons per acre of compost was found to be most beneficial for producing two or more crops of deciduous seedlings over a 4 1/2-year period in sandy loam soil (Gouin et al. 1978). Soils amended with 50 and 100 tons per acre of compost produced more seedlings with longer stems than treatments receiving no compost or 200 tons per acre.

Two methods of composting sludge are commonly used in the United States: the windrow system and the Beltsville aerated pile method. The windrow system has been used for many years by the Los Angeles, California, County Sanitation District. The newer method developed by Beltsville Agricultural Research Center is being successfully used in Bangor, Maine (even at temperatures of -20°F), and Camden, New Jersey.

Less Commonly Used Organic Amendments

The literature shows that the best and most inexpensive sources of mulch material are leaves of deciduous trees, pine needles, and wood residues such as sawdust, bark, and chips (Roberts 1978). Wood chips are commonly used where available and the same supplemental nitrogen should be applied as with sawdust and bark (see Table 7). Cones are being used successfully at Wind River Nursery as mulching material. They are first passed through a hammer mill and then applied to seedbeds.

Other mulch material commonly used depends on local availability. Hopwaste and bracken fern are frequently used in England. Nurseries located near sources of hopwaste may be able to utilize this material if available.

Experiments using refuse or landfill as mulch have shown several problems. If material is not ground up fine enough, seedlings may have difficulty germinating. Toxicity from boron has been observed because of the boron content in glues common to paper products.

Various chemicals and emulsions are marketed for use as mulch. Bark mulch was shown more effective in reducing evaporation than solutions of PVA, PAM, lignosulphonate, bitumen, or latex emulsions on sandy soil (Verplencke et al. 1978).

Various petroleum mulches are being applied experimentally. It was hoped that one, Agri Mulch (Docal 1055), would help protect seedlings from birds at Wind River Nursery. Thus far, no particular advantage of using this product has been observed.

Manure. The use of large amounts of manure has long been recognized as one ot the best methods of fertilizing crops and maintaining soil organic matter and productivity (Allison 1965). It was used for centuries, prior to the era of commercial fertilizers, as the primary source of plant nutrients. Average amounts of nutrients from various manures are given in Table 20. In operations of large nurseries, the cost of transporting manure may limit its use.

Ideally, manure provides needed nutrients and is a source of organic matter. Nutrient losses in animal manure commonly occur when stable or barnlot manure is allowed to accumulate for weeks or more before it is applied to soil. Large losses result from seepage into soil, leaching, and volatilization of ammonia. Substantial reduction of such losses occurs when manure is stored in concrete bins under anaerobic conditions (Allison 1965). Approximately one-half the total nitrogen and two-thirds the total potassium can be preserved if the liquid por-

Table 20 — Availability, moisture content, and nutrient content in manure of farm animals

Availability, moisture content, and nutrient	Dairy cattle	Beef cattle	Poultry	Swine	Sheep
Animal size, pounds	1,000	1,000	5	100	100
Wet manure, tons produced per year	11.86	10.95	.046	1.46	.73
Moisture content, percent	85	85	72	82	77
Nutrients, pounds per ton:					
Nitrogen (N)	10.0	14.0	25.0	10.0	28.0
Phosphorus (P)	2.0	4.0	11.0	2.8	4.2
Potassium (K)	8.0	9.0	10.0	7.6	20.0
Sulfur (S)	1.5	1.7	3.2	2.7	1.8
Calcium (Ca)	5.0	2.4	36.0	11.4	11.7
Iron (Fe)	.1	.1	2.3	.6	.3
Magnesium (Mg)	2.0	2.0	6.0	1.6	3.7
Boron (B)	.01	.03	.01	.09	—
Copper (Cu)	.01	.01	.01	.04	—
Manganese (Mn)	.03	—	—	—	—
Zinc (Zn)	.04	.03	.01	.12	—

— = No data.

Source: Tisdale and Nelson (1975).

tion of the manure is retained in storage (Olsen and Barber 1977). Depending on the moisture content of the manure, some absorbent material, such as sawdust or other wood products, may be needed for storage. Modern dairies and other operations that have concrete floors allow daily collections without loss of nutrients. Some sophisticated treatments involve aerobic digestion of liquid slurry containing manure. Manure is stored in an aerated lagoon or in an oxidation ditch in many swine operations. The partially purified residue can be pumped or allowed to flow into a lagoon where it can be stored for later application to the land (Brady 1974).

Manure is used as a mulch by some farmers. A 3-year test in Ohio using 10 tons of manure per acre as a surface mulch increased the yield of corn an average of 10 bushels more per acre than did the same amount of manure plowed under. Increased yield from the mulch was attributed to protection of soil from beating raindrops, greater infiltration of water, improved soil structure permitting roots to obtain more oxygen, and a cooling effect. However, to maximize utilization of its available nutrients, manure should be mixed into the soil. If fermented manure is left to dry on top of the soil without mixing it in, up to 25 percent of the nitrogen may be lost by volatilization in one day and as much as 50 percent in four days (Tisdale and Nelson 1975). The greatest disadvantage of using manure as a mulch is introduction of weed seeds.

Manure that does not contain litter, such as sawdust, or straw, and has a carbonto-nitrogen ratio of 25:1 does not require any nitrogen when it is incorporated into soil. If the manure contains appreciable amounts of litter, the percent plant material should be estimated; an appropriate amount of supplemental nitrogen is needed (amounts can be figured using the calculations shown in appendix A). For the most efficient utilization, manure should be plowed under the same day it is spread.

Brady (1974) outlined some generalizations regarding the use of manure. One ton of average farm manure is considered to apply as much nitrogen, phosphorus, and potassium as 100 pounds of 10-5-10 fertilizer. At commonly applied rates of 10-15 tons of manure per acre, the contribution of nutrients is economically important. Wide variations occur as to how much of the nutrients are readily available to crops. But on the basis of uptake by corn, one ton of average manure supplies five pounds of nitrogen, one pound of P_2O_5, and five pounds K_2O. There is a need to balance the nitrogen-phosphorus-potassium ratio by supplying phosphorus in addition to that contained in manure. Phosphorus can be added to barn floors, loaded in manure spreaders, or commercial fertilizer applied to the field can be adjusted. Maynard (1991) found that a one inch application of chicken manure compost improved soil physical properties and provided enough nutrients for eight different crops to equal or exceed yields from inorganic control plots.

Besides its cost of transport, the greatest disadvantage to using manure is the potential for introduction of weed seeds. Some believe it is unsuitable for use (Aldhous 1972, Armson and Sadreika 1974, van den Driessche 1969). Others recommend the use of herbicides to curtail weed growth (Brady 1974). Composting manure may alleviate weed problems if temperatures lethal to seeds are reached. Other problems associated with manure have resulted from high pH (Armson and Sadreika 1974, van den Driessche 1969). This problem could be avoided with analysis of manure and periodic analysis of the soil before and after application.

Fly Ash. Fly ash is produced when burning gases contact a cool surface of a firebox or wall of a burning chamber. It may be precipitated from the stacks of coal-burning electric-generating plants or from wood-fired steam generators at forest products facilities. Ash from coal burning has variable quantities of boron, phosphorus, and zinc. The highly soluble boron can be toxic to plants, but the ash is usually safe if it is weathered fly ash. It has been used successfully as a liming agent on the acid spoils of coal mines (Bengston 1978). Analysis should be run on flyash to determine the presence of relevant trace elements, pH, and feasibility of its use as an organic amendment.

The flyash from forest products is preferable for use in soil. Wood ash which contains phosphate, potassium, calcium, magnesium, and various trace elements has been used for centuries as a fertilizer. Flyash from bark, however, is considered a better fertilizer than wood ash because the inner bark contains more nutrients. Host and Pfenninger (1978) found growth response was still evident three years after ash application. Flyash is also used to improve heavy clay soil. Table 21 shows the average concentration of water-soluble material and the pH from four leachings of various flyash from bark-fired boiler plants. There is an enormous supply of flyash produced each year. Bark from about one million board feet of logs will provide one ton of flyash (Host and Pfenninger 1978).

Bottom Ash. Bottom ash is a relatively coarse, gritty material in contrast to fly ash which consists of very fine particles. Chen et al. (1991) found that additions of organic compost to bottom ash improved the physical and chemical properties and enhanced the microbial activity in the media suggesting that bottom ash coal cinder can be a satisfactory substrate when an organic component is added.

Cannery waste. Canneries are worth investigating as a source of organic material. Careful analysis of waste products is recommended,

Table 21 — Mean nutrient concentration and pH of various flyash from bark-fired boiler plants[1]

Nutrient and pH	Unit	Flyash A	Flyash B	Flyash C	Flyash D	Grand mean
Calcium (Ca)	ppm	1,250	1,250	2,200	107,200	27,975
Copper (Cu)	ppm	2.3	1.4	0.9	3.1	1.9
Iron (Fe)	ppm	7.0	1.0	0.6	2.9	2.9
Potassium (K)	ppm	1,280	1,848	1,056	6,168	2,588
Magnesium (Mg)	ppm	235	5,100	4,065	268	2,417
Manganese (Mn)	ppm	4.6	2.5	0.7	2.5	2.6
Sodium (Na)	ppm	[2]1,755	74	26	58	[3]52.7
Zinc (Zn)	ppm	.10	.04	.01	.57	.18
NO_3	ppm	4.3	8.7	6.5	82.3	25.5
PO_4	mg/l	6.6	2.0	0.6	0.4	2.4
pH	pH scale	9.5	8.5	8.6	12.2	9.7

[1] Flyash underwent 4 water leachings.

[2] Extremely high sodium content. Subsequent investigation revealed this flyash was contaminated from the effluent of a water clarification process.

[3] Excludes flyash A, which was contaminated.

Source: Host and Pfenninger (1978).

however, because salts or chemicals are sometimes used in processing. Toxic effects from mushroom waste in an Oregon nursery near Canby was thought to result from salts or chemicals used in processing. Various materials differ widely as to nutrient content, percent moisture, and ease of handling. It may be desirable to mix some materials with sawdust or another absorbent material before spreading it to facilitate uniform distribution. Composting may be feasible with some wastes.

Hop waste. Hop waste is a byproduct of the brewing industry and is an excellent amendment if economically available. It is applied at rates from 5 to 30 tons per acre. It provides nitrogen and phosphorus and is weed free (Aldhous 1972). If stored, it should be covered to minimize loss of nutrients by leaching. Hop waste reduced soil pH by 1.17 units after a dressing one-inch-thick was incorporated in a calcareous silt loam at East Kooteny Nursery in Canada (van den Driessche 1969).

Leaves. Many cities collect leaves in garbage bags as part of their usual sanitary pickup. Vacuum trucks are often used to remove leaves from streets. No information could be found that reported extensive use of dried leaves as a mulch or incorporated amendment in nurseries. Hill et al. (1982) found mulches of grass clippings and leaves retarded warming of soil, reduced evaporation, and in some cases, increased crop yields. Some nurseries in the South and East use leaves, often composting them first to remove viable weed seeds. Many home gardeners utilize leaves in composting. In many communities leaves and branches are available by the truckload. It is assumed that if a large quantity of leaves could be easily obtained, this source could be utilized as a good organic amendment. Beauchemin et al. (1992) found that phytotoxic effects of tree clippings as an organic amendment was significantly less for composted clippings than for fresh. About 10 pounds of supplemental nitrogen per ton of leaves should be added when incorporating leaves into soil or composting.

Peat. Peat is the residue product of sedges, mosses, grass, twigs, and roots that have decomposed partially and slowly under anaerobic conditions, and usually under water, for many years or centuries (Allison 1973). Peat is highly recommended in areas where it is easily obtained. It does not require additional nitrogen to decompose and, therefore, provides nitrogen more quickly than other materials. Peat is a valuable soil additive because of its high water and nutrient retaining characteristics and its ability to stimulate the growth of beneficial micro-organisms (Davey and Krause 1980). Peat from local pits needs to be checked to ensure it has not completely decomposed to "muck." The addition of peat at a rate of two inches or about 270 cubic yards per acre will help raise levels of organic matter.

At one English nursery, on fine-textured soils, peat improved the working properties of the soil and also acidified it (Aldhous 1972). Peat is useful in lowering pH values, but it is not considered as effective as an application of sulfur. The pH value of peat does vary, however (Armson and Sadreika 1974). It is recommended that peat meet the following criteria: acidity range of pH 4.0-5.5, cation exchange capacity of at least 75 milliequivalents per 100 grams, and nitrogen concentration of at least 1.0 percent (ovendry weight basis). Structure of moderately fine, fibrous, sedgewood peat with aggregates approximately 0.2 to 0.4 inch is best. If such peat is dug from bogs it can be spread directly on nursery soil, although stockpiling over winter often facilitates its mixing into the soil.

Peat is often used as a mulch in locations where it is found, although normally it is incorporated into the soil. The high cost of peat in other areas prohibits its use on a large scale. Experiments at Wind River Nursery showed peat to be the least effective mulch in preventing frost heaving. The order of ranking was sawdust, cone scales, straw, then peat. The greatest problem with using peat as a mulch is its tendency to blow away. In other research (van Nierop and White 1958), peat mulch did not improve moisture retention in nursery beds as much as mulches of wood chips or sawdust.

Seaweed. Seaweed is high in nitrogen and potassium and contains some phosphorus. Salt content, however, may be as high as two percent. Used as a source of organic matter, seaweed has caused some damage in English nurseries from salt (Aldhous 1972). The use of seaweed as an amendment would be of greater benefit if it were composted before being incorporated into the soil.

Wastewater effluent. Little data exists regarding application of wastewater effluent on conifer nurseries, but some implications can be drawn from other forested lands. Wastewater or sewage effluent can be used on the land with similar considerations as sludge. Nutrient constituents are high, and trace elements are present (Table 22). The value as fertilizer is evident from the amounts given in Table 23. At the rate of two inches per week in a Pennsylvania study (Richenderfer et al. 1975), applications of effluent provided constituents equivalent, on the aver-

Table 22 — Concentration of compounds and elements in effluent from municipal sewage[1]

Compound and element	Total amount applied[2]	Average concentration
	Pounds per acre	*Milligrams per liter*
MBAS[3]	5.40	0.37
Nitrogen:		
Nitrate	230.75	13.3
Organic	37.26	2.2
Ammonium	110.30	6.9
Phosphorus (P)	81.68	4.9
Calcium (Ca)	536.41	31.3
Potassium (K)	201.32	12.3
Chlorine (Cl)	711.20	41.3
Magnesium (Mg)	257.14	15.1
Sodium (Na)	357.01	20.6
Iron (Fe)	8.44	.4

[1] Data from a study on the Pennsylvania State University sewage treatment plant using municipal sewage of pH 7.9 (Richenderfer et al. 1975).

[2] Total amount of compound or element applied during a 24-week irrigation period when effluent was applied at a rate of 2 inches per week.

[3] Methylene-Blue-Active Substance. A method of determining the quantity of detergent in effluent.

Table 23 — Amount of nitrogen, phosphorus, and potassium applied annually from spray irrigation of effluent, central Pennsylvania

Irrigation period	Total amount of effluent applied	N	P	K
	inches[1]	*Pounds per acre*		
1963	46	119	54	127
1964	66	256	116	234
1965	60	139	122	199
1966	61	170	129	238
1967	56	157	98	176
1968	62	351	119	261
1969	56	275	66	175
1970	50	217	43	120
1971	55	184	40	174
Mean	57	208	87	189

[1] Applied at the rate of 2 inches per week.

Source: Richenderfer et al. (1975).

age, to the amount in approximately 2,000 pounds of a 10-10-11 fertilizer applied annually. In the study, treated municipal wastewater was spray irrigated for 9 years at rates of 1 to 2 inches per acre per week on sandy loam and silt loam soils. There were no indications that treatment had any detrimental effects on forest soils.

Many municipalities are successfully irrigating areas with their effluent (Figure 7). In an experiment in wastewater renovation in an immature conifer-hardwood plantation in Michigan, municipal effluent was applied at an average rate of 1.98 inches per week (Brockway et al. 1978). After 4 years, acidity decreased from pH 5.3 to 7.0 in the upper 5.9 inches of soil and from pH 5.9 to 6.6 in the 5.9- to 11.8-inch layer. Levels of macronutrients progressively increased. Cottonwood and Scots pine benefited substantially from treatment.

Figure 7. Effluent irrigation of fescue, orchard grass, and New Zealand clover. Vernon Thorpe Water Quality Control Plant, City opf Medford.

Monitoring the soil before and after application of effluent is desirable to document changes in pH and trace elements. If soils are deep and slopes gentle, moderate irrigation rates of effluent (one inch per week) should not be a problem. Monitoring runoff and ground water can ensure proper management.

Refuse. The nature of refuse is so heterogeneous that experimental results vary widely. Not only does the total content of various elements differ, but the chemical form of the elements is also highly variable. Potential phytotoxicity exists with trace elements boron, zinc, copper, and nickel. Boron seems to be a particular problem because of the high amount of available boron present in glues used in labels and corrugated paperboard. Incorporation of compost made from municipal refuse and sewage sludge significantly increased moisture-holding capacity, decreased bulk density, increased plant yields, and increased levels of pH, organic matter, K, Ca, Mg, and Zn (Mays et al. 1973). Growth of wheat was stimulated with garbage compost amendments combined with mycorrhizal inoculum (Ishac et al 1986). However, incorporating municipal refuse in soils and refuse composts in nursery soils does not appear practical at this time.

Organic Fertilizers. A number of materials might be considered organic amendments or organic fertilizers. Some have already been discused, such as manures and Millorganite. There are other materials used worldwide in place of inorganic fertilizers, which are costly and in short supply in many areas of the world, especially the developing countries. There is an increasingly important need to utilize agricultural, municipal, and certain industrial wastes as sources of plant nutrients, especially nitrogen.

A list compiled by Schwartz (1978) of materials that could be used as organic fertilizers and their analysis is given in Table 24. Schwartz's text provides extensive references to over a thousand research publications that relate to organic fertilizers and amendments.

Table 24 — Amount of nitrogen, phosphoric pentoxide, and potassium oxide in material used as organic fertilizer

Material	Nitrogen	Phosphoric pentoxide	Potassium oxide
		Percent	
Alfalfa hay	2.45	0.50	2.10
Bat guano	1–12	2.5–16	0
Blood meal or dried blood	10	1	0
Bone meal, steamed or raw $(Ca_3PO_4)_2$	2	25	0
Ground bone, burned	0	34.70	0
Coffee grounds	2.08	.32	.28
Corn cob, ground and charred	0	0	2.01
Cottonseed or linseed meal	7	2	1
Dog manure	1.97	9.95	.30
Egg shell	1.19	.38	.14
Fish scrap, fresh	2–7.5	1.5–6	0
Freshwater mud	1.37	.26	.22
Hair	12–16	0	0

Source: Schwartz (1978).

GREEN MANURE CROPS

Any plant material incorporated in the soil while green or soon after maturing for the purpose of improving the soil is a green manure. Crops grown for green manure are often grown for only part of a season, such as summer catch crops and winter cover crops. Green manure may also include crop material which is grown, dried, and later incorporated.

Green manuring is an ancient practice used to increase the productive capacity of soil. Records show that green crops, primarily legumes, were plowed under or composted at least 3,000 years ago in China (Allison 1973). In America, legumes were used almost exclusively along with limited use of cereals and grasses. With increasing availability of nitrogen fertilizers, nonlegumes such as rye, wheat, oats, sorghum, Sudangrass, and recently sorghum-Sudan hybrids have been used more. Green manuring is used in forest nurseries in conjunction with crop rotation.

Legumes

Legumes fix nitrogen from the air as they grow, thus they can provide nitrogen to the soil when used as a green manure. Legumes should be inoculated with the appropriate strain of nitrogen-fixing bacteria (*Rhizobium* spp.) when they are sown to ensure efficient fixation. The total plant nitrogen that is fixed is much less for plants growing in soils with abundant nitrogen than in soils poor in nitrogen. Before legumes fix nitrogen from the air, they will use nearly all available nitrogen in the soil. The maximum amount of nitrogen uptake occurs in the first 50-75 percent of the legume's growing period (Allison 1973). The nitrogen content increases steadily during growth of the legume until the plants reach seed production, then it levels off. The range of values of nitrogen fixed varies widely but is estimated to be: alfalfa 50-350, clovers 50-200, peas 30-140, and pastures with legumes 10-550 pounds per acre per year (Allison 1973). Comparative values from different species of legumes are given in Table 25.

Table 25 — Nitrogen content of tops and roots of legumes, and the amount of nitrogen fixed

Legume	Dry weight		Amount of nitrogen		Total N in tops plus roots	Amount of nitrogen fixed[1]
	Tops	Roots	Tops	Roots		
	Pounds		*Percent*		*Pounds*	
Alfalfa	2,000	1008.4	2.56	2.03	71.67	47.78
Red clover	2,000	1006.6	2.70	2.34	77.55	51.70
Sweet clover	2,000	721.0	2.41	2.04	62.90	41.93
Crimson clover	2,000	644.8	2.85	2.29	71.77	47.85
Vetch	2,000	418.4	3.34	2.16	75.84	50.56
Cowpeas	2,000	337.8	2.70	1.45	58.90	39.27
Velvet bean	2,000	304.2	2.34	1.27	50.66	33.77
Soybeans	2,000	277.4	2.58	1.91	56.90	37.93
Blue lupines	2,000	342.0	2.60	1.40	56.79	37.86
Yellow lupines	2,000	255.0	2.57	2.17	56.93	37.95
Field peas	2,000	90.0	2.80	2.52	58.27	38.85

[1]Two–thirds of the total is assumed to be fixed from air.
Source: Allison (1973).

Soil physical properties are improved by the effects of green manure on root systems. Deep-rooted legumes, such as alfalfa (Figure 8), sweet clover, lupines, and kudzu, can penetrate two feet or more. This penetration is below the root zone of most other crops in the rotation (Allison 1973). Other crops such as red clover, soy beans, cowpeas, and small grains also root deeply. Legumes are usually more effective than nonlegumes on dense soil and in penetrating a layer of hardpan or near-hardpan. By remaining in the soil, these roots supply nutrients to future crops. Also, subsequent crop roots often grow down old channels and take advantage of increased available water as a result (Allison 1973). Thus, the use of legumes may be important in managing nursery soil with hardpans.

Figure 8. Alfalfa is commonly used as a green manure crop if more than one growing season is allowed.

Benefits and Harmful Effects of Green Manures

Green manure is usually beneficial to soil that is well managed. Benefits attributed to green manuring include addition of nitrogen (when using legumes), addition of organic matter, increase in the conservation and availability of nutrients, improved physical condition of the soil, erosion control, and weed and disease control. The root systems of green manure crops also have a big effect in aggregation of the finer-textured soils, as discussed above. The most effective root systems for this purpose are those with finely divided and extensive, but not necessarily deep roots. Small-grain crops best meet this requirement.

Green manure crops also shade and cool the soil. By providing a dense vegetative cover, the damage to soil aggregation produced by raindrop splash is eliminated (Allison 1973). This reduces the tendency toward crust formation, a serious problem in many nurseries.

Green manuring is often used in rotation in agriculture for disease control. But the common pathogens of tree seedlings, such as *Pythium* spp., *Fusarium* spp., and *Rhizoctonia* spp., have a wide host range and their incidence does not appear greatly affected by crop rotation (Aldhous 1972). The one exception found in the literature is with western redcedar seedlings. In England (Aldnous 1972), these seedlings can be infected by the fungus disease *Didymascella (Kethia) thujina*, causing severe losses. Aggravation of losses occurs from cross-infection of first year seedbeds from older stock. Crop rotation is an effective control because it ensures that cedar is not grown in seedbeds for more than one year.

There is some disagreement about whether green manure actually provides an increase in the organic content of the soil. It appears that green manures may have a negligible effect on total levels of soil organic matter under systems of continuous cultivation (Allison 1973). They do add active, rapidly decomposing organic material. The actual percent organic matter in soils may be determined primarily by climate. Higher levels may be obtained by replacing crops with sod or periodic additions of organic material such as animal manure. Green manuring involves soil disturbance, and accelerated oxidation would counteract some of the possible increases that could be expected. Beneficial effects of green manuring are generally evident from other characteristics associated with addition of organic material.

The effect of green manure on humus is subtle. Slight increases, which may appear "negligible" to some, may be significant. Experiments in crop rotation have resulted in increased humus content of the soil by 0.12 percent over 12 years when compared to a single crop grown continuously. This is equivalent to an annual gain of 165 pounds of humus per acre. The gain from rotation under irrigation is equivalent to 227 pounds per acre (Stephenson 1941). Humus renewal is more effective under irrigated rotation than under dry-farm operations. The above values reflect considerable addition of humus associated with very slight increase in total humus content.

The excess fertilizer and other available soil nutrients may be leached in periods when ground is barren. As much as 25-30 pounds per acre of nitrate nitrogen, 10-20 pounds of potash, and 175-350 pounds of lime can be lost annually by leaching on bare soils (Stephenson 1941). The quantities of added fertilizers are sometimes in excess of the amount taken up by plants during the growing season. The green manure crop grown as a cover or catch crop is able to utilize excess fertilizer and minimize loss by leaching. Such benefits are realized by having an actively growing winter cover crop or by allowing a crop to be winter killed and remain undisturbed until time for spring plowing. This practice also gives good soil protection during winter rains. Physical benefits from root growth and improvement of tilth are also provided (Allison 1973).

Most of the harmful effects related to green manure occur only when the crop that follows is grown too soon after plant material is incorporated. Seedlings grown too soon after turning under a green manure crop are sometimes injured by damping-off fungi (Allison 1973). A green manure crop can deplete soil moisture temporarily while it decomposes. This problem is more critical with dry-land farming in areas of low rainfall. With irrigation, it is not a serious concern. Incorporation of non-legumes with high carbon-to-nitrogen ratios may deplete soil nitrogen during decomposition and depress uptake by succeeding crops. To avoid this, supplemental nitrogen fertilizer can be added at the time the nonlegume is incorporated. For a short period after such material is incorporated, there can also be an inhibiting and toxic effect on seedlings from high concentrations of nitrites and non-ionized ammonia (Allison 1973). After a few days, this does not appear to be a problem.

Toxic organic substances may be formed by some plants grown as a green manure crop. Phytotoxic substances are formed by some higher plants and micro-organisms associated in their decomposition. Antibiotics produced by soil organisms can also be toxic to some plants. Harmful products derived from green manures are usually destroyed within 2 to 3 weeks. Antibiotics are generally adsorbed by soil colloids (Allison 1973). Some plants known to have produced growth inhibitors are listed in Table 26. Unfortunately, little information is available regarding inhibition of tree seedling growth by other plants, but some indications of allelopathic plants important to forestry are provided in Table 27.

Green Manure Crops to Use

Selecting a Crop. Ideally, a green manure crop should be easily established and grow rapidly. There are a variety of legumes and nonlegumes that produce abundant growth in a short time. Choice of the crop should include consideration of the purpose for green manuring and climatic factors. A list of commonly used green manures is given in Table 28.

Nurseries in Oregon and Washington frequently use oats, rye, Austrian peas, Sudangrass, crimson clover, and lupines. Residues of sorghum-Sudangrass have suppressed growth of seedlings in nursery soils

Table 26 — Plants reported to produce differential growth inhibitors of known and unknown composition

Source plant	Chemical constitution	Plants inhibited	Parts of plant Inhibited	Plants resistant	Remarks
Tonka bean, sweet clover	Coumarin	Carrot, onion, lilly, alfalfa	Roots	Cress, cabbage	
Spreading pasque-flower, buttercup	Protoanemonin	Cress, corn			
Angelica glabra	Byakangelicin	Tomato			
Thamnosma montana	Byakangelicin, isopimpinellin, $C_{16}H_{15}O_5(OCH_3)$ with isobergaptene nucleus	Tomato			
Guayule	Transcinnamic acid	Guayule, pea		Tomato	Homologous
Encelia farinosa	3–acetyl–6 methoxy–benzaldehyde	Tomato, pepper, corn		Barley, oats, sunflower	Inhibitor in leaves
Mountain ash berry, wheat middlings, orange rind	Parasorbic acid	Onion, tomato	Roots		
Vanilla bean	Vanillin	Wheat seedlings	Roots		
Bergenia crassifolia	Arbutin	Wheat seedlings			Inhibitor in leaves
Pyrus communis, oats	Scopoletin	Oats			Homologous
Not listed	Umbelliterone	Red kidney bean, cucumber seedlings	Roots	Peas, corn, wheat	
Clover	Unknown	Kentucky bluegrass		Bromegrass	
Kentucky bluegrass	Unknown	Canada bluegrass	Foliage and roots		
Domestic ryegrass	Unknown	Kentucky bluegrass, Chewing's fescue			
Redtop	Unknown	Timothy,	Foliage and roots		
		Kentucky bluegrass,	Foliage		
		Chewing's fescue			
Bromegrass	Unknown	Bromegrass seedlings			Homologous
Mesquite	Unknown	Tomato			
Greasewood	Unknown	Tomato			
Viguiera reticulata	Unknown	Tomato			
Creosote bush	Unknown	Tomato			
Encelia frutescens	Unknown	Tomato			

Table 26 — continued

Source plant	Chemical constitution	Plants inhibited	Parts of plant Inhibited	Plants resistant	Remarks
White Bur–sage	Unknown	Tomato			
Wormwood	Unknown	Sage, groundsel		*Datura*, *Stellaria*	Inhibitor in leaves may be absinthin
Peach	Unknown	Peach			Homologous
Sorghum	Unknown	Other grasses			
Black walnut	Unknown	Broomsedge, poverty grass, blackberry, dock, common cinquefoil, red pine, white pine, apple, potatoes, alfalfa, tomatoes, hydrangea, lilac, chrysanthemum, asparagus	Leaves	Timothy, black raspberry, red–top, fleabane, ferns, asters, goldenrods, mints, violets, wild grape, clovers, Virginia creeper, thistle, ironweed, tall oat grass, meadow fescue, nimble–will, velvet grass, purple top, poison ivy, corn, oats, wheat, rye, buckwheat, peach, plum, pear	
Sunflower	Unknown	Sunflower			Homologous in spring
Rye	Unknown	Grapes			
Antennaria fallax	Unknown	*Antennaria fallax*			Homologous
Aster macrophyllus	Unknown	*Aster macrophyllus*			Homologous
Erigeron pulchellus	Unknown	*Erigeron pulchellus*			Homologous
Horse thistle	Unknown	Oats			
Euphorbia	Unknown	Flax			
Butternut	Unknown	Shrubby cinquefoil			
Tridax procumbens	Unknown	Other weeds			
Zacate	Unknown	Rice			
Black locust	Unknown	White pine, barley			
White ash	Unknown	White pine			

Table 26 — continued

Source plant	Chemical constitution	Plants inhibited	Parts of plant Inhibited	Plants resistant	Remarks
Oats, alfalfa, avocado. barley, cocklebur. Sudan grass	Unknown	Tomato crown gall			
Evergreen creosote bush	Unknown	Evergreen creosote seedlings			Homologous

Source: Allison (1973).

Table 27 — Some allelopathic plants important in forestry, chemicals they produce and plants they affect

Allelopathic species	Class of chemical produced	Example of species affected
Trees:		
Sugar maple	Phenolics	Yellow birch
Hackberry	Coumarins	Herbs, grasses
Eucalyptus	Phenolics, terpenes	Shrubs, herbs, grasses
Walnut	Quinone (juglone)	Trees, shrubs, herbs
Juniper	Phenolics	Grasses
Sycamore	Courmarins	Herbs, grasses
Black cherry	Cyanogenic glycosides	Red maple
Oaks	Courmarins, other phenolics	Herbs, grasses
Sassafras	Terpenoids	Elm, maple
Shrubs:		
Laurel	Phenolics	Black spruce
Manzanita	Courmarins, other phenolics	Herbs, grasses
Bearberry	Phenolics	Pine, spruce
Sumac	Phenolics, terpenoids	Douglas–fir
Rhododendron	Phenolics	Douglas–fir
Elderberry	Phenolics	Douglas–fir
Other:		
Aster	Phenolics, terpenoids	Sugar maple, black cherry
Goldenrod	Phenolics, terpenoids	Sugar maple, black cherry
New York fern	Phenolics	Black cherry
Bracken fern	Phenolics	Douglas–fir
Fešcue	Phenolics	Sweetgum
Short husk grass	Phenolics	Black cherry
Clubmoss	Phenolics	Black cherry
Reindeer lichen	Phenolics	Jack pine, white spruce

Source: Fisher (1980).

Table 28 — Commonly used green manure crops and the adaptability to difference climates

Legumes		Nonlegumes	
Adaptable in warm regions	Adaptable to wide range of climates	Adaptable to wide range of climates	
Crimson clover	Alfalfa[1]	Rye	Sudan grass
Bur clover	Red clover	Oats	Mustard
Lespedeza	Sweet clover	Millet	Rape
Vetch	Soybean	Ryegrass	Weeds
Austrian winter pea	Canadian field pea		
	Cowpea		

[1] More than one growing season is needed to fix appreciable amounts of nitrogen.

Source: Brady (1974, p. 549).

of Wisconsin (Iyer 1979). Green manuring with a sorghum-Sudangrass hybrid (Hyden grass) resulted in about 50-percent mortality of pine seedlings. The 10-week-old seedlings that survived were smaller and had much smaller root systems devoid of mycorrhizal short roots. Soil toxicity was still evident after a detoxification period of 4 winter months (Iyer 1979). Southern nurseries have used sorghum-Sudangrass without phytotoxic effects. Warmer soils (and perhaps better aeration) probably account for this apparent discrepancy. Production of phytotoxins is enhanced in cold, wet soils more than in warm, well-aerated soils (Toussoun 1969).

Barley has produced phytotoxic compounds under certain conditions (Toussoun 1969 and Linderman 1970). Use of barley as green manure, like sorghum Sudangrass, may be no problem in the South. Growing buckwheat in colder, wetter soils of the North could be monitored for possible phytotoxic effect.

Increase in *Fusarium* root rot in areas where buckwheat had grown as a cover crop was observed in the Saratoga Nursery in New York. When the cover crop was changed to another species, there seemed to be no problem.

Glossary

Aeration, soil - The process by which air in the soil is replaced by air from the atmosphere. In a well-aerated soil, the soil air is very similar in composition to the atmosphere above the soil. Poorly aerated soils usually contain a much higher percentage of carbon dioxide and a correspondingly lower percentage of oxygen than the atmosphere above the soil. The rate of aeration depends largely on the volume and continuity of pores within the soil.

Available nutrient - The quantity of nutrient element or compound in the soil that can be readily absorbed and assimilated by growing plants.

Available water - The portion of water in soil that can be readily absorbed by plant roots. Considered by most soil scientists to be that water held in the soil against pressure of up to approximately 15 bars.

Buffering capacity - The characteristic of a substance to resist sudden appreciable changes, used most often in relation to soil pH.

Bulk density (soil) - The mass of dry soil per unit bulk volume. The bulk volume is determined before drying to a constant weight at 105°C.

Carbon:nitrogen (C:N) ratio - Ratio of carbon content to nitrogen content. The C:N in plant residues is often a convenient predictor of decomposition rates but is not the only determinant.

Cellulose - A structural polysaccharide of plant cell walls.

Cation exchange capacity (CEC) - The sum total of exchangeable cations that a soil can absorb. Expressed in milliequivalents per 100 grams of soil. Clay and organic matter are the parts of soil that have most, if not all, of the cation exchange sites.

Chelate (Greek, claw) - A chemical compound in which a metallic ion is firmly combined with a molecule by many chemical bonds.

Compost - Organic residues or a mixture of organic residues and soil, that have been piled, moistened, and allowed to undergo biological decomposition. Mineral fertilizers are sometimes added. Often called "artificial manure" or "synthetic manure" if produced primarily from plant residues.

Crust - A surface layer on soils, ranging in thickness from a few millimeters to perhaps as much as an inch, that is much more compact, hard, and brittle when dry than the material immediately beneath it. A nursery soil that can form a crust around a young seedling can girdle the seedling if the crust is uncovered and heated by the sun. The crust can also prevent seeds from germinating properly.

Fertilizer requirement - (1) The quantity of certain plant nutrients needed, in addition to the amount supplied by the soil, to increase plant growth to a designated optimum. (2) The quantity of fertilizer required to supply nutrient needs of both higher plants and microorganisms for maximum crop production.

Fixation - The process of conversion of an element in the soil essential to plants from a readily available to a less available form. Some clays can fix phosphorus and calcium, making it unavailable to plants.

Green Manure - Any plant material incorporated in the soil while green or soon after maturing for the purpose of improving the soil.

Heat capacity - The amount of heat a given soil can hold. This is dependent upon moisture content and organic matter composition.

Heavy metals - Metals that can be precipitated by hydrogen sulfide in an acid solution. Examples are Ag, Au, Bi, Hg, and Pb. When metals occur in soils and are tanken up by the plants, they can reach levels toxic to animals and humans that consume the plants. Many of the metals mentioned are normally found in soils and plants but at minute levels. When they reach specific threshold levels, they are referred to collectively as "heavy metals".

Humus - The more or less stable fraction of the soil organic matter remaining after the major portion of added plant and animal residues have decomposed. Usually it is dark in color.

Immobilization - The conversion of an element from the inorganic to the organic form in microbial tissues or in plant tissues, thus rendering the element not readily available to other organisms or to plants.

Infiltration - The downward entry of water into the soil.

Infiltration rate - A soil characteristic determining or describing the maximum rate at which water can enter the soil under specified conditions, including the presence of an excess of water.

Lignin - Complex aromatic compounds in the cell walls of sclerenchyma, xylem vessels, and tracheids which make them rigid. Lignin is not easily broken down by microorganisms and has a high CEC.

Macronutrient - A chemical element necessary in large amounts (usually greater than 500 parts per million) for the growth of plants. ("Macro" refers to quantity used rather than how essential it is.)

Micronutrient - A chemical element necessary in only extremely small amounts (less than 50 ppm for the growth of plants. Examples are B, Cl, Cu, Fe, Mn, and Zn. ("Micro" refers to the amount used rather than to its essentiality.)

Mineralization - The conversion of an element from an organic form to an inorganic state as a result of microbial activity i.e. amino acid in a plant to nitrate nitrogen.

Millequivalent (meq) - One milligram of hydrogen or the amount of any other ion that will combine with it. Milliequivalents are units used in cation exchange capacity and fertility calculations. For example, 1 meq of a calcium ion (Ca^{++}) is computed as its atomic weight in grams (40) divided by the valence (2), or 20mg.

Mulch - Any material such as straw, sawdust, leaves, plastic film, or loose soil that is spread on the surface of the soil to protect the soil and plant roots from the effects of raindrops, soil crusting, freezing, evaporation, etc.

Mycorrhizae - The biological association, usually symbiotic, between plant roots and particular fungi. (myco = fungus, rhiza = root)

Nitrification - The biological fixation of ammonium to nitrite and nitrate, or a biologically induced increase in the oxidation state of nitrogen.

Nitrogen fixation - The biological conversion of elemental nitrogen (N_2) to organic combinations or to form readily utilizable nitrogen in biological processes.

Organic matter - Plant or animal residues at various states of decomposition.

Ped - A unit of soil structure, such as an aggregate, crumb, prism, block, or granule, formed by natural processes.

pH, soil - The degree of acidity (or alkalinity) of a soil as determined by means of a glass, quinhydrone, or other suitable electrode or indicator at a specified moisture content or soil water ratio, and expressed in terms of the pH scale.

Phytotoxins - Substances released by plants to the environment that inhibit germination or growth of other plants.

Porosity - The volume percentage of the total bulk not occupied by solid particles.

Runoff - The portion of the precipitation on an area discharged from the area through stream channels. What is lost without entering the soil is called surface runoff and what enters the soil before reaching the stream is called ground water runoff or seepage flow from ground water. (In soil science, runoff usually refers to the water lost by surface flow; in geology and hydraulics runoff usually includes both surface and subsurface flow.)

Saprophyte - Organisms, such as bacteria and fungi, that live on decaying organic matter.

Soil structure - The combination or arrangement of primary soil particles into secondary particles, units, or peds.

Tilth - The physical condition of soil as related to its ease of tillage, fitness as a seedbed, and its impedance to emergence of seedlings and penetration of roots.

Trace element - See micronutrient

Trichoderma - Beneficial fungi which are known to out-compete pathogenic fungi

Water holding capacity, soil - The amount of water a given soil can hold. This depends on particle size of the soil and is sometimes referred to as field capacity.

Wilting point (or permanent wilting percentage) - The moisture content of soil, on an oven dry basis, at which plants (specifically sunflower plants) wilt and fail to recover their turgidity.

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Appendix A. :Calculating the Amount of Supplemental Nitrogen Needed (Examples of calculations)

Sawdust. To incorporate 1 in. of sawdust/acre:

- Sawdust weighs 500 lbs/cu yd (oven dried) - (Davey 1984).
- Sawdust weighs 297 lbs/cu yd (dry) - 500-700 lbs/cu yd (green) - (Bollen 1969).
- Assume 500 lbs/cu yd; 1 in./ac = 134.4 cu yds/ac or 67,200 lbs or 33.6 tons/ac. Suggested rate of N (Bollen, 1969) is 10-20 lbs/ton of sawdust.
- 10 lbs/ton x 33.6 tons = 336 lbs N.
- 336 lbs N = 1600 lbs/ac 21-0-0 (ammonium sulfate) = 1120 lbs of 30-0-0 (ammonium nitrate-sulfate) = 988 lbs of 34-0-0 (ammonium nitrate).

(Note: The characteristics of sawdust, such as percent moisture, weight and C:N ratio vary. According to C.B. Davey, 1984, and Bollen, 1969) The sawdust should be applied early in the spring with split (3 to 5) applications of nitrogen so leaching and ground water contamination is not a threat.

Davey (1984) states:

"Immediate effect 100 cu yds of sawdust at 500 lb dry weight/cu yd = 50,000 lb/ac of sawdust; 50,000 of sawdust added to 2,000,000 lb/ac of soil represents an immediate increase of 2.5% in soil organic matter content. At end of 1 year research has shown that, generally, 2/3 of the sawdust will decompose during the first year and 1/3 remain in the soil; 1/3 of the immediate 2.5% gain represents a 0.8% gain in soil organic matter at the end of the first year. At end of rotation though 90% of the sawdust decomposes during the rotation, 10% remains in the soil; 10% of the 2.5% immediate gain represents a 0.25% gain in the nearly stable fraction of the soil organic matter. This may seem like a small victory, but it is solid progress nonetheless and is much better than can be done with cover or green manure crops."

Mulch. To apply 3 inches of sawdust mulch over 100 square feet, how much nitrogen is needed to decompose the organic material?

1 inch of mulch requires 100-200 pounds of nitrogen per acre with initial mulch application (from Table 7). Therefore, 3 inches of mulch would require 300-600 pounds of nitrogen per acre. There are 43,560 square feet in 1 acre. To find the number of pounds of nitrogen needed per 100 square feet:

$$\text{Nitrogen needed} = \frac{300 \text{ lb}}{43{,}560}$$

$$= 0.0069 \text{ lb/sq ft, or } 1.38 \text{ lb/100 sq ft}$$

Therefore, 0.069 to 1.38 pounds (or about 1 pound) of nitrogen per 100 square feet should be applied with initial mulch application. Half the amount (or about one-half pound) should be added the second time mulch is applied.

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