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). Be cause 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 • -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, sawdustapplication 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 addingbark 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).

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).

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

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 con trol 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 organic 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 the4east 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.

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).

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'
	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— 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 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.

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 cur-

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 SO_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).

rent 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 Dam1

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 Univerity 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 of 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_20. 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 plants1

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	21,755	74	26	58	352.7
Zinc (Zn)	ppm	.10	.04	.01	.57	.18
NO_3	ppm	4.3	8.7	6.5	82.3	25.5
PO_4	mg/I	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 ar 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).

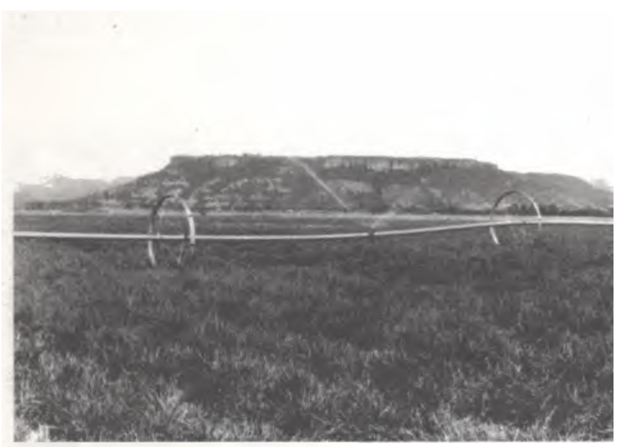

Figure 7. Effluent irrigation of fescue, orchard grass, and New Zealand clover. Vernon Thorpe Water Quality Control Plant, City opf Medford.

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.

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, v ich 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.