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Use of Composts in Revegetating Arid Lands

**C. A. Brandt
P. L. Hendrickson**

September 1991

**Prepared for the U.S. Department of Energy
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ARID LANDS

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Richland, Washington 99352

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SUMMARY

To understand the effects of soil amendments on plant growth, it is necessary to understand how soil and soil processes affect plant growth. Terrestrial plants obtain all elements required for growth from the soil, except for carbon and oxygen, which are obtained from the air. The initial abundance in soils of phosphorus and potassium, essential macronutrients, is the result of weathering of parent minerals. Nitrogen, the third major macronutrient, is derived solely from rainfall and fixation by soil microorganisms. In the Hanford soils, and especially in disturbed soils, levels of these nutrients are quite low; consequently plant growth depends upon the efficient recycling of nutrients from organic detritus introduced to the soil from dead plant material. This recycling depends on the abundance and population growth of soil microorganisms, which in turn depend on soil moisture, organic content, and temperature. Soil moisture that may be available for plant growth is largely a function of soil texture and organic matter content, with finer-textured soils and higher organic matter contents retaining more moisture. Decomposition rates on the Hanford Site are greatest under moist, cool regimes in soils with relatively high organic matter content.

Native plants at the Hanford Site are adapted to the low nutrient/moisture regimes common to this region. Weedy species, such as Russian thistle, are better adapted to higher nutrient levels and wetter soils; consequently these species readily invade disturbed sites where nitrogen and moisture levels may be temporarily high, especially after fertilization as part of a revegetation program. Consequences of soil disturbances include loss of organic matter and microorganism pools. Also, soils typically available for covering disturbed sites are coarse-textured, with poor moisture holding properties.

Composting is a process whereby organic wastes are converted into materials stable to leaching and hydrocarbon gas emissions, while containing nutrients in plant-available form. In terms of benefits to land restoration, composts, especially those based on municipal sewage sludge and wood by-products, provide a complete nutrient base, an inoculation of decomposing microorganisms, and an organic carbon pool that will sustain the microorganism population for a number of years without additional organic inputs. The addition of composts to disturbed soils may also alter the physical properties of the soil, improving the friability of fine-textured soils and the moisture-holding capacity of coarse-textured soils. The organic matter also serves as exchange sites for nutrient cations such as potassium, thereby increasing their availability to plants. Composts based on sewage sludge typically contain

elevated levels of some metals such as cadmium and lead; however, these remain bound to organic matter in the soil and are neither leached nor taken up by plants.

Tests of wood-chip/municipal sludge composts were conducted on the Hanford Site in 1989. Compost was incorporated into revegetation sites that had failed to support plant growth the previous year. The composted sites were then replanted with the same native plant mix as had been used the previous year. Plant survival and growth on the composted sites was more than twice that of the year before treatment. One grass (bottlebrush squirreltail) that did not establish on uncomposted sites did establish when compost was added. Grass density on the composted sites was three to five times greater than on untreated controls. Growth of Sandberg's bluegrass on composted sites was approximately twice that on untreated sites; no effect on growth was observed for bottlebrush squirreltail. Grass growth and survival during the first year after seeding was lower for sites seeded in 1989 than in 1988 for all sites except those receiving compost, where the opposite trend was observed.

The beneficial effects of compost cannot be duplicated using other mixtures. Tests of standard soil treatments such as mulching and fertilization were conducted as part of the Basalt Waste Isolation Project reclamation. All sites, including composted sites, were mulched with straw; sites seeded in 1989 also received a low-rate application of nitrogen fertilizer. Experimental tests of nitrogen fertilizer on survival and growth of Sandberg's bluegrass showed no effects due to fertilization. Thus, the beneficial effects of compost on revegetation of Hanford soils exceeded those arising from mulch or fertilizers, alone or in combination.

Even in the absence of plant cover, composts may provide benefits to land restoration. Compost enhances soil moisture-holding capacity and continues to decompose after application. Consequently, composts may lower the erodibility of soils while maintaining a pool of nutrients that can be utilized by plants seeded later.

Regulations applicable to sewage sludge composts derive from sewage sludge regulations. Permits for application are not required, although some restrictions on proximity to surface waters, residential areas, and water wells may apply. The Environmental Protection Agency will issue final regulations on the use and disposal of sewage sludge in January 1992 as 40 CFR 503. Washington regulations require a permit from the local health department for application of uncomposted sewage sludges on lands for beneficial uses; however, it is not certain that such regulations apply to the application of sludge-based composts.

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INTRODUCTION

Compost has been suggested as a soil amendment for arid lands at the U.S. Department of Energy's Hanford Site in southeastern Washington State. The operating contractor of the site, Westinghouse Hanford Company, requested that the Pacific Northwest Laboratory^(a) conduct a literature review to compile additional information on the use of compost amendments and their benefits. This report provides background information on the factors needed for plant growth and the consequences of severe soil disturbance. This report also discusses the characteristics of composts relative to other amendments and how they each affect plant growth. Finally, regulatory requirements that could affect land application of sludge-based compost on the Hanford Site are reviewed.

Two of the ways that compost can affect plant growth are providing necessary nutrients and increasing moisture capacity of the soil. To understand how compost can affect plant growth at the Hanford Site, it is necessary to understand how the elements necessary for growth are taken up by plants there and how moisture capacity of soils, especially in arid lands, affects plant growth. Also needed is an understanding of the consequences of severe soil disturbances, such as those at Hanford.

The elements necessary for plant growth, except carbon and oxygen, are obtained by terrestrial plants from the soil. Water and nutrients are taken up by root hairs at rates that differ among nutrients and among plants. Nutrients required in relatively large amounts are classed as macronutrients; these include nitrogen, phosphorus, and potassium. Micronutrients are required in only trace amounts (Table 1). All of the nutrients except nitrogen become available through weathering of minerals in the parent soil.

Nitrogen exists mainly in gaseous form in the air and is made available to plants through the action of nitrogen-fixing microorganisms, such as bacteria and blue-green algae, that occur as free-living organisms in well-developed soils, or as symbionts with certain plants such as legumes. Nitrogen may also be added to the soil dissolved in rainwater. Because of the lack of a soil source for nitrogen, this element usually limits plant growth in most undisturbed habitats, including the shrub-steppe of the Hanford Site (e.g., Skujins 1981; Whitford 1988).

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TABLE 1. Typical Concentrations (ppm) of Minerals in Plants and in Solution Sufficient to Support Growth in Sand^(a)

<u>Mineral</u>	<u>Plant Concentration</u>	<u>Solution Concentration</u>
carbon	450,000	N/A
oxygen	450,000	N/A
hydrogen	70,000	N/A
nitrogen	10,000	210
potassium	9,000	195
calcium	7,000	200
magnesium	1,500	35
phosphorus	1,500	30
sulfur	800	50
iron	70	5.5
chlorine	70	3.5
manganese	40	0.5
boron	8	0.05
zinc	8	0.01
copper	3	0.01
molybdenum	0.1	0.005

^(a)Bradshaw and Chadwick 1980.

Primary sources of nitrogen for soils on the Hanford Site are precipitation and nonsymbiotic fixation by soil lichens (Table 2).

Nitrogen supply to plants depends heavily on efficient cycling, in that nearly all the nitrogen a plant obtains from the soil is derived from previous plants. Assuming the total annual nitrogen input to soils on the Arid Lands Ecology (ALE) Reserve (Table 2) on the Hanford Site were converted to new plant biomass, the maximum plant productivity would be 40 g/m²/yr [= annual nitrogen input/average nitrogen content of plants (Table 1)]. However, above-ground productivity of the sagebrush-bunchgrass community at Hanford averages 70 g/m²/yr and productivity of cheatgrass (*Bromus tectorum*) averages 225 g/m²/yr (Rickard and Vaughan 1988). This productivity is supported primarily by microbial decomposition (mineralization) of organic material, which contains the accumulated store of nitrogen that has

TABLE 2. Estimated Annual Input to Soils and Output from Vegetation of Nitrogen on the Arid Lands Ecology Reserve^(a)

<u>Source</u>	<u>Flux, g/m²/yr</u>
<u>Annual Input</u>	
rainfall	0.15
dry deposition	0.05
symbiotic fixation	<0.05
nonsymbiotic fixation	0.20
direct absorption by plants	unknown; small
TOTAL INPUT	>0.40
<u>Annual Output</u>	
animal tissue	0.10
animal waste	0.20
redistribution	0.10
volatilization	<0.05
denitrification	0
leaching	0
runoff	0
TOTAL OUTPUT	0.40

^(a)Woodmansee 1979.

slowly increased in the soil over decades and centuries. Mineralization rates on the ALE Reserve have been shown to be a function of soil organic carbon and nitrogen levels, which are in turn related to plant cover (Bolton et al. 1990). Mineralization also requires adequate soil moisture: dry soils support little microbial activity; constantly wet soils may lose nitrogen through leaching (Herlihy 1979). In general, losses of nitrogen through volatilization are greater for sandy soils than for sandy loams; and increasing organic matter decreases the potential for volatilization by sorption and ion-exchange reactions (as reviewed by Woodmansee 1979). Because of the average low amount of organic matter and precipitation, Hanford Site soils may be characterized as having extremely low levels of nitrogen (Table 3).

TABLE 3. Characteristics of Undisturbed Soils on the Hanford Site^(a)

Texture	Sand ^(b)	Silt ^(b)	Clay ^(b)	pH	CEC ^(c)	Total N ^(d)	P ^(d)	K ^(d)	Organic C ^(b)
Sand	89.36	7.27	3.34	7.76	5.98	180	6	280	0.171
Loamy Sand	81.82	13.83	4.33	7.70	6.07	233	8	278	0.242
Sandy Loam	60.31	34.17	5.54	7.94	8.84	307	10	398	0.354
Loam	48.65	42.15	9.25	7.55	11.15	500	13	655	0.650
Silt Loam	28.55	64.69	6.80	8.08	13.21	600	23	798	0.678
Worldwide ^(e)	20	55	25	7.2	24	2000	30	400	7

^(a)Data from Brandt et al. 1990.

^(b)Percentage.

^(c)In meq/100 g.

^(d)In ppm.

^(e)Data from Bradshaw and Chadwick 1980.

Phosphorus, the fifth-most abundant macronutrient in plants, is taken up from the soil as the phosphate anion. It is released into soils by decay of minerals such as apatite and fluorapatite. Phosphate combines with many components of the soil, especially calcium in alkaline soils, forming insoluble complexes. Consequently, much of the soil phosphorus is unavailable to plants. Soluble phosphorus is produced by decay of organic materials and readily taken up by plants. Many plants have symbiotic relationships with mycorrhizal fungi, which, among other benefits, increases their uptake of phosphorus (e.g., Hetrick et al. 1990). Basalts are relatively rich in phosphorus compounds in comparison to sandstones (Bradshaw and Chadwick 1980). Consequently, the native sands and loamy sands on the lowlands of the Hanford Site are relatively low in phosphorus in contrast to basalt-derived soils on the uplands (Table 3).

With the notable exceptions of nitrogen and phosphorus, the macro- and micronutrients are cations. Cation supplies for plant growth are controlled largely by the density of cation exchange sites (negatively charged components) in soils, of which the cation exchange capacity (CEC) is the primary measure. The CEC of a given soil is largely the result of its clay and organic matter content (Askenasy and Severson 1988). Soils with higher CEC levels will have more plant-available cation nutrients than other soils, all things being equal.

Potassium is the most abundant cation in plants (see Table 1). Its abundance in soils is a function of the abundance of potassium-rich minerals such as orthoclase, biotite, and muscovite; the amount exposed to weathering; and the time of exposure. Basalts and sandstones contain relatively few of these minerals (Bradshaw and Chadwick 1980); consequently, soils of the Hanford Site contain relatively low concentrations of this nutrient compared to worldwide averages for productive soils (see Table 3).

MOISTURE CAPACITY AT HANFORD

Besides providing a nutrient pool, soils also constitute a medium for retaining precipitation. The capability of soils to store water depends largely on the soil's texture. However, the amount of water available to plants is not equal to the amount stored. Available water capacity is the difference between the amount of water that can be held by the soil against gravity (i.e., field capacity) and the amount held by the soil when plants begin to wilt (i.e., wilting point). Thus, although sandy loam has less than half the field capacity of clay loams, plant-available water is actually greater in the sandy loam (Table 4).

TABLE 4. Water Retention and Availability Versus Soil Texture^(a)

<u>Soil type</u>	<u>Field capacity^(b)</u>	<u>Wilting point^(b)</u>	<u>Available water^(c)</u>
sand	6.7	1.8	1.98
sandy loam	19.8	7.9	4.75
silt loam	35.3	12.7	7.05
clay loam	30.1	16.3	4.15

(a)Bradshaw and Chadwick 1980.

(b)Percentage water.

(c)cm water, assuming 30-cm rooting depth.

Sandy soils have the lowest water capacity; however, little moisture need be added to sandy soils to exceed the wilting point. This factor has important implications for seasonal plant growth and subsequent species distributions. Fall and winter precipitation on the Hanford Site typically occurs over several days, with periods of cool to cold weather in between with little evapotranspiration. In the typical late spring to early summer, precipitation occurs in episodes punctuated by extended periods of drought. Consequently, available water probably controls plant growth on sandy soils during the late fall to early spring period; however, in the following months, wilting point dominates plant growth, in that the short periods of rainfall produce small amounts of soil moisture that is available for plant growth on sandy soils, but is insufficient to rise above wilting capacity on sandy loams or silt loams. As a result, late-flowering native plants such as balsamroot (*Balsamorhiza careyana*) and pale evening primrose (*Oenothera pallida*) continue to bloom into the summer on sandy soils, yet are absent from less-coarse soils. Similarly, invasive alien annual weeds that perform most of their growth during the summer, such as Russian thistle (*Salsola kali*) and bur ragweed (*Ambrosia acanthicarpa*), perform best on the coarser soils.

Organic matter content of soils also affects moisture-holding capacity directly through absorption and surface-tension effects, and indirectly through effects on soil structure. Structure is the arrangement of primary soil particles and humic materials into secondary particles or aggregates, which are separated from adjoining aggregates by surfaces of weakness (Dollhopf and Postle 1988). Consequently, well-developed soils are aggregated into crumbs with intervening spaces that may be filled with air or water and from which plants obtain nutrients and water. Breakdown of aggregates by wetting and drying cycles or erosion results in loss of structure, reduced water infiltration, and crusting of the soil surface in finer-textured

soils, all of which inhibit plant establishment. The formation of water-stable aggregates in well-developed soils prevents formation of surficial crusts and promotes water infiltration into the soil.

CONSEQUENCES OF SEVERE SOIL DISTURBANCE

Soil disturbances may be classified within a spectrum based on their effects on soil structure and plant growth. Disturbances at the Hanford Site vary from offroad vehicular traffic at the relatively low-impact end of the spectrum to excavations and reapplication of quarried or scalped materials at the high-impact end. Compost application is pertinent primarily to the high-impact disturbances; consequently, the effects of these disturbances on vegetation-relevant characteristics of the soil will be briefly discussed.

Severe disturbances to soils may affect soil structure, organic carbon and nutrient pools, nutrient cycling processes, and moisture-holding capacity, preventing the establishment of desirable plant cover and increasing the likelihood of invasion by undesirable species. Severe disturbances produce material that lacks structure (EPA 1975); consequently, such soils are prone to formation of surface crusts after just a few periods of rainfall. Excavations generally cause mixing of soil horizons in which the shallow A horizon, which contains the bulk of the soil's organic carbon (Wildung and Garland 1988) and microbiotic communities, is intermixed with deeper layers that may contain high amounts of gravels and alkaline carbonates (USSCS 1975), depending on the location within the Hanford Site. Mined or scalped material generally lacks organic matter of any kind; furthermore, plant-available nutrients normally generated by weathering of parent materials are absent or occur at very low levels.

The lack or destruction of soil structure and loss or dispersal of soil organic material have severe consequences for soil microbiotic communities. The lack of a resistant organic carbon pool in mined or scalped materials prevents establishment of microbial flora (Whitford 1988). Even when topsoil is scalped and stored before use, or when excavated material is segregated by soil horizon and stored before replacement, essential microbiological constituents are lost within a few months (Miller 1984). Because of the essential role of microbiotic communities in cycling nutrients within arid land soils, severe soil disturbances produce conditions in which decomposition and nutrient cycling are drastically reduced (Schuman and Belden 1991; Whitford 1988); consequently, nutrients added through fertilization are quickly lost from the system through leaching or binding in plant tissue (Whitford 1988).

Most of the soils available for revegetation work on the Hanford Site are coarse-textured sands or loamy sands. As described earlier, such soils have a very low water-storage capacity, and a large proportion of the precipitation input may rapidly infiltrate such soils below the level at which germinating plants are able to send roots (Gee et al. 1988). Excavation and refilling may introduce gravels into the future seedbed, further decreasing the moisture-holding capacity of such soils (Ashby et al. 1984).

Severely disturbed soils are also prone to invasion by annual weedy species. Plants first to invade disturbed areas on the Hanford Site are typically Russian thistle, tumble mustard (*Sisymbrium altissimum*), and bur ragweed. These plants are able to colonize disturbed sites because of their minimal germination requirements, their widespread seed distribution, and their ability to take advantage quickly of ephemeral moisture produced during the sporadic spring storms at Hanford. These species do not prevent other species from establishing and do provide a measure of soil stabilization and organic input to the soil; however, Russian thistle and tumble mustard are considered undesirable in seedbeds over waste sites because of their potential to take up waste and redistribute it as the senescent plant is blown about the landscape.

BENEFITS OF COMPOST AS A SOIL AMENDMENT

The use of compost can benefit plant growth in a number of ways; however the compost chosen must conform to certain requirements. The requirements and benefits are discussed below.

REQUIREMENTS OF SEWAGE SLUDGE AS A SOIL AMENDMENT

Organic wastes (Table 5) in which nutrients and carbon are in forms unsuitable for plant growth can be converted through the activity of microorganisms into materials that are stable to leaching and unwanted gas emissions and contain nutrients in plant-available forms. Microorganism activity is supported by the relative amounts of nutrients and incompletely oxidized carbon contained in the waste materials. Carbon provides the primary energy source for composting, while nitrogen is necessary for synthesis of proteins by the microorganisms.

Moisture is also necessary for the composting process, both to meet the physiological needs of the microorganisms and as a vehicle for their migration through the composting medium (Miller 1989). Excessive moisture in some wastes, such as municipal sewage sludge, may lead to leaching as well as anaerobic conditions during composting; consequently, bulking agents are added to absorb moisture and increase porosity. Common bulking agents include wood chips or sawdust, paper, yard waste, and municipal solid waste. Microorganisms in composts include bacteria and fungi; fungi are the only organisms capable of efficiently utilizing wood and wood-based materials. Because fungi are killed or inactivated at temperatures above 60°C (Miller 1989), most commercial aerobic composting in the United States operates at temperatures between 35° and 55°C (Golueke 1989), the lower temperatures favoring fungal decomposition of wood fibers. Bacterial decomposition requires more nitrogen than does fungal decomposition (Schuman and Belden 1991), and proceeds at a faster rate.

Because compost is an organic material retaining a large microbial community, it continues to decompose during storage or after field application. As the compost ages, nitrogen sources in the material are gradually converted to nitrate from ammonia (Epstein et al 1978). Compared to ammonia, nitrate is nonvolatile and more readily accessible to most plants.

TABLE 5. Approximate Nitrogen Content and Carbon:Nitrogen Ratios of Some Compostable Materials^(a)

Material	N ^(b)	C:N ^(c)
slaughterhouse waste	7-10	2
poultry manure	6	25
human sewage	6	6-10
sheep manure	4	30
pig manure	4	40
sea weed	2	20
fruit waste	2	30
cow manure	2	40
horse manure	2	50
municipal solid waste	0.5-2	15-80
oat straw	1	50
yard waste	0.5-2	20-80
wheat straw	0.3	130
paper	0.2	170
sawdust	0.1	170-700

(a)Gotaas 1956; Poincelot 1975; Bradshaw and Chadwick 1980.

(b)Percentage dry-weight basis.

(c)weight:weight basis.

Sewage sludges and composts made from them typically contain elevated levels of heavy metals such as Cd and Pb; however, most remain bound with the organic matter in the sludge or sludge compost and are not taken up by plants (Alloway and Jackson 1991). Fields undergoing sewage sludge applications show elevated levels of heavy metals in soils, yet crops from those fields take up less than 0.05% of the annual additions of even the most mobile metals (Davis 1984). Sims and Kline (1991) found that additions of metals to soils via cocomposted sewage sludges had little effect on plant metal concentrations. Fresquez et al. (1990) found no effect of sludge application on soil or plant Cd or Pb even at application rates as high as 90 Mg/ha. Sewage sludges may also contain mutagenic organic compounds such as polychlorinated or polybrominated biphenyls and pesticides in very low levels, depending on the source of the sludge (EPA 1984). Fiedler et al. (1991) tested the uptake of mutagenic

organic compounds by plants grown in sludge-amended soils and found no translocation of these compounds into plants, despite their presence in the soils.

Guidelines for use of compost products for land application typically recommend that the compost carbon:nitrogen ratio be less than 20:1 (e.g., Willson 1989) because of the binding of plant-available nitrogen in microbial biomass when carbon sources are supplied in excess quantities. However, acceptable carbon:nitrogen ratios may be much higher if the primary carbon source is resistant to decomposition (Ocio et al. 1991; Schuman and Belden 1991). Sims (1990) compared the performance of dried cocomposted sewage sludge mixed with composted municipal refuse (C:N ratio 54:1) and dried cocomposted sewage sludge mixed 1:1 with a wood-chip-based sewage sludge compost (C:N ratio 33:1) as an amendment to three different soil types. Composts without wood chips immobilized soil nitrogen during the 20 weeks of the study, whereas no immobilization was observed for the wood-chip/sludge compost. Wood-products-based composts may even enhance soil nitrification rates over extended periods in extremely disturbed soils (Perucci and Giusquiani 1990; Whitford 1988).

BENEFITS OF COMPOST

Benefits of compost amendments to disturbed soils derive from the compost's structure, organic carbon pool, nutrient content and form, and microbiological inocula. The relative contributions of each to soil characteristics and plant growth will vary with compost characteristics, which depend on the types of materials and bulking agents used. Composts have little effect on soil pH (Fresquez et al. 1990; Sims 1990). All composts, however, provide a large amount of degraded organic matter, which may improve the friability of fine-textured soils and the moisture-holding capacity of coarse-textured soils (Bradshaw and Chadwick 1980). Physical characteristics of soils generally may be altered by additions of 25% compost by volume.

Nutrients compose relatively little of compost dry matter; however, because composts are based on plant or animal wastes, they contain the full range of plant macro- and micronutrients in proportions generally suitable to support plant growth (Table 6). Addition of composts to depleted or disturbed soils produces increases in nutrient abundance with consequent effects on plant growth (Bradshaw and Chadwick 1980). For example, Fresquez et al. (1990) found that soil macro- and micronutrient levels in semiarid soils increased linearly with the rate of addition of dried municipal sludge, as did plant growth rate. Sabey et al. (1990) found that municipal sewage sludge significantly enhanced growth of western

TABLE 6. Composition of Representative Composts^(a)

<u>Characteristic</u>	<u>Wood/Sludge</u>	<u>Yard Waste</u>	<u>Yard Waste/Sludge</u>
CEC ^(b)	53	54	54
pH	6-7	5-6	5
Total N ^(c)	1.1	1.5	1.6
P ^(d)	6000	4000	9000
K ^(d)	800	7000	4000
Ca ^(d)	6000	10,000	12,000
Mg ^(d)	2000	2500	2000
Organic material ^(c)	67	66	62

(a) Haub and Henry 1988.

(b) meq/100 g.

(c) Percentage dry-weight.

(d) In ppm.

wheatgrass (*Agropyron smithii*), big sagebrush, and fourwing saltbush (*Atriplex canescens*) over nonamended copper mine spoils under ample moisture regimes. They attributed this effect to the nutrients supplied by the sludge material .

One of the principal benefits of compost additions to depleted or disturbed soils is the initiation of nutrient cycling. This effect results from the inoculation into sterile soils of microbial decomposers present in the compost. Experimental studies of compost and municipal sludge amendments to soils have documented increased soil microbial biomass and resulting nutrient cycling (Fresquez and Lindemann 1982; Pichtel and Hayes 1990; Whitford et al. 1989). Perucci and Giusquiani (1990) found higher levels of organic carbon, organic nitrogen, nitrate, and phosphorus in clay-loam soils treated with 2.5% municipal waste compost than in untreated soils. The increase in phosphorus was not due to the phosphorus added in the compost, but was the result of soil microbial activity stimulated by the compost. Seaker and Sopper (1988) found similar increases in microbial biomass and nutrient cycling in coal mine spoils amended with dried municipal sewage sludge.

COMPOST EFFECTS ON VEGETATION GROWTH IN LAND RECLAMATION

No studies of the effects of compost on plant growth in revegetated arid lands have been found in the refereed literature. The following experimental analysis is summarized from an article by C. A. Brandt and W. H. Rickard, Jr., which is under review for publication in the Journal of Environmental Quality.

The experiment was conducted as part of the Basalt Waste Isolation Project reclamation effort to restore native vegetation on the Hanford Site. Disturbed areas to be revegetated consisted primarily of abandoned borehole pads ranging in size from 0.1 to nearly 8 ha in size. All borehole areas had been cleared of vegetation, leveled, and covered with up to 2 m of compacted pit-run gravels to provide a stable base for drilling. Sites had been treated with various herbicides over the years, with applications before 1985 being undocumented. Disturbances ranged in time from 15 years to 1 year before reclamation, with the majority between 6 and 8 years. Disturbed areas occurred in a number of soil types, comprising primarily sands or loamy sands. The objective for reclamation was to return native shrub-steppe grasses and shrubs to borehole sites (Brandt et al. 1990). A flow chart showing the reclamation process is presented in Figure 1.

Reclamation of the abandoned borehole sites began in 1988 with removal of up to several meters of gravels that had been applied to the sites as a stable support for drilling operations. Natural land contours were approximated by filling in excavated mud pits with salvaged gravel, grading the surrounding soils to cover the gravel fill, and smoothing the edges of the site to blend with the surrounding landscape. All sites were then machine-ripped to a depth of 30 cm and disced to a minimum depth of 15 cm. Site preparation continued through September 1989.

Grasses were seeded on approximately half of the sites during October to November 1988. The seeding phase consisted of first surface-compacting the seedbed with a cultipacker. Certified weed-free chopped wheat straw was then mechanically blown over the seedbed at a rate of 4500 kg/ha and crimped into the seedbed. Grass seeds were planted using a deep-furrowing drill. Seeding mixes consisted primarily of Sandberg's bluegrass (*Poa sandbergii*) and bottlebrush squirreltail (*Sitanion hystrix*). Tubeling shrubs were transplanted to all sites during November 1989. Shrub species included big sagebrush (*Artemisia tridentata*), grey

FIGURE 1. Flow Diagram of Basalt Waste Isolation Project Reclamation

rabbitbrush (*Chrysothamnus nauseosus*), green rabbitbrush (*C. viscidiflorus*), and spiny hopsage (*Grayia spinosa*).

Sites identified for remediation (Table 7) were sites seeded in the fall of 1988 that failed to develop stands of grasses by the following summer. These sites were treated with municipal sewage sludge composted with wood chips as bulking agent (GroCo® from METRO, Seattle, Washington), which was incorporated at a rate of 7% by volume into the top 15 cm of the seedbed by discing in August. Analysis of the compost material was N: 0.8%, P: 0.2%, K: 0.4%, and organic matter: 86%. These sites were then reseeded during October 1989 using the same seeding mixes and methods as used the previous year. Three sites (DC-7/8, DC-15, and DC-23) received straw mulch before reseeding; the remaining sites did not receive a second application of mulch because most of the straw from the previous year was still present.

Growth of grasses and shrubs on revegetated areas was assessed during March, May, and December 1989 and in March through June 1990.

COMPARISONS TO MATCHED SITES

Growth and survival differed among soil types, but bluegrass growth was improved on all soils by addition of compost (Table 8). Plant density was greatest on treated Rupert sand soils; least on untreated Hezel sand soils (Figure 2). The greatest improvement in bluegrass survival was realized on Burbank loamy sand, where the treated areas averaged over 4.5 times

TABLE 7. Characteristics of Remediated Sites prior to Sludge Compost Amendment

Site	Date Disturbed	Size(a)	Soil Type	pH	N(b)	P(c)	K(c)	Organic C(b)	CEC(d)
DC-7/8	1978	0.5	Burbank Loamy Sand	7.7	0.03	7	293	0.13	5.0
DB-14	1979	0.3	Hezel Sand	7.8	0.02	15	316	0.15	8.4
DB-12	1978	0.2	Burbank Loamy Sand	7.5	0.02	6	254	0.13	5.0
DC-7/8	1978	0.5	Burbank Loamy Sand	7.7	0.03	7	293	0.15	8.4
DC-15	1981	0.8	Rupert Sand	8.1	0.01	6	328	0.05	5.9
DC-23	1984	2.3	Rupert Sand	8.3	0.00	2	82	0.09	2.7
DH-26	1982	0.1	Hezel Sand	8.2	0.01	3	90	0.12	4.8

(a) In ha.

(b) Percentage.

(c) In ppm.

(d) In meq/100 g.

TABLE 8. Analysis of Variance of First-Year Grass Growth on Matched Sites

Source	<i>df</i>	Sum of Squares	Mean Square	<i>F</i>	<i>P</i>
<i>Poa sandbergii</i> Density					
Compost	1	2.036	2.036	7.281	0.0085
Soil Type	2	2.911	1.455	5.205	0.0075
Residual	80	22.367	0.280		
<i>Poa sandbergii</i> Height					
Compost	1	0.873	0.873	9.642	0.0026
Soil Type	2	0.647	0.324	3.575	0.0326
Residual	80	7.242	0.091		
<i>Poa sandbergii</i> Leaf #					
Compost	1	1.509	1.509	11.855	0.0009
Soil Type	2	0.773	0.389	3.056	0.0526
Residual	80	10.186	0.127		
<i>Sitanion hystrix</i> Density					
Soil Type	2	0.016	0.008	0.116	0.8906
Compost	1	0.011	0.011	0.167	0.6842
Residual	50	3.404	0.068		
<i>Sitanion hystrix</i> Height					
Soil Type	2	0.027	0.014	0.131	0.8776
Compost	1	0.043	0.043	0.418	0.5211
Residual	50	5.165	0.103		
<i>Sitanion hystrix</i> Leaf #					
Soil Type	2	0.031	0.015	0.208	0.8132
Compost	1	0.059	0.059	0.793	0.3775
Residual	50	3.690	0.074		

the number of plants per meter of seeded row versus the matched controls. Differences in plant growth showed patterns similar to survival, with plant height on treated Burbank loamy sand sites averaging nearly four times that on untreated controls.

No differences in growth or survival of bottlebrush squirreltail were found that could be attributed to soil or treatment conditions (Table 8 and Figure 2).

Treatment with composted sludge affected survival of big sagebrush differently in different soils (Table 9). Survival rates of big sagebrush transplants under compost treatment were lower than controls in Hezel sand, but higher in Rupert sands and unchanged in Burbank loamy sands (Figure 3). Survival of rabbitbrush was higher, on average, on composted sites than on untreated sites.

COMPARISONS TO PRETREATMENT GROWTH

Growth of grasses during the first spring after seeding on sites the year before compost treatment was significantly below growth of reseeded grasses after treatment with compost (Figure 4). Average density of bluegrass after treatment was over twice that found on the

FIGURE 2. Grass Density, Average Number of Leaves per Plant, and Plant Height during First Growing Season on Sites Treated with Compost and Matched Untreated Controls

TABLE 9. Analysis of Variance of Shrub Survival on Matched Sites

Source	<i>df</i>	Sum of Squares	Mean Square	<i>F</i>	<i>P</i>
<i>Artemisia tridentata</i>					
Soil Type	2	3.093E-5	1.546E-5	0.442	0.6449
Compost	1	2.002E-5	2.002E-5	0.572	0.4522
Compost * Soil Type	2	0.001	0.001	15.268	0.6001
Residual	66	0.002	3.502E-5		
<i>Chrysothamnus nauseosus</i>					
Soil Type	2	1.295E-4	6.474E-5	2.116	0.1356
Compost	1	2.471E-4	2.471E-4	8.079	0.0074
Compost * Soil Type	2	2.266E-4	1.133E-4	3.703	0.0348
Residual	35	0.001	3.059E-5		
<i>C. viscidiflorus</i>					
Soil Type	2	1.253E-4	6.267E-5	1.440	0.2659
Compost	1	2.633E-4	2.633E-4	6.053	0.0256
Compost * Soil Type	1	9.449E-7	9.449E-7	0.022	0.8847
Residual	16	0.001	4.351E-5		

same sites before treatment ($F_{1, 82} = 6.295$, $P = 0.0141$). Similar trends were noted for average leaf number per plant ($F_{1, 82} = 13.559$, $P = 0.0004$) and average plant height $F_{1, 82} = 11.498$, $P = 0.0011$). No bottlebrush squirreltail grew during the first year on any site identified for treatment with compost, but did after treatment. Shrubs were not planted on remediation sites before treatment with compost, and so could not be compared on this basis.

COMPARISONS OF FIRST-YEAR GROWTH ON ALL SITES

First-year growth of grasses was compared among all reclamation sites, with sites classified as to whether they were to receive treatment with compost (B and D in Figure 1) or not (A and E in Figure 1). First-year growth of bluegrass on all sites seeded in 1988 (A and B in Figure 1) showed significant differences between sites destined for treatment with compost (B in Figure 1) and the remaining sites (Date * Treatment interaction effect in Table 10). Sites destined for treatment supported less than one-tenth the average density of bluegrass before composting and reseeding as did the remaining sites (Figure 5). Similarly, bluegrass height and average leaf number/plant were less than half that obtained on the unremediated sites in 1988/89. For sites seeded in 1989 (D and E in Figure 1), the situation was reversed, with sites receiving compost (D) significantly outperforming those not receiving treatment (E), at least with respect to bluegrass.

Performance of bottlebrush squirreltail relative to treatment was more mixed. Sites destined for treatment supported no growth of bottlebrush squirreltail in 1988, while the

FIGURE 3. First-Year Survival Rates of Transplanted Shrubs on Sites Treated with Compost and Matched Untreated Controls

FIGURE 4. Grass Density and Average Number of Leaves per Plant during First-Year Growing Season on Sites before and after Treatment with Compost

TABLE 10. Analysis of Variance of First-Year Grass Growth by Year of Seeding and Whether or Not Sites Were to Receive Treatment with Compost

Source	df	Sum of Squares	Mean Square	F	P
<i>Poa sandbergii</i> Density					
Seeding Date	1	8.710	8.710	30.726	0.0001
Treatment	1	5.045	5.045	17.799	0.0001
Date*Treatment	1	32.308	32.308	113.973	0.0001
Residual	339	96.096	0.283		
<i>Poa sandbergii</i> Leaf #					
Seeding Date	1	0.003	.003	0.037	0.8480
Treatment	1	0.005	.005	0.068	0.7950
Date*Treatment	1	4.994	4.994	70.434	0.0001
Residual	339	24.037	0.071		
<i>Poa sandbergii</i> Height					
Seeding Date	1	0.077	0.077	1.498	0.2218
Treatment	1	0.030	0.030	.589	0.4433
Date*Treatment	1	4.040	4.040	78.737	0.0001
Residual	339	17.394	0.051		
<i>Sitanion hystrix</i> Density					
Seeding Date	1	0.419	0.419	5.727	0.0175
Treatment	1	0.040	0.040	.553	0.4577
Date*Treatment	1	0.723	0.723	9.884	0.0019
Residual	246	17.992	0.073		
<i>Sitanion hystrix</i> Leaf #					
Seeding Date	1	0.051	0.051	1.074	0.3010
Treatment	1	0.127	0.127	2.645	0.1051
Date*Treatment	1	0.119	0.119	2.487	0.1161
Residual	246	11.785	0.048		
<i>Sitanion hystrix</i> Height					
Seeding Date	1	0.157	0.157	2.224	0.1372
Treatment	1	0.088	0.088	1.244	0.2657
Date*Treatment	1	0.278	0.278	3.957	0.0478
Residual	246	17.316	0.070		

remaining sites seeded that year supported sparse growth. The situation was significantly reversed the following year, with treated sites supporting almost twice the density of bottlebrush squirreltail as untreated sites seeded in 1989. Treated sites performed marginally better than untreated sites in terms of average plant height (Date * Treatment interaction effect in Table 10), but there was no significant effect of treatment on average leaf number per plant.

BASIS FOR RESULTS

The effects of compost on plant survival and growth in the previous experiment were probably due in large part to the effects of compost on soil moisture. Plants in soils of low water capacity (e.g., sands) experience greater variation in available water than do plants in

FIGURE 5. Grass Density and Average Number of Leaves per Plant during First-Year Growing Season on All Revegetated Sites

finer-grain soils, or soils with high organic content. Such variation will increase mortality of establishing plants and may affect plant development, especially during early growth. Survival rates of bluegrass during the first eight months of growth on Hanford reclamation sites were strongly related to soil textural class. Survival was significantly lower in unamended sandy soils than in unamended silt loams after the 1988 seeding, while emergence in unamended loamy sands was intermediate (Brandt et al. 1990). However, soil texture bore no significant relationship to leaf number or plant height.

Under conditions of ample water, nitrogen is the primary nutrient limiting growth in the non-agricultural plant communities of the shrub-steppe region (Bolton et al. 1990). In composted sludges, nitrogen occurs primarily in organic forms not immediately available to plants. A small percentage (<4%) of the nitrogen in composted sludges is present as ammonia, which may be taken up immediately by plants; the remainder of the nitrogen may be mineralized at a rate of 20%/year during the first year under optimal moisture conditions (Parker and Sommers 1983). However, optimal moisture conditions did not occur during the 1989/90 growing season. Precipitation from December to March was less than one-third of normal (Brandt et al. 1991). Consequently, nitrogen mineralization rates were likely to have been low.

Furthermore, the plants involved in this study are relatively insensitive to nutrient additions. Growth of native plants from nutrient-poor regions is less affected by nitrogen limitation than is growth by other species adapted to more benign conditions (Chapin 1980). Plants adapted to low nutrient levels, such as bluegrass, probably engage in luxury consumption of nitrogen during periods of high nutrient availability (Black and Wight 1979). When nutrient levels decrease, the plant is able to utilize the stored nitrogen for production of roots, which should enhance survival through periods of nutrient shortage. Because nutrient uptake is generally limited by diffusion to the roots (Chapin 1980), the addition of moisture-holding additives to the soil could significantly enhance the transfer of nutrients from the soil to the plant roots.

BENEFITS OF COMPOST AMENDMENTS VERSUS INORGANIC FERTILIZERS AND MULCHES

Compost provides in a single source nearly all the needs of most disturbed soils. No single alternative to compost possesses the full suite of attributes of compost. One of the primary benefits of compost in revegetation of disturbed arid lands derives from its effects on moisture-holding capacity. This benefit may be obtained from other organic sources, such as straw or wood-fiber mulches that are incorporated into the soil column (Schuman and Beldon 1991). These, however, may decrease nitrogen availability for plants through uptake by decomposer organisms (Ocio et al. 1991; Sims 1990). They also do not provide nutrients or decomposer organisms to sterile soils. Consequently, rates of decomposition and nutrient cycling in soils receiving only mulch will generally be lower than those of compost-treated soils.

The type of carbon source applied to the soil as a mulch or incorporated as an amendment can affect the longevity of the microbial community and subsequent decomposition rates and nutrient cycling. Wood and fiber decomposition is accomplished primarily by fungi, which are able to metabolize structural carbohydrates and lignins while conserving nitrogen (Schuman and Belden 1991). Fibers resistant to decay, such as wood chips and bark, allow development of a complete soil microfauna able to prey upon the fungi, which, in turn, keeps the fungi providing a continuous stream of organic carbon to the soil, thereby maintaining nutrient-cycling organisms such as bacteria and blue-green algae (Whitford 1988; Whitford et al. 1989). Experimental support for this notion includes a study by Elkins et al. (1984) in which New Mexico soils were amended with either wood chips and bark or barley straw. These were then compared on the basis of the rate of decomposition of a second introduction of barley straw to both soils. Straw decomposition was significantly greater in the wood-chip/bark treatment than in the straw treatment. Perucci (1990) found that Italian soils depleted of organic matter as a result of agricultural practices responded with increased microbial biomass and nutrient cycling when treated with composted municipal solid waste. However, because the compost was composed primarily of readily decomposed household garbage, soil microbial biomass returned to approximately pretreatment levels within 3 months of treatment.

Because disturbed lands are seriously deficient or imbalanced in plant nutrients, fertilization is often recommended (e.g., Bauer et al. 1978; EPA 1975). However, field data indicate that fertilization is less effective in restoring imbalances in arid sites (Aldon 1978). Furthermore, the nutrient deficiencies of disturbed lands can seldom be met by a single application of fertilizer (Bradshaw and Chadwick 1980). Attempts to meet these needs in a single application generally result in invasion of the site by annual weeds (DePuit and Coenenberg 1979; Huenneke et al. 1990; Rennick et al. 1984), many of which, such as Russian thistle, would be undesirable on revegetation sites at Hanford. Fertilization may also adversely affect carbon:nitrogen balance (Schafer and Nielssen 1978) and microbial colonization of disturbed soils (Klein et al. 1984). Indeed, Rennick et al. (1984) recommend against the use of fertilizers in attempting to establish cool-season grasses on disturbed sites. All the primary native and revegetation grasses at Hanford are cool-season grasses generally adapted to low-nutrient soils. In contrast to inorganic fertilizers, compost provides a low rate of release of nitrogen and other nutrients, while at the same time providing for rapid recycling of organic nutrients in amounts low enough not to encourage invasion by annual weeds but rapid enough to supply the needs of most arid-land perennial plants (e.g., Muller and Garnier 1990).

Plants are adapted to the nutrient and moisture regimes of their native soils, such that plants from relatively fertile soils show marked increases in growth in response to increasing nutrient levels. Plants native to less-fertile soils, such as occur on the Hanford Site, generally are unresponsive to fertilization. In 1989, an experiment was conducted on newly seeded plots revegetated with Sandberg's bluegrass in which nitrogen in the form of ammonium nitrate was applied to emerging grasses at three levels (14, 28, and 56 kg nitrogen/ha) plus a control in a Latin square design (Brandt et al. 1991). Fertilizer was applied in March and subsequent growth of bluegrass was assessed in May and December 1989. Nitrogen addition had no effects on density, leaf number per plant, or average leaf height at either assessment period (Brandt et al. 1991). Similarly, sewage sludge treatments on a high-altitude reclamation site in Colorado produced higher levels of native plant cover than did additions of nitrogen or nitrogen and phosphorus inorganic fertilizers (Berg et al. 1986).

BENEFITS OF COMPOST AMENDMENTS IN ABSENCE OF PLANT COVER

The Hanford Site is subject to perhaps the lowest annual precipitation in the North American shrub-steppe region (Helvey and Fowler 1982). Precipitation at Hanford is characterized as much by its variability as by its average value (Brandt et al. 1990). Widespread plant mortality derives from extended period of drought during early stages of plant growth (Frasier 1989); consequently, years in which winter precipitation is inadequate to support plant establishment are to be expected. Also, arctic cold fronts occasionally enter the Hanford Site during the winter (Stone et al. 1983) with severe consequences for plant establishment on revegetated sites (Brandt et al. 1991). This variability is relevant because even the best-managed revegetation programs can be expected to fail with some regularity. In such cases, the benefits of nitrogen fertilizers and straw mulches may be lost entirely (Rennick et al. 1984); however, the benefits of compost, especially of composts composed of wood products, will remain in large measure intact. Much of the mineralized nitrogen will remain (Epstein et al. 1978), as will the less mobile phosphorus and potassium. Because of its slow rate of decomposition, wood-based composts will continue to provide a carbon source, nutrient supply, and microbial nutrient-cycling pool in the absence of plant cover.

Composts may also limit, to some extent, the erodibility of soils. Soils on the Hanford Site are subject to extended periods of high winds throughout the year (Stone et al. 1983), resulting in high rates of erosion from barren disturbed soils. Soils in reclamation areas on the Hanford Site are primarily composed of sands, loamy sands, and sandy loams (Brandt et al. 1990). Potential erodibility of these soils is inversely proportional to the percentage of dry soil aggregates greater than 0.84 mm (Table 11). Wetting and drying cycles cause soils to form water-stable aggregates held together by insoluble cementing materials. Enhanced soil moisture may therefore decrease susceptibility of soils to wind erosion via formation of water-stable aggregates and through surface-tension adhesion of particles. Decomposition of organic matter in soils produces water-stable aggregates from decomposition residues such as gums and other polysaccharides either synthesized by microorganisms or resistant materials remaining in the organic matrix. These residues enhance the resistance of the soil to erosion during the period of decomposition, although the effect declines as decomposition reaches completion (Finkel 1986). Use of resistant bulking material, such as wood bark, wood fiber, and paper, would lengthen the period during which decomposition could occur and therefore lengthen the period during which amended soils would be more resistant to wind erosion.

TABLE 11. Erodibility of Principal Hanford Site Soils^(a)

<u>Soil Textural Class</u>	<u>Dry soil aggregates^(b)</u>	<u>Soil erodibility^(c)</u>
sands	1	696
loamy sands	10	301
sandy loams	25	193

^(a)Hayes 1972.

^(b)Percentage.

^(c)mton/ha/yr.

REGULATORY REQUIREMENTS AFFECTING LAND APPLICATION OF SLUDGE

COMPOST ON HANFORD

Regulatory requirements affecting application of sewage sludge composts on nonagricultural land exist at the federal, state, and local level. The principal requirements are likely to result from the Environmental Protection Agency's (EPA) regulations for sewage sludge use and disposal promulgated under Section 405 of the Clean Water Act (33 USC 1345). The Washington State Department of Ecology (WDOE) also has existing regulatory requirements that will affect application of composts containing sewage sludge. The WDOE regulations will likely need to be modified when the EPA regulations become final. Application of a sludge compost will probably not add new regulatory issues beyond those associated with application of sewage sludge alone, provided that the composting materials are not hazardous materials under the regulations at 40 CFR 261. Sewage sludge composts that are determined to be hazardous substances under this regulation are to be managed and disposed of under the Resource Conservation and Recovery Act (42 USC 6901 et seq.). In addition, the use and disposal of sewage sludge composts containing greater than 50 ppm of polychlorinated biphenyls (PCBs) are subject to special regulations at 40 CFR 761 issued under the authority of the Toxic Substances Control Act.

It is likely that applicable federal, state, or local regulations will apply to sludge compost application at Hanford (i.e., Hanford will not be exempted because it is a federal facility). The Clean Water Act (33 USC 1323) and the Resource Conservation and Recovery Act (42 USC 6901) require federal agencies to comply with applicable federal, state, and local pollution control requirements.

FEDERAL REGULATORY REQUIREMENTS

The basis for the federal requirements applicable to beneficial use of sewage sludge composts is Section 405 of the Clean Water Act. Section 405(d) requires the EPA to issue regulations covering the use and disposal of sewage sludge. The EPA issued proposed regulations on February 6, 1989 (54 FR 5746). The EPA's most recent Regulatory Agenda (56 FR 18011, April 22, 1991) indicates that the final regulations are scheduled to be issued in January 1992 and will appear at 40 CFR 503. The final version of these regulations would be applicable to sludge compost use at Hanford.

Subpart B of the February 6, 1989 proposed regulations (54 FR 5878) contains provisions for the land application of sewage sludge. These provisions include 1) general requirements for land application of sewage sludge, 2) maximum pollutant limits in sewage sludge applied to nonagricultural land, and 3) nonagricultural land management practices. The proposed regulations are likely to be changed in the final version. On November 9, 1990 (55 FR 47210), the EPA issued the results of its National Sewage Sludge Survey and discussed the anticipated impacts of the survey results on the 40 CFR 503 regulations. The EPA's planned revised approach for regulating nonagricultural land application of sewage sludge is to establish specific numeric pollutant limits and management requirements for different categories of nonagricultural land (55 FR 47249 to 47252). The proposed use of sludge at Hanford appears to fit within the proposed category "soil reclamation sites." One proposed management practice for soil reclamation sites is that buffer areas are to be maintained between the sludge application area and 1) surface waters and draining areas, 2) residential areas, and 3) public and private water wells. Compliance with such a management practice should be possible at Hanford.

In May 1989 the EPA issued regulations covering state sludge management programs. The regulations appear at 40 CFR 501. The regulations cover the procedures that the EPA will follow in approving, revising, and withdrawing state sludge management programs operating under Section 405 of the Clean Water Act. Approved state sludge management programs are to be applicable to all federal facilities in the state [40 CFR 501.1(d)(1)]. States or local governments may operate sludge management programs that are more stringent or broader in scope than federal requirements [40 CFR 501.1(i,j)]. In general, all treatment works are required to have a permit (40 CFR 501.15). Recipients of sewage sludge who apply the sludge to land for beneficial purposes are not included, however, within the definition of treatment works and are not required to have a permit (40 CFR 501.2, 54 FR 18731).

The EPA has existing requirements covering land application of sewage sludge at 40 CFR 257. In particular, 40 CFR 257.3 to 257.5 places restrictions on the application of sludge containing cadmium and PCBs to land used for the production of food-chain crops, and 40 CFR 257.3 to 257.6 requires treatment of sludge to significantly reduce pathogens before land application. The EPA plans to have the forthcoming 40 CFR 503 regulations supersede the provisions in 40 CFR 257 applicable to land disposal of sewage sludge (54 FR 5876).

STATE AND LOCAL REGULATORY REQUIREMENTS

The WDOE has existing regulations for land application of sewage sludge (WAC 173-304-300); the regulations will likely need to be revised when the 40 CFR 503 regulations are issued in final form. Under the existing regulations, application of sewage sludge and other organic wastes on land for beneficial use requires a permit from the local health department [WAC 173-304-300(3)(a)]. The local department with jurisdiction over the Hanford Site is the Benton-Franklin District Health Department. The regulation does not contain an exception to the permit requirement for one-time sewage sludge applications. Health department representatives are to be allowed entry for inspection purposes and to determine compliance with applicable rules [WAC 173-304-300(3)(d)]. The application of sewage sludge is to be consistent with the WDOE's Sludge Utilization Guidelines (WDOE 1982) or the landspreading disposal standards at WAC 173-304-450 [WAC 173-304-300(4)].

CONCLUSIONS

Compost provides an array of benefits on soils requiring reclamation that cannot be duplicated with other amendments. These benefits derive primarily from the nutrient, organic, and microbial components of composts. Compost has been shown to improve survival and growth of reclamation plants under arid-land conditions by three to five times over that obtained using traditional amendments such as inorganic fertilizers and straw mulch. Compost use as a soil amendment can produce a substrate capable of supporting plant growth in otherwise difficult environments on the Hanford Site. Compost usage on the Hanford Site would be covered by EPA's sludge management regulations should composts be formulated using municipal sewage sludge.

The primary beneficial effects of compost will vary for different soils. A brief listing is provided in Table 12 of the reclamation soils commonly encountered on the Hanford Site, their specific problems as far as establishment of plant cover, and the specific beneficial effects of compost for those conditions. Additionally, estimates of compost requirements are given on a volume basis. Appropriate types of compost for each reclamation situation have not been studied. In general, however, aerobic composts with C:N ratios of 15:1 to 40:1 may provide the greatest benefits. High ratios of C:N should be limited to composts with a large component of wood or wood-product bulking agents.

TABLE 12. Reclamation Soil Problems and Relevant Benefits of Compost Amendments

<u>Soil Type</u>	<u>Soil Problems</u>	<u>Compost Benefits</u>	<u>Amendment Rate</u>
Disturbed surface sands	<ul style="list-style-type: none"> • low water-holding capacity • wind erodibility • low organic/nutrient content 	<ul style="list-style-type: none"> • fine organics increase water-holding capacity • formation of soil aggregates • complete macro- and micro-nutrient and organic C 	25%
Excavated sands	(above plus -) <ul style="list-style-type: none"> • no nutrient cycling capacity • no plant-available nutrients 	<ul style="list-style-type: none"> • microbial inoculum and organic C food source • complete macro- and micro-nutrient and organic C 	25-40%
Disturbed surface silts/loams	<ul style="list-style-type: none"> • compaction decreases water infiltration • formation of surficial crusts inhibiting plant emergence, water infiltration • wind erodibility 	<ul style="list-style-type: none"> • increased friability due to floc formation • formation of water-stable aggregates due to microbial by-products • formation of soil aggregates 	10%
Excavated silts/loams	(above plus -) <ul style="list-style-type: none"> • no plant-available nutrients • no nutrient cycling capacity 	<ul style="list-style-type: none"> • complete macro- and micro-nutrient and organic C • microbial inoculum and organic C food source 	15-25%

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