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Project Summary

Critical Factors Controlling Vegetation Growth on Completed Sanitary Landfills

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This study summarized here identifies some of the critical factors that affect tree and shrub growth on reclaimed sanitary landfill sites and determines which woody species are adaptable to the adverse growth conditions of such sites. Trees planted at the Edgeboro landfill, East Brunswick, NJ, produced less shoot and stem growth and shallower roots than trees on the adjacent control plot. Of 19 woody species planted 4 years ago on the 14-year-old landfill, black gum and Japanese black pine proved to be the most tolerant and green ash and hybrid poplar the least tolerant to landfill conditions. Root systems of the more tolerant species proved to be shallower than those of the landfill-intolerant species. Smaller planting stock (30 to 60 cm tall) appeared to be better suited for landfill planting than large trees (3 to 4 m tall). Balled and burlapped trees showed better growth on the landfill plot than bare-rooted material. Of five gas barrier systems tested, three proved effective: a soil trench underlaid by plastic sheeting over gravel and vented by means of vertical PVC pipes, a 0.9-m mound of soil underlaid with 30 cm of clay, and a 0.9-m soil mound with no clay barrier.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The sanitary landfill is presently the least expensive environmentally acceptable means of municipal waste disposal available. Advantages attributed to landfilling are neatness, safety, and relatively low cost. Though early landfill sites were located far from residential areas, rapid urban and suburban expansion has brought many once-remote sites within developed areas. As such, they provide attractive sources of much needed land for recreational uses, and some municipalities have even considered them acceptable for commercial purposes.

Regardless of the ultimate use of landfill sites, certain disadvantages exist, including groundwater pollution, production of explosive gases, surface settlement, and high ground temperatures. Because abnormally high incidences of plant mortality were found on many landfills, a nationwide mail survey was initiated to determine whether such occurrences were common throughout the United States (Flower et al., 1978). Results indicated that the problem was indeed of national magnitude.

The goal of this project was to help develop the scientific knowledge necessary to convert former landfill sites into recreational areas by determining:

1. the relative adaptability of 19 woody species to landfill conditions,

2. the relationship of rooting depth to the tree's tolerance of landfill soil,
3. whether small planting stock can survive on completed landfills better than large specimens,
4. whether balled and burlapped plant material is better suited for landfill plantings than bare-rooted material,
5. the effects of irrigation on tree growth in landfill soil, and
6. the feasibility of constructing barriers to the passage of toxic gases from the refuse into the root zone of gas-sensitive species.

The full report also includes information on whether the leaf tissue nutrient content of trees in landfill soil differs from that of trees in nonlandfill soil and the effects of high concentrations of landfill gas (carbon dioxide and methane) on the availability of soil nutrients.

Methods and Materials

Literature Review

A literature review was conducted to determine the extent of existing data on vegetation growth on landfills and to study the effects of soil moisture on plant growth, environmental factors on leaf transpiration, soil conditions on nutrient uptake, and soil conditions on root growth. Detailed reports describing vegetation on landfills were scarce. Many attempts to vegetate completed sanitary refuse landfills with trees and shrubs have been unsuccessful (Flower et al., 1978). Gilman et al. (1980) report that tree and shrub species have varied tolerances to commonly occurring landfill gases in the soil.

Tree Planting

The tree-planting segment of the study included a species screening experiment and studies of gas barrier techniques, irrigation and tree growth, and planting stock size and type. Landfill and control plots were used to plant specimens and observe results. Cultural methods included applications of 10-6-4 granular fertilizer, liming, irrigation, pest control (Sevin* and malathion), use of chicken wire to protect against rabbit damage of young seedlings, and weed control by mowing, pulling, and chemical applications (Princep).

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Environmental Protection Agency.

Sampling methods used in this study included soil measurements (gas content, temperature, bulk density, moisture content, and nutrient concentrations), tree measurements (shoot length, stem area, root biomass, leaf weight, tissue nutrient content, and transpiration rate), and meteorologic measurements (air temperature, humidity, and total wind movement). Various chemical analyses were conducted to determine leaf tissue content. Roots were examined by excavating each root system completely with a small hand trowel from the point of emergence at the main stump to the root tips.

Results and Discussion

Species Screening Experiment

During the spring of 1976, 10 replicates of 19 woody species (Table 1) were planted on both the completed 14-year-old Edgeboro sanitary landfill in East Brunswick, NJ, and on a nearby control site that had not been landfilled. Data presented in this report were collected during 1978 and 1979, and compiled with portions of data collected in 1976 and 1977 (Gilman 1978).

Relative Viability of Plants—

Plant viability after 4 years of growth on the completed landfill varied greatly among species. By the end of 1979, all of the weeping willows, rhododendrons, and euonymus had died on the landfill plot. Willows and rhododendrons were obviously unable to withstand the periods of desiccation characteristic of such sites during midsummer. The euonymus shrubs on the site that were not girdled by rabbits during the winter of 1977–78 also appeared to have become desiccated during midsummer from lack of soil moisture. Several sweet gum, black gum, bayberry, and pin oak died from undetermined causes. Landfill gas contamination of the root zone and low soil moisture during mid-July 1978 were suspected as contributing factors in the sweet gum deaths. Since the concentrations of carbon dioxide, oxygen, and methane at the 20-cm (8-in.) soil depth can reportedly vary from day to day, some tree deaths may have resulted from undetected landfill gas migrations into the root zone (i.e., samples might have been collected only on days of low concentrations). Arthur (1978) indicates that short periods of high landfill gas concentrations may adversely affect tree growth. Also, gases other than carbon dioxide and methane may have migrated into the cover soil of the Edgeboro landfill and adversely affected plant growth. In spite of the numerous plant deaths, enough replicates of 16 of the original 19 species remained alive during 1978 and 1979 to evaluate statistically their ability to tolerate landfill soil conditions.

Relative Growth of Surviving Plants—

Determination of landfill tolerance of the surviving trees was based on shoot length and stem area increase for each

Table 1. Species Selected for Vegetation Growth Experiment at Edgeboro Landfill

Latin name	*Common name*
Acer rubrum	*Red maple*
Euonymus alatus	*Euonymus*
Fraxinus lanceolata	*Green ash*
Ginkgo	*Ginkgo*
Gleditsia triancanthos	*Honey locust*
Liquidambar styraciflua	*Sweet gum*
Myrica pensylvanica	*Bayberry*
Nyssa sylvatica	*Black gum*
Picea excelsa	*Norway spruce*
Populus spp.	*Hybrid poplar (saplings)*
Populus spp.	*Hybrid poplar (from rooted cuttings)*
Plantanus occidentalis	*American sycamore*
Pinus strobus	*White pine*
Pinus thunbergi	*Black pine*
Quercus palustris	*Pin oak*
Rhododendron hyb. 'Roseum Elegans'	*Rhododendron*
Salix babylonica	*Weeping willow*
Tilia americana	*American basswood*
Taxus cuspidata var. capitata	*Japanese yew*

species on both the landfill and control plots. Relative tolerance of landfill conditions depended both on the growth parameter measured and the growing season in which measurements were collected. During the 1978 growing season when landfill plot growth was compared with that of the control plot, black pine shoot and stem growth was better than that for any other species. During 1979, however, shoot growth of black pine on the landfill was fourth and stem growth was tenth best of all species. Thus, black pine appeared to be less tolerant of landfill conditions in 1979 than in 1978. In the 1978 comparison, honey locust shoot and stem growth were fifteenth and sixteenth in rank, respectively, among the species tested; but during 1979, honey locust shoot growth was best, and stem growth was fifth best of all species tested. Evidently, a tolerance list based on growth measurements during one particular growing season does not necessarily represent a reliable estimate of an overall tolerance to landfill conditions.

Since landfill tolerance also appears to depend on the particular growth measurement in question, the critical growth criteria must be identified when selecting species. For example, either shoot growth, stem growth, or both may be critical for a particular vegetation project.

When the total amount of shoot growth produced on the landfill from 1976 through 1979 was compared with that in the control plot, ginkgo, black gum, and Japanese yew appeared to be most tolerant; green ash, sweet gum, and hybrid poplar saplings appeared least tolerant of landfill conditions. But comparisons of percent stem area increase show Japanese yew, white pine, and Norway spruce to be most tolerant and hybrid poplar cuttings, hybrid poplar saplings, and green ash to be least tolerant of landfill conditions.

Since no single growth parameter is best suited for comparing tree growth on the landfill with that on the control plot, shoot and stem growth data were combined for 1976, 1977, 1978, and 1979 and analyzed as a unit. Two different statistical methods were chosen to analyze the combined growth rate to rank the test species for overall tolerance to landfill conditions.

One method consisted of averaging hoot growth during 1976 (when stem rowth was not available) and shoot and stem growth for 1977 through 1979 control plot. A rank of one was given the species that produced the greatest amount of shoot or stem growth on the landfill as compared with that on the control plot. The species that grew most poorly on the landfill as compared with its growth on the control plot was ranked last (16th). Thus seven rank lists were formed, and the tolerance rank values from the lists were totaled for each species for an overall landfill tolerance rank (Table 2).

Principal components analyses of shoot and stem data from 1976 through 1979 made up the second method (Table 3). A factor score was calculated for each species on each plot. The differences in scores between plots were aligned from smallest to largest. The ranking of species from most to least landfill tolerant by this system was similar to the first analytical method. Only two species changed positions dramatically; Japanese yew moved from most tolerant by the first method to eighth according to the principal components analysis, and hybrid poplar cuttings moved from eighth in tolerance by the first method to least tolerant by the second analysis. As a result of both methods of analysis, black gum, black pine, and bayberry appeared to be most tolerant, and hybrid poplar saplings, green ash, and honey locust appeared least tolerant of landfill conditions.

A final way of assessing relative tolerance to landfill conditions is to total the rank values from the two methods of analysis (Table 4). Black gum appears most tolerant and Japanese yew is second most tolerant of landfill conditions. Japanese yew appears to have been ranked very tolerant because growth on the control was inhibited by "wet feet" conditions.

In all the landfill tolerance lists, the species were generally distributed in a similar manner throughout tolerance ranks: That is, those at the top of one list generally appeared toward the top of the other lists and vice versa.

Stress on the intolerant trees provided by low moisture, or elevated carbon dioxide and methane concentrations, or both was reflected in greater variability in growth on the landfill plot than on the control. Since tolerant species were apparently more capable than the intolerant species of withstanding the low soil moisture and elevated gas levels of the landfill plot, the lower variability among tolerant trees on the landfill comes as no surprise.

From the previous discussion, the following questions must be answered before plant material is selected: Should the plant produce a quick vegetative

Table 2. *Sum of Landfill Tolerance Ranks* for Shoot and Stem Measurements 1976-1979*

Species	*Sum of Tolerance Rank Values*⁺	*Landfill Tolerance Rank*
Japanese yew	*37*	*1*
Japanese black pine	*42*	*2*
Black gum	*45*	*3*
Bayberry	*45*	*3*
Ginkgo	*46*	*5*
White pine	*49*	*6*
Norway spruce	*50*	*7*
Hybrid poplar (rooted cuttings)	*50*	*7*
American basswood	*54*	*9*
American sycamore	*60*	*10*
Red maple	*60*	*10*
Honey locust	*72*	*12*
Pin oak	*77*	*13*
Sweet gum	*83*	*14*
Green ash	*87*	*15*
Hybrid poplar (saplings)	*102*	*16*

**Each number is the sum of that species' rank in seven rank lists relative to the other species. The seven rank lists are the following: stem area increase measurements from 1977, 1978, and 1979, and shoot length measurements from 1976, 1977, 1978, and 1979.*

⁺The lower the number, the more tolerant the species is to landfill conditions.

Table 3. Average Factor Scores for 16 Species from Landfill and Control Plot Data, 1976-1979*

Species	Landfill	Control	Difference (control-landfill)	Landfill Tolerance Rank⁺
Black gum	-0.02	-0.14	-0.12	1
Japanese black pine	-0.23	-0.28	-0.05	2
Bayberry	-0.65	-0.69	-0.04	3
Ginkgo	-1.08	-1.11	-0.03	4
White pine	-0.61	-0.63	-0.02	5
American basswood	-0.57	-0.54	-0.03	6
Norway spruce	-0.57	-0.50	-0.07	7
Japanese yew	-0.43	-0.36	-0.07	8
Sweet gum	0.18	0.31	0.13	9
American sycamore	0.02	0.17	0.15	10
Red maple	0.15	0.53	0.38	11
Pin oak	-0.22	0.36	0.58‡	12
Hybrid poplar (saplings)	0.12	0.71	0.59‡	13
Green ash	-0.57	0.30	0.87‡	14
Honey locust	0.31	1.33	1.02‡	15
Hybrid poplar (rooted cuttings)	2.96	4.04	2.96‡	16

*Principal Axis Factor Method was used to calculate factor patterns and factor scores for shoot and stem data from 1976 through 1979.

⁺The lower the number, the more tolerant the species is to landfill conditions.

‡Significant @ $P < 0.05$.

cover? Must it grow in a manner similar to trees on sites that are not landfilled? Should it produce good shoot growth, good stem area increase, or both?

Tolerance of Rapid Versus Slow Growers

Seven of the eight most intolerant species have been classified as rapid growers (Table 4); most of the tolerant species are slow growers. Apparently, those species with the capacity to grow very quickly cannot maintain this rapid growth rate on completed landfills, whereas species that naturally have a slower growth rate can maintain a rate on the landfill comparable with that on the control. Since fast growing trees are likely to withdraw more moisture from the soil, they may become subjected to water stress more quickly than the slow growers, and irrigation may be more essential for their establishment. Thus when growth on the landfill was compared with growth on the control, rapidly growing trees proved intolerant of landfill conditions. But many of these supposedly intolerant (based on landfill growth compared with control growth) rapid-growing species (hybrid poplar rooted cuttings, honey locust, and American sycamore) actually produced more absolute vegetative growth on the landfill than other so-called tolerant species growing on the landfill.

Tolerance of Drought-Sensitive and Flood-Tolerant Species

The characteristic low-moisture-holding capacity of landfill cover soils was demonstrated on the experimental landfill plot during the years 1977 and 1978. Species most likely to be affected by water stress are those that naturally grow in areas associated with a high water table. Five of the eight species (green ash, honey locust, sweet gum, pin oak, and red maple) observed to be landfill-stressed in these investigations (Table 4) cannot tolerate drought, whereas only one of the eight tolerant species is reported drought sensitive. Several of these intolerant species (green ash, red maple, honey locust) may have proved to be landfill tolerant if adequate amounts of water had been provided.

A reasonable assumption may be that those species that can withstand periods of flooding can also tolerate landfill conditions, since both environments generally lack sufficient oxygen for normal root respiration. But since the soil on the Edgeboro landfill was often lacking in moisture, these species were probably not afforded the opportunity to exhibit their low-oxygen adaptability. Thus their growth on the landfill was much reduced compared with the control.

Effect of pH on Tolerance

Evidence exists to show that soil pH may affect species tolerance to landfill conditions. Stem area increase data indicated that acid-loving plants (Japanese black pine, Norway spruce, black gum, and bayberry) were more tolerant of landfill soil with a low pH (4.5 as opposed to 6.2). Shoot-length data, however, showed no recognizable relationship between soil pH and landfill tolerance. Stem area increase may thus be a more sensitive indicator for the tolerance of woody species to landfill conditions.

Effect of Soil Compaction on Tolerance

High soil bulk density is another factor that may have influenced the response of a number of the test species to the soil environment created on the landfill plot. Optimum levels of soil bulk density for a variety of crops vary between 1.3 and 1.5 g/cm^3. Since bulk density on the landfill plot during the current investigations was 1.8 g/cm^3, the lowered oxygen content of the soil may have affected some species.

Tolerance of Shallow- Versus Deep-Rooted Species

The species that adapted to the landfill plot most quickly (Japanese black pine, Norway spruce) had shallower and more extensive root systems on the landfill than did the intolerant species (honey locust, green ash, hybrid poplar). This study presents evidence that the root systems of these presently intolerant species are making their way toward the soil surface and may in several years be able to tolerate landfill conditions. Their root systems will probably grow away from the high carbon dioxide and methane concentrations (and, consequently, low oxygen concentrations) in the deeper soil strata, and they will probably require extensive irrigation to maintain growth comparable with the control.

Root Adaptations

The root adaptation mechanism of hybrid poplar associated with landfill tolerance appeared to be different from that of green ash. Deep poplar roots (30 cm) grew toward the soil surface and

*Table 4. Relative Tolerance of 16 Species to Landfill Conditions**

Species	Sum of Landfill Tolerance Rank Values
Black gum (4, 8)⁺ -R‡	10
Japanese yew (9, 4) -	13
Japanese black pine (10, 9) -	14
Ginkgo (7, 9) -S	17
White pine (10, 10) -S	21
Bayberry (9, 9) -	23
Norway spruce (8, 8) -S	26
American basswood (9, 10) -S	31
American sycamore (10, 10) -R	34
Red maple (9, 10) -I	41
Hybrid poplar (rooted cuttings) (10, 5) -R	44
Pin oak (9, 10) -R	48
Sweet gum (1, 6) -R	51
Honey locust (10, 10) -R	52
Green ash (10, 10) -R	59
Hybrid poplar (saplings) (2, 7) -R	60

*Tolerance was established by totaling the landfill tolerance rank values for each species from Tables 8, 9, 10, and 11.

⁺Number of replicates living on the landfill and control plots respectively at the end of 1979.

‡R=rapid growth rate, I=intermediate growth rate, S=slow growth rate, N=data not available - from Fowells (1965).

proliferated there, whereas ash roots at the same depth did not extend to the soil surface. Instead, a shallow root system was provided for by roots that sprouted from the root collar 2 cm below the soil surface. The ash roots proliferated at this depth, resulting in a shallow root system.

American basswoods suffered a decrease in total root length and a reduction in the depth of maximum root penetration when levels of soil carbon dioxide and methane were high and oxygen concentrations were low. This result indicates that at least 1 in. of irrigation per week is needed on completed landfills to maintain good tree growth. Though American basswood roots did not maintain good growth when landfill gas concentrations were high, moderate gas concentrations permitted roots to grow toward the soil surface and avoid the contaminated soil environment below.

Tolerance of Small Versus Large Trees

Small trees (30 to 60 cm tall) appear to be more adaptable to landfills than large trees (3 to 4 m tall). Shoot growth for small trees of four (pin oak, green ash, sugar maple, hybrid poplar) out of five species tested was as good on the landfill as on the control, but shoot growth on the large specimens (saplings) was significantly lower ($P < 0.10$) on the landfill.

Tolerance of Balled and Burlapped Versus Bare-Rooted Material

Another practice involving root characteristics that may help trees adapt to stressed environments is the use of balled and burlapped material rather than bare-rooted stock. In this investigation with a single species (sugar maple), balled and burlapped trees produced longer shoots and greater leaf volume than bare-rooted trees on the landfill plot, but not on the control plot. Obviously there was some advantage in having a less pruned root stock. Better mycorrhizae inoculum may also have existed in the soil ball. Whether this is a characteristic of one species or many remains to be determined.

Tolerance of Irrigated Versus Nonirrigated Plants

Sugar maple was used to assess the value of supplemental irrigation in adapting trees to landfill cover soils. This species generally grew better in the control soil, with its higher moisture and oxygen and lower carbon dioxide, than in the landfill. Irrigated maples produced significantly more ($P < 0.01$) leaf tissue than nonirrigated trees on the landfill, but not on the control plot during 1978 and 1979. Shoot length was enhanced by irrigation in both plots, but the increase was not statistically significant. Possibly the failure of irrigation to stimulate growth in the control plot was a result of the sufficient rainfall that occurred during the growing season; thus moisture was not a limiting factor for growth of sugar maple on the control as it was on the landfill.

Decreased height of sugar maples on the landfill plot was undoubtedly because of the combined effects of low soil moisture, slightly elevated soil carbon dioxide, and depressed oxygen concentration. Also, the elevated carbon dioxide levels may have caused the production of a shallower root system on the landfill than on the control and may therefore have predisposed the maples to drought damage. Gingrich and Russell (1957) report that oxygen and moisture content interact so that at high oxygen concentrations, low moisture content has a more deleterious effect on corn growth than at low oxygen contents. Since the oxygen concentration in the landfill soil was only slightly depressed, low soil moisture could have had a strong effect on maple development.

Arthur (1978) observed an increase in stomatal resistance and hence reduced transpiration of sugar maples after several days of exposure to simulated landfill gas mixtures. A similar effect was observed in sugar maples growing in the landfill plot. Elevated soil carbon dioxide concentrations (7.8%) in the nonirrigated portion of the landfill caused significantly increased stomatal resistance in the sugar maples from late morning until early evening over that of the trees located on the landfill where carbon dioxide averaged 2.8%. Irrigation throughout the growing season did not significantly reduce the stomatal resistance below that of the nonirrigated area.

Air temperature, relative humidity, and other meteorological parameters are also known to affect stomatal aperture. But the effects of an adverse gas environment and reduced moisture content on stomatal aperture in the landfill plot apparently overrode the recognized effects of temperature, humidity, and wind.

Gas Barrier Experiment

Landfill gases (primarily carbon dioxide and methane) must be kept away from the root system of trees and shrubs to promote good vegetation growth. Five gas barrier systems were tested, and three proved to be effective: (a) a soil trench underlaid with plastic sheeting over gravel and vented by means of vertical PVC pipes, (b) a 0.9-m mound of soil underlaid with 30 cm of clay, and (c) a 0.9-m soil mound with no clay barrier. Concentrations of carbon dioxide, oxygen, and methane in the two mounds and in the trench were similar to those in the control plots, thus indicating that these gas barrier techniques are suitable for application in landfill vegetation projects.

Evaluations were made of the effects of varied soil environments on American basswood growth and on the total nutrients they accumulated in each gas barrier test area. American basswoods growing in 0.9-m (36-in.) soil mounds (either unlined or lined with a 30-cm (12-in.) clay barrier) and in the gravel/plastic/vents trench generally produced more stem and shoot growth than trees in unmodified landfill soil. The other two gas barrier trench systems did not promote better tree growth than the unmodified landfill areas. Basswoods in the gravel/plastic/vents trench and in the clay-lined mound accumulated more of eight plant nutrients (nitrogen, potassium, magnesium, calcium, manganese, iron, zinc, and copper) than did the trees in the unmodified landfill screening area.

Conclusions

1. Woody species differ in their adaptability to landfill soil.
2. Slow-growing trees appear to be better adapted to landfill conditions than rapid-growing trees.
3. Trees and shrubs planted as small specimens appear to be better adapted to landfill conditions than large specimens.
4. Species with a natural propensity for producing shallow roots are better suited for landfill vegetation projects than naturally deeper-rooted species.
5. Species reportedly tolerant to low oxygen environments will not grow well on landfills unless they are irrigated very thoroughly.
6. Balled and burlapped plant material appears to be better adapted than bare-rooted material to landfill soil.
7. Landfill gases (primarily carbon dioxide and methane) must be kept away from the root system of trees and shrubs to promote good vegetation growth. Two types of methods shown to be effective are (a) a mound of soil (0.9 m) over existing cover (with or without a clay liner), and (b) a lined and vented trench backfilled with suitable soil.

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The complete report, entitled "Critical Factors Controlling Vegetation Growth on Completed Sanitary Landfills," (Order No. PB 81-246 324; Cost: $17.00, subject to change) will be available only from:
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