LANDFILL GAS, WHAT IT DOES TO TREES AND HOW ITS INJURIOUS EFFECTS MAY BE PREVENTED[1]

by Franklin B. Flower, Edward F. Gilman, and Ida A. Leone

Abstract. The conversion of former refuse landfills into post closure uses generally involves the planting of trees for aesthetic and occasionally commercial purposes. The authors have noted that it is frequently difficult to obtain satisfactory tree growth when the gases of anaerobic decomposition of the organic matter contained in the refuse are present. The lack of oxygen and the presence of excessive quantities of carbon dioxide in the soil root zone appear to be the cause of much tree injury and death when the trees are grown above or adjacent to former refuse fills. Thin, low-nutrient-content cover soils, lack of adequate soil moisture, excessive compaction, and surface settlement have also been identified as problems found associated with former refuse deposit areas.

Methods are suggested for preventing the entry of landfill gases into the root zones of the trees and in accommodating other tree growth problems found associated with former refuse dumping areas. These include gas venting and blocking, irrigation, planting adaptable species, using small sized specimens in preference to large, and providing adequate maintenance.

Landfill gases are generated primarily by the anaerobic decomposition of organic matter after it has been buried in the refuse landfill. The gases produced by a stabilized landfill are primarily methane (CH_4) and carbon dioxide (CO_2). Minor fractions of other gases such as hydrogen sulfide, hydrogen, ammonia, nitrogen, oxygen, carbon monoxide, volatile organic acids, and the paraffin and cyclic hydrocarbons have also been reported (Ham et al 1979). In addition traces of other gases might arise from the volatilization of solid or liquid waste deposited in the refuse fill. It has been estimated that up to 7 cu. ft. of gas may be produced for each pound of municipal solid waste that decomposes completely within the landfill (Ham et al 1979). This would result in the total production of 260 cubic feet of gas for every cubic foot of refuse within a landfill which contains the expected 1000 pounds of refuse per cubic yard. Since the gases produced by the anaerobic decomposition occupy so much more space than the material from which they were generated, these gases must move out of the landfill. It is this movement of gases both horizontally and vertically that has caused growth problems for vegetation growing on and adjacent to refuse landfills.

Refuse Landfilling

Landfilling has been and is the major disposal method for solid waste within the United States and much of the world. The area in which the refuse is landfilled should be one which will not be conducive to the generation of water pollution. Natural or manmade provisions should also be made for the prevention of lateral migration of the gases through the soil. The modern refuse landfill is constructed by depositing the solid waste materials on the ground, spreading them in thin layers, compacting the refuse to the smallest practical volume, and covering with an inert soil (Brunner and Keller 1972). The refuse is spread in thin layers in order to facilitate compaction. High compaction of the refuse is desired in order to obtain the maximum use of space available for the landfill. In addition, it refuces the surface settlement that will develop as the landfill ages. Daily cover is used as an aid to reducing litter, rainwater infiltration, rodent and insect harborage. This system of refuse deposition and compaction followed by daily soil cover results in a series of horizontal refuse cells 10 to 20 feet deep. After the horizontally available volume is filled it is frequently the practice of the landfill operator to construct a second series of cells over the first. Each horizontal series of cells is called a lift. Today it is not uncommon to find refuse landfills consisting of enough lifts to result in completed landfills with depths of 60-100 or more feet (Fig. 1)). The landfills frequently cover a horizontal area of scores to hundreds of acres. Therefore, millions of tons of

[1] This research was supported by the Municipal Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Grant No. R 803762-02-3 and was performed at the New Jersey Agricultural Experiment Station, Cook College, New Brunswick, N.J. 08903.

Presented at the annual conference of the International Society of Arboriculture in Hartford, Connecticut in August 1980.

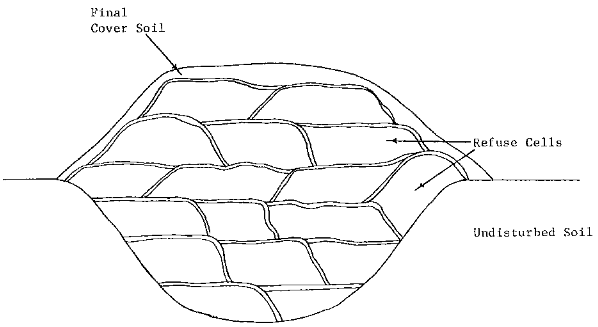

Figure 1. Cross section of a refuse landfill.

Figure 1. Cross section of a refuse landfill.

refuse may be found in one large landfill. It is such areas that the arborist will frequently come in contact as land use pressures encourage the development of former refuse fills into parks.

Landfill Gas Generation

When the refuse is first deposited in the landfill, the bases within it contain oxygen. This results in decomposition beginning with the aerobic stage, which primarily produces carbon dioxide and water vapor. Generally within 6 months the oxyen in the refuse atmosphere is consumed and decomposition continues in the anaerobic phase. Because of the depth of the refuse, its high compaction, and the soil cover, diffusion of oxygen from the ambient air into the landfill is limited to the surface layers. Therefore, decomposition continues in the anaerobic phase. This will last for many years. There have been reports of the gasea of anaerobic decomposition of buried organic matter being produced up to 75 years after burial of the materials (Rovers et al. 1977).

The gas produced in greatest quantity during anaerobic decomposition is methane, a colorless, odorless gas which is combustible in concentrations of 5-15% by volume in air. Methane is also the major combustible component of natural gas; therefore, it can cause potential problems of fire and/or explosions.

Although methane contributes up to 60% of landfill gas by volume, it does not seem to exert any direct toxicity effect upon vegetation. However, through the displacement of oxygen it can cause anaerobic soil conditions which are detrimental to plants. Carbon dioxide makes up about 40% by volume of the gases produced through anaerobic decomposition. It too can displace oxygen in the soil thereby causing the soil to become anaerobic. Methane consuming bacteria also produce carbon dioxide from the methane. Such high concentrations of carbon dioxide may cause direct toxic effects upon vegetation (Leone et al. 1979).

Carbon dioxide is also odorless and tasteless but it is 50 times more soluble in water than methane. The dissolution of carbon dioxide tends to cause the water to be slightly acidic as carbonic acid is formed. The density of carbon dioxide is about 1½ times that of air while methane's density is about half that of air. The unpleasant odors associated with the landfill gases are probably due to other minor gas volume components.

Landfill Gas Movement

As the gases are generated they tend to move out of the landfill through diffusional flow caused by partial pressure gradients and pressure flow caused by total pressure gradients (Rovers et al. 1977). Gas pressures within landfills are normally recorded as a few inches of water. However, pressures as high as 5 lbs. per square inch (138 inches of water) have been reported (Flower et al. 1977). The authors have found landfill gases in the soil as far as 1000 feet from the landfill where they were generated. These gases travelled through the subsurface soils without the aid of manmade channels. In this particular instance it appears that nature constructed its own conduits. Soil borings indicated that the soils in this area were series of parallel layers of sand and gravel and clay. Apparently the clay layers served as pipes and the sand and gravel as the permeable space in which the gas travelled. The gas was discovered in the surface soils after tests were made for combustible gas following the death of vegetation (Fig. 2). The areas of vegetation death were generally oval in shape, apparently developing as the gases moved vertically upward through an opening in the horizontal clay barriers. It is much more common to find the migration distance to be within a hundred feet of the refuse landfill.

The distance of lateral migration of the landfill gases will depend upon the depth of the refuse

Figure 2. Dead corn in the Hunter Farm Field.

beneath the ground, the depth to the water table or impermeable subsoils, the tightness of the refuse cover, the amount and kind of refuse deposited in the landfill, and the permeability of the adjacent soils. Generally the more difficult it is for the gas to leave the landfill through the cover, the greater will be its tendency to travel laterally out of the landfill. Also, the greater the distance to the water table and the greater the depth of vertical contact of the refuse with the adjacent ground, the greater will be the chance of lateral migration into adjacent soils. In practice, most problems with lateral migration of landfill gases have been associated with former sand and gravel pits which have been filled with refuse. Soils adjacent to former sand and gravel pits are frequently quite permeable and allow the gases to pass readily through them.

Water tables, saturated clay soils, and the ambient air act as natural barriers to the subsurface travel of landfill gases. If they do not reach the root zone of vegetation, they will not cause injury. Surveys of over 70 landfills during the past dozen years (Flower et al. 1978) revealed that the landfill gases generally do not have a uniformly vertical movement through the final landfill cover. This final cover is generally required to have a minimum thickness of 2 feet. We found some situations where 20 or more feet of soil were put over the top of the landfill as final cover. Whether the final soil cover is 2 or 20 feet we generally find that landfill gases move from the refuse through the cover into the ambient air at unpredictable locations. Old landfills left to nature frequently develop a scattered growth of volunteer trees in those areas where landfill gases are absent. However, certain of these cover soils become anaerobic from the passage of the landfill gases through them. It is generally impossible to grow vegetation at these locations.

Effect of Landfill Gases on Plant Growth

Our surveys of operating and completed landfills over the past dozen years, together with our greenhouse fumigation and landfill tree growth experiments (Fig. 3) have indicated that when the soil becomes anaerobic due to the presence of landfill gases, it is not possible to grow trees. We believe that the problem is caused by one or more of the following factors: a) lack of oxygen in the root zone; b) toxicity of carbon dioxide to the roots, or c) anaerobic conditions of the soil permitting heavy metals such as iron, manganese and zinc to become available to the vegetation in toxic concentrations. As example of trees dying adjacent to a landfill affected by the lateral migration of landfill gases is shown in Figure 4. In some cases although the trees died, the shallow rooted ground vegetation continued to live. Generally when landfill gases are present in the surface soil the concentration increases at deeper soil layers. Diffusion of ambient air into the soil and diffusion of landfill gases out of the soil frequently result in the soils nearest the surface (top several inches) remaining in an aerobic condition, whereas the

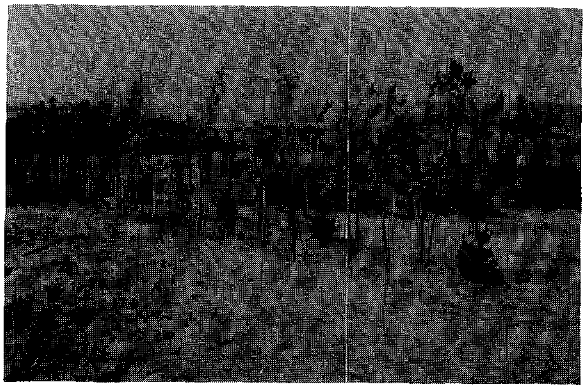

Figure 3. Experimental tree growth experiments at the Edgeboro Landfill, New Jersey.

levels where the deepest roots are present can be anaerobic.

According to the literature there is a good deal of variability in tolerance to low oxygen in the root zone among different species of plants. The growth of red and black raspberries was inhibited by exposure to 10% O_2 (Rajappan and Boyton 1956), whereas apple trees required 10% oxygen in the soil in order to sustain growth (Boynton and Compton 1943). Tomato plants grown in solution culture exhibited marked reduction in growth and ability to take up potassium when exposed to 3% oxygen in the root zone (Valmis and Davis 1944).

Figure 4. Dead trees next to a landfill killed by migrating landfill gases.

At the termination of a 48-day experiment comparing the effects of simulated landfill gases with those of flooding on twp maple species (Leone et al. 1979) both red maple (*Acer rubrum*) and sugar maple (*Acer saccharum*) trees fumigated with a mixture of 3% oxygen, 40% carbon dioxide, 50% methane and 7% nitrogen, were in noticeably worse condition than the controls which were treated with ambient air. The main symptoms were chlorosis and abscission of the lower leaves. By the 24th day the rate of the transpiration for the fumigated sugar maples was found to be significantly less than for the controls, but the fumigated red maple seedlings showed no significant difference in transpiration from the control at any time during the experiment. In summary, Leone et al. (1979) reported that red maple, which is flood-tolerant, was also more tolerant of

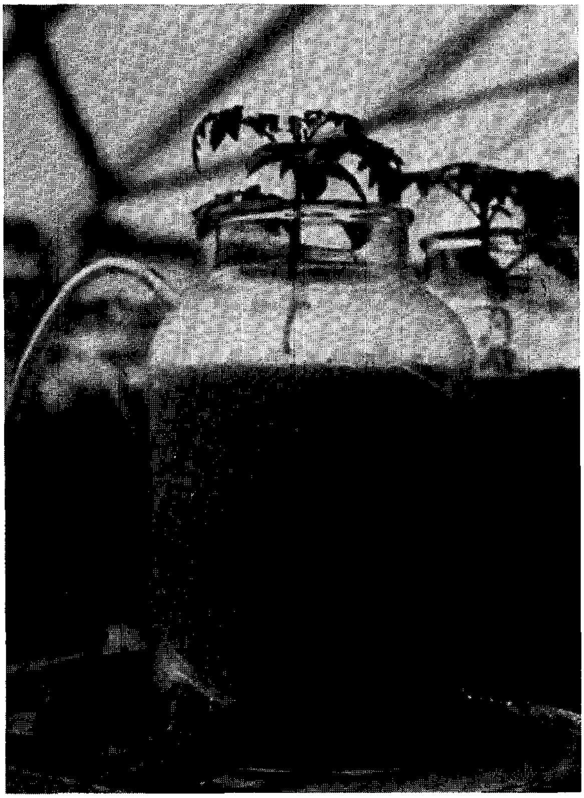

Figure 5. Glass fumigation chamber with gas inlet on bottom right and gas outlet on upper left.

soil contaminated by simulated landfill gas than sugar maple, which is not tolerant of flooding. Adequate water was supplied to these trees during the fumigation study.

In our experiments (Fig. 5), the fumigation of tomato plants with synthetically mixed landfill gases (65% N_2, 18% CO_2, 17% O_2) produced total chlorosis on tomato plants after 2½ weeks (Leone et al. 1979). Another series of tomato plants were subjected to 44% CH_4, 50% N_2, and 6% O_2, but no CO_2. These plants did not develop stress symptoms until the oxygen concentration began to drop below 4% and one to two percent CO_2 developed in the root zone area. This loss of $O_2$and the concomitant development of CO_2 we believe was due to the metabolism of the methane by methane-consuming bacteria. Therefore, our experiments indicated that CO_2 was directly toxic to the tomato, but methane was not directly phytotoxic. Rajappan and Boyton reported in

1956 that concentrations of CO_2 as low as 10% in the root zone can be toxic to roots. Sensitivity of roots to CO_2 is species dependent. Carbon dioxide concentrations of 60% or greater have been found to be toxic to all cotton plants so exposed (Leonard and Pinkard 1946). The mechanism by which CO_2 damages plant roots is not known, but the evidence indicates it is not the same mechanism by which lack of O_2 damages plants (Valmis and Davis 1944). Low O_2 supply to plant roots frequently stimulate the production of toxic compounds in root tissues.

Aside from differences between species, environmental factors can also influence plant response to low oxygen. High temperatures have been found to increase the need for oxygen by growing root tips (Rajappan and Boyton 1956). A dense soil can also increase the oxygen requirement. This is believed to be due to the extra energy required to push the root tips through the soil (Gill and Miller 1956). The O_2 concentration in the soil is a function of the ability of air to diffuse into and through the soil, and the rate of diffusion is largely dependent on the texture and degree of compaction of the soil. Sandy soils generally exhibit ample gas exchange, whereas finely textured soils with pore spaces of less than 10% are prone to poor soil aeration (Vomocil and Flocker 1961, Wiegand et al. 1959). Excessive compaction in soils containing large amounts of clay was found to result in O_2 concentrations of less than 2% and CO_2 concentrations as high as 20.5% (Yelenosky 1964).

Our literature, greenhouse and field studies, and research all confirm that the presence of landfill gases in the root zones of vegetation can be injurious to the extent of causing the death of vegetation. The major characteristics of landfill gas deleterious to plants when found in the root zone were the high carbon dioxide and methane and low oxygen concentrations resulting from anaerobic refuse decomposition. It is possible that some of the minor fractions of the landfill gases may also have some direct toxic effects upon vegetation. However, we did not investigate this aspect of the problem.

Our studies were also directed to developing measures to encourage good vegetation growth on former refuse landfills. These studies evaluated various ways to prevent the entry of landfill gases into the root zone and the cultural practices required on refuse landfills.

Excluding Landfill Gases from the Root Zone

The best way to prevent injurious effects of landfill gases to trees is to keep the gases away from the root zone of the trees. This can be done by planting the trees in areas where there are no gases, placing barriers between the gases and the root zone of the trees, or removing the gases from the root zones of the trees. Whenever plans are made for tree plantings on or near landfills, it is best to first examine the soil in the areas where the trees are to be placed. If this soil is in the anaerobic state, then the trees should not be planted as in most cases they will die. However, even when the soils are aerobic it is possible that changes in the physical structure of the landfill due to future settlement may bring gases into areas that had previously been aerobic. This in turn could cause injury or death of the trees at a future date. Therefore, positive methods for preventing landfill gases from reaching the root zone should be considered where there is a possibility that at some future date landfill gases may migrate toward the root zone of the trees.

Gas Barriers

In our Edgeboro Landfill tree growing experiments five different gas barrier systems were tested (Fig. 6) (Leone et al. 1979). One of them was a 3 ft. mound of soil placed over a standard landfill cover. The second, was a similar mound of soil placed over a one foot thick layer of clay that replaced the normal landfill cover soil immediately beneath the soil-mound. The last three barriers were trench systems which were dug to a depth of four feet. A gas barrier was placed at the bottom of each trench. In two of the trenches the gas barrier consisted of a one foot thick clay layer. In the third trench the gas barrier consisted of 1-foot of 1-inch road gravel overlaid by a 4-mil plastic sheet. This system was surrounded by ten 4-inch diameter vertical PVC pipes placed four feet apart which were perforated with a continuous series of

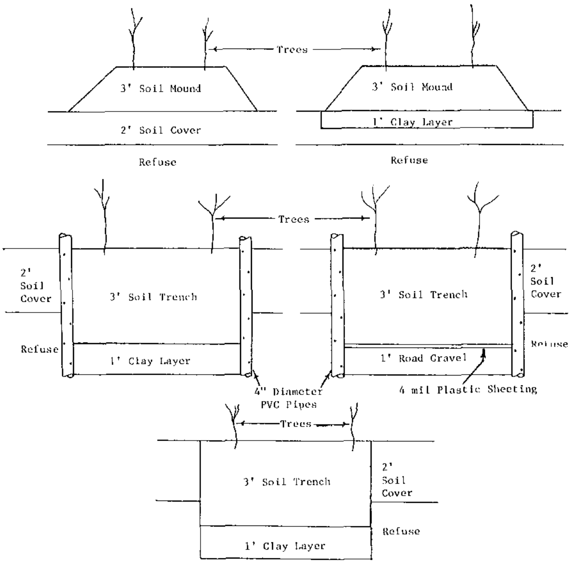

Figure 6. Five experimental landfill gas barrier systems.

one-inch holes. A similar series of pipes was placed around one of the clay bottom trenches. The other clay bottom trench had no venting pipes. All three trenches were backfilled with three feet of sand-loam topsoil in which were planted American basswood and Japanese yews. We had hoped that the bottom gas barriers would prevent the gas from moving upward through the trench and that the vertical pipes would relieve the pressure of laterally moving gases preventing their intrusion into the trench.

In general growth on the mounds and in the gravel-plastic-vents trench was excellent. No landfill gases were found within these barrier systems. All plants died in the clay-vents trench due to the influx of high concentrations of landfill gases (12% CH_4, 32% CO_2 and 4% O_2 at one foot), during much of the experiment. However, the clay trench showed a very modest intrusion of landfill gases (methane, generally less than 1%, and carbon dioxide less than 10%, and oxygen around 16%). Growth of vegetation on the clay trench was somewhat reduced over that on the mounds and gravel-plastic-vents trench. Since we installed only one model for each of the barrier systems we cannot be certain of the true effectiveness of these barrier systems. It is possible that the clay-vents trench was installed in a "hot spot" on the landfill where there was already a high concentration of landfill gases while the clay trench was installed in an area that contained only minor amounts of gas under very low pressures. However, these tests did again confirm that when landfill gases are barred from the root zone, trees can grow quite well on a completed landfill. Although, the mounds did seem to do the job of preventing gases from migrating into the tree root zone, our field studies indicated that in some cases landfill gases will infiltrate some soil mounds. Therefore, we recommend that when installing mounds it is best to construct them over an impermeable layer of soil or other material.

In Ocean Township, N.J., a shopping center has been developed on a former refuse landfill. All the refuse was removed from the area where the stores were constructed and to a distance of 20 feet beyond the stores. At this point a vertical clay soil barrier was placed to prevent lateral migration of the gases into the shopping center and the vegetation planted adjacent to it. However, the inner parking lot was placed over heavily compacted former refuse covered with a soil cement layer. Several of the parking lot "islands" were constructed with a saucer shaped plastic liner inserted in the bottom of the island and soil mounds above the level of the parking field (Fig. 7). Vents were placed through the plastic to relieve the pressure of the landfill gases to the ambient air. Because water is likely to accumulate at the bottom of the plastic saucer during heavy rains, one should also insert a U-tube or something similar through the bottom of the plastic (Fig. 8) for drainage of the water from the planting area while preventing the migration of landfill gas into the soil. The height of the water column in the U-tube should be greater than the gas pressure built up beneath the landfill. The plastic liner must be of such a nature and thickness as to withstand pressures put on it by settlement of the refuse. As long as there is material to be decomposed beneath this area within the landfill it will continue to settle over an extended period of time. Differential settlement could strain the plastic which may cause it to rupture. If ruptured, it may then permit gases to enter the island and cause vegeta-

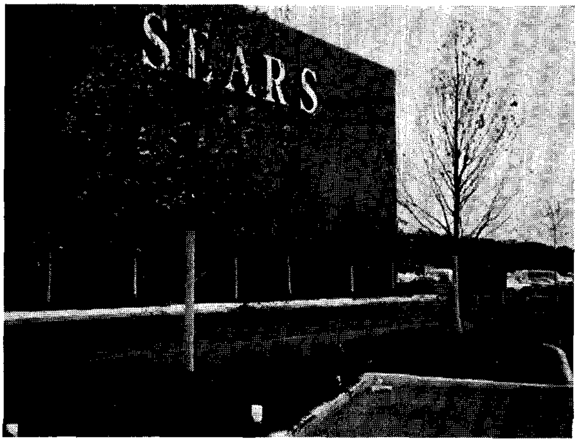

Figure 7. Vegetation island and background planting at Sea View Square Mall.

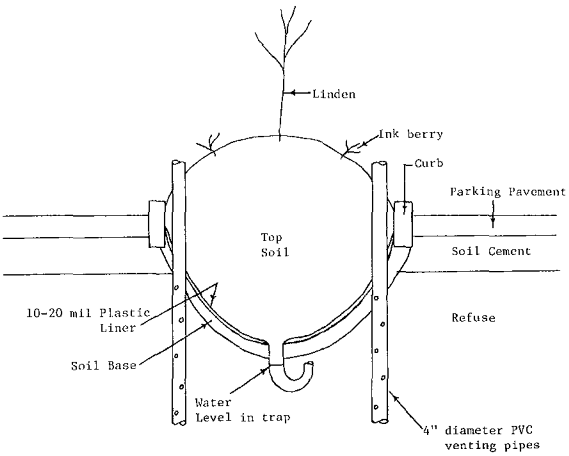

Figure 8. Gas protection for vegetation planting island in a paved parking lot located over a former refuse landfill.

tion growth problems. Another method to aid the growth of vegetation would be to install these gas barriers over areas left unfilled by refuse. The refuse could be removed and replaced with ordinary soil which would not generate landfill gases nor settle excessively.

Gas Extraction

Because of the shortages and increasing prices of fossil fuel energy, landfill gases are being examined as a possible fuel source. In the United States there are currently in operation a half dozen commercial landfill gas extraction systems. Gases are pumped from the landfills via gas extraction wells placed throughout the landfill. These gases, in some cases, are used following minor processing to remove excessive moisture and possibly some sulfur compounds. In other cases the gases may be extensively processed to produce pipeline quality natural gas. The removal of gases from a landfill should aid in the establishment of vegetation growth in the cover soils. The more gas removed the less gas that remains to cause vegetation growth problems. If a commercial market is not available for the gas it can be flared on site. Positive gas extraction can also be used to prevent underground migration.

Other Landfill Soil Problems

While gases are one of the major causes of poor vegetation growth on landfills other soil characteristics can also inhibit growth. The temperature of these soils is frequently higher than that of the native soil. In most cases this difference is only a degree or two Fahrenheit, but occasionally we have found soil temperatures well over 100°F. Such excessively high soil temperatures would cause stress on the vegetation. Another problem we found associated with landfill soils is that they have frequently been highly compacted by the equipment which passes repeatedly over them as construction of the landfill is completed. Therefore, it may be necessary to loosen these soils and add organic matter prior to planting in order to provide a suitable substrate for trees. These soils are frequently found to have low nutrient content and unsatisfactory pH ranges for the selected vegetation. Correction of these matters should be made prior to planting. Soil moisture on landfills is generally lower than that of the same soil off the landfill. We attribute this, at least in part, to the difficulty for water, in rising through the refuse, to reach the cover soils during the dry periods. The refuse, we feel, probably lacks the continuity for water passage that is found in normal soils. Also the fact that many of these cover soils were highly compacted during construction may have led to a higher percentage of runoff and therefore less infiltration of rainwater than similar adjacent undisturbed soils. Because these landfill soils are dryer than normal, it is recommended that a means for irrigation be provided. If permanent irrigation systems are installed, provision must be made for the continual settlement of the landfill, otherwise there will be many problems with pipe breakage.

Species Selection

One method frequently suggested for obtaining better tree growth over landfills is to select species that can adapt to landfill conditions. We have been conducting a four-year-old species selection experiment by growing 10 replicates of 19 species on the Edgeboro Landfill in East Brunswick, New Jersey. For a control we treated an area off the landfill in the same manner; that is, installed the same cover and topsoils on this land as on the landfill, and planted ten replicates of these same nineteen species. Table 1 presents the relative growth rank obtained for these nineteen over this four-year test. Species ranking at the top of the list had the best growth compared to the growth of the same species in the control plot off the landfill. As you move toward the bottom of the table the growth of the landfill specimens becomes steadily poorer as compared to the controls. These comparisons were made on the basis of shoot length and stem area increase. From these data it appears that black gum, Japanese yew, and Japanese black pine were the most suitable for the conditions on Edgeboro Landfill.

This landfill had approximately 30 feet of municipal solid waste beneath the planting area. The waste had been in place approximately ten years prior to our adding the soil-cover and planting the first trees. We based our test species selection upon the following criteria: 1) tolerance of low oxygen environment, 2) ubiquity, 3) seasalt tolerant, 4) tolerant to city conditions and 5) susceptability to landfill gases. We felt that all these trees could be selected for aesthetic landscaping purposes. Species tolerant to low oxygen environments (especially green ash and honey locust) were located very low on the tolerance list. Lack of sufficient moisture may have curtailed growth for these water-loving species (Gilman 1980).

Root systems of the more tolerant species (Japanese black pine and Norway spruce) were found to be much shallower, both on the landfill and the control area than were those of the less tolerant species (Table 2). Therefore, the ability to develop a shallow root system may be one of the over-riding factors in the adaptability of trees to landfill conditions. Those species able to grow the shallowest root systems are more likely to avoid contact with the higher concentrations of toxic or growth-curtailing gases produced by the landfill, since the concentration of gases generally increases as you move deeper into the cover soils. Therefore, the shallow rooted species can grow best in most landfill conditions provided they receive adequate water.

Table 1. Relative Tolerance of Species to Landfill Conditions.

Species	*Rank*[a]
Black gum	1
Japanese yew	2
Japanese black pine	3
Ginkgo	4
White pine	5
Bayberry	6
Norway spruce	7
American basswood	8
American sycamore	9
Red maple	10
Hybrid poplar (rooted cuttings)	11
Pin oak	12
Sweet gum	13
Honey locust	14
Green ash	15
Euonymus	16
Hybrid poplar (saplings)	17
Weeping willow	18
Rhododendron	19

[a]Rank 1 = best growth when landfill plot is compared to the control plot, i.e., most tolerant to landfill conditions.

Table 2. Mean Root Depth[a] For Several Species On The Landfill and Control Plots

Species	*Landfill (inches)*	*Control (inches)*
Japanese black pine	3.1	3.7
Norway spruce	2.0	1.7
Hybrid poplar (rooted cuttings)	2.5	5.5
Honey locust	3.3	6.5
Green ash	3.7	5.8
Hybrid poplar (saplings)	3.3	5.0

[a]Species are arranged from most tolerant to least tolerant of landfill soil conditions according to shoot and stem measurements.

In comparing the depth of the roots of five tree species growing on the control area and on the landfill it was found that the trees of four species in the control area off the landfill grew deeper roots than the same species growing on the landfill (Table 2). However, we find that those species that normally grow shallow roots, as indicated by the depth of the roots on the control area, were the trees which did the best on the landfill. In summary, *we recommend that you select trees for* landfill plantings which normally grow shallower roots.

Other Selection and Growth Factors

The fact that trees which grow with shallow roots do best on landfills is another reason for the need to supply additional irrigation.

Another factor which appears to improve the chances of survival of landfill planted trees is the *choice of small trees as opposed to larger sizes.* In our landfill experiments six of the top seven best adaptable trees were of a smaller size physically at the time of planting than the less adaptable species. Our data have shown that this is related to the ability of a small tree to adapt its root system to the adverse environment in the cover soil by producing roots closer to the surface; whereas, roots of larger trees start much deeper and cannot grow to the surface before being killed by landfill gases.

We also conducted a test in which both balled and burlap sugar maples were planted, and we found that the balled trees grew better than the bare-rooted trees. We assume that the balled trees could adapt more easily to the landfill conditions since they bring along with them the soils in which they originally grew.

Because former landfills are frequently large open spaces they are exposed to wind and other extreme weather elements. Since landfill vegetation receives very little weather protection it is best to plant trees that can withstand strong winds and extreme microclimatological conditions. Since the winds over landfills are frequently strong, and the root structures are shallow it is best not to plant trees that grow to extreme heights. These trees will be subject to wind toppling during heavy storms, due to their shallow root system and their exposure. It is also best to adequately stake new plantings so that they are not blown over prior to their growing a more adequate root system.

Table 3 summarizes measures that can be taken to aid the growth of trees on former landfills.

Table 3. Measures That Can Be Taken to Aid Tree Growth on Landfills.

1. Landfill Construction
   a. Provide proper slope and compaction, adequate depth and quality of cover soil.
   b. Possibly remove refuse from under areas of cluster tree planting.
2. Gas Extraction
   Consider gas removal by induced draft. May be able to burn gas from heat recovery.
3. Soil Amendments
   Cultivate and/or mulch with suitable organic matter to loosen compacted cover soils.
4. Select Suitable Species
   Such as those trees which:
   a. Normally grow shallow roots
   b. Can withstand generally adverse growing conditions.
5. Cultural Methods
   Provide adequate cover soil quality and quantity, fertilizer, pH and water.
6. Planting Techniques
   a. Use tree planting mounds, gas barriers, and/or gas pressure release systems.
   b. Check tree planting locations individually for soil condition.
   c. Plant small trees.
   d. Plant balled rather than bare-rooted trees.
   e. Adequately stake the trees.

Summary

As urban population continues to grow, we can anticipate greater stimuli for converting former landfill sites into recreational areas. Communities may be persuaded to turn these former unused wastelands into parks, golf courses, and nature areas. Previously, the scientific know-how for these conversions has not been available. Despite the apparent difficulties one may expect to encounter when vegetating completed landfills, they can be and have been overcome in a few instances throughout the United States. At these sites, those charged with designing and maintaining vegetation growth projects were aware of several of the aforementioned obstacles. However, the majority of individuals charged with implementing such planting programs were unadvised of the potential problems. We must remember that the suggested corrective measures should be undertaken to counter the normally adverse vegetation growth environment found on former refuse landfills.

Literature Cited

Boynton, D. and O.C. Compton. 1943. *Effect of Oxygen Pressure in Aerated Nutrient Solution on Production of New Roots and on Growth of Roots and Tops of Fruit Trees.* Proceedings of the Am. Soc. Hort. Sci., 42:53-58.

Brunner, D.K. and D.J. Keller. 1972. Sanitary Landfill: Design and Operation, (USEPA Report #SW-65ts), 59 pgs.

Flower, F.B., I.A. Leone, E.F. Gilman, and J.J. Arthur. 1977. *Vegetation Kills in Landfill Environs.* Proceedings of the Third Annual Municipal Solid Waste Research Symposium (USEPA Report #600/9-77-026), pp. 218-236.

Flower, F.B., I.A. Leone, E.F. Gilman, and J.J. Arthur. 1978. A Study of Vegetation Problems Associated with Refuse Landfills, (USEPA Report #600/2-78-094), 142 pgs.

Gill, W.R. and R.R. Miller. 1956. *A Method for Study of the Influence of Mechanical Impedance and Aeration on Growth of Seedlings Roots.* Soil Sci. Soc. of Am. Proc., 20:154-156.

Gilman, E.F. 1980. Determining the Adaptability of Woody Species, Planting Techniques and the Critical Factors for Vegetating Completed Refuse Landfill Sites. Ph.D. Thesis, Cook College, Rutgers University, 340 pgs.

Ham, R.K., K.K. Hekimian, S.L. Katten, W.J. Lockman, R.J. Lofy, D.E. McFaddin, and E.J. Daley, 1979. Recovery, Processing, and Utilization of Gas from Sanitary Landfills, (USEPA Report #600/2-79-001) 146 pgs.

Leonard, O.A. and J.A. Pinkard. 1946. *Effects of Various O_2 and CO_2 Levels on Cotton Root Development.* Plant Physiol., 21:18-36.

Leone, I.A., F.B. Flower, E.F. Gilman, and J.J. Arthur, 1979. Adapting Woody Species and Planting Techniques to Landfill Conditions: Field and Laboratory Investigations (USEPA Report 600/2-79-128), 134 pgs.

Rajappan, J. and C.E. Boyton. 1956. *Responses of Red and Black Raspberry Root Systems to Differences in O_2, CO_2, Pressures and Temperatures.* Proc. of the Am. Soc. Hort. Sci., 75:402-500.

Rovers, F.A., J.J. Trembley, and H. Mooij. 1977. Procedures for Landfill Gas Monitoring and Control, (Waste Management Branch Report #EPS 4-EC-77-4) Environmental Protection Service, Fisheries and Environment, Ottawa, Ontario Canada, 34 pgs.

Valmis, J. and A.R. Davis. 1944. *Effects of Oxygen Tension on Certain Physiological Responses of Rice, Barley, and Tomato.* Plant Physiol., 18:51-65.

Vomocil, J.A. and Flocker. 1961. *Effects of Soil Compaction on Storage and Movement of Soil, Air and Water.* Trans. Am. Soc. of Agronomy, 4:242-245.

Wiegand, J.D., L. Johanson and W.E. Norris. 1959. *Effect of CO_2 on Respiration of Excised Onion Root Tips in High O_2 Atmospheres.* Soil Science, 88:144-149.

Yelenosky, G. 1964. *Tolerance of Trees to Deficiencies of Soil Aeration.* Proc. of the International Shade Tree Conference, 40:127-144.

Respectively:
Extension Specialist in Environmental Science
Post Doctoral Research Fellow and
Professor of Plant Pathology
Cook College,
Rutgers University
New Brunswick, New Jersey

ABSTRACT

Shank, B.F. 1980. **2,4,5-T suspension reveals need for equally effective ROW controls.** Weeds Trees & Turf 19(1): 19-20.

The temporary suspension of 2,4,5-T by the Environmental Protecton Agency has increased interest in other herbicides for right-of-way vegetation control. In anticipation of suspension and cancellation proceedings against silvex and 2,4,5-T, and to compare the effectiveness of all registered products for right-of-way vegetation control, Asplundh Environmental Services conducted studies over the past four years. Their report indicates that loss of 2,4,5-T would affect costs and would require consideration of new combinations of herbicides to accomplish acceptable vegetation control at a reasonable cost. Herbicides which achieve the same broad spectrum control as 2,4,5-T and are comparable in cost present new characteristics to consider such as persistence, unwanted control of desirable vegetation, or ineffectiveness on a few prime weed tree species. However, the report clearly indicates that the loss of 2,4,5-T, although significant, would not cause severe disruptions in current right-of-way spray programs.