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DAMAGE TO WOODY SPECIES BY ANAEROBIC LANDFILL GASES[1]

by Ida A. Leone, Franklin B. Flower, John J. Arthur, and Edward F. Gilman[2]

Refuse landfills are constructed on areas of land set aside for depositing solid waste. Current practice dictates that the refuse be spread and compacted, before being covered daily with a 6-in. layer of soil., for environmental protection, to save space, and to reduce the amount of settlement that will take place in the area after the landfill is completed. Soil cover is placed over the refuse to improve aesthetics; prevent papers from blowing; reduce odors; control insects, rodents and birds; reduce the hazard of fire; and reduce water infiltration into the refuse. The initial soil cover is supposed to be increased from 6 in to a 12-in-thick intermediate cover after a limited period of time, and the final soil cover for the refuse is supposed to be at least 2 ft deep. Many landfills have been completed, however, with less than 2 ft of soil over their top surface. It is in this top layer of soil cover that any vegetative cover will be planted.

Although many uses have been proposed for completed landfills, experience has shown that they are generally unsuitable for excavation or for construction purposes. Open-space recreational areas, such as parks, playgrounds, picnic areas, and golf courses, therefore, are deemed to be a suitable use for such sites. In some locations attempts have been made to use the completed landfills for agricultural purposes. Depending on the composition of the fill and the environmental conditions within it, however, there are serious inherent disadvantages, not the least of which are ecological upsets due to pollution of water supplies, the production of toxic and explosive gas mixtures from anaerobic microbial decomposition of the organic matter present and surface settlement. Excessive landfill ground temperatures have also been reported.

Prior to 1965 landfills were frequently operated as open-burning dumps. While this caused air pollution and vector control problems at the time of their operation, the result was that most of the material left in the landfill was nonbiodegradable, resulting in much less ultimate settlement of the landfill and much less anaerobic gas development after the landfill was closed. The present-day landfill does not permit open burning; therefore, it provides more nutrients for the microorganisms that generate the gases, mainly carbon dioxide and methane, that present problems for growing vegetation.

High concentrations of carbon dioxide in the root zone of plants have been reported to be directly toxic to vegetation (4,5). Although methane has not been reported to be phytotoxic per se, perhaps, when combined with the carbon dioxide, it can remove oxygen from the root zone of the vegetation by direct displacement, by utilization of the oxygen by methane-consuming bacteria, or by a combination of these. The end

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2 Professor, Plant Biology Department; Extension Specialist, Department of Environmental Science; and Research Interns, Plant Biology Department, Rutgers University—The State University of New Jersey, Cook College, New Brunswick 08903.

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result is a very low or zero oxygen tension in the root zone of the vegetation, which could be phytotoxic (2). In addition, there are frequently minor fractions of a number of other gases present in the landfill soil atmosphere, including ammonia, hydrogen, hydrogen sulfide, mercaptans, ethylene, etc. (1). One or more of these have been known to exhibit direct toxicity to vegetation.

Within the past few years observers have noted that trees and other vegetation in parks and golf courses constructed on completed landfills have died or fared poorly. Death to vegetation has also occurred in areas adjacent to landfills. One such case in Glassboro, New Jersey involved the death of scores of peach trees after an adjacent 20-ft-deep sand and gravel pit was filled with municipal-domestic refuse. The pit belonged to the peach grower who had planned to have it filled with the refuse and then to extend his peach orchard over the completed landfill. He found, however, that the trees planted adjacent to this landfill began to die a year or two after the refuse had been placed against the bank nearest his orchard. Examination showed that the soil in the areas where the trees had died contained high concentrations of the gases of anaerobic decomposition. Gas concentration gradients indicated that the gases had flowed directly from the landfill. Although the landfill was only 20 ft deep, the gases had traveled as far as 70 or 80 ft in concentrations sufficient to cause death or injury to the peach trees. This problem recurred when an attempt was made to plant new trees in the gassed soil areas.

The township of Cherry Hill, New Jersey has experienced landfill gas migration problems since 1968 when some homeowners noticed that their backyard vegetation was dying. The yards of these homes abut a former sand and gravel pit, which the municipality was filling for eventual use as a park. Gases were detected up to about 90 ft from the landfill, and in two of the homes the anaerobic gases caused fires.

The township is still attempting to transform the former landfill into a park, even though most of the Scotch and Austrian pine trees planted have died within the past several years. Examinations indicate that, although many of the trees died apparently because of poor transplanting practices, a number of them succumbed to landfill gases.

A mail survey and subsequent site visits to landfills throughout the United States and Puerto Rico, funded by the U.S. EPA Solid and Hazardous Wastes Division, has revealed numerous cases of difficulty in establishing vegetative covers on or adjacent to landfills.

Field observations in the site visits included evaluating plant species (particularly woody species) on or adjacent to former landfills and selecting healthy and poorly growing specimens of a given species for an in-depth examination. Also, the soil atmospheres in the root areas of the trees exhibiting poor and good growth were analyzed for combustible gas, carbon dioxide, and oxygen.

Almost invariably, the results showed a high correlation between concentrations of combustible gas or carbon dioxide (CO_2) and poor growth of the tree or shrub. Examples of this relationship are presented for the northeastern U.S. (hot summers and cold winters) in Table 1. At a landfill in Battle Creek, Michigan, the soil atmosphere beneath a red pine exhibiting only a needle tip necrosis contained no combustible gas, 6.5% CO_2, and 19.5% oxygen at a 1-ft depth. The root zone of a dead red pine, on the other hand, contained 50% combustible gas, 21% CO_2, and only 12% oxygen. Similarly, healthy, 20-ft-tall willows on a landfill in Auburn, New York

TABLE 1. Field Data, N.E.U.S. (1975)

			% at 1-ft depth		
Site	**Species**	**Condition**	**Com. gas**	**CO_2**	**O_2**
Auburn, N.Y.	Willows	20 ft tall	0	0	20
	Willows	Dead	U>L	0	18.5
Holyoke, Mass.	Bl. cherry	Healthy	0	0	19
	Bl. cherry	Dead	100	1	20
Nashua, N.H.	Am. elm	Healthy	3		
	Am. elm	Dead	U>L		
Battle Creek, Mi.	Red pine	Tip necrosis	0	6.5	19.5
	Red pine	Dead	50	21	12
Guilderland NY	Poplars	4-8 ft tall	(20)	15	19
	All veg.	Dead	(>100)	36	2
Detroit, Mich.	Black oak	Dead	(30)	0	19.5
Battle Creek, Mi.	Blue sp.	Healthy	>100	14	12.5
	Blue sp.	Br. needles	>100	—	—

contained no combustible gas or CO_2, and 20% oxygen at the 1-ft depth; whereas, beneath a dead willow nearby, there was a high combustible gas reading and decreased oxygen concentration.

Results for southwestern California (hot summers, warm winters, and a concentration of the year's modest precipitation in the winter) are represented by data from the South Coast Botanic Garden in Los Angeles, which has been built on a former landfill (Table 2). Here, the soil beneath a *Cytisis racemosis* in good condition contained no combustible gas or CO_2 at the 1-ft depth, whereas, beneath a dead *Cytisis*, combustible gas had risen to 22% and CO_2 to 15%, and oxygen content had decreased to 11.5%.

TABLE 2. Field Data, Cal. (1975)

Site	Species	Condition	Com. Gas (% at 1-ft depth)	CO_2 (% at 1-ft depth)	O_2 (% at 1-ft depth)
South Coast	Cystis racemosis	Healthy	0	0	19.5
Botanic Garden	Cytisis racemosis	Dead	22	15	11.5
South Coast County Park	Melaleuca	Health 12 ft	4	5	7
	Melaleuca	Dead	>50	43	3.5
South Coast	Aleppo pine	Green 65 in	< 1	0.5	17
	Aleppo pine	Chlorotic	>50	25	11
Mountain Gate Golf Course	Aleppo pine & Eucalyptus	Good	0	0	20
	Aleppo pine & eucalyptus	Poor	>50	5	9.5
Mission Canyon	Aleppo pine	Healthy	0	0	21
	Aleppo pine	Yellow color	0	1	19.5
	Aleppo pine	Yellow tips	<1	6	20

Samples of top and subsoil taken from the areas of good and poor tree growth were analyzed for major and trace elements and other soil characteristics. Statistical analysis of the data from atop landfills (South Coast Botanic Garden) and from sites adjacent to landfills (northeastern sites) revealed significant increases in ammonia-nitrogen, moisture, iron, and zinc in soils containing landfill gas (Table 3). It is proposed that the highly reduced state of the soil, due to displacement of oxygen by landfill gas and to the activity of microorganisms in removing the oxygen, is responsible for the increased availability of trace elements (6).

TABLE 3. Results of Soil Analyses, lb/acre

	On landfill		Adjacent	
	No gas	Gas	No gas	Gas
pH	7.3	7.0	5.7	5.9
Magnesium	2308	2417	208.7	195.7
Phosphorus	1074	1130	140.4	121.2
Potassium	163	143.5	112.1	149.8
Calcium	3275	2508**	1964.4	2349.4
No_3-N	27.8	29.6	461.0	471.3
NO_4-N	4.83	9.0*	10.5	33.8**
Organic matter	5.12	7.56	3.44	2.15
Moisture	22.72	26.83**	14.79	15.82
Iron	2.47	4.25**	.40	62.4
Manganese	13.56	11.07	4.80	10.80
Copper	5.09	6.18	0.15	0.45
Zinc	5.22	7.72*	0.80	7.08

*Significance at P=0.05
**Significance at P=0.01

As a result of the mail survey and site visits, a list of susceptible species was compiled (Table 4). The sensitivity of American elm and sugar maple was corroborated by other investigators.

Woody species adaptable to flooded or poorly aerated soils cited in the literature are listed in Table 5 (3), and species potentially resistant to landfill gases by virtue of specialized characteristics are listed in Table 6.

TABLE 4. Species Sensitive to Landfill Gases (Rutgers)

Douglas fir	Slippery elm
Shagbark hickory	Mountain ash*
White spruce	American basswood
Blue spruce*	Japanese yew*
Black oak	American elm**
Lombardy poplar	Sugar maple**
Black cherry*	Apple**
Red pine	

*Intolerant of flooding
**Corroborated by more than one other investigator

TABLE 5. Species Adaptable to Flooded or Poorly Aerated Soils (Hook 1972)

White willow	White birch
Brittle willow	Scotch pine
Creeping willow	Norway spruce
Sycamore	Sweet gum
Swamp tupelo	Yellow poplar
Sour gum	Sweet gum
Green ash	

TABLE 6. Species Potentially Resistant to Landfill Gases

Green ash[abc]	Cottonwood[d]
Sour gum[ab]	American sycamore[d]
Sweet gale[ab]	Juniper[d]
White ash[ad]	Pussy willow[d]
Red cedar[ad]	Silver maple
White willow[ad]	Thornless honeysuckle
Red maple[d]	

[a]Transports O_2 to roots
[b]Oxidizes rhizosphere
[c]Initiates 2 deg. roots
[d]Tolerates flooding

TABLE 7. Species in Landfill Screening Experiment

American basswood	Japanese yew
American sycamore	Mixed poplar
Bayberry	Norway spruce
Black gum	Pin oak
Black pine	Red maple
Euonymus	Rhododendron
Ginkgo	Sweet gum
Green ash	Weeping willow
Honey locust	White pine
Hybrid poplar	

From these lists, 19 species (Table 7) were selected for a field experiment at Rutgers University, designed to screen species for adaptability to landfill conditions. The experimental plot is located on a former landfill in East Brunswick, New Jersey, and a nearby natural woodland site was cleared as a control area. The 19 species were planted in replicates of 10, and tree height and girth, shoot elongation, fruiting, and the presence of heart rot are being observed. The rhizosphere of each tree is also being analyzed for gas composition, including combustible gas, carbon dioxide, and oxygen, and for soil temperature. Soil samples are also being taken for analyses of the chemical constituents of the soil.

Besides the screening program, five planting techniques have been employed, including two mounds and three trenches with no gas protection, or underlain either by 1 ft of clay or by a plastic sheet over a gravel base, with and without vertical venting pipes.

Arborists or other growers confronted by the need to establish vegetation on former landfills would be well advised to observe the following characteristics before proceeding with the planting:

1. Is there unhealthy or dead vegetation in the vicinity? Obviously, many things could cause poor or dead vegetation, but there is always the possibility that it might have been caused by landfill gases.
2. Do you notice any unpleasant odors in the vicinity? Again, unpleasant odors come from many sources. Those odors from landfills or soils turned septic by landfill gases are generally of a putrid nature. In moving over a former landfill one can occasionally detect the odors as they are discharged through surface cracks; as one works the soil the septic odor may become obvious.
3. Soil examination. It is easy to draw a soil sample and examine it in the field.

Table 8 might be used as a general guide to the aerobic or anaerobic condition of soils. Under certain circumstances there will be exceptions to these general guidelines, but those who work with soils know the typical characteristics of a healthy soil and will easily recognize the poor qualities associated with an anaerobic soil.

Soil temperature differences are sometimes extreme and sometimes very modest. Temperature differentials have been recorded in anaerobic soils up to 30 deg. F higher than in nearby healthy aerobic soil. In most cases, however, the difference is very small, and occasionally one may find the anaerobic soil at a lower temperature than the aerobic.

The high moisture content of anaerobic soils

TABLE 8. Guide for Evaluating Landfill Soil Gas Problem

Characteristic	*Anaerobic soil*	*Aerobic healthy soil*
Odor	Septic	Pleasant
Color	Darker	Lighter
Moisture content	Higher	Lower
Friability	Poor	Good
Temperature	Higher	Lower
Combustible gas	Higher	Very low or zero
Oxygen	Lower	Higher
Carbon dioxide	Higher	Lower

TABLE 9. Control Techniques

1. Suitable Species—
   Shallow rooted, adapted to anaerobic conditions.
2. Cultural Methods—
   Adequate lime, fertilizer, top soil for cover, irrigation.
3. Soil Amendments—
   Shredded refuse, mulch, sewage sludge.
4. Landfill Construction—
   Proper grading, compaction, adequate depth and quality of top soil.
5. Planting Techniques—
   Vented or lined trenches, mounds, subsurface gas seals.
6. Gas Collection—
   Extractor wells and evacuation pumps.

may be due to the condensation of the water vapor generated by decomposition of the organic matter within the landfill. The darker color of these anaerobic soils in probably due to their septic nature.

Of course, one can always look for combustible gases in the soil. One way would be to use an instrument for reading combustible gases, preferably one that uses the catalytic combustion principle for making its basic measurement. Many of the gas company meters work on a thermal conductivity principle that is calibrated for methane alone. A landfill gas mixture contains air, methane, and carbon dioxide. Meters that work on the thermal conductivity principle may give inaccurate results for concentrations of methane from landfills because of the presence of high concentrations of carbon dioxide. The Mine Safety Appliance Company and the Bacharach Instrument Company, both of Pittsburgh, Pennsylvania, supply catalytic combustible gas meters.

Other methods of detection would be to measure the oxygen content of the soil atmosphere, which would be low in a problem area. Carbon dioxide content, on the other hand, would be high in a problem area. We use Bacharach Instrument Company fyrite instruments for this, but other equipment is also available.

Finally, we recommend examinations for any unusual ground settlement. Differential settlement plus a number of surface cracks in the soil are generally good indicators that there might possibly have been organic refuse buried there in the past.

Meaningful results of the field and greenhouse experiments in progress will not be immediately forthcoming. When the data have all been collected, however, it is hoped that they will permit better understanding of landfill vegetation problems and recommendations of species and techniques for successful planting on landfill sites. In the meantime the control measures in Table 9 might help to combat the problems associated with establishing woody species on former landfill sites.

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Plant Biology Department
Rutgers University
New Brunswick, New Jersey