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Environmental factors affecting growth of grasses, herbs and woody plants on a sanitary landfill

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Abstract——The present study aims at studying relationships between various environmental factors and plant performance on a completed sanitary landfill. Three sites were chosen for comparison: an on-site low landfill gas region with a rich vegetation growth (Site L), an on-site high landfill gas region with a poor vegetation growth (Site H), an off site control region (Site N) which located close to the Gin Drinkers' Bay landfill. In Site H, where the levels of methane and carbon dioxide were higher, growth of trees, shrubs and climbing plants are adversely affected, but not herbs and grasses. Analysis of correlation coefficient indicated that carbon dioxide and methane showed a negative correlation with the growth of trees and shrubs. In Site H, the higher levels of conductivity, Kjeldah-N, Ammonium-N, and various heavy metals, such as Mn were also exerted their adverse effect on plant growth. Trees tolerant to landfill gas, e.g. *Acacia confusa*, would be a better choice for planting on sanitary landfills, in addition to the use of shallow-rooted trees. Grasses and herbs are less susceptible to landfill gas due to their shallow-root systems. Hydroseeding of grasses would ensure a better plant coverage in areas with a moderate level of landfill gas. Installation of a ventilation system might be needed for areas with a high level of landfill gas.

Keywords: sanitary landfill; restoration; vegetation; landfill gas; soil factors.

1 Introduction

It has been more than ten year since the closure of the Gin Drinkers' Bay landfill in Hong Kong. The landfill site has been developed into a recreation park. However, problem has been encountered as to the selection of plant species which can tolerate the landfill conditions. Growth constraints are mainly due to landfill gas (high levels of methane and carbon dioxide, and a low level of oxygen) and substances which contained in the landfill leachate such as excessive nitrogen, heavy metals and other toxic pollutants, resulting from biological degradation of the refuse.

In a sanitary landfill, refuse is dumped above the liner, in the arrangement of

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"cell" in which compacted waste is encapsulated within soil. Adjoining cells of the same height constitute a "lift". Between each lift is laid with a thin layer of soil that functions to check the migration of landfill and leachate. Upon finishing of controlled dumping, the top of the site is covered with a layer of inert materials, usually soil of about 1m in depth (Fuller, 1985).

The adverse effect of landfill gas on plant growth has been investigated by many workers. A survey of 65 sanitary landfills in the United States revealed that among all environmental limitations, such as low fertility, lack of moisture, high underground temperature and high availability of metal content, that affect plant establishment; the major causes were due to the presence of high level of landfill gases and particularly carbon dioxide and methane (Leone, 1982). Tomato plants grown under simulated landfill gas condition produced unhealthy symptoms due to direct toxic effect of carbon dioxide and indirect effect of methane (Arthur, 1985). Another simulation experiment showed that the flood tolerant red maple was more tolerant than the flood sensitive sugar maple towards landfill gas (Arthur, 1981). However, drought condition is commonly observed on top of landfills (Chan, 1991), and therefore flood tolerant tree species cannot thrive in drought areas of landfills, despite the fact that they may be more tolerant to landfill gas.

Another survey of landfill sites near Merseyside, UK showed positive correlations between the level of underground landfill gas (methane) with decreased vegetation cover, and in areas relatively free of landfill gas, the concentrations of mineralized N had significant correlations with the dry weighers of vegetation, indicating the necessity of applying available nitrogen fertilizer (Wong, 1988). It is expected that the quality of top soil is therefore an important factor in hindering plant growth in landfills, especially areas relatively free of landfill gas.

With the above background in mind, the present project attempts to quantify the relationships between growth performance of different groups of plants (including grasses and herbs, shrubs and trees, and climbing plants); and levels of landfill gas, and various soil factors. Grasses and herbs are pioneer species to colonize these man-made habitats, and therefore they should receive equal importance as shrubs and trees.

2 Site description

Gin Drinkers' Bay lies in the south-eastern part of Tsuen Wan, New Territories, Hong Kong, facing the eastern coast of Tsing Yi Island. By the time when the site was closed in February, 1979, the bay was converted into a plateau with an area of 27 ha, and a maximum height of 57 m above ground. In 1973, suggestion was first made on the possibility of converting the completed landfill area into a public park. To minimize the problems associated with the migration of landfill gas and the percolation of leachate, several measures were undertaken. Sixteen vertical gas vent pipes joined together with an underground horizontal pipeline network were constructed on the plateau so that periodical monitoring of landfill gas was made possible. On the side-slope, gas migration was restricted by the relatively impervious soil layer. The leachate was diverted and collected by a sub-surface drainage system and eventually disposed of into the sea (Wong, 1987).

3 Materials and methods

3. 1 Site selection

Two sites were chosen on the north-east facing slope of the landfill. Site L has a rich vegetation growth and a low landfill gas content, while Site H has a relatively poor plant growth and a higher landfill gas content. A control site (Site N) is located on the opposite side of the Gin Drinkers' Bay Road. This site also faces north-east and has a slope similar to that of Sites L and H.

3. 2 Vegetation survey

Within each site (L, H and N), a line transect was laid along the slope and five 5m × 2m quadrates were selected (denoted as Q1 to Q5 from the lowest position of the slope). In each quadrant, all plant species were identified and their abundance, in terms of percentage coverage recorded. A 1m×1m quadrate was chosen randomly within each 5m×2m area, where all the plant biomass (except the aerially intercepting tree branches) and plant litter were collected for dry weight determination.

3. 3 Landfill gas monitoring

Three gas sampling tubes were drilled into each of the quadrates in the three sites in a zig-zag manner along the transects. The sampling tubes were made of PVC, with 1m in length and 3. 9cm internal diameter. Eight rows of holes were driven on the 35 cm portion that was to be installed underground (Chan, 1991). Gas monitorings were carried out in three occasions on 20th Sept., 1988; 17th Dec., 1988; and 31th March, 1989. Methane was measured using Portable Gas Detector Type 73GR (Growcon Inst. Ltd., Oxford, England); carbon dioxide was measured by Gas aspirator (Kitkagawa model Ap-1, adapted with dry-color-defecter-tub model 126SH); and oxygen was measured by Oxygen meter (Kitagawa Pocket Size Oxygen Meter OM-5, Supplied by Komyo Rikagaku Kogyo KK, Kawasaki, Japan). All gas samples were measured as percent volume.

3. 4 Soil analysis

Soil samples (the top-most 10 cm) were collected from each of the quadrates. Three random points were selected within each quadrate and the soil samples obtained in these three points were mixed together as one representative sample of that quadrate. Fresh samples were used for the determination of moisture content (weight loss at 105℃). For other analyses the soil samples were air-dried and passed through a 2 mm mesh sieve, before they were tested for the following items: pH(1:1 w/v soil to distilled water measured by Kerno pH/Temperature Meter Model 671), conductivity (1:1 w/v soil to distilled water, measured by Fisher Conductivity Meter Model 152), loss on ignition (muffle furnace, 450℃), extractable phosphate (Olsen's agent, determined by stannous chloride-molybdate blue method), total-nitrogen (micro-Kjeldahl method), extractable inorganic nitrogen including ammonia, nitrate and nitrite (extracted with 2 mol/L KCl, determined by steam distillation), total metal contents (K, Na, Mg, Mn, Zn, Ni, Cu, Cd, Pb, digested by concentrated sulfuric acid and concentrated nitric acid, 1:1, and then determined by a flame atomic absorption spectrophotometer). The methodology for these variables followed Allen (Allen, 1989) and Page *et al.* (Page, 1982).

4 Results

4.1 Vegetation survey

The results of vegetation survey are shown in Table 1. It was obvious that the number of species grown in Site H was smaller than in Site L. All except two species *Kummerowia striata* and *Mussaenda pubescens* that found in Site H were also present in Site L. However, they were of minor importance when compared with other dominant species in that site. As for Site N, the control site, the total number of plant species was similar to that of Site L (33 vs 31 plant species).

In quadrates 4 and 5 of Site L, and along the whole transect of Site H, which had a sparse coverage of trees and shrubs, were dominated by herbs and grasses. Site N had the highest total coverage of all plant species. However, the similar abundance of herbs and grasses in the three site indicated that the abundant vegetation in Site N was only due to the other two broad groups of plants.

The amount of biomass and ground litter from the three sites are shown in Table 2. In general, Site N had the highest biomass, followed by Site L and then Site H. In the case of ground litter, the trend was slightly different. Both Site L and N had a similar figure which was three times higher than Site H.

4.2 Landfill gas monitoring

The levels of methane, carbon dioxide and oxygen in the three transect are shown in Table 2. The levels of the three gases measured in Site N were not significantly different ($p>0.05$) from that of the ambient air. The levels of methane and carbon dioxide in Site H were much higher, and oxygen much lower than that in Site L ($p<0.05$);

while the levels of the three gases of both Sites L and N were not statistically different ($p>0.05$). However, it was noted that the readings of oxygen level were rather stable (with a lower value of standard deviations) in Site N. In addition, no methane was detected, and the level of carbon dioxide obtained was very low in this control site, as expected.

Table 1 Vegetation survey along the three transacts

a: Trees and shrubs

Species/site	H1	H2	H3	H4	H5	L1	L2	L3	L4	L5	N1	N2	N3	N4	N5
Litsea qlutinosa	--	--	--	--	--	0.4	0.9	--	--	--	198.5	1.6	40.4	138.1	--
Bridelia monoica	--	--	--	--	--	0.6	23.0	--	--	--	75.2	65.5	15.0	--	--
Lantana camara	--	--	--	--	--	--	35.0	--	--	--	10.0	20.0	25.0	--	6.0
Breynia fruticosa	--	--	--	--	--	8.0	36.0	11.8	--	0.2	0.1	--	--	--	--
Sapium sebiferum	--	--	--	--	--	60.8	0.1	--	--	--	--	3.0	--	--	--
Quercus sp.	--	--	--	--	--	0.1	--	--	--	--	--	--	--	--	--
Tristania conferta	--	--	--	--	--	--	--	55.0	--	--	--	--	--	--	--
Bauhinia purpurea	--	--	--	--	--	--	--	5.0	--	--	--	--	--	--	--
Podocarpus sp.	--	--	--	--	--	--	--	--	10.5	--	--	--	--	--	--
Leucaena levcocephala	--	--	--	--	--	--	--	--	--	0.3	--	--	--	--	--
Sesbania cochinchinensis	--	--	--	--	--	--	--	--	--	5.0	--	--	--	--	--
Delonix reqia	--	--	--	0.6	--	2.4	--	1.2	--	--	--	--	--	--	--
Eucalyptus torelliana	--	8.0	--	25.0	--	--	0.8	35.0	--	--	--	--	--	--	--
Celtis sinensis	--	--	4.9	--	--	--	--	--	1.6	--	5.0	0.6	--	--	--
Acacia confusa	10.0	--	--	--	--	32.0	25.0	15.0	--	--	--	--	--	--	13.0
Phus hypoleuca	--	--	--	--	--	--	--	--	--	--	--	--	--	12.0	--
Cratoxylum ligustrinum	--	--	--	--	--	--	--	--	--	--	--	0.7	--	--	--
Ficus variegata	--	--	--	--	--	--	--	--	--	--	11.9	--	--	--	--
Photinia benthamiana	--	--	--	--	--	--	--	--	--	--	3.0	--	--	--	--
Schefflera octophylla	--	--	--	--	--	--	--	--	--	--	4.7	--	--	--	--
Eucalyptus robusta	--	--	--	--	--	--	--	--	--	--	--	0.4	--	--	--
Microcos paniculata	--	--	--	--	--	--	--	--	--	--	24.2	0.5	--	15.0	--
Sub-total*	10.0	8.0	4.9	25.6	15.0	104.3	120.8	123.0	12.1	5.5	332.6	91.7	80.4	165.1	19.0
Total			63.5					365.7					688.8		

4.3 Soil analysis

The results of general soil properties and metal contents of the three sites are illustrated in Table 3 and 4, respectively. The pH values of both Sites H and N were similar (6.01 compared with 6.0) while Site L had a value of 6.49. Site H showed maximum mean values of all the items tested, followed by Site L, and the lowest values were

Table 1 (continuous)

b: Herbs and grasses

Species/site	H1	H2	H3	H4	H5	L1	L2	L3	L4	L5	N1	N2	N3	N4	N5
Ageratum conyzoides	--	--	--	--	--	1.0	0.1	2.3	--	--	--	--	--	--	--
Neyraudia reynaudiana	--	--	--	--	--	10.0	--	--	--	--	--	--	--	--	--
Desmodium triguetrum	--	--	--	--	--	1.0	--	--	--	0.3	--	--	--	--	--
Panicum repens	60.0	60.0	70.0	50.0	5.0	40.0	--	50.0	80.0	--	--	--	--	--	--
Paspalum sp.	0.5	0.2	0.2	--	80.0	--	--	--	--	80.0	--	--	--	--	50.0
Fimbristylis dichotoma	--	1.0	--	--	0.5	--	--	--	--	0.3	--	--	--	--	--
Phynchelytrum repens	--	--	--	--	1.0	--	--	--	--	0.5	--	--	--	--	--
Kummerowia striata	--	5.0	0.2	--	--	--	--	--	--	--	--	--	--	--	--
Cynodon dactylon	5.0	--	1.0	--	5.0	3.0	0.3	--	--	5.0	--	--	--	--	0
Mimosa pudica	--	--	--	--	--	--	--	--	--	10.0	--	--	--	--	--
Bidens bipinnata	--	--	--	--	--	--	--	--	--	0.4	--	--	--	--	--
Panicum maximum	2.0	--	0.3	35.0	--	25.0	10.0	--	--	--	10.0	2.0	40.0	10.0	--
Stachytarpneta jamaicensis	--	--	--	--	--	0.8	--	10.0	10.0	--	--	--	5.0	3.0	--
Miscanthus floridulus	--	--	--	--	--	--	--	--	--	--	--	90.0	20.0	40.0	50.0
Maesa perlarius	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.1
Conyza canadensis	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.1
Paperomia pellucida	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.1
Phyllanthus urinaria	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.2
Miscanthus sinensis	--	--	--	--	--	--	--	--	--	--	--	--	--	--	15.0
Pteris semipinnata	--	--	--	--	--		--	--	--	--	2.0	--	--	--	--
Sub-total*	67.5	66.2	71.7	85.0	91.5	80.8	10.4	62.3	90.0	96.5	12.0	92.0	65.0	53.0	116.0
Total			381.9					340.0					338.0		

c: Climbing plants

Species/site	H1	H2	H3	H4	H5	L1	L2	L3	L4	L5	N1	N2	N3	N4	N5
Cassytha filiformis	--	--	--	--	--	5.0	--	--	--	--	--	--	--	--	--
Pueraria lobata	--	--	--	--	--	1.0	--	--	--	--	--	--	--	--	--
Mussaenda pubescens	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Passiflora foetida	12.0	0.5	5.0	0.3	1.0	5.0	--	15.0	1.0	2.0	--	--	--	--	--
Paederia scandens	1.0	--	--	0.1	--	20.0	0.5	1.0	--	7.0	--	--	5.0	20.0	5.0
Zanthoxylum dissitum	--	--	--	--	--	--	--	--	--	--	20.0	--	--	--	--
Ipomoea cairica	--	--	--	--	--	--	--	--	--	--	1.0	--	--	--	--
Morinda parvifolia	--	--	--	--	--	--	--	--	--	--	10.0	--	--	--	--
Dioscorea persimilis	--	--	--	--	--	--	--	--	--	--	--	15.0	10.0	--	--
Smilax china	--	--	--	--	--	--	--	--	--	--	--	3.0	--	5.0	--
Gymnema alterniflorus	--	--	--	--	--	--		--	--	--	--	1.0	--	--	--
Smilax reparia	--	--	--	--	--	--	--	--	--	--	5.0	--	--	--	15.0
Sub-total*	14.0	0.5	5.0	0.4	1.0	31.0	0.5	16.0	1.0	9.0	36.0	19.0	15.0	25.0	20.0
Total			20.9					57.5					115.0		
Total coverage	191.5	74.7	81.6	111.0	107.5	216.1	131.7	201.3	103.1	111.0	380.6	202.7	160.4	243.1	155.0
Overall coverage			466.3					763.2					1141.8		
Bare ground**	*30.0	30.0	15.0	15.0	15.0	0.0	0.0	0.0	10.0	20.0	0.0	8.0	5.0	0.0	5.0

Notes: All figures after each plant species represent the percentage coverage of the species in each quadrate

* Sum of percentage coverage of the three groups of plants in each quadrate

** Percentage bare ground in each quadrate

Table 2 Landfill gas content, weights of biomass and ground litter along the three transects

Site	O_2, %	CH_4, %	CO_2, %	Biomass, g	Litter, g
H	12.70(5.75) a	10.29(12.76) b	15.09(12.5) b	693(569) a	226(22) a
L	18.29(3.77) b	1.23(3.28) a	3.72(8.32) a	929(806) a	642(225) b
N	20.30(0.29) b	0.00(0)	0.17(0.45) a	1058(921) a	603(311) b

Figure are means of gas content measured in 15 gas sampling pipes, and means of biomass and letter weights of 5 quadrats along each transect. The figures in brackets are the standard deviations of the means. Different letters within the same column indicate that means are significantly different at the 5% level according to Duncan's multiple range test.

observed in Site N, with a few exceptions where the values of loss on ignition, extractable phosphate, and Kjeldahl-N recorded in Site L were lower than Site N. Among all the parameters tested, only the value of nitrate-N in Site H was significantly higher than Site N ($p<0.05$). No general pattern was observed in the casé of metal concentrations, but significantly higher ($p<0.05$) contents of K, Mg and Mn were obtained in Site H than Site L.

5 Discussion

According to the analysis of correlation coefficient (Table 5), strong negative correlations between oxygen and methane, and between and carbon dioxide; and strong positive correlation between methane and carbon dioxide, were revealed (all with $p<0.05$). These findings indicated oxygen was displaced by methane and carbon dioxide.

When the results of vegetation performance and landfill gas contents were compared, it was obvious that the relatively lower plant coverage in Site L and H were consistent with the higher methane and carbon dioxide levels (and a lower oxygen level). In Site N, where there was more abundant plant growth, the underground gas composition was very close to that of the ambient air.

Another interesting point worth mentioning is that in cases where there were high levels of methane and carbon dioxide, and a low content of oxygen, a low total plant coverage occurred along the whole transect of Site H. However, the growth of herbs and grasses in these areas did not show considerable inhibition, and in fact Site H had the highest coverage of herbs and grasses among the three sites, followed by Site L and the lowest was noted in Site N. According to Table 5, oxygen showed positive correlations with all vegetation parameters (from 0.27 to 0.54, at $p<0.05$) except with herbs and grasses (-0.08, at $p>0.05$) and bare ground (-0.64, at $p<0.05$).

Table 3 Major physical and chemical properties of soil

Site	pH	Conductivity, mS/cm	Loss on ignition, %	Moisture content, %	Extractable phosphate, μg/g	Kjeldahl nitrogen, μg/g	Ammonium nitrogen, μg/g	Nitrate nitrogen, μg/g	Nitrite nitrogen, μg/g
H	6.01 a	0.42 a	6.32 a	23.80 a	25.03 a	1186.4 a	31.35 a	98.38 a	8.79 a
	(0.55)	(0.31)	(2.96)	(8.05)	(8.74)	# (828.7)	(24.78)	(78.35)	(11.63)
L	6.49 a	0.26 a	4.01 a	21.70 a	20.90 a	669.6 a	15.05 a	37.21 ab	11.68 a
	(0.69)	(0.18)	(1.36)	(7.11)	(5.97)	(307.9)	(13.48)	(21.33)	(21.42)
N	6.00 a	0.16 a	5.86 a	19.70 a	21.95 a	771.8 a	10.11 a	24.16 b	2.85 a
	(0.86)	(0.05)	(1.48)	(3.18)	(10.16)	(382.7)	(2.77)	(6.96)	(2.32)

Figures are means of 5 quardrats of each transect. The figures in brackets are the standard deviations of the means. Different letters within the same column indicate that means are significantly different at the 5% level according to Duncan's multiple range test.

Table 4 Metal contents of soil along the three transacts

Site	Concentration, μg/g soil								
	Nickel	Copper	Magnesium	Zinc	Sodium	Manganese	Cadmium	Lead	Potassium
H	28.17 a	24.13 a	573.80 b	125.22 a	73.56 a	661.53 b	3.10 a	48.65 a	1947.94 b
	(5.63)	(10.70)	174.14)	(38.98)	(160.2)	(155.19)	(4.13)	(9.98)	(804.73)
L	30.84 a	18.96 a	689.31 ab	117.28 a	105.74 a	654.65 b	4.23 a	61.53 a	1647.69 ab
	(12.98)	(4.43)	(132.15)	(11.31)	(54.81)	(191.10)	(0.43)	(20.01)	(648.98)
H	25.38 a	24.93 a	326.54 a	128.48 a	98.09 a	103.89 a	2.85 a	61.88 a	1095.37 a
	(5.37)	(5.62)	(67.31)	(73.32)	(12.43)	(25.15)	(1.71)	(25.70)	(200.14)

Figures are means of 5 quardrats of each transect. The figures in brackets are the standard deviations of the means. Different letters within the same column indicate that means are significantly different at the 5% level according to Duncan's multiple range test.

As to carbon dioxide and methane, negative correlations with all vegetation parameters, as expected, were observed (varied from -0.27 to -0.52, at $p<0.05$); except in the case of weak positive correlation between herbs and grasses and methane (0.01, at $p>0.05$).

According to the results of soil properties of three different sites, it seems apparent that apart from the high levels of landfill gas (i.e. methane and carbon dioxide) and the lack of oxygen, the high concentrations of Kjeldahl-N, ammonium-N, conductivity, and various metals have also exerted their harmful effects on the growth of trees, shrubs, and climbing plants. With the generation of anaerobic soil conditions due to the displacement of oxygen by landfill gases and by the depletion of oxygen due to micro-organisms, a highly reduced state of soil resulted. This leads to a significant increase in ammonia-N and moisture content (Leone, 1977; 1982). The adverse effects of high levels of ammonia-N and/or gaseous ammonia, mainly associated with application of animal manure on agricultural soils have been demonstrated (Adriano, 1973; Wong, 1983). Elevated concentrations of heavy metals such as Fe, Mn, Cu and Zn are frequently encountered under reduced conditions and effects on plant growth have been thoroughly studied (Hogan, 1979; Wong, 1982).

Table 5 Correlation between landfill gas content and vegetation performance along the three transects

	O_2	CH_4	CO_2
O_2	1.0000		
CH_4	−0.9348	1.0000	
CO_2	−0.9837	0.9757	1.0000
Trees and shrubs	0.5054	−0.4381	−0.4803
Herbs and grasses	−0.0764	0.0061	−0.4760
Climbing plants	0.4691	−0.4250	−0.4637
Total coverage	0.5397	−0.4871	−0.5168
Bare ground	−0.6448	0.6276	0.6117
Biomass	0.2717	−0.2673	−0.2928
Ground litter	0.3789	−0.4225	−0.3713

Note: significance level $p<0.05$

A large scale of tree plantation was carried out on the landfill site by a landscaping company, and the mortality rates of planted trees were high (Wong, 1987). *Acacia confusa*, *Eucalyptus torelliana*, and *Celtis sinensis* seem to be more tolerant than other planted tree species as indicated in the present survey of plant performance. It was also demonstrated that *A. confusa* was able to root deeply in an experiment where tree seedlings were fumigated with simulated landfill gas (Chan, 1991). Therefore, choice of tree species tolerant to landfill gas is important, instead of choosing shallow-rooted tree species, which are more susceptible to drought condition. It has been observed that a very high carbon dioxide concentration in cover soil limits the depth of root system. Trees with a shallow root system become very susceptible to water stress (Wong, 1987). *Acaca confusa*, *Albizzia lebbek*, and *Tristana conferta* (all woody plants) are suited for growth on subtropical completed landfills mainly due to their gas tolerance and/or drought tolerance (Chan, 1991).

Being having shallow-root systems, grasses and herbs seemed to be able to thrive in the high-gas area (Site H), as the level of landfill gas (methane and carbon dioxide) is usually lower and oxygen level higher in the surface soil (Wong, 1988). In addition, strains of grasses tolerant to heavy metals are frequently reported (Wu, 1976; Wong, 1982, 1985). Hydroseeding of grasses, especially indigenous species, would therefore ensure an successful establishment of plant cover in areas with a moderate level of landfill gas, However, in areas where landfill gas is prevalent, a ventilation system, with an insulation layer, consisting of gravel, between the refuse and the topsoil might be necessary.

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