Int. J. Environ. Res., 7(3):801-806,Summer 2013
ISSN: 1735-6865

Vegetation Dynamics on Waste Landfills in the Seoul Metropolitan Area

Kim, K. D.*

Department of Environmental Education, Korea National University of Education, Chungbuk,
Republic of Korea

Received 17 Oct. 2012; Revised 19 Jan. 2013; Accepted 20 March 2013

ABSTRACT: The goal of this study was to survey the natural vegetation on waste landfills and suggest a restoration plan. In the study, I identified 63 families, 275 species, and 34 varieties of aboveground vascular flora. *Robinia pseudo-acacia* was the dominant tree, with a basal area density of 1.51 ¡ 3/ha, followed in decreasing order by *Salix koreensis* and *Populus sieboldii*. TWINSPAN resulted in the classification of 6 communities. The result of Detrended Canonical Correspondence Analysis(DCCA) of 24 environmental variables and vegetation data was that the presence of artificial turf, human disturbance, landfill age, presence of periodic management and soil Na levels were correlated with the first axis. Soil chemical analyses showed that total nitrogen was greater at control sites than in landfills, but levels of K, Na, Ca, Mg, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn were greater in landfills than at control sites. Current planning by central and local governments calls for converting waste landfills into ecological parks or golf courses. In the initial stages of a landfill closure, a landfill restoration plan must be made to select soil for capping the landfill and to plan for future facilities. If vegetation is present near the landfill to provide a propagule source, the recommended course of action is to allow for natural restoration to occur through propagule dispersal and successional processes. However, if the landfill stands as a secluded island without a nearby propagule source, artificial restoration methods are suggested.

Key words: DCCA, Restoration, Robinia pseudo-acacia, Soil chemical, Succession, South Korea, TWINSPAN, Vegetation, Waste landfill

INTRODUCTION

Waste landfilling is a widespread and cost-effective method used as an alternative to incineration or composting of refuse (Ahel *et al*., 1998). A landfill is defined as an artificial environment composed of multiple layers of refuse dumps that are subsequently covered with soil. The fill materials generate landfill gases and leachate, polluting the contents of the landfill and the surrounding ecosystem.

Waste landfilling requires land near the city area, and the conversion of filled areas into parks, golf courses and botanical gardens has been the source of environmental problems (Chiras, 1998). Many programs for wildlife and recreation have transformed landfills into attractive areas (Clarke, 1997). Currently, diverse techniques such as soil bioengineering and ecological restoration are integrated into restoration plans for landfills (Johnson, 1996).

Secondary succession has occurred on waste landfills following colonization by pioneer plant species (Wong & Yu, 1989). The Ministry of the Environment identified 898 waste landfills in Korea; these were generally non-sanitary landfills with a shallow soil cover, lacking systems for gas collection and leachate treatment (ME, 1997). Landfill gases, leachate, and soil subsidence make landfill areas ecologically unstable, and the restoration of these degraded areas is needed. However, a lack of funding has left most non-sanitary landfills untouched. We expected to see natural restoration through secondary succession on non-sanitary waste landfills. These landfills represent unique opportunities to study successional processes in artificial environments that share similar parent material and environmental conditions. To date, whether natural succession occurs on non-sanitary waste landfills or not is unclear because surveys to determine the ecological status of these landfills have been rare. The aims of this study were to assess the current state of the vegetation and soil environments at non-sanitary waste landfills in the Seoul metropolitan area and to examine succession processes. Study objectives included predicting vegetation change on waste landfills through quantitative analysis of existing plant communities and

---

*Corresponding author E-mail:kdkim@knue.ac.kr

studying interrelationships between vegetation variation and environmental variables using ordination analyses.

MATERIALS & METHODS

The study sites were selected from waste landfills within the Seoul metropolitan area, including areas in the capital city of Seoul, the city of Incheon and the province of Gyeonggi, between 37°58′ and 37°00′ latitude and between 126°38′ and 127°29′ longitude. Ten sites with natural vegetation recovery and low levels of disturbance were chosen. A chronosequence approach was used based on landfill age (0.25, 5.25, 5.75, 6.25, 6.51, 7.25, 9.4, 10.83, and 11.33 years). For comparisons of soil chemical properties, ten control sites were selected from the forest edge nearest to each site. Seoul metropolitan area is located in a climate zone with four distinct seasons. During the winter, from December to January, it is cold and dry under the dominant influence of the Siberian air mass. In the summer, from June to August, the weather is hot and humid with frequent heavy rainfalls associated with the East-Asian Monsoon, locally called "Changma." During spring and fall, it is mild and calm, with transient high and low pressure systems passing through periodically. Annual mean temperatures range from 10 to 16°C in South Korea. The warmest month is August, whereas January is the coldest. Monthly mean temperatures range from 20 to 26°C in August and -5 to 5°C in January. Annual precipitation is approximately 1300 mm in the central part of South Korea, including the Seoul metropolitan area (Korea Meteorological Administration, 2002).

In the vegetation survey, a complete species inventory was performed to determine which species invaded and colonized from 1999 to 2000. To survey the trees, a total of 29, 10 × 10 m^2 quadrats were established in subjectively selected, physiognomically representative patches in landfill stands that ranged from 0.25 to 11.33 years in age, from closure to Sep., 1999. In the quadrats, we recorded cover, height, diameter at breast height (DBH), number of individuals and number of seedlings. DBH measurements were converted into basal area values to estimate cover (Webb & Kaunzinger, 1993). For herbaceous vegetation, a total of 136, 1 × 1 m^2 quadrats were set up at 5-m intervals along a transect through the landfill (Jose *et al.*, 1996). In the quadrats, cover was estimated using the Braun-Blanquet scale (Fuller & Conard, 1932). The nomenclature followed Lee (1999) and Lee (1998) for native vascular plants and Park (1995) for exotic plants. All grasses in the quadrats were cut with scissors and sickles and removed to the laboratory, where they were dried to a constant weight at 80°C for 24 hours and then weighed to measure aboveground biomass. The percentage of exotic plant species at each waste landfill was calculated as follows:

$$\mathrm{PE} = \times 100 \frac{NE}{NT} \qquad (1)$$

where PE = the percentage of exotic plant species, NE = the number of exotic species and NT = the total number of native and exotic species.

At 10 randomly selected points in the grass quadrats, soil samples were collected at 0 - 10 cm depth and pooled into a single sample. Soil moisture content and bulk density were measured in the laboratory immediately after the samples were retrieved from the field. Soil samples were stored in a cold room at 4°C until being removed for further analysis. Concentrations of total-N, available-P, exchangeable cations (Ca, K, Mg and Na) and heavy metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn) were obtained. Analysis methods were as follows: soil pH and EC (w/v=1:5); organic matter content (Walkley-Black method); total-N (Kjeldahl method); available-P (Ammonium molybdate-Ascorbic acid method); Ca, K, Mg and Na (Ammonium acetate extraction method); and Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn (HCl extraction method). Soil pH and EC were measured with a Fisher 230A pH meter (Fisher Scientific International Inc., Hampton, New Hampshire, USA) and an EC 214 electric conductivity meter (Hanna Instruments, Woonsocket, Rhode Island, USA; Page *et al.* 1982). K, Na, Ca and Mg were determined with an AA-6501F atomic absorption spectrophotometer (Shimadzu Corporation, Kyoto, Japan). Anion concentrations of F^-, Cl^- and SO_4^{-2} were analyzed by ion chromatography with a Model DX-500 chromatograph (Dionex Corporation, Sunnyvale, California, USA; Page *et al.*, 1982). Analysis of Al, As, B, Cd, Co, Cu, Fe, Mn, Ni, Pb and Zn was performed on a Model ICPS-1000 IV ICP emission spectrometer (Shimadzu Corporation, Kyoto, Japan). The grass community was classified with TWINSPAN using PC-ORD 4.27 (McCune & Mefford, 1999). The TWINSPAN analysis used percentage cover data that were transformed using intermediate values of the Braun-Blanquet scale (5 →87.5%, 4→ 62.5%, 3 → 37.5%, 2→15%, 1 → 2.5%, 0+ → 0.1%; Mueller-Dombois & Ellenberg, 1974). A community group was defined as an assembly appearing at the first branched dichotomy, and a community was defined as an assembly that split from a community group. Each community group or community was named after all species with over 10% mean cover and over 10% mean frequency in all quadrats in the group.

Ordination analysis was performed using detrended canonical correspondence analysis (DCCA). Relative cover (RC) and relative biomass (RB) were calculated based on the cover and biomass of each species recorded in the herbaceous quadrats, according Curtis and McIntosh (1951):

$$RC = \times 100\,(\%)\,\frac{C_i}{T_i} \qquad (2)$$

where C_i = cover for a species, and T_i = the total cover for all species.

$$RB = \times 100\,(\%)\,\frac{B_i}{T_i} \qquad (3)$$

where B_i = the biomass for a species, and T_i = the total biomass for all species.

Importance values (IV) were calculated by summing the relative cover (RC) and relative biomass (RB):

$$V = RC + RB \qquad (4)$$

Importance values were ordinated by 24 environmental variables (bulk density, organic matter content, moisture content, total-N, available-P, K, Na, Ca, Mg, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn, distance from landfill edge, landfill age, landfill size, human disturbance, presence of periodic management, slope, and presence of artificial turf) using DCCA (Detrended Canonical Correspondence Analysis) in CANOCO 4.0 (ter Braak & Smilauer, 1998). Landfill age was the number of years elapsed since landfill closure. The statistical validity of the resulting ordination was evaluated using an unrestricted Monte Carlo permutation test (ter Braak, 1990).

Because of problems with assumptions of normality, a non-parametric Wilcoxon 2-sample test was performed to compare physical and chemical soil properties between waste landfill and control sites. All data were analyzed using SAS 6.12 (SAS Institute, 1985).

RESULTS & DISCUSSION

Robinia pseudo-acacia established on waste landfills and gradually formed closed woodland islands with sparse herb layers. This woody species was taller than most tree species observed in the waste landfills. It is presumed that *R. pseudo-acacia* invasions occur through dispersal in the soil layers used by landfill managers to cover waste dumps. Together with *Robinia pseudo-acacia*, *Salix koreensis* formed the vegetation canopy on the waste landfills. The density of *Robinia pseudo-acacia* was 769 individuals per ha.

The result of TWINSPAN was the classification of 6 communities: *Setaria viridis-Digitaria ciliaris-Echinochloa crus-galli* Community, *Panicum dichotomiflorum-Eleusine indica-Cyperus microiria-Portulaca oleracea* Community, *Zoysia japonica-Artemisia princeps* var. *orientalis* Community, *Arundinella hirta* Community, *Zoysia japonica* Community and *Erigeron canadensis-Erigeron annuus* Community. Of the species found in these 6 communities, *Panicum dichotomiflorum*, *Erigeron canadensis*, and *Erigeron annuus* were exotic plants with origins outside of South Korea. It is expected that the quantity of exotic or invasive plants increases continually on landfills because of artificial influence and interference. Among herbaceous species, *Humulus japonica* showed the highest important value across all communities (Table 1).

The disturbances found in waste landfills are divided into two types: anthropogenic and pollutic. Differences between fill materials and natural soils, disturbance from management of gas collection facilities and leachate treatment systems, and soil compaction as a result of landfill construction are all anthropogenic disturbances. Soils transported from urban areas and forests to cap landfills are polluted or nutrient-poor, and artificially vegetated landfill areas are left bare due to poor management. The second disturbance type is pollution. Landfill gases such as CH_4, CO_2, CO, N_2, O_2 and NH_4 are produced during waste decomposition. Landfill gases displace the oxygen-rich air in soil pores, preventing root respiration and causing plant growth to decline. Leachate formed by precipitation and decomposing organic materials pollutes landfills and surrounding ecosystems by travelling along surface and subsurface waterways. Waste landfill soils subside due to volume reduction from waste decomposition. However, vegetation growth through spontaneous succession can function as a neutralizing agent for these unbeneficial effects.

Waste landfills are artificial environments created by waste dumps capped with anthropogenic soils. These anthropogenic soils include disturbed forest edge soils and urban subsoils obtained from construction areas. Soil profiles of waste landfills are composed of two layers: a layer of waste dumps and an overlying soil cover layer. The upper anthropogenic soil layer is very important for sustaining aboveground vegetation.

Evidence of soil degradation in capped landfills includes soil compaction, decreased permeability, lack of organic material, diminished soil fauna, inappropriate texture and lack of structure (Ewing, 2002). Non-sanitary landfills, which have been filled with layers of

Table 1.The cover of dominant species (> 10% mean cover) and ground-cover for each community

Community	Ia	Ib	IIa	IIb	IIc	IId
Number of plots	34	3	6	1	43	1
Setaria viridis	37	+	+	·	+	·
Digitaria ciliaris	22	·	+	+	+	·
Echinochloa crus-galli	16	·	·	·	+	·
Panicum dichotomiflorum	11	+	·	·	·	·
Ambrosia artemisiifolia var. elatior	·	30	·	+	·	·
Festuca arundinacea	19	+	·	·	·	·
Humulus japonica	59	·	+	·	+	·
Glycine soja	30	·	+	·	+	·
Aster pilosus	18	·	·	·	·	·
Eleusine indica	+	·	·	·	·	·
Cyperus microiria	+	30	·	·	·	·
Portulaca oleracea	·	13	·	·	+	·
Zoysia japonica	·	11	55	·	57	·
Artemisia princeps var. orientalis	37	·	11	·	+	·
Cosmos bipinnatus	+	·	15	·	+	·
Amphicarpaea edgeworthii var. trisperma	·	·	13	·	+	·
Arundinella hirta	+	·	·	38	·	·
Erigeron canadensis	+	·	·	·	+	38
Erigeron annuus	+	+	+	·	+	15

Values are means of the nearest 10%: + = < 10%, · = absent. Community symbols: Ia = Setaria viridis-Digitaria ciliaris-Echinochloa crus-galli;> b = Panicum dichotomiflorum-Eleusine indica-Cyperus microiria-Portulaca oleracea; a > a = Zoysia japonica-Artemisia princeps var. orientalis;a > b = Arundinella hirta;a > c = Zoysia japonica;a > d = Erigeron canadensis-Erigeron annuus.

Table 2. The summary of DCCA results

Axes	Axis 1	Axis 2	Total inertia
Eigenvalues	0.648	-0.472	17.518
Species-environment correlations	0.894	-0.821	
Cumulative percentage variance: Of species data	3.7	-6.4	
Cumulative percentage variance: Of species-environment correlation	17.2	-29.7	
The presence of turf field	*0.7819	-0.0186	
Human disturbance	0.5789	-0.1062	
Landfill age	0.5526	-0.2179	
Periodic management	0.5336	-0.1169	
Na	0.6102	-0.0120	
Ca	0.1971	-0.3112	
Mn	0.0510	-0.2739	
Fe	-0.0239	-0.2577	
Sum of unconstrained eigenvalues			17.518
Sum of canonical eigenvalues			3,772

*Inter-set correlations of environmental variables with axes in bold

wastes and soils that have little structure, contain soils that are rich in organic material but otherwise resemble the degraded soils found in other landfills. The soil chemical analysis from our study showed that total nitrogen was greater at the control sites than in the landfills, but the quantity of K, Na, Ca, Mg, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn was greater in the landfills than at the control sites.

The DCCA, using 24 environmental variables and the vegetation data, showed that the presence of artificial turf, human disturbance, landfill age, presence

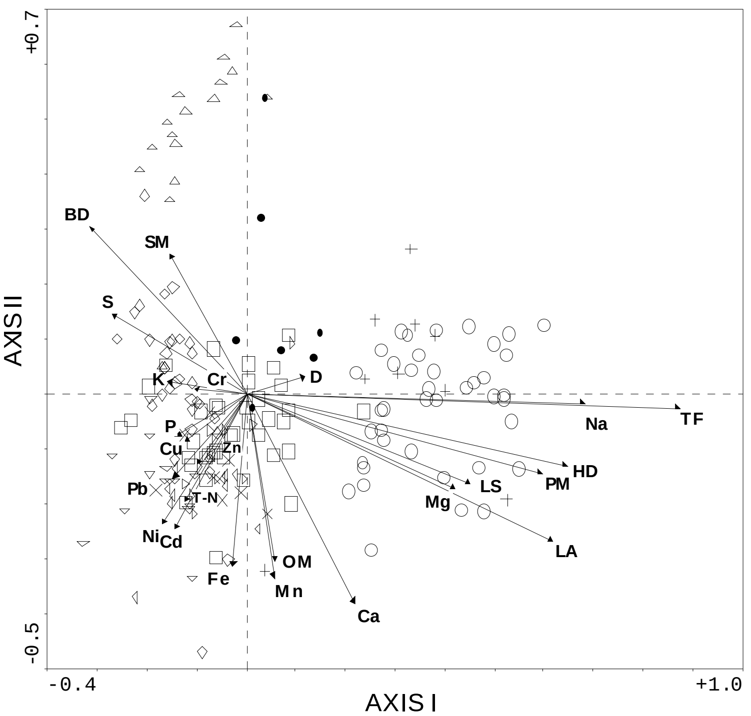

Fig. 1. Ordination diagram from DCCA for the first two axes showing the relationship between waste landfill sites and environmental variables. Quadrat names omitted. (Environmental variables: BD = bulk density; Ca = Calcium; Cd = Cadmium; Cu = Copper; Cr = Chromium; D = distance from landfill edge; Fe = iron; HD = human disturbance; K = potassium; LA = landfill age; LS = landfill size; Mn = manganese; Na = sodium; Ni = nickel; OM = organic matter content; P = available phosphate; PM = presence of periodic management; Pb = lead; S = slope; SM = soil moisture content; TF = presence of artificial turf; T-N = total nitrogen; Zn = zinc). (Study sites: (∇) = BunSuh-Ri, PaJu; (◁ = DoGi-Ri, PaJu; (✧) = Hasanun-Dong, SongNam; (×) = KoMae-Ri, YougIn; (□) = Kyoung-Seo Landfill 2 Section, Incheon; (Δ) = MoJeon-Ri, IChon; (●) = SangPae-Dong, DongDuCheon; (▷) = ShinDae-Dong, PyongTaek; (+) = Wonchang-Dong, 196, Incheon; (❍) = Wonchang-Dong, 420, Incheon)

of periodic management and soil Na contents were correlated with the first axis, and soil Ca, Na, and Fe contents were correlated with the second axis (Fig. 1 and Table 2).

Of the tree species, *Robinia pseudo-acacia* dominated on the waste landfills. The remaining sites were dominated by grasses.

The results of the soil analyses suggest that salinization occurs in waste landfills and that nitrogen levels are low. Based on the results of the ordination, plant community composition varied among the waste landfill sites, and this variation was explained by soil salinity and the presence of artificial vegetation such as turf grass. The ordination revealed that the aboveground and belowground vegetation were similar. Our results are consistent with a recent study on a dry sandy landfill site, which found that spontaneous vegetation development on unmown plots was constant over a 5-year period (Rebele & Lehmann, 2002). The positive effects of spontaneous succession are powerful, especially if the disturbed site is small, surrounded by natural vegetation, and if the site conditions were not significantly altered by the initial disturbance (Prach & Pyšek, 2001).

CONCLUSION

This study was carried out to investigate the condition of the vegetation and the soil chemical environment in 10 non-sanitary waste landfills. Non-sanitary waste landfills offer a unique opportunity to study ecological processes such as succession in isolated, nutrient-poor environments. Multivariate analyses were used to test hypotheses about vegetation succession in non-sanitary waste landfills, including the role of soil chemical processes. Of the tree species identified in the study, *Robinia pseudo-acacia* was widespread and had the highest cover (1.51

m^2/ha) and highest frequency of any species. *R. pseudo-acacia* was the single species forming the canopy (height > 2 m). Where trees had not colonized, the vegetation was dominated by herbs and grasses that are known to be adapted to disturbed areas, such as *Humulus japonica, Setaria viridis* and *Artemisia princeps* var. *orientalis* (IV > 19). As the area of non-sanitary waste landfills increased, the total number of species increased significantly ($P < 0.05$), and as landfill age increased, species richness per unit area decreased. This result indicates that as time since landfill closure elapses, the number of species stabilizes. TWINSPAN classified the vegetation into 6 communities. In the DCCA, the presence of artificial turf, human disturbance, landfill age, periodic management and soil Na were correlated with the first axis. Soil Ca, Na, and Fe were correlated with the second axis. The variation in plant community composition among non-sanitary waste landfills was explained by soil salinity and the presence of artificial vegetation such as turf grass. The soil chemical analyses showed that total nitrogen was greater at the control sites than in the landfills ($P < 0.05$), but K, Na, Ca, Mg, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn levels were greater in the landfills than at the control sites ($P < 0.05$). The results of our study suggest that soils in non-sanitary waste landfills have low levels of nitrogen and high soil salinity. *Robinia pseudo-acacia*, a nitrogen-fixing dominant deciduous tree species, appears to be well-adapted to the disturbed artificial environment found in non-sanitary waste landfills. The results of this study suggest that if *R. pseudo-acacia* was planted with an evergreen species such as *Pinus densiflora* on landfills, the degraded soils and vegetation would develop into stable forests. To improve species diversity in disturbed urban ecosystems such as waste landfills, increased fertilization and improved management of water supply are suggested to improve soil fertility and to reduce salinity.

ACKNOWLEDGEMENTS

I thank Professor Eun Ju Lee, Professor Jong Uk Park and Dr. Sang Mo Lee of Seoul National University; Professor Byeong Mi Min of Dankuk University; and Jong Min Kim of the National Institute of Environmental Research for reviewing this manuscript.

REFERENCES

Ahel, M., Mikac, N., Cosovic, B., Prohic, E. and Soukup, V. (1998). The impact of contamination from a municipal solid waste landfill (Zagreb, Croatia) on underlying soil. Water Science Technology, **37,** 203-210.

Barbour, M. G., Burk, J. H., Pitts, W. D., Gilliam, F. S. and Schwartz, M. W. (1999). Terrestrial plant ecology. New York: Benjamin/Cummings, Inc.

Chiras, D. D. (1998). Environmental science. Belmont: Wadsworth Publishing Company.

Clarke, A. (1997). From waste to wildlife. Geomechanics Abstracts, **1,** 57.

Curtis, J. J. and McIntosh, R. P. (1951). An upland forest continuum in the prairie forest border region of Wisconsin. Ecology, **32,** 476-496.

Ewing, K. (2002). Mounding as a technique for restoration of prairie on a capped landfill in the Puget Sound Lowlands. Restoration Ecology, **10,** 289-296.

Johnson, J. (1996). Near prairie crossing in lake county, Illinois, the countryside landfill assumes the character of the vernacular landscape with sixteen miles of trails. Landscape Architecture, 40-45.

KMA, (2002). Korea Meteorological Administration http://www.kma.go.kr/ema/esub/em_sub_body04. htm.

Lee, T. B. (1999). Illustrated flora of Korea, Seoul: HyangMunSa.

Lee, Y. N. (2002). Flora of Korea, Seoul: Kyohak Publishing CO., LTD.

McCune, B. and Mefford, M. J. (1999). Multivariate analysis of ecological data. Version 4, 27. Gleneden Beach MjM Software.

ME, (1997). Ministry of Environment, The results of census on the status of landfill and strategy of preventing underground water pollution. Seoul: Ministry of Environment.

Mitchell, R. J., Marrs, R. H., Le Duc, M. G. and Auld, M. H. D. (1997). A study of succession on lowland heaths on Dorset, southern England: changes in vegetation and soil chemical properties. Journal Appled Ecology, **34,** 1426-1444.

Mueller-Dombois, D. and Ellenberg, H. (1974). Aims and methods of vegetation ecology. New York: John Wiley & Sons.

Park, S. H. (1995). Colored illustrations of naturalized plants of Korea. Seoul: Ilchokak.

Prach, K. and Pyšek, P. (2001). Using spontaneous succession for restoration of human-disturbed habitats: Experience from Central Europe. Ecological Engineering, **17,** 55-62.

Rebele, F. and Lehmann, C. (2002). Restoration of a landfill site in Berlin, Germany by spontaneous and directed succession. Restoration Ecology, **19,** 340-347.

Ter Braak, C. J. F. and Smilauer, P. (1998). CANOCO reference manual and user's guide to Canoco for Windows: Software for canonical community ordination. Version 4.0. (Ithaca: Microcomputer Power).

Ter Braak, C. J. F. (1990). Update notes: CANOCO Version 3.10. Wageningen: Agricultural Mathematics Group.

Wong, M. H. and Yu, C. T. (1989). Monitoring of Gin Drinkers' Bay landfill, Hong Kong. Gas contents, soil properties, and vegetation performance on the side slope. Environmental Management, **13,** 753-762.