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PROFILE
Potential Tree Species for Use in the Restoration of Unsanitary Landfills

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ABSTRACT / Given that they represent the most economical option for disposing of refuse, waste landfills are widespread in urban areas. However, landfills generate air and water pollution and require restoration for landscape development. A number of unsanitary waste landfills have caused severe environmental problems in developing countries. This study aimed to investigate the colonization status of different tree species on waste landfills to assess their potential for restoring unsanitary landfills in South Korea. Plot surveys were conducted using 10 × 10-m quadrats at seven waste landfill sites: Bunsuri, Dugiri, Hasanundong, Gomaeri, Kyongseodong, Mojeonri, and Shindaedong. We determined the height, diameter at breast height (DBH), and number of tree species in the plots, and enumerated all saplings ≤ 1 m high. Because black locust, *Robinia pseudoacacia*, was the dominant tree species in the waste landfills, we measured the distance from the presumed mother plant (i.e., the tallest black locust in a patch), height, and DBH of all individuals in black locust patches to determine patch structure. *Robinia pseudoacacia*, *Salix koreensis*, and *Populus sieboldii* formed canopy layers in the waste landfills. The basal area of black locust was 1.51 m^2/ha, and this species had the highest number of saplings among all tree species. The diameter of the black locust patches ranged from 3.71 to 11.29 m. As the patch diameter increased, the number of regenerated saplings also tended to increase, albeit not significantly. Black locust invaded via bud banks and spread clonally in a concentric pattern across the landfills. This species grew well in the dry habitat of the landfills, and its growth rate was very high. Furthermore, black locust has the ability to fix nitrogen symbiotically; it is therefore considered a well-adapted species for waste landfills. Eleven woody species were selected for screening: *Acer palmatum*, *Albizzia julibrissin*, *Buxus microphylla* var. *koreana*, *Ginkgo biloba*, *Hibiscus syriacus*, *Koelreuteria paniculata*, *Ligustrum obtusifolium*, *Liriodendron tulipifera*, *Pinus koraiensis*, *Pinus thunbergii*, and *Sophora japonica*. As a result of a comparison of the total ratio (sum of shoot extension and diameter growth at the landfill relative to a reference site) and mortality, six species (*Liriodendron tulipifera*, *Albizzia julibrissin*, *Ligustrum obtusifolium*, *Buxus microphylla* var. *koreana*, *Hibiscus syriacus*, and *Sophora japonica*), which had a total ratio >1 and experienced low mortality, are recommended as potentially suitable species for waste landfill remediation. We suggest that mixed plantations of ubiquitous adaptable species and naturally occurring black locust will enhance the landscape through synergistic effects.

Landfilling is a commonly used method for the disposal of refuse. Waste landfills cause many environmental problems, including the production of biogas and leachates, and they constitute noxious landscapes in urban areas. A public census reported approximately 1170 closed domestic waste landfills and 232 active domestic landfills in South Korea (Ministry of Environment 2003). Furthermore, most waste landfills are unsanitary, i.e., they do not vent biogas and have no ventilation facilities, no leachate treatment plants, poor soil cover layers, and no capping liners. Government and local authorities therefore must restore a large number of unsanitary waste landfills. However, determining a suitable revegetation strategy for restoring waste landfills is a very complex and difficult problem. Landfill managers plan to plant 1 million trees on the Sudokwon waste landfill, which is the largest waste landfill in Asia, for restoration into an ecological park. For revegetation purposes, it is most efficient and economical to use naturally occurring vegetation on unsanitary waste landfills. Furthermore, it is important to select species that are adapted to waste landfills for quick restoration of these disturbed areas. Some studies have at-

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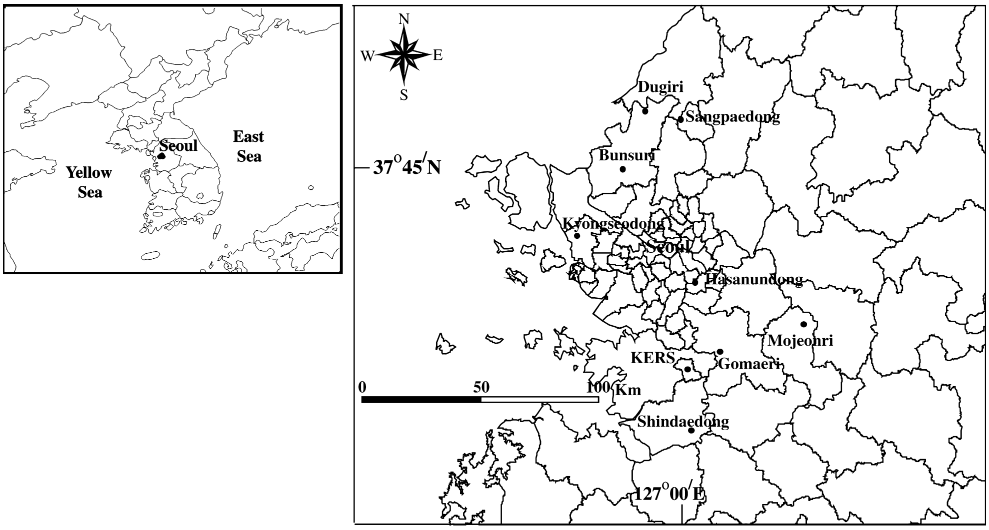

Figure 1. Location of study sites. FERS: Forest Environment Research Station, Osan.

tempted to determine which species should be maintained in sanitary landfills (Gilman and others 1981). However, there has been little information from developing countries with respect to the vegetation that becomes established on its own or to which species are adapted to unsanitary landfills. We investigated tree invasion status and growth patterns of commercially available tree species on unsanitary landfills and evaluated whether these species should be selected for planting.

Methods

Site Description

This study was conducted in landfills at Bunsuri, Dugiri, Gomaeri, Hasanundong, Kyongseodong, Mojeonri, and Shindaedong. All of these sites are located in the province of Gyeonggi in the west-central region of the Korean peninsula (37°00′ to 37°46′ latitude, 126°39′ to 127°29′ longitude; Figure 1). The elevation of the study sites ranges from 3 to 47 m asl. Further details of the study sites are provided in Table 1. The Mojeonri landfill closed most recently (5.25 years ago), and the other waste landfills closed between 5.75 and 9.33 years ago (Table 1). The size of the waste landfills ranged from 600 to 22,000 ha (Table 1), and all of them had accepted domestic wastes. All of the sites had been left unattended after landfilling, except Hasanundong, which was landscaped with grass hydroseeding for general amenity purposes. All landfills were surrounded, in the main, by forests, although Dugiri, Kyongseodong, and Shindaedong had fields, a lake, a river, reclaimed lands, and paddy fields in their surrounding areas (Table 1). All sites were covered with topsoil and subsoil from the nearest forest edges or construction subsoils to a depth of 0.6 m (Table 5). Kyongseodong, where a growth comparison experiment was conducted, was closed 7.25 years ago; it is located on reclaimed land in Incheon, South Korea. General refuse filling was completed at this site in the winter of 1992. After closure, 2 m of soil was placed over the refuse as a final cover on the plateau, while the fill depth on other slopes was 0.6 m (Table 5). The reference sites for the growth comparison were the nursery stands of the Forest Environment Research Station at Osan (Figure 1). This area has been landfilled to a depth of 2 m over paddies and fields since 1995. Both paddies and fields were reclaimed and mixed prior to landfilling. The area of the nursery stands totals ca. 1.8 ha.

The mean annual temperature at the study sites is 11 to 13°C; it is lower in the mountainous areas of the northeast and higher in the coastal areas and wide plains of the southwest. In a typical January, the temperature decreases further inland and the daily difference in temperature on any given day increases. Mean annual precipitation in the area is about 1100 mm. All study sites experience a temperate climate (Gyeonggi Provincial Government 2004).

Growth Measurement of Naturally Occurring Trees on Unsanitary Waste Landfills

Tree plot surveys were performed for *Robinia pseudoacacia* (black locust), *Populus sieboldii*, and *Salix koreensis* stands because visual examination indicated

Table 1. Characteristics of the study sites

Waste landfill sites	Closure time (elapsed time after closure)	Size (ha)	Elevation (m)	Land use status	Neighboring habitats	Plot numbers established	Tree species number invaded naturally
Bunsuri	1993 Dec. (6.25 years)	900	4	Idle land	Forest	1	3
Dugiri	1993 Dec. (6.25 years)	1000	3	Idle land	River and fields	3	4
Gomaeri	1993 Mar. (6.41 years)	1100	9	Idle land	Forest and lake	1	3
Hasanundong	1994 June (5.75 years)	6500	47	Idle land	Forest	6	5
Kyongseodong	1992 Dec. (7.25 years)	22000	27	Idle land	Reclaimed land	3	3
Mojeonri	1994 Dec. (5.25 years)	1500	8	Idle land	Forest	7	5
Shindaedong	1990 Apr. (9.33 years)	600	5	Idle land	River and paddy fields	8	3

that these were the dominant species on the landfills. Identification and nomenclature follow Lee (1999).

We established 10 × 10-m plots in subjectively selected, well-vegetated sites at which trees dominated and the grass layer was poorly developed. Tree height, diameter at breast height (DBH), and number of all tree species were measured from August to October 1999. Growth estimates were made based on the measured tree height and DBH. The height criterion for distinguishing the tree layer from the shrub or grass layer was 2 m. Trees $\leq$ 1 m tall were considered seedlings and were counted. The number of plots differed per site because tree invasion was minimal and trees were distributed unevenly (Table 2). DBH values were converted to basal area for coverage estimation.

The patch structure of black locust was investigated in October 2000. Black locust formed patches with separate canopies all across the landfills; these patches were assumed to have become established mainly by vegetative propagation, because digging revealed that all individuals within a patch were connected by subterranean stems (personal communication with landfill managers). Therefore, it was thought that the tallest black locust growing at the center of each patch was the mother plant, from whose roots all other individuals grew adventitiously. Patches established by seed dispersal were excluded, because black locust has a very low seed germination rate, owing to its impermeable seed coat (Converse 1984). We measured height, DBH_{20} (diameter at 20 cm above ground), and distance of all black locusts from the mother plant in each patch, using an aluminum ruler (centimeter scale) and vernier calipers (millimeter scale; Wyckoff and Webb 1996). Individuals $\leq$ 1 m tall were treated as seedlings and counted, and their distances from the mother plant were measured to estimate future growth trends of black locusts. In total, we surveyed 12 patches: 10 in Kyongseodong, 1 in Bunsuri, and 1 in Mojeonri.

Comparison of Growth of Commercial Trees on Unsanitary Landfills

Eleven woody species were selected for screening on the basis of their commercial ubiquity and aesthetic landscaping value: *Acer palmatum*, *Albizzia julibrissin*, *Buxus microphylla* var. *koreana*, *Ginkgo biloba*, *Hibiscus syriacus*, *Koelreuteria paniculata*, *Ligustrum obtusifolium*, *Liriodendron tulipifera*, *Pinus koraiensis*, *Pinus thunbergii*, and *Sophora japonica*. Among the seven landfills, Kyongseodong was selected for tree planting because it was relatively secluded, it was the largest of the selected landfills, and it had a plateau suitable for planting. We planted 220 individuals (20 replicates of 11 species) at Kyongseodong and at a reference site in March 1997. The planting area was located on the plateau of the landfill. Sandy subsoil was filled to a depth of 2 m over the experimental landfill area to reduce the bulk density (0.83 to 1.46 g/cm^3) and to enhance drainage, after digging up the original soil cover down to 2 m. The areas that were planted in the landfill and at the reference site were flat. Trees were planted in a nested design in two plots (landfill and reference), with 20 quadrats nested within each plot, and one tree of each of the 11 species nested within each quadrat. Finally, 20 replicates of each species were planted at ~5-m intervals along a line transect. The reference sites were landfill sites covered with soil over paddies and fields at the Forest Environment Research Station, Osan (Figure 1). The reference sites were chosen because they shared similarities with respect to cover layer depth (2 m), easy access, and minimal anthropogenic disturbance. Identical individuals of the same tree species were planted at the reference site in March 1997. Tree heights were measured with an aluminum ruler (centimeter scale) in October 2000. To compare twig shoot extension, the five longest shoots were selected from each of 20 trees. The length from the 1999 bud scale scar to the apical bud that developed in fall 2000, when the plants stopped growing, was measured. Using ver-

Table 2. Tree composition and stand attributes within plots subjectively positioned to survey naturally growing trees on landfills

Species	Density (No./ha)	Relative density	Mean DBH (average ± SE; cm)	Basal area (m^2/ha)	Relative dominance
Tree					
Robinia pseudoacacia	769	34.1%	3.59 ± 0.21	1.51	53.7%
Salix koreensis	310	13.8%	4.76 ± 0.42	0.97	34.4%
Populus sieboldii	155	6.9%	2.40 ± 0.30	0.11	3.9%
Morus alba	31	1.4%	2.19 ± 0.35	0.01	0.4%
Ailanthus altissima	10	0.4%	4.72 ± 1.76	0.02	0.8%
Paulownia coreana	7	0.3%	1.7[a]	<0.01	<0.1%
Populus deltoides	4	0.2%	1.8[a]	<0.01	<0.1%
Diospyros kaki	4	0.2%	1.5[a]	<0.01	<0.1%
Albizzia julibrissin	4	0.2%	2.67[a]	<0.01	<0.1%
Shrub					
Amorpha fruticosa	531	23.6%	1.48 ± 0.05	0.12	4.1%
Lespedeza cyrtobotrya	200	8.9%	1.52 ± 0.12	0.03	1.2%
Lespedeza maximowiczii	159	7.1%	1.34 ± 0.07	0.02	0.8%
Lespedeza bicolor	69	3.1%	1.39 ± 0.08	0.01	0.4%
Total	2253			2.82	

[a]Only one individual was found and measured.

nier calipers, we measured stem diameters five times, at five different angles (0°, 72°, 144°, 216°, 298°) from due north of the fixed marked height of each tree, in March and October 2000. *Buxus microphylla* var. *koreana* and *Pinus koraiensis* were measured at 5 and 10 cm from ground level, respectively, and the remaining nine species were measured at 20 cm from the base of the trunk. Stem diameters were converted to stem areas. The difference between March and October measurements was assumed to be diameter growth within a finite period. Based on diameter data, relative growth rates (RGRs) were calculated following Equation (1) below (Norgren 1996), and compared between landfills and the reference site.

$$\text{RGR(relative growth rate)} = \frac{(\ln W_2 - \ln W_1)}{(t_2 - t_1)} \quad (1)$$

where W is the diameter at a specific height and t is the elapsed time.

Shoot extension ratio, diameter growth ratio, and total ratio of each species were calculated as follows:

$$\text{Shoot extension ratio (SER)} = \text{shoot extension rate in a landfill relative to that in reference site} \quad (2)$$

$$\text{Diameter Growth Ratio (DGR)} = \text{diameter growth rate in a landfill relative to that in reference site} \quad (3)$$

$$\text{Total ratio(TR)} = \text{SER} + \text{DGR} \quad (4)$$

Mortality was calculated by dividing the number of dead individuals by the number of individuals planted initially (20). Trees with dried apical parts and no leaves were considered dead.

Soil Analysis

In September 2001, we established 0.25-m^2 square quadrats at 5-m intervals along each line transect, perpendicular to seven landfill edges and nearest forest edges (controls), to measure the physical and chemical properties of the soil (Jose and others 1996). If the area of the landfill was >6500 ha, two line transects were set up in parallel at a certain distance along the shorter axis of the landfill, and if the area was <6500 ha, two line transects were laid out perpendicular to each other. Surface soils were removed from randomly selected locations within each quadrat by scraping the surface to a depth of 10 cm with a sterile hand shovel. Large organic debris was removed from the samples before they were placed in vinyl bags and transported to the laboratory. The samples were air-dried at room temperature in the shade. Soil moisture content and bulk density were measured according to Allen (1974) and Page and others (1982), and sand, silt, and clay contents were analyzed by the hydrometer method (Sheldrick and Wang 1993). Soil pH and conductivity measurements were made by shaking 5 g of dried material in 25 ml of distilled water for 1 hr. The resulting solutions were then measured using a pH meter (Fisher 230A) and a conductivity meter (Philips PW9509/20). Organic matter content was quantified following the Wakley-Black method (Page and others 1982), and total N and available P were measured with the Kjeldahl method and the Bray No. 1 method, respectively (Page and others 1982). Exchangeable cations (Ca, K, Mg, and Na) were extracted with a 1 *N* ammonium acetate solution for atomic absorption spectrophotometer analyses (Page and others 1982). Soils were acidified with 0.1 *N* hydrogen chloride prior to analysis by a Model ICP-1000 IV ICP emission spectrometer for Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn. The soils were sampled at a depth of 10 cm, at 10 points, in 14 sites, selected randomly within plots at Kyongseodong and the reference site, at which commercial trees were planted. These soils were pooled in bags on a sampling point basis, dried for 2 weeks, and then sieved through 2-mm mesh ($N = 14$). Total N, available P, and exchangeable cations (Ca, K, Mg, and Na) were analyzed.

Statistical Analysis

All data were analyzed using SAS ver 6.12 (SAS Institute 1985). The density of black locust and the chemical content of soils were compared by a Wilcoxon rank sum test. This nonparametric test was chosen because the data did not fit a normal distribution. Regression analysis was conducted to examine the relationships between height, DBH_{20}, and the distance of all black locusts from the mother plant. A Spearman rank correlation test was conducted to compare the relationship between black locust patch diameter and the number of regenerated sprouts. Because the quadrat numbers were unequal among the landfill sites, we used the GT2 method to test all differences in soil physical and chemical properties (Sokal and Rohlf 1995).

Results

Growth of Naturally Occurring Trees

In total, 20 plots were surveyed for trees. Because trees were unevenly distributed, the plots were established in clumped patches. *Robinia pseudoacacia* dominated the canopy layer in 14 plots, and *Salix koreensis* and *Populus sieboldii* dominated the canopy layers in the remaining 15 plots. Therefore, the populations of trees on the waste landfills were divided into three groups: *Robinia pseudoacacia*, *Salix koreensis*, and *Populus sieboldii*. *Robinia pseudoacacia* had the highest density, at 769 individuals per ha (Table 2). Following black locust, the decreasing order of tree density was: *Salix koreensis*, *Populus sieboldii*, *Morus alba*, *Ailanthus altissima*, *Paulownia coreana*, *Populus deltoides*, *Diospyros kaki*, *Albizzia julibrissin*. The decreasing order of shrub density was: *Amorpha fruticosa*, *Lespedeza cyrtobotrya*, *Lespedeza maximowiczii*, *Lespedeza bicolor*. *Salix koreensis* had the highest DBH values among the trees and showed the greatest diameter growth (4.76 ± 0.42). *Ailanthus altissima* and *R. pseudoacacia* showed the second and the third highest diameter growth (Table 2). The basal area of *R. pseudoacacia* was the highest (1.51 m^2/ha), covering approximately 54% of the basal area of all trees (Table 2); black locust also had the highest number of seedlings (301/ha), followed by *Populus sieboldii* (238/ha). For shrubs, *Lespedeza cyrtobotrya* produced more seedlings (23/ha) than *Amorpha fruticosa* and *Lespedeza maximowiczii* (Figure 2).

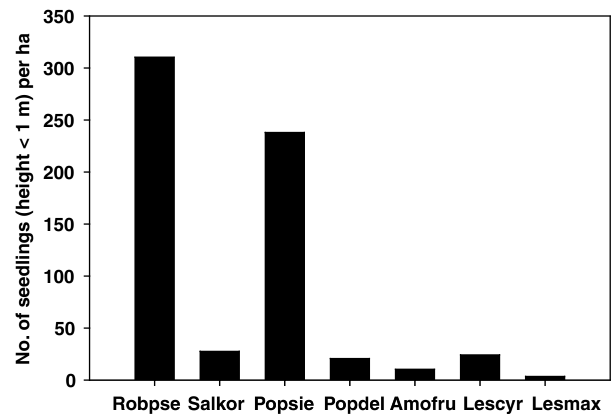

Figure 2. Numbers of tree and shrub seedlings by species. Robpse, Salkor, Popsie, Popdel, Amofru, Lescyr, and Lesmax represent *Robinia pseudoacacia*, *Salix koreensis*, *Populus sieboldii*, *Populus deltoides*, *Amorpha fruticosa*, *Lespedeza cyrtobotrya*, and *Lespedeza maximowiczii*, respectively. The other four study species are not shown here because they produced no seedlings.

Black Locust Patches

Of the 14 plots in which *R. pseudoacacia* dominated the canopy layer, the number of individuals >1 m tall was significantly higher in landfills over 7 years old (Kyongseodong and Shindaedong) than in landfills between 5 and 7 years old (Hasanundong and Mojeonri; Wilcoxon rank sum test, $P < 0.05$; Figure 3). Similarly, the number of individuals <1 m tall was higher in landfills over 7 years old than in landfills between 5 and 7 years old, although the number of seedlings showed no significant differences. Twenty-three patches of black locust were observed at Kyongseodong. The regression analysis between height and DBH of *R. pseudoacacia* and distance from the mother plant showed significant decreasing trends in height and DBH with increased distance from each mother plant ($P < 0.05$; Figure 4). The distance from the mother plant to the patch edge ranged from 3.71 m to

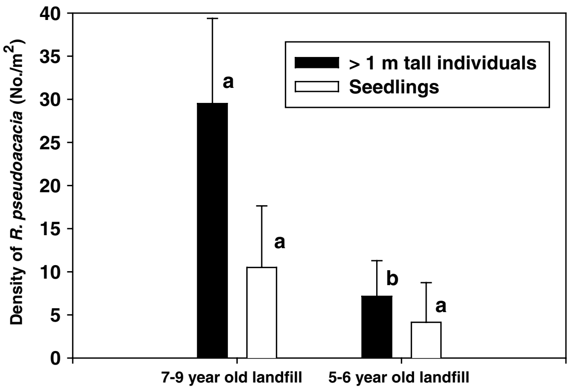

Figure 3. Density of *Robinia pseudoacacia* in 10 × 10—m^2 stands (black bar, $n = 4$; white bar, $n = 7$). Dissimilar letters above bars indicate significant differences based on a Wilcoxon rank sum test ($P < 0.05$).

11.29 m. Regenerated twigs and seedlings <1 m tall tended to become taller with increased patch diameter, but these relationships were not significant (Spearman rank correlation: $P > 0.05$).

Stem Growth Estimates of Planted Trees

Pinus thunbergii showed the greatest ratio of shoot extension rate in waste landfills to that in the reference (2.86; Table 3). In other species, this ratio decreased in the following order: *Liriodendron tulipifera*, *Albizzia julibrissin*, *Ligustrum obtusifolium*, *Pinus koraiensis*, *Sophora japonica*, *Buxus microphylla* var. *koreana*, *Hibiscus syriacus*, *Koelreuteria paniculata*, *Acer palmatum*, and *Ginkgo biloba* (Table 3). *Liriodendron tulipifera* had the highest ratio of diameter growth rate in waste landfills to that in the reference site (1.74). The ratio of diameter growth in other species decreased in the following order: *Pinus thunbergii*, *Pinus koraiensis*, *Ligustrum obtusifolium*, *Albizzia julibrissin*, *Hibiscus syriacus*, *Acer palmatum*, *Buxus microphylla* var. *koreana*, *Koelreuteria paniculata*, *Ginkgo biloba*, and *Sophora japonica* (Table 3). *Pinus thunbergii* had the highest mortality rate, followed by *Pinus koraiensis*, *Buxus microphylla* var. *koreana*, *Koelreuteria paniculata*, and *Acer palmatum*. All individuals of the remaining six species survived (Table 3). The total ratio, calculated by adding the shoot extension ratio to the diameter growth ratio to compare growth ability, decreased in the following order: *Liriodendron tulipifera* (4.26), *Pinus thunbergii* (4.14), *Albizzia julibrissin* (2.59), *Pinus koraiensis* (2.3), *Ligustrum obtusifolium* (2.3), *Buxus microphylla* var. *koreana* (1.42), *Hibiscus syriacus* (1.38), *Sophora japonica* (1.30), *Koelreuteria paniculata* (1.00), *Acer palmatum* (0.95), *Ginkgo biloba* (0.72; Table 3). Therefore, *Liriodendron tulipifera* showed the best

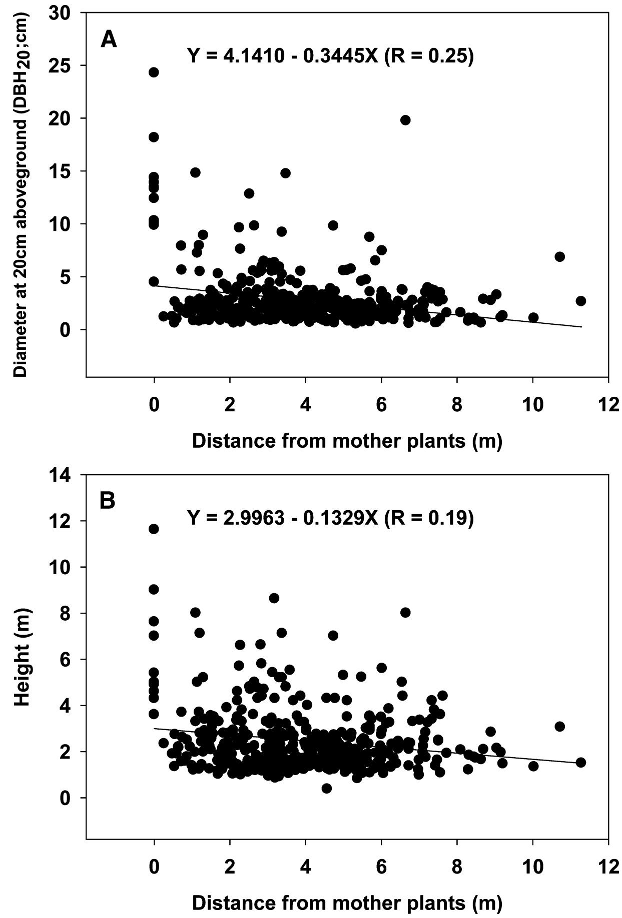

Figure 4. Distribution of *Robinia pseudoacacia* with increasing distance from the mother plant. A total of 12 black locust patches was analyzed. The equation in the upper corner represents a linear regression equation.

growth on the landfills relative to the reference site. No trees died in the reference plot during the 3-year study. Relative to other trees at Kyongseodong, *Sophora japonica* showed the greatest height growth over 2 years (121.7 cm; Table 3). The height growth in other species was as follows: *Albizzia julibrissin* (80.6 cm), *Pinus thunbergii* (50.2 cm), *Liriodendron tulipifera* (33.4 cm), *Hibiscus syriacus* (32.9 cm), *Ligustrum obtusifolium* (31.8 cm), *Pinus koraiensis* (18.3 cm), *Acer palmatum* (16.3 cm), *Buxus microphylla* var. *koreana* (6.3 cm). We measured little height growth in *Koelreuteria paniculata* and *Ginkgo biloba* over 2 years (Table 3).

Soil Conditions

Soil moisture content and bulk density at Hasanundong, Mojeonri, and Shindaedong were significantly higher than they were at the other three landfills ($P < 0.05$; Table 5). Soil textures of the landfill and

Table 3. Total height, height growth, shoot extension, and diameter (means ± SE) of 11 woody species at the Kyongseodong landfill and the reference site. Mean shoot extension, diameter growth ratio, and total ratio of Kyongseodong to the reference site, as well as mortality in 2000, are presented. Mortality was calculated by dividing the number of dead individuals by the number of individuals planted initially (20).

Species	Total height[a] (cm)	Height growth[b] (cm)	Shoot extension at the landfill[c] (cm)	Shoot extension at the reference site[d] (cm)	Relative diameter growth rate at the landfill[e] (× 1000 mm/days)	Relative diameter growth rate at the reference site[f] (× 1000 mm/days)	Shoot extension ratio[g]	Diameter growth ratio[h]	Total ratio[i]	Mortality (%)
Liriodendron tulipifera	191.2 ± 5.7	33.4	12.13 ± 0.06	4.81 ± 0.19	1.58 ± 0.17	0.90 ± 0.20	2.52	1.74	4.26	0
Pinus thunbergii	118.4 ± 5.8	50.2	28.18 ± 1.87	9.84 ± 0.51	1.63 ± 0.27	1.28 ± 0.35	2.86	1.28	4.14	60
Albizzia julibrissin	249.9 ± 11.1	80.6	33.18 ± 1.23	19.70 ± 1.10	2.01 ± 0.16	2.22 ± 1.06	1.68	0.91	2.59	0
Pinus koraiensis	120.6 ± 5.7	18.3	17.79 ± 1.23	15.12 ± 0.61	1.32 ± 0.12	1.18 ± 0.11	1.18	1.12	2.30	35
Ligustrum obtusifolium	165.9 ± 4.7	31.8	17.19 ± 1.04	13.03 ± 0.74	0.84 ± 0.24	0.86 ± 0.13	1.32	0.98	2.30	0
Buxus microphylla var. *koreana*	32.2 ± 1.9	6.3	5.56 ± 1.22	5.24 ± 0.21	1.13 ± 0.45	3.18 ± 0.20	1.06	0.36	1.42	15
Hibiscus syriacus	130.3 ± 5.0	32.9	15.90 ± 0.66	18.01 ± 1.20	0.93 ± 0.11	1.88 ± 0.16	0.88	0.50	1.38	0
Sophora japonica	183.4 ± 7.5	121.7	25.71 ± 1.73	22.62 ± 0.91	0.45 ± 0.21	3.91 ± 0.18	1.14	0.16	1.30	0
Koelreuteria paniculata	107.6 ± 8.9	-[j]	7.18 ± 0.80	10.97 ± 1.42	0.28 ± 0.19	0.82 ± 0.18	0.66	0.34	1.00	10
Acer palmatum	160.0 ± 7.5	16.3	13.22 ± 0.87	23.61 ± 0.80	0.63 ± 0.22	1.60 ± 1.04	0.56	0.39	0.95	5
Ginkgo biloba	125.9 ± 5.1	-[j]	12.46 ± 0.45	26.41 ± 1.16	0.31 ± 0.07	1.23 ± 0.09	0.47	0.25	0.72	0

[a]Total height was measured on Kyongseodong landfill after 3.6 years since plantings.
[b]Height growth was the differences of tree height for 2 years between 1998 and 2000.
[c]Twig shoot growth between 1999 and 2000 on Kyongseodong landfill.
[d]Twig shoot growth between 1999 and 2000 on Osan landfill, a reference site.
[e]Relative diameter growth rate between March and October on Kyongseodong landfill.
[f]Relative diameter growth rate between March and October on Osan landfill, a reference site.
[g]Shoot extension ratio is the value of shoot extension at landfill divided by shoot extension at reference site.
[h]Diameter growth ratio is the value of diameter growth at landfill divided by diameter growth at reference site.
[i]Total ratio is shoot extension ratio added to diameter growth ratio.
[j]This species showed little height or diameter growth.

reference sites were sandy loam, and the pH of soils at most landfills except Mojeonri indicated low acidity (Table 5). The soil at Kyongseodong had the highest conductivity (Table 5), while the organic matter content was highest in the soils at the reference site. Total N content of Kyongseodong and the control were significantly higher than at the other six landfills ($P < 0.05$; Table 5). Available P did not show significant differences among landfills and the control (Table 5), and Kyongseodong had the highest Na content (Table 5). Cr, Cu, and Zn content of the soils did not differ between the landfills and the control (Table 5). Total N and available P content of soils were significantly higher in the reference plot than in the landfill plots within which growth comparisons of trees were made ($P < 0.01$). Na, Mg, K, and Ca content of the soils were similar in all plots.

Discussion

Plantings

Recently, many studies have screened native species for revegetating newly restored landfills in other countries (Chong and Chu 2002). Closed landfills in Hong Kong have been converted into a contained form, no longer affected by landfill factors such as gas and leachate contamination. However, most waste landfills in developing countries are unsanitary and are detrimentally affected by landfill factors. The restoration of these uncontrolled landfills is a complicated scientific and technical problem, because of the heterogeneous processes that take place inside the waste mass (Mavropoulos and Kaliampakos 1999). Without a landfill cap, trees on unsanitary landfills are susceptible to direct influences of the refuse. Soil compaction, waterlogging, drought, shallow soil, and poor soil quality are primary causes for poor tree growth on unsanitary landfills (Dobson and Moffat 1999). In this study, the DBH of all trees used in the growth comparison ranged from 0.5 to 2.0 cm. This size is considered suitable for planting on unsanitary landfills.

Characteristics of Black Locust That Facilitate Adaptation to Unsanitary Landfills

Black locust formed characteristic patches and was a dominant species on the unsanitary landfills. This species is widespread on landfills and has been recommended for revegetating landfills in other countries (Robinson and Handel 1995; Marton 1996). This tree is often used for revegetation, as a restoration species for surface mining, and for timber production (Batzli and others 1992), as it shows fast growth with a short life span (Boring and Swank 1984). Moreover, this species is being considered for remediating environmental pollution and has been recommended for revegetating polluted areas (Cho 1999; Woo and others 1997). Black locust invades via the distribution of bud banks and grows clonally, spreading concentrically. This concentric spread pattern occurs in the absence of a mediator that would otherwise spread a plant (Robinson and Handel 2000). Black locust patches play structural and functional roles in unsanitary landfills because their connected subterranean roots reduce soil erosion and provide nitrogen. Productivity of black locust is strongly correlated with meteorological factors, such as rainfall, and the nitrogen content of the soil (Converse and Betters 1995). The nitrogen content of soils in black locust patches is enhanced by the nitrogen-fixing capacity of this species. Black locusts require initial nitrogen for growth, but the nitrogen content of soils in unsanitary landfills is very low. Nitrogen is a limiting element for tree growth (Panagopoulos and Hatzistathis 1995), and a nitrogen content of 0.2% is beneficial to plants (Wilde 1958). The nitrogen content of the landfill soils ranged from 0.054 to 0.143% (Table 5; Kim 2001). This minimal level of mineral N is needed to support the nodulation of black locust (Reinsvold and Pope 1987). Because black locust is adaptable to dryness, grows fast, and has the ability to fix nitrogen (Converse and Betters 1995), it occupies a broad ecological niche (Maekawa and Nakagoshi 1997). Moreover, black locust displays fast initial growth, intense sprouting, and rapid nitrogen enrichment (Panagopoulos and Hatzistathis 1995).

The roots of black locust sprout profusely in disturbed areas (Boring and Swank 1984; Hong and Song 1990); therefore, it is assumed that it is the most adaptable species in unsanitary landfills. However, black locust grows gradually, and if it reaches an inert refuse layer, its roots die off (Dobson and Moffat 1999), although saplings from its upper parts may resprout from clonal growth. Black locusts planted in forests are strongly competitive with oaks. However, as a helophytic species, it seldom invades forests, although it can colonize disturbed sites (Yun and others 1999). It is thought that the black locust community in forest ecosystems near urban areas eventually succeeds to a *Quercus mongolica* community (K. Lee and others 1996); however, oaks rarely invade landfills. Black locust has a high mortality rate because of landfill pollution sources, which decrease the stability of vegetation in the waste landfills. Therefore, if the evergreen *Pinus densiflora* is mixed with the deciduous black locust, it will improve the landscape. A mixed plantation at a ratio of 60:40 (black locust: an evergreen conifer adapted to landfills) will result in rapid landfill restoration (Panagopoulos and Hatzistathis 1995).

Comparison of Species Recommended in Other Countries

Many tree species have been recommended for sanitary waste landfills in other countries (Table 4). These different species were chosen because of climate and geographical adaptations to the study area. Common factors to consider in sanitary landfills are the shallowness of the roots, tolerance to dryness, and high adaptability. Pollution tolerance is necessary on unsanitary waste landfills, owing to uncontrolled pollution levels. In this study, *Pinus thunbergii*, *Pinus koraiensis*, and *Buxus microphylla* var. *koreana* showed high transplant mortality and lower survival rates on unsanitary landfills (Table 3), although *Pinus thunbergii* could be recommended as an adaptable species if transplant stress is mitigated (Table 4). Although these results are restricted to temperate regions of Korea, growth comparisons of trees on unsanitary landfills are available for many other developing countries.

Soil Characteristics and Landfill Gases in Unsanitary Waste Landfills

The significantly higher conductivity value at Kyongseodong was thought to result from a higher Ca, Mg, and Na content in the soil (Table 5). Anaerobic decomposition of organic materials in the cover layer increases the CO_2 and CH_4 content (Gilman and others 1976). Other gases such as H_2S, NH_3, amine, and mercaptane are also produced. These gases move horizontally, seep through the sides of unsanitary landfills, and impede tree growth. The anaerobic conditions of the waste landfills may concentrate heavy metals in these soils (Tosh and others 1994); Fe, Mn, Cu, and Zn are consistently higher in anaerobic soils than in aerobic soils (Duell and others 1986). The gases and increased Fe, Mn, Cu, and Zn concentrations in soil systems of landfills have detrimental effects on tree growth (Gilman and others 1981). While the leachates generated from domestic landfills contain small amounts of heavy metals (Kim and others 1997), the primary source of heavy metals in surface soils of unsanitary landfills is likely to be the presence of leachates, in addition to the use of previously contaminated cover soils. Some studies have shown that leachates from unsanitary landfills such as Nanjido are highly toxic and represent complex mixtures of numerous toxic compounds (Kaur and others 1996). Leachates from unsanitary landfills can form streams and pools that continuously seep from the sides because of the uncontrolled nature of these landfills. However, no studies have evaluated the impact of such leachates on surface soils and vegetation. In this study, we showed that the Fe content of unsanitary landfill soils was significantly higher than that of control soils, whereas the Mn, Cu, and Zn concentrations were similar to control soils (Table 5). If the soils in landfills contain gases, then the Fe and Zn concentrations of the soils increase more than in landfill soils without gases (Leone and others 1979). If landfill gases replace O_2, and microorganisms using O_2 are active, then the soils become reductive; this results in an increase in the concentration of microelements, including Fe and Zn (Leone and others 1979). The concentrations of CH_4 and CO determined from the outlets of 42 ventpipes at Nanjido, an unsanitary landfill, were 7.31 ± 2.75 and 1.40 ± 1.21 ppm, respectively (Kim and others 2002). The analyzed concentrations of H_2S and NH_3 after adsorption onto activated carbon at the same landfill were 0.2-1.9 ppb and 0.25-0.5 ppm, respectively (S. Lee and others 1996). Hybrid poplars on landfills with a high gas content (CO_2, 12.8%; CH_4, 4.8%; and O_2, 12.1%) died from the gases of anaerobic refuse decomposition (Gilman and others 1982). Therefore, it is thought that the concentrations of landfill gases are high in local parts of unsanitary landfills, and that they may impact tree germination and growth.

Considerations for the Restoration of Unsanitary Waste Landfills

Any one growth parameter cannot adequately describe the growth of trees in landfills and control sites, and different results may be derived based on which growth parameters and season are measured (Gilman and others 1981). However, length and diameter growth are good indices of plant growth conditions and were used as tree growth parameters in this study. The high temperature and low soil moisture content of landfill soils have stressful effects on plants. Soil bulk densities ranging from 1.25 to 1.6 g/cm^3 restricted root growth and suppressed tree growth. Soil compaction has an effect on the vertical distribution of roots, which grow in the uppermost layer of the soil (Gilman and others 1987), and soil dryness decreases the effects of soil compaction on the hydraulic conductivity of roots. If bulk density increases by 0.1 g/cm^3, height growth of trees decreases by 5% and volume growth decreases by 5% (Dobson and Moffat 1999). Therefore, after a landfill has stabilized, it is necessary to till it with excavators. The bulk density of soils in Kyongseodong exceeded 1.25 g/cm^3 in parts but was typically <1.25 g/cm^3. Except at Bunsuri and Dugiri, however, the bulk density of all remaining

Table 4. Trees recommended for revegetating landfills in other countries

Scientific name	Common name	Specific condition	Reference
Acacia confusa	Formosa acacia	Completed sanitary landfill, subtropical region	Chan and others (1991); Chan (1997)
Acer platanoides	Norway maple	adequate soil cover	Marton (1996)
Aesculus hippocastanum	Horse chestnut	Completed landfill containment sites, substrate aerobic for at least 1 meter	Crook (1992)
Ailanthus altissima	Tree of heaven	adequate soil cover	Marton (1996)
Albizzia lebbek	Womans tongue tree	Completed sanitary landfill, subtropical region	Chan and others (1991)
Alnus glutinosa	Alder	Completed landfill containment sites, substrate aerobic for less than 0.5 meter	Crook (1992)
Alnus incana	Grey alder	Completed landfill containment sites, substrate aerobic for less than 0.5 meter	Crook (1992)
Betula pendula	Silver birch	Completed landfill containment sites, substrate aerobic for less than 0.5 meter	Crook (1992)
Betula pubescens	Hairy birch	Completed landfill containment sites, substrate aerobic for less than 0.5 meter	Crook (1992)
Carpinus betulus	Hornbeam	Completed landfill containment sites, substrate aerobic for at least 1 meter	Crook (1992)
Casuarina equisetifolia	Ironwood	Completed sanitary landfill, subtropical region	Chan (1997)
Fagus silvatica	Beech	Completed landfill containment sites, substrate aerobic for at least 1 meter	Crook (1992)
Fraxinus chinensis	Chinese ash	Earth layer 60 cm thick	Wanru and others (1994)
Fraxinus excelsior	Ash	Completed landfill containment sites, substrate aerobic for at least 1 meter	Crook (1992); Simmons (1999)
Ginkgo biloba	Ginkgo	Total cover on the landfill to approximately 60 cm	Gilman and others (1981)
Leucaena leucocephala	Wild tamarind	Completed sanitary landfill, subtropical region	Chan and others (1996)
Ligustrum lucidum	Glossy privet	Earth layer 60 cm thick	Wanru and others (1994)
Melia azeclarach	Chinese ash	Earth layer of 60 cm thick	Wanru and others (1994)
Nyssa sylvatica	Black gum	Total cover on the landfill to approximately 60 cm	Gilman and others (1981)
Picea abies	Norway spruce	Adequate soil cover	Marton (1996)
Picea pungens	Colorado spruce	Adequate soil cover	Marton (1996)
Pinus strobus	Eastern white pine	Adequate soil cover	Marton (1996)
Pinus thunbergii	Black pine	Total cover on the landfill to approximately 60 cm	Gilman and others (1981)
Platanus × *acerifolia* London	Plane tree	Adequate soil cover	Marton (1996)
Prunus avium	Gean cherry	Completed landfill containment sites, substrate aerobic for at least 1 meter	Crook (1992)
Prunus padus	Bird cherry	Completed landfill containment sites, substrate aerobic for at least 1 meter	Crook (1992)
Psuedotsuga mensiesii	Douglas fir	Completed landfill containment sites, substrate aerobic for at least 1 meter	Crook (1992)
Quercus palustris	Pin oak	adequate soil cover	Marton (1996)
Quercus petraea	Sessile oak	Completed landfill containment sites, substrate aerobic for at least 0.5 meter	Crook (1992)
Quercus robur	Pedunculate oak	Completed landfill containment sites, substrate aerobic for at least 0.5 meter	Crook (1992)
Robinia pseudoacacia	Black locust	adequate soil cover; earth layer 60 cm thick	Marton (1996); Wanru and others (1994)
Salix alba	White willow	adequate soil cover	Marton (1996)
Sorbus alba	Whitebeam	Planted as nurse species	Simmons (1999)
Taxus cuspidate	Japanese yew	adequate soil cover	Marton (1996)
Tristania conferta	Brisbane box	Completed sanitary landfill, subtropical region	Chan and others (1991)

Table 5. Soil physical and chemical characteristics (means ± SE) of landfills in Bunsuri, Dugiri, Gomaeri, Hasanundong, Kyongseodong, Mojeonri, and Shindaedong, South Korea (pooled quadrats; n = 3 to 41). Different superscripts within rows indicate values that are significantly different among landfills and controls ($P < 0.05$; GT2 method).

	Sites							
Soil characteristics	Bunsuri	Dugiri	Gomaeri	Hasanundong	Kyongseodong	Mojeonri	Shindaedong	Control
Fill depth (m)	0.6	0.6	0.6	0.6	0.6 (2 m in the plateau)	0.6	0.6	-[2]
Soil moisture content (%)	$8.59^{a} \pm 2.30$	$10.64^{a} \pm 1.03$	$15.50^{a} \pm 1.69$	$13.03^{b} \pm 0.55$	$4.63^{a} \pm 0.32$	$17.87^{b} \pm 0.90$	$22.40^{b} \pm 2.48$	-[2]
Bulk density (g/cm^3)	$0.90^{a} \pm 0.06$	$0.95^{a} \pm 0.00$	$1.29^{a} \pm 0.01$	$1.48^{b} \pm 0.01$	$1.21^{a} \pm 0.01$	$1.30^{b} \pm 0.02$	$1.37^{b} \pm 0.03$	-[2]
Sand[1] (%)	80.0	83.4	75.6	83.9	70.4	72.6	79.1	67.9 ± 4.2
Silt[1] (%)	10.1	4.1	12.0	6.4	14.5	12.8	7.1	14.9 ± 2.1
Clay[1] (%)	9.9	12.5	12.4	9.7	15.1	14.6	13.8	17.1 ± 2.5
pH	$7.91^{a} \pm 0.04$	$6.38^{a} \pm 0.42$	$7.00^{a} \pm 0.42$	$6.14^{a} \pm 0.66$	$7.83^{a} \pm 0.14$	$5.67^{b} \pm 0.75$	$7.94^{a} \pm 0.11$	$4.50^{c} \pm 0.15$
Conductivity (μS/cm)	$147.3^{a} \pm 20.3$	$106.0^{a} \pm 5.1$	$90.4^{a} \pm 25.8$	$89.0^{a} \pm 7.5$	$435.9^{b} \pm 134.7$	$65.3^{a} \pm 7.4$	$160.5^{a} \pm 28.0$	$63.8^{a} \pm 4.0$
Organic matter content (%)	$0.45^{a} \pm 0.08$	$1.03^{a} \pm 0.20$	$1.58^{a} \pm 0.26$	$3.25^{a} \pm 0.30$	$0.58^{a} \pm 0.09$	$0.75^{a} \pm 0.27$	$1.75^{a} \pm 0.32$	$5.20^{b} \pm 0.51$
Total N (%)	$0.059^{a} \pm 0.014$	$0.077^{a} \pm 0.009$	$0.055^{a} \pm 0.011$	$0.118^{a} \pm 0.019$	$0.143^{b} \pm 0.015$	$0.054^{a} \pm 0.009$	$0.116^{a} \pm 0.010$	$0.199^{b} \pm 0.018$
Available P (mg/kg)	$8.00^{a} \pm 2.13$	$14.23^{a} \pm 3.18$	$2.80^{a} \pm 0.74$	$7.85^{a} \pm 1.07$	$7.57^{a} \pm 0.56$	$8.13^{a} \pm 1.72$	$12.55^{a} \pm 1.85$	$11.80^{a} \pm 2.79$
Ca (mg/kg)	$1955.3^{a} \pm 231.8$	$1153.1^{ab} \pm 281.6$	$1093.8^{ab} \pm 136.5$	$1537.2^{a} \pm 117.2$	$1711.8^{a} \pm 112.3$	$380.7^{b} \pm 64.7$	$2326.3^{a} \pm 498.3$	$187.3^{b} \pm 49.5$
K (mg/kg)	$111.0^{a} \pm 23.7$	$184.4^{ab} \pm 20.6$	$90.1^{a} \pm 17.5$	$123.0^{a} \pm 10.0$	$138.9^{a} \pm 12.3$	$152.6^{ab} \pm 25.1$	$230.9^{b} \pm 39.5$	$95.5^{a} \pm 24.5$
Mg (mg/kg)	$59.7^{a} \pm 9.7$	$109.9^{a} \pm 10.0$	$166.2^{b} \pm 32.1$	$123.9^{b} \pm 8.4$	$194.3^{b} \pm 13.8$	$85.6^{ab} \pm 7.4$	$168.5^{b} \pm 16.3$	$44.3^{a} \pm 16.3$
Na (mg/kg)	$6.31^{a} \pm 0.53$	$12.35^{a} \pm 3.13$	$15.95^{a} \pm 3.58$	$6.05^{a} \pm 0.52$	$33.43^{b} \pm 4.84$	$9.99^{a} \pm 3.77$	$24.08^{a} \pm 5.50$	$5.71^{a} \pm 1.26$
Cd (mg/kg)	$2.219^{a} \pm 0.532$	$0.059^{b} \pm 0.011$	$0.029^{b} \pm 0.008$	$0.073^{b} \pm 0.006$	$0.177^{b} \pm 0.013$	$0.004^{b} \pm 0.003$	$0.111^{b} \pm 0.021$	$0.069^{b} \pm 0.007$
Cr (mg/kg)	$0.118^{a} \pm 0.018$	$0.074^{a} \pm 0.008$	$0.030^{a} \pm 0.010$	$0.157^{a} \pm 0.015$	$0.225^{a} \pm 0.031$	$0.027^{a} \pm 0.006$	$0.144^{a} \pm 0.027$	$0.034^{a} \pm 0.008$
Cu (mg/kg)	$6.32^{a} \pm 1.75$	$3.91^{a} \pm 0.83$	$27.78^{a} \pm 24.85$	$3.10^{a} \pm 0.43$	$5.99^{a} \pm 0.59$	$3.57^{a} \pm 1.33$	$3.06^{a} \pm 0.88$	$1.89^{a} \pm 0.36$
Fe (mg/kg)	$60.3^{a} \pm 14.3$	$95.8^{ab} \pm 15.3$	$37.4^{a} \pm 13.1$	$170.9^{b} \pm 16.9$	$126.7^{ab} \pm 14.5$	$27.7^{a} \pm 9.2$	$97.9^{ab} \pm 19.6$	$47.0^{a} \pm 3.2$
Mn (mg/kg)	$152.5^{a} \pm 19.8$	$59.9^{b} \pm 7.5$	$44.7^{b} \pm 9.9$	$97.7^{ab} \pm 6.3$	$178.3^{a} \pm 17.5$	$34.2^{b} \pm 2.5$	$82.6^{ab} \pm 9.6$	$24.4^{b} \pm 3.3$
Ni (mg/kg)	$0.170^{a} \pm 0.053$	$0.297^{a} \pm 0.07$	$0.193^{a} \pm 0.040$	$1.060^{b} \pm 0.137$	$0.754^{b} \pm 0.096$	$0.095^{a} \pm 0.029$	$0.591^{ab} \pm 0.080$	$0.228^{a} \pm 0.048$
Pb (mg/kg)	$53.41^{a} \pm 15.93$	$3.25^{b} \pm 0.63$	$3.32^{b} \pm 0.99$	$2.54^{b} \pm 0.15$	$7.42^{b} \pm 0.91$	$9.34^{b} \pm 4.84$	$4.92^{b} \pm 2.30$	$4.34^{b} \pm 0.81$
Zn (mg/kg)	$57.1^{a} \pm 11.2$	$3.4^{a} \pm 0.5$	$3.7^{a} \pm 2.3$	$3.7^{a} \pm 0.4$	$149.6^{a} \pm 39.3$	$23.3^{a} \pm 17.4$	$58.3^{a} \pm 40.9$	$3.3^{a} \pm 0.5$

[a]It was measured one time after soil samples at the same site pooled; [b]It was not measured.

landfills was >1.25 g/cm^3 (Table 5). The soil depth of the cover layer in the study sites was variable, with refuse exposed or covered up to 60 cm, except for the 2-m cover depth at the planted and reference sites. Therefore, the influence on vegetation depends upon the site. It is possible that tree growth was not impacted by landfill factors in this growth comparison study, because a 2-m cover depth may have minimized their influences on the rooting zone. Soils that are penetrated by landfill gases are usually black, malodorous, and have a high moisture, Mn, and Fe content (Gilman 1981). All unsanitary landfills, except Mojeonri, had a higher Mn and Fe concentration than the reference sites. Landfill gases in the study sites may have had effects on the vegetation. Tree roots grew less in unsanitary landfills than at control sites, and the roots grew beneath the soil surface (Gilman 1981). However, tree species with shallow roots are more adaptable to landfills than those with deep roots (Gilman 1980). The root depth of tolerant trees is shallower than that of intolerant trees, because the shallow-rooted trees are likely to be under less stress on the landfill (Gilman 1989). Shallow-rooted trees also seem to adapt to unsanitary waste landfills with defective soil cover layers, which are widespread in developing countries, because the roots are less likely to come into contact with refuse and leachate. *Liriodendron tulipifera*, *Albizzia julibrissin*, *Ligustrum obtusifolium*, *Buxus microphylla* var. *koreana*, *Hibiscus syriacus*, and *Sophora japonica*, which had a total ratio of >1 and low mortality rates, were considered suitable species for revegetating unsanitary waste landfills (Table 3). Of these, *Liriodendron tulipifera* and *Albizzia julibrissin* showed greater height and diameter growth relative to the other species in the landfill (Table 3). Unsanitary landfills are open, dry, and nutrient-poor environments. Soil salination from high Mg and Ca concentrations is also common in unsanitary landfills (Kim 2001). Therefore, species adapted to these conditions should be selected. *Albizzia julibrissin* is helophytic, drought tolerant, and well adapted to disturbed areas, and this species has been observed to naturally colonize unsanitary landfills. *Hibiscus syriacus* is also helophytic (Korea Landscape Gardening Corporation 1978). *Sophora japonica* and *Ligustrum obtusifolium* are easy to transplant, and *Hibiscus syriacus* and *Ligustrum obtusifolium* are salt-tolerant species. Species with high sprouting ability, such as *Ligustrum obtusifolium*, *Hibiscus syriacus*, and *Sophora japonica*, can facilitate natural restoration by propagating spontaneously (Korea Landscape Gardening Corporation 1978). The ability of different species to survive in waste landfills will shape the landscape of waste landfills after restoration (Chan and others 1991). Irrigation, soil texture, depth of soil cover layers, nutrient status of soils, and post management are all critical factors that determine revegetation success in waste landfills (Chan and others 1991). The promotion of native species on landfill sites has been recommended as a realistic postclosure landfill use (Sabre and others 1994). In conclusion, unsanitary landfills should be revegetated with a combination of native and commercially available plants. In particular, many naturalized tree species are recommended on unsanitary landfills as an enhancement of the landscape.

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