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Relationship between Plant Species Covers and Soil Chemical Properties in Poorly Controlled Waste Landfill Sites

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ABSTRACT: The relationships between the cover of herbaceous species and 15 soil chemical properties (organic carbon contents, total N, available P, exchangeable K, Na, Ca and Mg, HCl-extractable Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn) in nine poorly controlled waste landfill sites in Korea were examined by correlation analysis and multiple regression equations. Species showed different patterns of correlation between their cover values and soil chemical properties. The cover of *Ambrosia artemisiifolia* var. *elatior*, *Aster subulatus* var. *sandwicensis* and *Erechtites hieracifolia* were negatively correlated with the contents of Fe, Mn and Ni within landfill soils. Total cover of all species in quadrats was positively correlated with the contents of Cd and negatively correlated with the contents of Mn and Fe from stepwise regression analysis with 15 soil properties. Canonical correspondence analysis demonstrated that the distribution of native and exotic plants on poorly controlled landfills was significantly influenced by the contents of Na and Ca in soils, respectively.

Key words: Canonical correspondence analysis, Plant cover, Poorly controlled waste landfill, Regression analysis, Soil chemical property

INTRODUCTION

Abandoned landfills are potential resources because they are increasingly common in close proximity to urban areas (Walker and del Moral 2003). Spontaneous succession happens on landfill sites after the fill is capped and left unmanaged (Rebele and Lehmann 2002). Some specific herbaceous species colonize landfill sites from the first year after closure and they decrease subsequent species richness (Lehmann and Rebele 2002). Sanitary landfills are constructed to the proper standards including a liner, cap, leachate and gas-collection systems and erosion controls. Compared to this practice, poorly controlled landfills do not have landfill gas and leachate treatment systems and have a final soil covering of minimal thickness and low quality. Ecological redevelopment on poorly controlled landfills is more limited than that on sanitary landfills because of two main factors: landfill gas and leachate. Park (1998) found a mixture of native and undesirable non-native growing at Nanjido, a poorly controlled landfill, four years after the site was closed. Continuous management was necessary to drive succession on the fill toward high native species richness.

Herbaceous plants are used to control soil erosion on landfills. They grow fast and well on these dry and barren areas. A mixture of nonnative herbs and legumes is commonly used for revegetation of landfills. Recently, a native wildflower mixture was evaluated for an alternative to those standard revegetation mixtures (Sabre et al. 1997). However, financial constraints have meant that many poorly controlled landfills are unmanaged, and revegetation is left to natural succession. Herbaceous plants become dominant initially on these degraded lands. Annuals constitute a high portion of the first invaders on refuse tips and succession proceeds to include biennials and perennials (Darlington 1969). Notwithstanding differences of species and performance on diverse landfills, the vegetation cover is often complete within two years (Bradshaw and Chadwick 1980). So, their management is necessary to restore them to a condition of high native species diversity.

Herbaceous plants which establish on poorly controlled waste landfills can be used as phytoremediation sources but studies of the adaptability of herbaceous plants to these disturbed poorly controlled landfills is rare. Furthermore, studies that explain the performance of plants based on single soil property are limited because diverse factors are present in soils. Objectives of this study are:

1. To identify herbaceous species colonized on poorly controlled landfills
2. To investigate the relationships between plant performance and soil chemical property on poorly controlled landfills and to estimate the relative importance of the different soil chemical properties

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MATERIALS AND METHODS

Site Description

Considering degrees of natural colonization, human disturbance level and landfill age among the 127 waste landfills in Seoul metropolitan area and adjacent Kyonggi Province, nine sites were selected. All study sites lie in the central western part of the Korean Peninsula. Study Sites were Bunsuri, Dugiri, Hasanundong, Komaeri, Kyongseodong, Mojeonri, Sangpaedong, Shindaedong and Wonchangdong waste landfill.

The sizes of the waste landfill sites are various, ranged from 600 to 22,000 ha. Details of the sites are given in Table 1. All sites are located in middle latitudes of the Northern Hemisphere (N37°18'～54' and E126°39'～127°29') and the temperate zone with four distinct seasons. During the winter, from December to February, it is cold and dry under the dominant influence of the Siberian air mass. Meanwhile, the summer, from June to August, is hot and humid with frequent heavy rainfalls associated with the East-Asian Monsoon, locally called 'Changma'. It is mild and serene during spring and fall with fairly periodic passages of the transient high and low pressure systems. The annual mean temperature is 12.3℃ except in the high mountain areas. The annual precipitation is about 1,400 mm (KMA 1995～2000). More than half of the annual precipitation falls during the Changma season. The winter precipitation is less than 10% of the total. Humidity reaches the highest in July, marking 70～80%. On the contrary, the lowest means of the monthly humidity are 30～40% in January and April. Bunsuri, Hasanundong, Komaeri, Mojeonri, and Sangpaedong waste landfill neighbor on forest areas. Dugiri and Shindaedong waste landfills are adjacent to rivers. Kyongseodong and Wonchangdong waste landfill are surrounded by reclaimed lands. All sites have undergone natural succession after closure because they were left neglected and unmanaged. The main parts of the waste landfills are grasslands with patches of shrubs, such as *Amorpha fruticosa* L., *Lespedeza cyrtobotrya* Miq., *Lespedeza maximowiczii* Schneid., and *Lespedeza bicolor* Turcz. and trees, such as *Robinia pseudoacacia* L., *Salix koreensis* Anderss., *Populus sieboldii* Miq., *Morus alba* L., *Ailanthus altissima* Swingle, *Paulownia coreana* Uyeki., *Populus deltoides* Marsh., *Diospyros kaki* Thunb., and *Albizzia julibrissin* Durazz.

Vegetation Survey

A quadrat survey for herbaceous species was performed using the belt transect method in the waste landfills (Barbour et al. 1999). Vines were included in this study. The areas which showed typical and representative vegetation on the poorly controlled landfills were chosen for the transects. We established four 0.25 m^2 (0.5 m × 0.5 m) quadrats at 5 m interval along each line transect traversing the landfill interiors perpendicular to landfill edges on September 2002 when most plants were vigorously growing (Jose et al. 1996). Four replicate transects were sampled. If the area of landfill was over 6,500 ha, line transects were set up parallel at two locations across the landfill and if it was under 6,500 ha, line transects were established in a cross form. The total number of quadrats on all nine sites was 188. All vegetation that appeared in quadrats was recorded and percentage cover of each species was estimated visually using the Braun-Blanquet cover scale (Goldsmith et al. 1986). Covers of two species overlapped were recorded separately according to methods of Wong and Yu (1989). Total cover was calculated as summing the covers of all species in a quadrat. After recording vegetation, all aboveground plants in each quadrat were clipped with

Table 1. Characteristics of the study sites in Korea. Closure time represents when the landfills were completed. Years after closure indicate the time elapsed between closure and 2002, when this study started. The Kyongseodong and Wonchangdong landfill were operated on coastal lands reclaimed since the 1980's.

Waste landfill sites	Closure time (years after closure)	Size (ha)	Present landuse status	Neighboring habitats
Bunsuri	1993 Dec. (7.25)	900	Idle land	Forest
Dugiri	1993 Dec. (7.25)	1,000	Idle land	River and fields
Hasanundong	1994 Jun. (6.75)	6,500	Idle land	Forest
Komaeri	1993 Mar. (9.79)	1,100	Idle land	Forest and lake
Kyongseodong	1992 Dec. (8.25)	22,000	Idle land	Reclaimed land
Mojeonri	1994 Dec. (6.25)	1,500	Idle land	Forest
Sangpaedong	1999 Dec. (1.25)	600	Idle land	Forest
Shindaedong	1990 Apr. (11.4)	2,100	Idle land	River and paddy fields
Wonchangdong	1989 May (13.63)	37,000	Turf field	Reclaimed land

a sickle and knife and transferred into laboratory. The plant sampled was dried at 80℃, for one day in a drying oven and weighed to determine biomass. Relative cover and relative biomass of each species were calculated according to Curtis and McIntosh (1951). Relative cover values and biomass values were added to produce importance values (*IV*). Trees were not included in this study because their distributions are localized. Identification and nomenclature follow Lee (1985) and Park (1995). Exotic plants were classified according to Park (1995, 2001). The species that could not be identified in the field were brought to the laboratory for complete identification.

Soil Analysis

Surface soils were taken from ten randomly selected points within each quadrat by scraping the surface from 0～10 cm depth with a sterile hand shovel after the harvest and then pooled to one sample. The soils sampled were put into vinyl bags and transported to the laboratory. They were air-dried at room temperature in the shade and passed through a 2 mm mesh sieve. The chemical analyses were performed for each of the 188 quadrats. Organic carbon content was quantified following the Walkley-Black method (Nelson and Sommers 1996). Total nitrogen (N) and available P were measured according to the Kjeldahl and Bray No. 1 methods (Brenner 1996, Kuo 1996). Exchangeable cations of Ca, K, Mg, and Na were extracted with 1 N ammonium acetate solution for atomic absorption spectrophotometer analyses (Helmke 1996, Suarez 1996). The soils were extracted with 0.1 N HCl prior to analysis by inductively coupled plasma spectrophotometer for Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn (Amacher 1996, Bartlett and James 1996, Gambrell 1996, Loeppert and Inskeep 1996, Reed and Martens 1996).

Data Analysis

Correlation analysis was conducted to investigate the relationships between plant cover and 15 soil chemical variables (Sokal and Rohlf 1995). The plant species with importance value > 0.33 and frequency of more than 4 were included in the correlation analysis but plants having insufficient sample sizes ($N < 3$) were excluded. Multiple regression analysis was performed to determine the effects of various soil chemical properties on plant cover with plant cover of each species as the dependent variable and the following as independent variables: organic carbon contents, total N, available P, K, Na, Ca, Mg, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn (Sokal and Rohlf 1995). Multiple regression analysis was conducted with stepwise selection at 0.05 significance level and the correlation and multiple regression analysis were performed using the SAS statistical program (SAS Institute 1985). Cover of each species that had been recorded inside quadrats was transformed into relative cover. These relative cover values were ordinated by 15 soil chemical variables through canonical correspondence analysis using CANOCO ver. 4.02 to investigate significantly important soil chemical factors for species distributions (ter Braak and Smilauer 1998).

RESULTS

A total of 116 herbaceous species were found at all the quadrats on the waste landfills. The importance value of *Humulus japonica* was greatest (Table 2). These species were classified into four groups: herbs, forbs, sedges and vines. The herbs were the largest group (Table 2). Vines such as *Humulus japonica*, *Glycine soja*, *Pueraria thunbergiana*, *Persicaria perfoliata* were widespread on the poorly controlled landfills and they had high cover values. The number of exotic species among plants (28) with >1 importance value (*IV*) was 12 (Table 2).

The soil chemical characteristics sampled in the quadrats are presented in Table 3. Each plant species showed different patterns of association with soil chemical variables (Table 4). More species were positively or negatively correlated with Ca, Pb and organic carbon than with other factors (Table 4). Soil chemical factors that showed the correlation of two numbers of times with species are total N, available P, K, Na, Fe and Mn.

Total cover, in which covers of all species were summed, was positively correlated with the contents of Cd and negatively correlated with the contents of Mn and Fe from stepwise regression analysis with 15 soil variables (Table 5). Mn was the most influential factor on the total cover. The relation between the soil chemical factors and each plant cover can be expressed with different linear equations (Table 5). Multiple regression analysis shows that 13 species among 28 plants with $IV > 1$ had significant equations (Table 5). The regression equations on 15 soil factors were different according to plant species (Table 5). The significance of *F*-test in the regression equations decreased in the following order: *Aster subulatus* var. *sandwicensis*, *Cosmos bipinnatus*, *Carex humilis*, *Chenopodium album*, *Persicaria nodosa*, *Ambrosia artemisiifolia* var. *elatior*, *Artemisia princes* var. *orientalis*, *Aster subulatus*, *Erechtites hieracifolia*, *Eleusine indica*, *Erigeron canadensis*, *Cassia mimosoides* var. *nomame*, *Echinochloa crus-galli*. The cover of *Aster subulatus* var. *sandwicensis* was regressed with K, Ca, Ni, Cu and organic carbon content (Table 5). Positive coefficients of K, Ca, and Cu mean that increase of these ion amounts make the cover of *Aster subulatus* var. *sandwicensis* higher and is considered to have statistically positive relationships with the growth of *Aster subulatus* var. *sandwicensis*. As the coefficients of Ni and organic carbon content were negative, they might have statistically negative relationships with the growth of *Aster subulatus* var. *sandwicensis*. The signs

Table 2. List of all plant species with an importance value > 1 on waste landfills studied. Plant species are ranked according to importance value. 188 quadrats are analyzed. *IV* value consists of Mean ± SE (*N* = 188). The a, c, and p characters represent annual, biennial and perennial

Scientific name	Classification	*IV* (%)	Life form
Humulus japonica S. et Z.	Vine	25.3 ± 0.4	a
Setaria viridis (L.) Beauv.	Herb	21.7 ± 0.3	a
Artemisia princeps var. *orientalis* (Pampan.) Hara	Herb	20.0 ± 0.2	p
Ambrosia artemisiifolia var. *elatior* Descourtils*	Herb	14.6 ± 0.2	a
Digitaria ciliaris (Retz.) Koel	Herb	14.6 ± 0.2	a
Glycine soja S. et Z.	Vine	14.0 ± 0.2	a
Echinochloa crus-galli (L.) Beauv.	Herb	12.9 ± 0.2	a
Festuca arundinacea Schreb.*	Herb	9.8 ± 0.2	p
Aster pilosus Willd.	Herb	7.8 ± 0.2	p
Panicum dichotomiflorum MICHX.*	Herb	7.4 ± 0.1	a
Kummerowia striata (Thunb.) Schindl	Herb	6.9 ± 0.2	a
Pueraria thunbergiana Benth	Vine	4.3 ± 0.1	p
Lactuca indica var. *laciniata* (O. Kuntze) Hara	Forb	3.1 ± 0.1	a
Persicaria nodosa Opiz	Forb	3.0 ± 0.1	a
Persicaria perfoliata H. Gross	Vine	2.9 ± 0.1	a
Eragrostis curvula Nees*	Herb	2.7 ± 0.1	p
Cosmos bipinnatus Cav.*	Herb	2.1 ± 0.1	a
Arundinella hirta (Thunb.) Tanaka	Herb	2.0 ± 0.1	p
Chenopodium album L.*	Forb	1.8 ± 0.1	a
Eleusine indica (L.) Gaertner	Herb	1.7 ± 0.1	a
Erechtites hieracifolia Raf.*	Forb	1.6 ± 0.1	a
Phragmites australis Trin	Herb	1.6 ± 0.1	p
Aster subulatus MICHX. var. *sandwicensis* A. G. Jonwes*	Herb	1.5 ± 0.1	a
Ambrosia trifida L.*	Forb	1.5 ± 0.1	a
Cassia mimosoides var. *nomame* Makino	Herb	1.4 ± 0.1	a
Carex humilis Leyss	Sedge	1.3 ± 0.1	p
Erigeron annuus (L.) Pers.*	Herb	1.2 ± 0.0	b
Aster subulatus Michx.*	Herb	1.2 ± 0.1	a

*denotes exotic plants.

Table 3. Soil chemical characteristics of the soils sampled in the waste landfills

Soil characteristics	Mean ± SE (Standard Error)
Total N (%)	6.5 ± 3.8
Available P (mg/kg)	26.5 ± 15.0
K (mg/kg)	142.9 ± 12.6
Na (mg/kg)	34.4 ± 15.9
Ca (mg/kg)	1377.9 ± 82.6
Mg (mg/kg)	149.0 ± 26.7
Cd (mg/kg)	3.8 ± 2.0
Cr (mg/kg)	2.2 ± 1.2
Cu (mg/kg)	11.9 ± 5.1
Fe (mg/kg)	103.5 ± 7.7
Mn (mg/kg)	100.3 ± 6.8
Ni (mg/kg)	4.6 ± 2.7
Pb (mg/kg)	11.7 ± 2.4
Zn (mg/kg)	54.6 ± 11.6
Organic carbon content (%)	7.2 ± 1.3

of the coefficients in each regression equation were plus in following variables (frequency): Cr (3), organic carbon (3), Ca (2), Cd (2), Cu (2), Fe (2), K (2), Na (2), Ni (2), available P (1), Fe (1), Mg (1) and total N (1). The signs of the coefficients in each regression equation were minus in following variables (frequency): Mg (4), Fe (3), Ni (3), available P (2), organic carbon (2), total N (2), Na (2), Zn (2), Ca (1), Cr (1), Cu (1), K (1) and Mn (1). In particular, Pb was not a key factor to describe the regression model. The *F* values are index of the degree of contribution of the different factors (Guofan and Tingxiu 1991). The factors with the largest *F* value must have the greatest effects on the plant cover as a dependent variable. Therefore, the covers of *Ambrosia artemisiifolia* var. *elatior*, *Artemisia princeps* var. *orientalis* and *Cassia mimosoides* var. *nomame*, *Aster subulatus* var. *sandwicensis* and *Chenopodium album*, *Aster subulatus*, *Carex humilis*, *Echinochloa crus-galli*, *Eleusine indica*, *Erigeron canadensis*, and *Persicaria nodosa* were positively related with Cd, organic carbon, Ca, Fe, Na, available P, total N and Cr, respectively. The covers of *Cosmos bipinnatus* and *Erechtites hieracifolia* were negatively related with K and Fe, respectively.

In the case of canonical correspondence analysis of native plants, two groups were segregated (Fig. 1). One group was assembled in the center of ordination space and other group, composing of 4 species was clustered in the upper right corner. The 4 species were

TABLE 4

Table 5. Multiple regression analyses between each plant cover and soil chemical factors. Multiple regression analyses were conducted according to stepwise selection

Species	Optimum equations	N	Total R	Total F	SEE
Ambrosia artemisiifolia var. *elatior*	$Y = 0.2219 - 0.0006X_9 + 0.0432X_{13}$	48	0.2249	6.53**	1.5723
Artemisia princes var. *orientalis*	$Y = 0.0346 - 0.0086X_1 - 0.0021X_3 - 0.2135X_7 + 0.0006X_9 + 0.0446X_{15}$	73	0.2782	5.16**	1.5140
Aster subulatus var. *sandwicensis*	$Y = 0.0392 + 0.0008X_5 + 0.0001X_6 - 0.0638X_{10} + 0.0131X_{11} - 0.0310X_{15}$	7	0.9999	254080**	0.0000
Aster subulatus	$Y = -0.8247 + 0.0031X_5 + 1.0780X_7 + 0.0017X_9 - 0.0099X_{12}$	6	0.9999	5164.56*	0.0000
Carex humilis	$Y = 0.0650 - 0.8153X_1 - 0.0033X_2 + 0.0012X_4 - 0.0010X_9 + 0.0298X_{10}$	7	0.9999	11643.0**	0.0000
Cassia mimosoides var. *nomame*	$Y = 0.0016 - 0.0206X_2 + 0.0358X_{15}$	15	0.4385	4.69*	0.1369
Chenopodium album	$Y = 0.1003 - 0.0012X_4 + 0.0002X_6 - 0.2701X_{10}$	12	0.9672	78.80**	0.0224
Cosmos bipinnatus	$Y = 0.6601 - 0.0023X_5 + 0.6021X_7 - 0.0816X_{10} - 0.0849X_{11} - 0.0279X_{15}$	7	0.9999	47614.9**	0.0000
Echinochloa crus-galli	$Y = -0.0145 + 0.0015X_3 + 0.0176X_{15}$	47	0.1559	4.06*	0.5614
Eleusine indica	$Y = -0.0635 + 0.0197X_2$	8	0.6534	11.31*	0.0647
Erechtites hieracifolia	$Y = 0.5571 - 0.0027X_3 - 0.0027X_4 - 0.0086X_9 + 0.7326X_{10} + 0.0012X_{11}$	7	0.9999	2964.66*	0.0000
Erigeron canadensis	$Y = 0.0186 + 0.7557X_1 - 0.0004X_4$	10	0.6741	7.24*	0.0102
Persicaria nodosa	$Y = 0.1454 + 0.0062X_3 - 0.0006X_4 - 0.00006X_6 + 0.4246X_7$	11	0.8908	12.24**	0.0602
Total cover	$Y = 1.1618 - 0.0017X_8 - 0.0005X_{12} + 0.0814X_{13}$	139	0.1864	10.31**	15.9755

*$P<0.05$, **$P<0.01$.

SEE = Standard error of estimate.

term of the equation: X_1-Total N, X_2-Available P, X_3-Na, X_4-Mg, X_5-K, X_6-Ca, X_7-Cr, X_8-Mn, X_9-Fe, X_{10}-Ni, X_{11}-Cu, X_{12}-Zn, X_{13}-Cd, X_{14}-Pb, X_{15}-Organic carbon content. Bold style factor have the greatest *F* value in each equation.

Cyperus sanguinolentus, *Eleusine indica*, *Persicaria nodosa* and *Solanum nigrum*. The first axis was negatively correlated with the concentrations of Na ($R = -0.6176$) and positively correlated with Cr ($R = 0.5771$). In the case of canonical correspondence analysis of exotic plants, the species were spread out in the ordination space. The first axis was positively correlated with the contents of Ca ($R = 0.7736$) and Na ($R = 0.6342$). In ordination space, the distribution of exotic plants was apparently more segregated than that of native plants (Figs. 1 and 2).

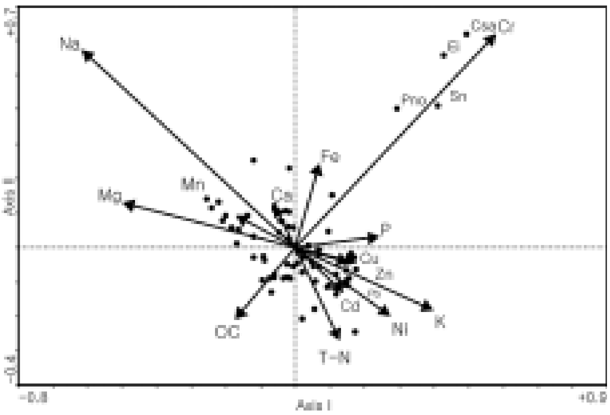

Fig. 1. Native species-environmental variables biplot from canonical correspondence analysis result of waste landfill. The Eigen values of the first axis and the second axis were 0.46 and 0.37, respectively. The species names of plants clustered are omitted (Species abbreviation: Csa = *Cyperus sanguinolentus*; Ei = *Eleusine indica*; Pno = *Persicaria nodosa*; Sn = *Solanum nigrum*; Soil chemical variables abbreviation: Ca = Calcium; Cd = Cadmium; Cu = Copper; Cr = Chromium; Fe = Iron; K = Potassium; Mn = Manganese; Mg = Magnesium; Na = Sodium; Ni = Nickel; OC = Organic carbon; P = Available phosphorus; Pb = Lead; T-N = Total nitrogen; Zn = Zinc).

DISCUSSION

Characteristics of Soils in Waste Landfills

Subsoils dug for basement construction, soils from forests and river sediments are used to cover mounded landfills that have been placed on the soil surface in areas of shallow ground water in South Korea. Similar soils are used for trench landfills where ground water level is deep and waste is landfilled beneath soil surface and area landfills where valleys or quarries are filled. Soil nutrients are usually less than the level required for plant growth because of severe environmental changes before and after landfilling (Koo et

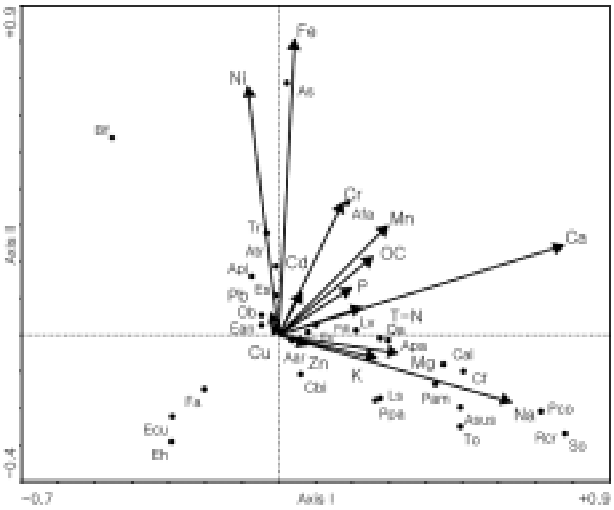

Fig. 2. Exotic species-environmental variables biplot from canonical correspondence analysis result of waste landfill. The Eigen values of the first axis and the second axis were 0.62 and 0.59, respectively. (Species abbreviation: Aar = *Ambrosia artemisiifolia* var. *elatior*; Afa = *Avena fatua*; Apa = *Amaranthus patulus*; Api = *Aster pilosus*; As = *Aster subulatus*; Asus = *Aster subulatus* var. *sandwicensis*; Atr = *Ambrosia trifida*; Bf = *Bidens frondosa*; Cal = *Chenopodium album*; Cbi = *Cosmos bipinnatus*; Cf = *Chenopodium ficifolium*; Ean = *Erigeron annuus*; Ec = *Erigeron canadensis*; Ecu = *Eragrostis curvula*; Eh = *Erechtites hieracifolia*; Es = *Euphorbia supina*; Fa = *Festuca arundinacea*; Ls = *Lactuca scariola*; Lv = *Lepidium virginicum*; Ob = *Oenothera biennis*; Pam = *Potentilla amurensis*; Pco = *Persicaria cochinchinensis*; Pdi = *Panicum dichotomiflorum*; Ppa = *Potentilla paradoxa*; Qa = *Quamoclit angulata*; Rcr = *Rumex crispus*; So = *Sonchus oleraceus*; To = *Taraxacum officinale*; Tr = *Trifolium repens*, Soil chemical variables abbreviation: Ca = Calcium; Cd = Cadmium; Cu = Copper; Cr = Chromium; Fe = Iron; K = Potassium; Mn = Manganese; Mg = Magnesium; Na = Sodium; Ni = Nickel; OC = Organic carbon; P = Available phosphorus; Pb = Lead; T-N = Total nitrogen; Zn = Zinc).

al. 1999). Furthermore, materials leaching out from landfills can cause soil pollution (Simmons 1999).

Ca contents were higher than other ions in these waste landfills. Ca is known to mitigate heavy metal toxicity (Proctor and Woodwell 1975). High soil salinity results from high evapotranspiration in semiarid and arid area (Hernández et al. 1999). High temperature and insufficiency of rainfall is reported to increase salts like a NaCl to form (Chapman 1996). Plants can become stressed as salinity is elevated. Production of landfill gas may increase soil temperature and atmospheric temperature and subsequent evapotranspiration can make soil salinity higher. Halophytes such as *Diplachne fusca* and *Chloris virgata* invaded and grew on Kyongseodong landfill where the contents of Na, Ca and Mg were greatest of all the landfills measured (Kim 2001). *Diplachne fusca* exudes salts through salt glands and *Chloris virgata* is known to be salt tolerant (Chapman 1996). The standard errors of the concentrations of K, Na, Ca and Mg showed differences among quadrats in this study. This probably results from the heterogeneity of soils created during the covering landfills (Sabre et al. 1997).

Different concentrations of heavy metals at different landfill sites are probably the result of different sources of mineral in soils (Wong and Yu 1989). Other factors to explain site differences might be contamination by decomposition solutions and leachate. The concentration of N (NO_3^- and NH_4^+) was low in soils of the waste landfills. In the study sites, the total N content of landfills was lesser than forest control sites and the amount of total N (0.105% ± 0.077 SD, N = 188) was similar to the results in the study of Wong and Yu (1989).

The Fe and Zn contents of soils impacted by landfill gas are higher than soils unimpacted by landfill gas (Leone et al. 1979). The concentrations of Fe and Zn in landfill of these study sites were greater than those of control sites (Kim 2001). Microelements including Fe and Zn will increase when reduction of soils occurs as a result of microorganism activity and by displacement oxygen of landfill gas (Leone et al. 1979). The concentration of heavy metals in soils of study sites belonged to the general range of soils (Kabata-Pendias and Pendias 1992).

Relationships between Soil Chemical Property and Plant Cover

Plant cover has been reported to be negatively correlated with the concentrations of ammonia, total N, and Pb of soils in landfills and positively correlated with phosphorous (Wong and Yu 1989). Furthermore, the coverage of grasses among herbaceous species is most closely related to soil properties, because grasses have deeper root systems than sedges and vines and they are most sensitive to soil properties. This study showed that the concentrations of Mn and Zn generally were negatively correlated with total plant cover (Table 5). The Mn content of soils in landfills has been reported to be negatively correlated with plant cover (Wong et al. 1992). The concentration of heavy metals has enhanced plant growth or has detrimental effects on plant growth, depending on the amounts. *Ambrosia artemisiifolia* var. *elatior*, dominant on waste landfills, thrived on polluted and disturbed urban areas, showed negative correlations with the contents of Fe and Ni (Table 4). Furthermore, *Aster subulatus* var. *sandwicensis* was negatively correlated with the contents of Fe and Mn and *Setaria viridis* was negatively correlated with the content of Pb. Although herbaceous plants can establish on infertile and polluted ecosystems and soil chemical property may not be a causal factor, this study shows the possibility that heavy metals such as Fe, Ni and Mn have depressing effects on growth of most plants on poorly controlled waste landfills. The *F*-test indicates that Ca, K and Mg were the main factors influencing the covers by *Aster subulatus* var. *sandwicensis*, *Carex humilis* and *Cosmos bipinnatus*, respectively. These cations will have accelerating or depressing effects on plant growth depending locally different their concentrations on waste landfills.

Relationships between Soil Environments and Plant Distribution

Canonical correspondence analysis showed clearly the relationships between soil chemical properties and plant distributions (Figs. 1 and 2). Waste landfill sites have higher exotic plant species ratios (Kim et al. 2004). Soil chemical characteristics can predict the variation in exotic species richness and cover (Bashkin et al. 2003). The exchangeable cations such as Na and Ca in this study explained the distributions of native and exotic plants. Thus, the contents of Na and Ca are the important factors on the plant distribution in the waste landfills. The plants may make specific mosaic patterns along Na and Ca contents of soils. Cr was also a significant factor to divide native plants into two groups from canonical correspondence analysis (Fig. 1). Plants show various tolerances to Cr in growth and development (Shanker et al. 2005).

Mechanisms that accelerate germination, for example, light and nitrate ions function to establish the plants in disturbed areas (Bungard et al. 1997). Waste landfills are open, light sites. Seed dispersal, propagule sources and seed bank can play an important role in determining vegetation pattern in the initial successional stages of the landfills but the scenario can work in which soil chemicals have an effect on germination and growth of plants and finally on plant distributions. Active options such as mounding for native grass species to establish on poorly controlled landfills are needed as Ewing's study on a capped landfill (Ewing 2002).

CONCLUSIONS

The herbaceous species on poorly controlled landfills were first invaders to make landscape of the landfills a grassland ecosystem. The study of soil chemical property in soils of poorly controlled landfills relating to herbaceous plants is needed to manage invasives. *Humulus japonica* was the vine with greatest importance value. Other twenty-seven species with >1 importance value were sorted. The covers of most plants were negatively correlated with the contents of Fe, Mn, Ni and Pb within landfill soils. The multiple regression analysis indicates that Ca, K and Mg are the main factors influencing the covers by *Aster subulatus* var. *sandwicensis*, *Carex humilis* and *Cosmos bipinnatus*, respectively. The distribution of native and exotic plants on poorly controlled landfills was significantly segregated by the contents of Na and Ca in soils in canonical correspondence analysis. Extractable cations and heavy metals may impact the germination and growth of plants differently. They can be predictor of plant distribution and trigger distribution scenario at these sites. If we know soil characteristics of poorly controlled landfills, this study can be used specifically for developing management of herbaceous species according to soil chemical contents.

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Table 4. Correlation coefficients between plant cover and soil chemical factors (mean N = 22)

	Total N	Available P	K	Na	Ca	Mg	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn	OC[a]
Ambrosia artemisiifolia var. *elatior*	−0.06834	−0.09940	−0.05706	−0.09390	−0.00732	−0.28240	0.35809**	−0.25823	0.07515	−0.32557**	−0.07212	−0.30791*	0.31222*	−0.09961	−0.12456
Ambrosia trifida	−0.08368	0.19910	0.64590	−0.13004	−0.96260*	0.38705	−0.18470	−0.85033	0.99938***	−0.63769	−0.38593**	−0.66859	0.71357	0.24950	0.23918
Artemisia princeps var. *orientalis*	−0.06506	0.05619	−0.01291	−0.12381	−0.04246	0.09482	0.05283	−0.10280	−0.04700	0.07309	−0.00624	0.02823	0.02354	−0.13974	0.26465*
Aster pilosus	−0.12197	0.14248	0.24027	0.02331	−0.03321	0.21794	−0.03207	0.01576	−0.20287	0.21020	−0.08286	0.16773	0.01491	−0.02054	0.09363
Aster subulatus var. *sandwicensis*	0.20676	−0.14296	0.92204***	0.78549*	0.88079***	0.11662	−0.48077	−0.22995	−0.15653	−0.83528**	−0.76184*	−0.53655	−0.51364	0.12571	0.59054
Aster subulatus	−0.15582	−0.56645	−0.32528	0.16928	0.42826	−0.29071	0.65296	0.64312	−0.16830	0.78795	0.65258	0.33687	−0.25697	0.18622	0.15842
Carex humilis	−0.64010	−0.35457	−0.56822	0.31448	0.12878	0.42898	0.05497	0.13350	0.47742	−0.12019	0.12828	−0.55886	0.48899	0.49908	0.03290
Cassia mimosoides var. *nomame*	0.45051	−0.18563	0.29465	−0.10235	−0.50653	−0.31512	−0.20480	−0.27447	0.36272	−0.08677	−0.31251	0.23869	−0.09697	−0.30529	0.53731*
Chenopodium album	0.32395	0.26605	0.55701	−0.40162	0.64629*	−0.32429	−0.52368	−0.36680	−0.41190	−0.46403	−0.24845	−0.49770	−0.55458	−0.10048	−0.08507
Cosmos bipinnatus	−0.19267	−0.71596	−0.77760*	−0.15095	0.05418	0.30134	−0.34689	−0.32505	−0.39078	−0.35139	−0.32737	−0.18904	−0.41751	−0.31165	−0.33600
Cyperus iria	0.72529	0.36910	−0.16661	0.80802	−0.18121	0.65881	0.45711	0.04532	−0.05834	0.50235	0.61527	0.30811	−0.11545	−0.14044	0.47794
Digitaria ciliaris	0.02790	0.10442	−0.00230	0.04816	−0.17543	0.09523	−0.19318	−0.08830	0.04686	−0.03905	−0.05928	0.12082	−0.01676	−0.17425	−0.04354
Echinochloa crus-galli	0.15743	0.06098	−0.10705	0.31042*	−0.01421	0.13511	−0.17584	0.05705	0.06974	0.24423	0.14627	0.06949	−0.18499	−0.14706	0.22468
Eleusine indica	0.55954	0.80834**	0.46493	−0.15591	−0.62612	−0.11377	−0.47372	0.30733	0.26252	−0.26029	−0.56031	0.37929	−0.41772	−0.56457	0.30545
Eragrostis curvula	−0.61415	0.51560	0.68340	−0.35370	−0.61717	0.64340	−0.80717	−0.72301	0.42452	−0.79875	−0.69811	−0.44230	0.89262*	−0.12550	−0.64928
Erechtites hieracifolia	−0.76314**	−0.68834	−0.44463	−0.26568	−0.68147	−0.77980*	−0.68097	−0.61634	0.25603	−0.73717	−0.78297*	−0.63474	−0.13162	−0.16672	−0.49750
Erigeron canadensis	0.65306*	0.63194*	0.15929	0.05267	−0.18432	−0.34953	−0.22181	0.23452	0.62911	0.22597	−0.14864	−0.14310	0.08843	−0.08854	0.64156*
Festuca arundinacea	−0.06591	0.09167	0.43779	−0.24902	−0.20051	−0.29147	−0.33412	−0.32705	−0.46538	−0.24787	−0.30210	0.12054	−0.29762	−0.26574	−0.16268
Kummerowia striata	−0.27847	0.17928	−0.06046	−0.28492	−0.37459	−0.31167	−0.28170	−0.14819	0.13809	0.24721	−0.19734	0.17094	−0.26443	−0.13453	−0.05306
Lactuca indica var. *laciniata*	−0.00083	0.32816	−0.03391	−0.27193	−0.29838	−0.03662	−0.17295	0.06827	−0.07829	0.25786	−0.18740	0.06798	−0.28912	−0.35137	−0.21451
Panicum dichotomiflorum	−0.01953	0.22953	0.09201	−0.14028	0.11731	−0.02413	−0.03093	0.07887	0.28753	−0.10676	−0.12728	0.13425	−0.08207	−0.21439	0.06861
Persicaria nodosa	−0.01141	0.39963	−0.13268	0.39410	−0.38130	−0.49776	0.33019	0.58833	0.23802	0.56564	−0.04811	−0.00039	0.16904	−0.14061	−0.54016
Phragmites communis	−0.16976	−0.05579	−0.19885	−0.28739	0.30917	−0.54328	−0.01595	0.67566	−0.24128	0.43783	0.35386	0.63169	−0.27342	−0.00975	0.38285
Setaria viridis	0.32840	0.24790	0.54257	−0.41284	0.64915**	−0.31524	−0.53128	−0.37834	−0.41184	−0.47053	−0.24666	−0.50351	−0.55517*	−0.12031	0.10067
Trifolium repens	−0.27943	−0.77350	−0.08029	−0.06911	0.40055	0.05026	0.10343	0.11027	0.06989	0.10894	0.33407	0.15628	−0.14193	0.23390	−0.17475

Degree of significance: $^{*}P<0.05$, $^{**}P<0.025$, $^{***}P<0.01$.

OC[a] indicates organic carbon content.