J. Ecol. Field Biol. 30 (2): 161～170, 2007

Species Alterations Caused by Nitrogen and Carbon Addition in Nutrient-deficient Municipal Waste Landfills

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ABSTRACT: The ultimate target of restoring waste landfills is revegetation. The most effective method for increasing species richness and biomass in nutrient limited waste landfills is the use of fertilizers. The aim of the present study was to investigate the effects of nitrogen fertilizer, and the addition of carbon through sawdust, sucrose and litter, on vegetation dynamics at a representative municipal waste landfill in South Korea: Kyongseodong. A total of 288 permanent plots (0.25 m^2) were established and treated with nitrogen fertilizer (5, 10 and 20 N g/m^2), sawdust (289 g/m^2), sucrose (222 g/m^2) and litter (222 g/m^2). The aboveground biomass was significantly enhanced by nitrogen fertilizer at 5 and 10 N g/ m^2, compared with the control plots. The total cover of all plant species increased significantly on plots treated with 5 and 20 N g/m^2, as well as on those treated with sawdust and sucrose, compared with the control plots. The higher species richness after nitrogen fertilization of 10 to 20 N g/m^2, and the sawdust and sucrose treatment demonstrated that this was an appropriate restoration option for nutrient deficient waste landfills. This study demonstrated positive nutrient impacts on plant biomass and species richness, despite the fact that municipal waste landfills are ecosystems that are highly disturbed by anthropogenic and internal factors (landfill gas and leachate). Adequate N and C combined treatments will accelerate species succession (higher species richness and perennial increase) for restoration of waste landfills.

Key words: Carbon addition, Disturbance, Nitrogen addition, Nutrient impact, Species alteration, Waste landfill

INTRODUCTION

Waste landfills are artificial ecosystems that experience internal disturbance by atmospheric and water pollution, stabilization construction, management and anthropogenic effects. These pressures, both physical and chemical, lead to biodiversity loss. During this continual process, imbalances of natural cycles cause the disappearance of species (Wilson 1988). In particular, municipal waste landfills are nutrient-deficient artificial ecosystems with disturbances produced by biogases and leachate in developing countries, including South Korea. Municipal waste landfills do not incorporate landfill gas and leachate treatment systems, and including a final soil covering of low depth and quality (Kim et al. 2004).

Waste landfills are considered to be examples of primary succession in which severe degradation occurs, and then exotic plants invade and become established (Robinson and Handel 2000) whereas Korean waste landfills experience secondary succession with the cover layer soils from urban construction subsoils and the nearby forest edge topsoils (Kim et al. 2004). Waste landfills are a public priority due to environmental pollution, unsightly appearance and management costs, and it is important to restore them to better functioning ecosystems and communities (Sabre et al. 1997). Although the restoration of waste landfills is complex, costly and requires an interdisciplinary approach (Berger 1990), it is essential that they are used as effective spaces in urban areas as cities expand (Lee et al. 1992).

The final stage of restoration for the landfills discussed here is a forested spatial structure. Vegetation plays a role in the prevention of erosion and leachate output by reducing soil-water storage levels (Waugh et al. 1994). Management and restoration after closure, and the control of pollution generated by waste landfills are important problems to be solved in landfill restoration (Simmons 1993). Waste landfills, unlike other disturbed areas, are landscape elements that are isolated from their surroundings, and have detrimental effects on humans and wildlife if they are left unmanaged for a long period (Robinson and Handel 1995). Abandoned landfills are common in developing countries and need to be assessed ecologically. Thus, vegetation buildup on landfills is focused on trees because of the speed with which they positively modify the landscape. However, trees are influenced by landfill gases, soil-moisture shortages and increases in ammonia, Fe, Mn, Zn and Cu (Gilman 1981). The negative factors affecting plant growth following the revegetation of waste landfills include poor drainage, low-quality cover soils, shallow

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cover soils, a lack of organic matter and soil dryness (HURI 1995).

The most common methods for restoration involve changing the vegetation through chemical treatments, mainly using nitrogen, which is one of the three essential nutrients for plant growth. Nitrate contributes to the growth of plants through its accumulation in leaves (Dolling 1996). Nitrogen fertilizers are known to promote the dominance of grasses on highly disturbed soils and decline species diversity in meadows (Doerr and Redente 1983, Mountford et al. 1996). Carbon addition can be used to lower soil nitrogen levels and favor later seral species. The hypothesis that succession is accelerated and dominant species grow better if nitrogen is removed or depleted has not been tested in diverse habitats (Morgahn and Seastedt 1999).

Few studies have examined the effects of chemical treatments in waste landfills on succession and species replacement. It is hypothesized that nitrogen fertilizations and carbon amendments will have different effects on species composition, species dominance will be different at various chemical treatments and subsequently poor plant communities occupying infertile sites of the waste landfills are positively responsive to nutrient addition in terms of total cover, biomass and species richness.

The goals of the present study were to assess the impacts of nitrogen and carbon fertilizers on changes in biomass, cover and species diversity in municipal waste landfills and to evaluate an effective application tool for restoration of infertile disturbed sites.

MATERIALS AND METHODS

Study Site

This study was conducted in landfills at Kyongseodong, South Korea. This site is located in the province of Gyeonggi in the west-central region of the Korean peninsula (37°34' N, 126°39' E; Fig. 1). Further details of the study sites are provided in Table 1. Kyongseodong landfill had accepted domestic wastes and then it had been left unattended after landfill closure in 1992. This site was an uncapped landfill covered with topsoil and subsoil from the nearest forest edges or construction subsoils to a depth of 0.6 m without a liner. The elevation of the study site is 27 m above sea level. Kyongseodong landfill was surrounded by reclaimed lands. The mean annual temperature at the study sites is 12℃. Mean annual precipitation in the area is about 1,100 mm (Korea Meteorological Administration 1995～2000). Study site experiences a temperate climate (Gyeonggi Provincial Government 2004). The plant communities around the study site is composed of six forest vegetation, four forest edge vegetation, thirty one grassland vegetation (Kim and Jung 1995). *Miscanthus sinensis-Pteridium aquilinum* var. *latiusculum*, *Pennisetum alopecuroides*, *Spodiopogon sibiricus-Miscanthus sinensis*, *Xanthium strumarium-Ambrosia artemisiifolia* var. *elatior*, *Chelidonium majus* var. *asiaticum-Equisetum arvense*, *Arthraxon hispidus*, *Plantago asiatica-Polygonum aviculare* and *Oenothera odorata-Kummerowia striata* are common grassland communities (Kim and Jung 1995).

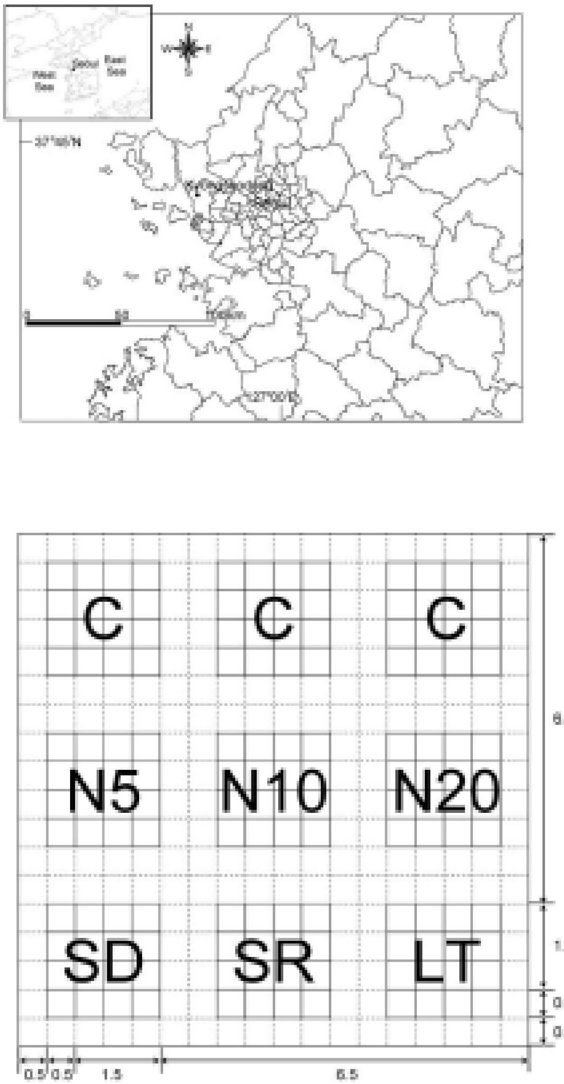

Fig. 1. Map of study sites and diagram of 9-m^2 permanent macroplot treated with seven ways: control (C), nitrogen fertilizer at 5 (N5), 10 (N10) and 20 (N20) g/m^2, sawdust (SD), sucrose (SR) and litter (LT). The permanent macroplot was subdivided into nine 3-m^2 subplots, which were divided into 16 0.5-m^2 microplots. A closed circle within the map indicates the waste landfill surveyed (Kyongseodong landfill).

Plot Establishment

The four sites chosen were Kyongseodong landfill (Kyongseo-

Table 1. Characteristics of study site. All means ± standard error (S.E.) are based on means of 42 individual samples

Parameter	Kyongseodong landfill
Bulk density (g/cm^3)	1.21 ± 0.01
pH	7.83 ± 0.14
Electrical conductivity ($\mu S/cm$)	435.9 ± 134.7
Organic matter content (%)	0.58 ± 0.09
Total N (%)	0.143 ± 0.015
Available P (mg/kg)	7.57 ± 0.56
K (mg/kg)	138.9 ± 12.3
Na (mg/kg)	33.43 ± 4.84
Ca (mg/kg)	1711.8 ± 112.3
Mg (mg/kg)	194.3 ± 13.8
Cd (mg/kg)	0.177 ± 0.013
Cr (mg/kg)	0.225 ± 0.031
Cu (mg/kg)	5.99 ± 0.59
Fe (mg/kg)	126.7 ± 14.5
Mn (mg/kg)	178.3 ± 17.5
Ni (mg/kg)	0.754 ± 0.096
Pb (mg/kg)	7.42 ± 0.91
Zn (mg/kg)	149.6 ± 39.3

dong, Incheon, South Korea) 7 years after its closure (Fig. 1). Selection standards were high landfill stability, access easiness and low disturbance. A total of four 9 m^2 permanent macroplots (two plots per landfill) were established. Each macroplot was subdivided into nine 3 m^2 subplots. The subplots were divided into 160.5 m^2 microplots >0.5 m inside the borders of the subplots to avoid edge effects (Fig. 1). The coverage and sociability of species in each microplot were recorded according to the Braun-Blanquet scale (Fuller and Conard 1932) from September to October 1999, prior to the chemical treatments.

Chemical Treatments

The nitrogen and carbon treatments listed below were carried out in six subplots within the four macroplots from April to August 2000. The three untreated subplots were used as controls. The nitrogen fertilizer (Urea fertilizer, Namhae Chemical Corp., Yeosu, South Korea) contained 46% nitrogen. The treatments were as follows:

i) Nitrogen fertilization I: 100 g nitrogen fertilizer was sprayed as granules onto each subplot once during April when the growth of the grasses started (5 N g/m^2).

ii) Nitrogen fertilization II: 200 g nitrogen fertilizer was sprayed as granules onto each subplot once during April (10 N g/m^2).

iii) Nitrogen fertilization III: 400 g nitrogen fertilizer was sprayed as granules onto each subplot once during April (20 N g/m^2). The nitrogen amounts added followed the method of Lee and Kim (1996).

iv) Sawdust addition: 289 g/m^2 coniferous sawdust (Domestic sawdust, Forestry Cooperatives Federation, Suwon, South Korea) was added twice in May and July (Morghan and Seastedt 1999).

v) Sucrose addition: 222 g/m^2 sucrose (Ultrapure, WWW Chemicals, Atwood, USA) was added as powders on a monthly basis from April to August (Morghan and Seastedt 1999).

vi) Litter addition: 222 g/m^2 litter, which was sampled from forests near the Kyongseodong landfill, was added during May. The litter was composed of leaves of *Pinus rigida* Mill.

The locations of the treatments were initially assigned using random tables (Petersen 1985). Subsequently, the treatments were conducted in the same subplots according to this pattern.

Vegetation Analysis

The coverage and sociability of species after the treatments in the 16 microplots within the nine subplots were recorded from September to October 2001. The total cover was calculated by summing the cover of all plant species within the plots. The species richness was defined as the total number of plant species within the 0.5 × 0.5 m^2 microplots. The ratio of the number of annual species to the number of total species (*A/T*) and the ratio of the number of perennial species to the number of total species (*P/T*) were calculated. Species gain or loss was estimated as the difference in the number of species before and after the treatments. The aboveground parts of the plants were clipped with pruners to compare the biomass among plots treated with the nitrogen and carbon fertilizers. The results from four of the 16 microplots were pooled to give one sample with four repetitions. The samples were transported to the laboratory and dried in an oven (10SDO-135, Youngjin, Seoul, South Korea) at 80℃ until they reached a constant weight. After drying, the weights were measured using a balance (KERN EW 6000-1M, KERN & Sohn GmbH, Balingen, Germany).

Soil Chemical Measurement

The soils within the treated subplots were sampled at a depth of 0～10 cm to measure the total nitrogen and organic carbon contents once every 2 months during May to September. The soils were sampled at 10 random points per subplot, which were pooled as one sample. The total nitrogen and organic carbon contents of the soils were measured using the micro Kjeldahl method and the Walkley Black method (Brenner 1996, Nelson and Sommers 1996). The two ratios of total nitrogen versus organic carbon contents and total organic carbon versus nitrogen contents were calculated to compare the ratios bimonthly.

Statistical Analysis

Nonparametric methods were conducted because most of the data were non-normally distributed. The Kruskal-Wallis test was used to analyze plant biomass sampled within differently treated plots, and species gain and loss among the treatments, employing the SAS program (SAS Institute Inc., SAS, 2001, Version 8.02). Data on the total cover of all species, and the species richness before and after the treatments, were compared using the paired-plot *t*-test. The *A/T* and *P/T* ratios before and after the treatments were tested using the Wilcoxon rank-sum test. The significance of cover change between species with >15% cover after the treatments was tested using the Wilcoxon rank-sum test (SAS Institute Inc. 2000).

RESULTS

Biomass Changes

The dry weights of plants on plots with different treatments showed significant differences (Fig. 2; *P*<0.01). The dry weights of plants on plots treated with 5 and 10 N g/m^2 were significantly greater than those of the other plots (*P*<0.01). In contrast to the controls, the mean dry weights in plots treated with 5, 10 and 20 N g/m^2 and with litter increased by 65, 40, 7 and 20%, respectively, whereas the mean dry weights of plants treated with sawdust and sucrose addition decreased by 21 and 17%, respectively.

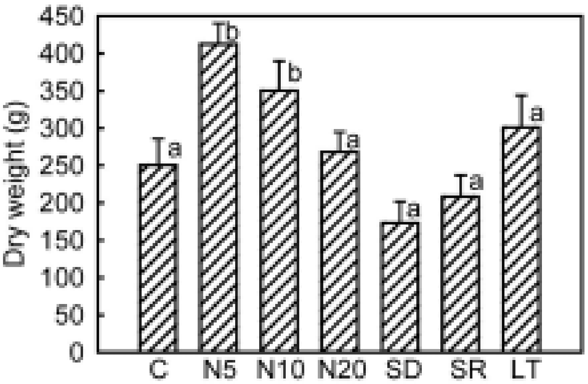

Fig. 2. Aboveground biomass per m^2 in plots treated with control (C), nitrogen fertilizer at 5 (N5), 10 (N10) and 20 (N20) g/m^2, sawdust (SD), sucrose (SR) and litter (LT). The means are the combined averages over the four macroplots (*n*=16, +1 S.E.). Different letters above the bars indicate statistically significant differences according to the Kruskal-Wallis test (*n*=16; *P* < 0.01).

Species Development

Considering the changes in species with >15% cover in the 16 microplots (0.5 × 0.5 m^2), *Setaria viridis* cover increased from 37 to 66%, *Pueraria thunbergiana* invaded plots treated with 5 N g/m^2 and *Digitaria ciliaris* cover increased from 11 to 23%. In plots treated with 10 N g/m^2, the domination patterns of the perennial *Artemisia princes* var. *orientalis* and the annual *S. viridis* were reversed (*A. princes* var. *orientalis* > *S. viridis* → *S. viridis* > *A. princes* var. *orientalis*), the perennial *Festuca arundinacea* disappeared and the cover of the perennial *Cymbopogon tortilis* var. *goeringii* increased. In plots treated with 20 N g/m^2, the annual *Kummerowia striata* invaded and became a dominant species. A Wilcoxon rank-sum test showed no significant differences between species with >15% cover before and after treatment with the three different levels of nitrogen fertilizer (*P*>0.05). In the plots treated with sawdust, *A. princeps* var. *orientalis* was displaced by *Cosmos bipinnatus,* the *S. viridis* cover decreased from 17 to 5%, the *C. tortilis* var. *goeringii* cover decreased from 42 to 32% and the *D. ciliaris* cover increased from 32 to 34%. In the plots treated with sucrose, *F. arundinacea* and *A. princeps* var. *orientalis* were dominant before treatment, whereas after treatment the cover of each of *D. ciliaris*, *Ambrosia artemisiifolia* var. *elatior* and *Cassia mimosoides* var. *nomame* was over 15%. As a result, the overall species diversity was greater than before. *S. viridis*, *F. arundinacea* and *Eragrostis ferruginea* were dominant before the treatment, whereas *S. viridis* and *A. artemisiifolia* var. *elatior* were dominant and *E. ferruginea* died away after the treatment. In addition, the dominance of *Aster ciliosus* over *A. artemisiifolia* var. *elatior* was reversed. In the plots with litter treatment, the dominance of *Echinochloa crus-galli* over *A. artemisiifolia* var. *elatior* changed, and the *C. tortilis* var. *goeringii* cover increased from 17 to 35%. A Wilcoxon rank-sum test between species with >15% cover before and after sawdust treatment showed that the *D. ciliaris* cover increased significantly and was 1.59-times greater after treatment (*P*<0.01). After sucrose treatment, *F. arundinacea* cover was 2.35-times lower (*P*<0.05) and *A. artemisiifolia* var. *elatior* cover was 3.8-times greater than before the treatment (*P*<0.05). After litter treatment, *S. viridis* cover was 0.82-times lower than before the treatment (*P*<0.05).

In the nitrogen-fertilized plots, a paired-plot *t*-test of the total cover of all species pre- and post-treatment showed significant differences in the plots treated with 5 and 20 N g/m^2 (Fig. 3; *n*=64, *P*<0.01). The total cover after treatment in the plots receiving 5 N g/m^2 was 1.29-times greater than that before treatment (Fig. 3; *n*=64, *P*<0.01). The total cover after treatment in the plots receiving 20 N g/m^2 was 1.37-times greater than that before treatment (Fig.

3; n=64, P<0.01). There were no significant differences in the control plots. Similarly, the total cover in plots treated with 10 N g/m^2 showed no significant differences (Fig. 3; n=64, P>0.05). The total cover of plants in plots treated with sawdust was 1.38-times greater, and the total cover of plants in plots treated with sucrose was 1.27-times greater, after the treatments (Fig. 3; P<0.01). There were no significant differences in the plots pre- and post-treatment with litter (Fig. 3; P<0.01).

A paired plot *t*-test of species richness before and after treatment in plots treated with 5 N g/m^2 showed that this parameter decreased significantly from 3.41 to 3.09 (Table 2; P<0.01). Species richness in plots treated with 10 N g/m^2 showed no significant differences before and after treatment (P>0.01). Species richness in plots treated with 20 N g/m^2 increased significantly from 2.69 to 3.11 (Table 2; P<0.01). Species richness in plots treated with sawdust increased significantly and was 1.33-times greater after treatment (Table 2; P<0.01). Species richness in plots treated with sucrose increased significantly and was 1.21-times greater after treatment (Table 2; P<0.01). Species richness in plots treated with litter showed no significant differences before and after treatment (P>0.01).

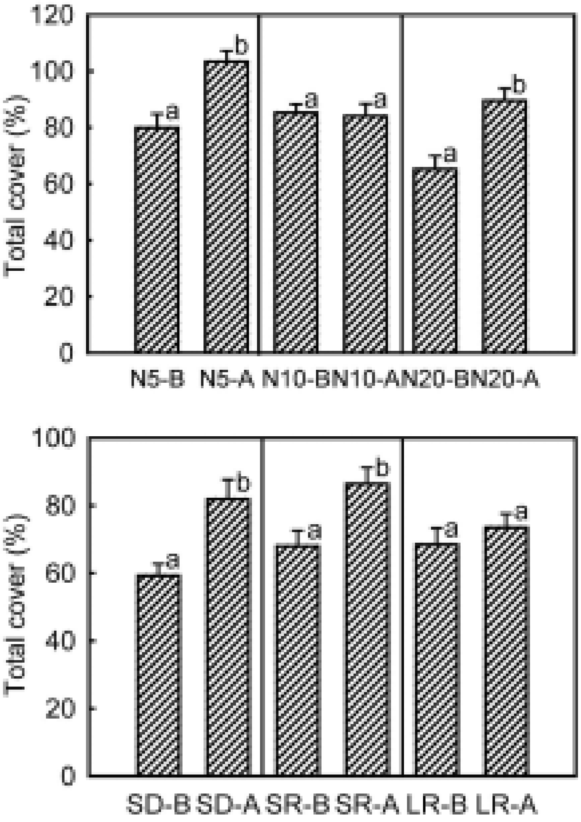

Fig. 3. Total cover of all species in the plots (0.5 × 0.5 m^2) treated with 5 (N5), 10 (N10) and 20 (N20) g/m^2 of nitrogen fertilizer and sawdust (SD), sucrose (SR) and litter (LT). The means are the combined averages over the four macroplots (n=64, +1 S.E.). Different letters indicate statistically significant differences between the bars (P<0.01). The letters '-B' and '-A' indicate before and after treatment, respectively.

A Wilcoxon rank-sum test of the ratio of the number of annual and perennial species to the number of total species (A/T and P/T) in plots treated with 5 and 10 N g/m^2 showed no significant differences (Table 2; P>0.05). In plots treated with 20 N g/m^2, the ratio of the number of perennial species to the number of total species (P/T) decreased significantly after nitrogen fertilization (P<0.05), but the ratio of the number of annual species to the number of total species (A/T) showed no significant difference (P<0.05). The ratio of the number of annual and perennial species to the number of total species (A/T and P/T) in plots treated with sawdust and litter showed no significant differences (Table 2; P>0.05). After sucrose treatment, the ratio of the number of perennial species to the number of total species (P/T) decreased significantly and was 0.75-times smaller (P<0.05), whereas the ratio of the number of annual species to the number of total species (A/T) showed no significant difference (P<0.05).

A Kruskal-Wallis test on species gain and loss after treatments showed that species gain was significantly different in plots treated with 20 N g/m^2 (P<0.05), whereas there were no significant differences in plots treated with 5 and 10 N g/m^2 (P>0.05). There were no significant differences in the carbon-added treatments, which consisted of sawdust, sucrose and litter (Table 2; P>0.05).

Finally, the invasion, decline and dominance mode of species at different chemical treatments (nitrogen and carbon) were different whereas total cover and species richness after chemical treatments showed increase trends. Thus, plant communities on the nutrient poor waste landfills strongly responded to nutrient additions.

Nutrient Dynamics

Measuring the total nitrogen and organic carbon contents revealed that the ratio of total nitrogen versus organic carbon contents in the soil in plots treated with nitrogen fertilizer increased after treatment (Fig. 4). The total nitrogen content ranged from 0.11 to 0.22% and showed no significant differences between months (P>0.05). Comparing the ratio of organic carbon relative to the total nitrogen contents in the soil in plots treated with sawdust, sucrose and litter revealed that the values increased after treatment (Fig. 4). The ratio of organic carbon relative to the total nitrogen contents ranged from 4.52 to 15.17 for the sawdust treatments, from 5.73 to 32.21 for the sucrose treatments and from 5.09 to 20.26 for the litter treatments. The ratio of total nitrogen versus organic carbon contents in the soil in quadrats treated with nitrogen fertilizer showed a decrease trend during a growing season whereas the ratio

Table 2. The effects of nitrogen and carbon addition on species richness (*n*=64), the ratio of the number of annual species to the number of total species (*A/T*; *n*=16), the ratio of the number of perennial species to the number of total species (*P/T*; *n*=16), and species gain and loss (*n*=64). Means ± standard error (S.E.) denoted by different letters are statistically significantly different according to the paired-plot *t*-test for species richness ($P<0.01$), the Wilcoxon rank-sum test for *A/T* and *P/T* ($P<0.05$), and the Kruskal-Wallis test for species gain and loss ($P<0.05$). The letters 'B' and 'A' indicate before and after treatment, respectively

Treatments	Species richness	*A/T*	*P/T*	Species gain	Species loss
	B	*B*	*B*		
	A	*A*	*A*		
N5	3.41 ± 0.12 a	0.51 ± 0.01 a	0.46 ± 0.01 a	0.61 ± 0.10 a	0.86 ± 0.14 a
	3.09 ± 0.19 b	0.48 ± 0.01 a	0.50 ± 0.01 a		
N10	2.95 ± 0.20 a	0.45 ± 0.01 a	0.49 ± 0.02 a	0.61 ± 0.12 a	0.67 ± 0.11 a
	2.98 ± 0.23 a	0.48 ± 0.02 a	0.44 ± 0.02 a		
N20	2.69 ± 0.18 a	0.42 ± 0.01 a	0.53 ± 0.00 a	1.17 ± 0.16 b	0.77 ± 0.15 a
	3.11 ± 0.16 b	0.53 ± 0.01 a	0.42 ± 0.01 b		
Sawdust	2.39 ± 0.15 a	0.62 ± 0.02 a	0.34 ± 0.02 a	1.41 ± 0.21 a	0.63 ± 0.13 a
	3.19 ± 0.23 b	0.75 ± 0.01 a	0.20 ± 0.01 a		
Sucrose	2.78 ± 0.02 a	0.47 ± 0.01 a	0.51 ± 0.01 a	1.06 ± 0.18 a	0.53 ± 0.10 a
	3.36 ± 0.03 b	0.57 ± 0.01 a	0.38 ± 0.01 b		
Litter	2.70 ± 0.14 a	0.38 ± 0.01 a	0.60 ± 0.02 a	0.88 ± 0.18 a	0.75 ± 0.15 a
	2.81 ± 0.16 a	0.52 ± 0.01 a	0.44 ± 0.02 a		

Species richness is the total number of species within 0.5 × 0.5 m^2 plots.
Species gain and loss are the change of species numbers after treatments.
N5, N10 and N20 represent treatments of 5, 10 and 20 N g/m^2, respectively.
Sawdust indicates the addition of 289 g/m^2 sawdust.
Sucrose indicates the addition of 222 g/m^2 sucrose. Litter indicates the addition of 222 g/m^2 litter.

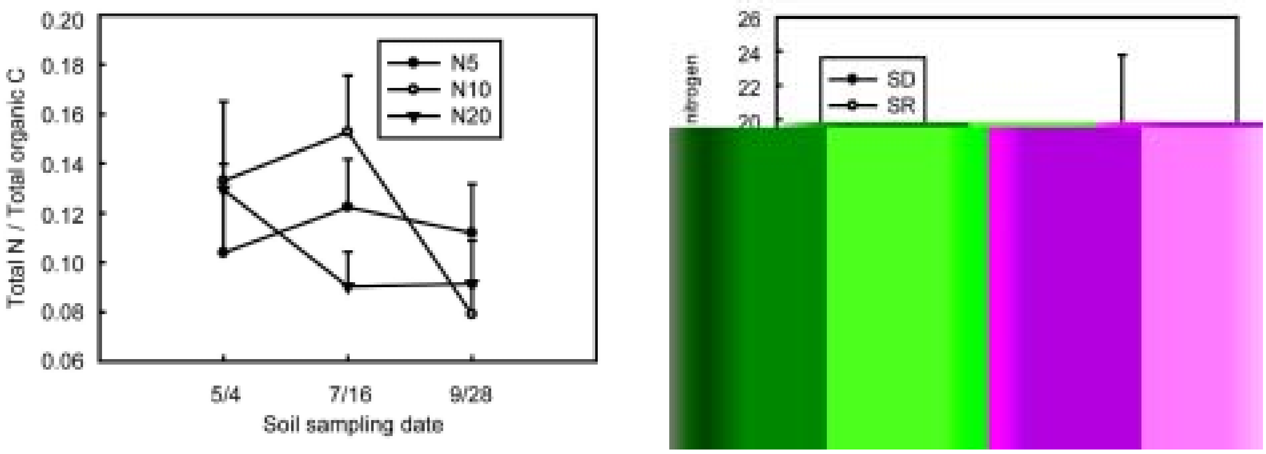

Fig. 4. Monthly changes of the ratio of total nitrogen versus organic carbon contents in the soil in quadrats treated with nitrogen fertilizer and the ratio of total organic carbon versus total nitrogen contents in the soil in quadrats treated with sawdust (SD), sucrose (SR) and litter (LT). N5, N10 and N20 represent fertilizer sprayed at 5, 10 and 20 g/m^2, respectively. Sawdust, sucrose and litter indicate the additions of 289 g/m^2 sawdust, 222 g/m^2 sucrose and 222 g/m^2 litter.

of total organic carbon versus nitrogen contents in the soil in quadrats treated with sawdust, sucrose and litter increased during the time (Fig. 4). This showed faster turnover rates of nitrogen fertilizers and their higher availability to plants, compared with slower transform processes of carbon additions (sawdust, sucrose and litter) in the soils of the waste landfills.

DISCUSSION

Nitrogen Fertilization

The urea fertilizer (H_2NCONH_2) used on soils is hydrolyzed and transformed into NH_4-N forms, and then adsorbed onto the surface of the soil rather than leaching (Broadbent et al. 1958). The form of NH_4-N changed by microorganisms is $(NH_4)_2CO_3$. If soils are divided into oxidation and reduction layers, urea might be leached as the NO_3-N form through the nitration processes (Benson and Barnette 1939, Lee et al. 1995). In this case, nitration occurs in the oxidation layer and denitrification occurs in the reduction layer (Ponnamperuma 1972). There is an increased potential for denitrification in waste landfills, where the soils are reduced by the oxidation of CH4. Nitrate and ammonia are in a stable condition if intense oxidation or reduction occurs (Bohn et al. 1979). Plants use NH_4-N and NO_3, which are products of the breakdown of urea, as nitrogen sources (Crawley 1986), and nitrogen fertilizers increase the nitrogen concentration in plants (Estavillo et al. 1997). The nitrogen contents of mineral and reclaimed soils are 0.06 to 0.5%, and that of subsoil is 0.02%. Peat deposits have nitrogen contents of 0.5 to 1.5% (Allen 1974). Waste landfills, including our study site, have nitrogen contents ranging from 0.054 to 0.143% (Kim and Lee 2005). Therefore, waste landfills are relatively low in nitrogen content. Furthermore, nitrogen provision by nitrogen fixing plants is limited in these artificial ecosystems. If nitrogen is provided in nitrogen-limited ecosystems, primary production is augmented (Tamm 1991). The biomass and coverage was increased by nitrogen fertilizer treatments in the present study (Figs. 2, 3). These results suggest that leachate did not contaminate the soils of the entire waste landfills, because ammonia is a major component of leachate and a product of the breakdown of proteins in refuse, according to Watson-Craik (1998). The nitrogen contents in plots treated with nitrogen fertilizer ranged from 0.11 to 0.22%, which represented an enrichment of nitrogen.

Plant species respond positively or negatively to nutrient additions (Bakelaar and Odum 1978). Nitrogen fertilizer has a negative impact on the oxidation of CH_4 (Singh et al. 1997), but grasses mitigate such an oxidation effect (Hilger et al. 2000). Therefore, anaerobic conditions caused by CH_4 are predicted to have a negative effect on grass growth in the cover layer. Nitrogen fertilizer treatment in waste landfills might have positive impacts on the cover and biomass of the grasses (Figs. 2, 3). Nitrogen fertilization significantly increased the aboveground biomass (Huberty et al. 1998). Nitrogen addition is also known to have a significant effect on plant cover and productivity in urban disturbed areas (Bloomfield et al. 1982). Furthermore, it increases the belowground biomass (Benning and Seastedt 1997). In nitrogen-fertilized plots, a paired-plot *t*-test of the total cover of all species pre- and post-treatment showed no significant differences in the total cover in plots treated with 10 N g/m^2, whereas those treated with 5 and 20 N g/m^2 presented significant differences pre- and post-treatment. This might have been caused by interspecies competition, which was maximized after nitrogen fertilization. In the present study, nitrogen fertilization at 20 N g/m^2 was above the 12 N g/m^2 level examined by Huberty et al. (1998). Nitrogen fertilizer at 10 N g/m^2 was not an optimal treatment to increase plant biomass. Nitrogen addition increased species density per unit area (Huberty et al. 1998). Species richness in plots treated with 20 N g/m^2 increased, those treated with 5 N g/m^2 showed a significant decrease and those treated with 10 N g/m^2 showed an increase with no significant differences (Table 2). These patterns are similar to those seen in abandoned fields, where plant biomass increased, light density decreased and species richness declined (Lee and Kim 1996). Although nitrogen was provided in nitrogen-deficient waste landfills, interspecies or intraspecies competition could not be eliminated. Such competition did not occur in the waste landfills when nitrogen was deficient and the biomass was small. In the case of specific types of fertilizer, the impacts on plant growth should be surveyed and this information used for landfill restoration. Larger amounts of nitrogen fertilizer make a small number of species dominant, whereas nitrogen fertilizer applied at <40 kg/ha increases species diversity (Davis et al. 1985). Considering higher perennial establishment and species richness and biomass increase, nitrogen fertilization of 10 to 20 N g/m^2 is recommended for herbaceous plant development of municipal waste landfills.

Carbon Addition

Organic carbon in soil is provided through carbon input and the decomposition of organic materials (Bohn et al. 1979). The organic carbon content in the control plots was 1.66% ± 0.49 (n=12). This is relatively low for productive systems, compared with levels of 0.5% in deserts and 5% in the surface soils of temperate regions (Bohn et al. 1979). Organic materials added to landfills facilitate the establishment and growth of trees (Nixon et al. 2001). With sawdust treatment, the total mean biomass decreased compared with the controls (Fig. 2); this showed the impacts on plant growth. The total plant cover in plots after sawdust treatment increased significantly compared with before the treatment, yet species with >15% cover showed no significant differences, with the exception of *Digitaria ciliaris*. It was therefore thought that other species invaded and contributed separately to the total cover levels (Fig. 3). The higher species richness after sawdust treatment explained these trends (Table 2). Therefore, sawdust methods are appropriate restoration options for waste landfills. Sawdust can block light, reduce soil temperature, decrease evaporation and control plant growth. Sucrose treatments influenced plants with higher cover levels. The cover of the perennial exotic *Festuca arundinacea* diminished and that of the native perennial *Artemisia princeps* var. *orientalis* increased. The annuals *Ambrosia artemisiifolia* var. *elatior* and *D. ciliaris* both increased in cover. This demonstrated that sucrose treatment had diverse effects on different species. Certain species decreased in density and dry weight after sucrose treatment (Young et al. 1998). Such sucrose treatments increase annuals and the number of soil seed banks. This study suggests that the patterns of domination of species in waste landfills should be assessed initially, and then different chemical treatments should be applied to make them stable by increasing perennials and replacing species. However, the specific selection of chemical treatments will depend on the type of carbon source and the speed of the recovery from the contamination caused by the treatment. Plant invasion through seed rains might affect the results. The overall reduction in grass biomass caused by sucrose addition helped trees to become established for landfill restoration (Fig. 2). Litter treatment, among the carbon fertilizers, had no obvious effects on species change (Table 2), but increased the perennial native *A. princeps* var. *orientalis* cover and decreased the perennial exotic *F. arundinacea* cover. Inorganic ions leached from leaves are transported into the soil; K is leached at levels of up to 80～90% per annum, and P and Mg are also leached rapidly (Dickinson and Pugh 1974). Litter treatment was shown to have an effect on soil and plant growth because of the higher decomposition rate after May according to Mun and Joo (1994). Varying the amount of litter has the potential to hinder or facilitate tree establishment. Carbon addition reduces the amount of ammonia, but this effect will diminish if carbon is no longer added (Morghan and Seastedt 1999). The weight ratio of carbon to nitrogen in soil is known to be approximately 10 (Bohn et al. 1979). This ratio was increased to up to 20 by carbon addition in the waste landfills. If the ratio of carbon to nitrogen exceeds 15～17, nitrogen availability is limited (Alexander 1989). In the present study, the ratio was over 15, which signifies effects on nitrogen availability. In terms of species diversity, sawdust addition had significant potential for use in restoration methods in waste landfills because it allowed alternative species to invade. Sawdust addition also inhibited sun-light, and reduced soil temperature and evaporation. Its ability to decrease non-beneficial conditions, such as high atmosphere and soil temperature, in waste landfills encourages plant growth.

Management Implications

Replacement control of vegetation is a means of measuring the replacement of plants and removing harmful species by indirect ecological methods (Piemeisel 1954). Replacement control establishes superior species and induces the natural processes of secondary succession. If resource availability is controlled directly, plant establishment, growth and competition are transformed, and if the nutrient content of the soil is changed, the community develops in alternative directions (Luken 1990). Plants in municipal waste landfills are associated with concrete, rocks and refuse, and this soil heterogeneity leads to mosaic characteristics that provide higher standard errors (Ettala 1988).

This study showed that nitrogen fertilization enhanced plant biomass and total covers significantly and carbon addition made species invasion increase in a nutrient-deficient municipal waste landfill. The present study demonstrated positive nutrient impacts on plant biomass and species diversity, despite the fact that municipal waste landfills are highly disturbed ecosystems.

ACKNOWLEDGEMENTS

I thank Gillian Kerby for reviews of the manuscript and Hyun Ju Song for statistical analysis. This work was supported by National Institute of Environmental Research.

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(Received May 9, 2007; Accepted May 16, 2007)