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Ameliorating Topsoil Conditions by Biosolid Application for a waste Landfill landscape

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ABSTRACT: Sanitary landfills, created for the disposal of solid waste, usually are developed into parks after they are closed. However, soil amelioration with organic matter is usually needed to restore fertility and promote revegetation. Sewage sludge creates a massive waste disposal problem. The use of composted sewage sludge (biosolid) as a soil conditioner might restore the soil fertility at landfill sites and simultaneously alleviate the need for sewage sludge disposal. We applied biosolid to waste landfill soil and evaluated its effects on soil properties and tree growth in a field experiment. Biosolid improved soil characteristics including moisture, organic matter, and nitrogen content and also increased tree height and diameter at breast height. Physiological measures, such as chlorophyll content and photosynthetic rate, showed positive responses in trees grown in biosolid treatments. Heavy metal concentrations in soil and tree leaves after applying compost did not differ from concentrations measured at control sites. Therefore, we conclude that the use of biosolid in waste landfills would be an efficient, environmentally beneficial, and cost-effective method to restore the conditions of landfill soil for plants.

Key words: Monitoring, Sanitary landfill, Soil restoration, Photosynthetic rate, Sewage sludge, Biosolid

INTRODUCTION

The efficient disposal and recycling of waste and domestic sewage presents increasingly serious challenges. Sanitary landfilling is one of the most common methods for solid waste disposal (Chen *et al.,* 2003). After closure, sanitary landfills are usually developed into parks, nature areas, and other multiple-use facilities (Gilman *et al.,* 1985). The restoration of vegetation on the final cover soil is critical to achieving these end objectives, but effective vegetation restoration programs often are compromised by vehicular traffic and repeated filling and topping with new, often poor, cover soil (Ettala *et al.,* 1988). Plans have been developed to convert the Sudokwon Landfill (Incheon, South Korea) into an environmental ecological park upon its closure (SLMC 2011). Soil that previously had been excavated, to prepare trenches for waste, will be used to reclaim the landfill. This soil, however, generally is nutrient poor with low organic matter which, exacerbated by disturbances inherent in management practices, and impedes plant growth (Kim & Lee 2005). Therefore, as in most such projects, successful landfill restoration requires heavy use of organic fertilizer to promote revegetation.

Biosolid, consisting of composted sewage sludge, can provide organic matter (OM) to waste soil, and serves as an effective fertilizer (Walker *et al.,* 2004) while decreasing the availability of heavy metals and improving soil structure. Because it contains concentrated organic matter, biosolid offers an economical solution to landfill restoration, especially compared to expensive commercial fertilizers that would be required for treating such large areas (Athy *et al.,* 2006). Although rich in organic matter, most sewage sludge today is discarded. Of the 7631 tons of sludge produced daily in South Korea in 2007(KME 2008), 68.5% was disposed in the ocean while only 18.5% was recycled (KME 2008). Reclaiming sewage sludge thus provides important environmental as well as economic benefits.

Biosolid has high organic matter and nutritional content that makes it suitable as a horticultural soil fertilizer to promote biomass production (Casado-Vela *et al.,* 2007). Although the application of sewage sludge to crops (Wei and Liu, 2005, J. Casado-Vela et *al.,* 2007) and its biological effects have been investigated (Korboulewsky *et al.,* 2002), little is known about its long-term effects on soil, plants, and barren fields (Mantovi *et al.,* Kidd *et al.,* 2007, Pengcheng *et al.,* 2008). Given that it is produced in large quantities on landfills, its application as fertilizer potentially can fill the need for a more efficient method to facilitate re-

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vegetation (Ingelmo *et al.,* 1998) that minimizes transport costs but environmental consequences associated with its application require study(Businelli *et al.,* 2009). The potential benefits of using biosolid as a fertilizing agent for landfill slopes thus appear to be great (Kirkeby *et al.,* 2006; Song & Lee 2010). Our previous studies investigated these benefits using composting methods in pot experiments (Song & Lee 2010). Here we examine the effects of composted sewage sludge application to reclaimed soils on the slopes of a landfill site. We measured physical properties of the soil, changes in its nutrient contents, heavy metal accumulation, and ecological and physiological responses of plants growing in the reclaimed soils.

MATERIALS & METHODS

Biosolid was composted using a mixture comprised of 70% sewage sludge and 30% sawdust and bark (by mass). A solution of aerobic microorganisms (0.1 % by mass) with photosynthetic bacteria (*Anabaena* sp.), bacilli, yeast, and lactic acid bacteria was mixed with the mixture using a 30 m^3 fermentor with a continuous air supply of 3.6 m^3/min, following the Beltsville Aerated Pile method (Parr *et al.,* 1978). The dried sewage sludge, with 65% moisture content, was provided by Sudokowon Landfill after collection from the Seoul metropolitan area. After composting for 20 days, temperature-stable compost was piled to a height of 2 m before application. The Sudokwon Landfill is located at Incheon, Korea (37° 34´ 52" N and 126° 37´ 29" E). The annual average temperature is 11.4 °C and the annual precipitation is 1170 mm (KMA 2005). With a gross area of approximately 20,000,000 m^2, the Sudokwon Landfill is one of the largest sanitary landfills in the world (SLMC 2011) and it processes 6700 tons of leachate and 600 tons of sludge daily (Song & Lee 2010, SLMC 2011). From 1992 until its planned closure in 2025, a total of 250 million tons of waste should be reclaimed. Current plans envision the construction of an eco-park and eco-resort after it ceases operation. Two areas located on the slopes of the landfill were selected for field trials. The first area was planted in 2000 with 10 13-year-old sawtooth oaks (*Quercus acutissima* Carruth.). The topsoil on this had been disturbed, by additional reclaiming, a year prior to the experiment. A second area, recently reclaimed, was planted with 3-year-old Japanese black pine (*Pinus thunbergii* Parl.) saplings a month prior to the experiment. We thus were able to compare responses of two species (deciduous and coniferous), as well as effects of compost application in newly planted versus old areas.

In the sawtooth oak area, ten 4 × 5 m quadrats were established in late April, 2006, with each quadrate containing between 10 and 14 trees. The average tree height was 5.3 m. In the Japanese black pine area, ten 3 × 3 m quadrates for each treatment were established in late April, 2006 and each quadrate contained between 10 and 18 trees. The average tree height was 67 cm. Only small quadrates could be established due to roads and slopes that limited the width of the planted area to about 4 m. Quadrates for each species were designed to include at least 10 individuals. We set up four treatments, with two replicates for each tested in separate quadrates. In the ‘Biosolid 1’ and ‘Biosolid 2’ treatments, we applied biosolid to the surface of the planted areas in concentrations of 800 g/m^2 and 400 g/m^2 respectively. In the ‘Osmocote’ treatment, we applied controlled release fertilizer (Osmocote Plus, 13(N) + 13(P) + 13(K) + 2MgO; Scotts International B.V.) at a rate of 75 g/m^2. In the ‘Reed’ treatment, we applied 1 kg/m^2 of mulch made from reed (*Phragmites australis* (Cav.) Steud.). The Biosolid 1 and Osmocote treatments contained10 g/m^2 of nitrogen, the optimal fertilizing rate determined for the landfill (Kim 2001). The Biosolid 2 treatment, with biosolid reduced by half, was designed to examine outputs including possibly reduced side-effects of a more economical application regimen. Changes in soil moisture content were assessed using the Reed treatment. Within each treatment, 20 random individual trees were selected for growth measurements. Four individuals were selected randomly for photosynthetic rate measurements and 5 individuals were selected randomly for measurement of chlorophyll and nutrient contents.

We collected core samples of soil (5 cm length, 100 cm^3; Eijkelkamp, B.V.). A composite of 4 cores was made for each sample, and we assessed 3 samples (12 cores). The soil was dried for 48 h at 105 °C to measure its moisture content. Soil organic matter content was determined by loss on ignition (combustion at 550 °C for 4 h) using the formula of Dean (1974). The pH and electrical conductivity (EC) of the soil and biosolid were determined using suspensions of air-dried soil samples in water (20 g/30 mL). The soil respiration rate was measured using an EGM-4 (PP Systems) gas analyzer. The C, N, and H contents of the soil and biosolid samples were measured using an elemental analyzer (Flash EA 1112, Thermo Electron Co.) in October. An NH_4^+-N, NO_3-N analysis was performed using a Kjeldahl Protein/Nitrogen analyzer (Kjeltec Auto 1035 System, Tecator AB).

For heavy metal analysis, three random samples of plant materials and soils were selected for measurement. One gram of dried and milled soil (or biosolid) was pretreated with 60% HNO_3 for 24 h and subsequently heated to 80 °C for 2 h. Then, 10 mL of 70% perchloric acid was added and heated to 200°C until the solution became clear. The heavy metal content of the samples was measured using an ICP Emission spectrometer (ICPS-1000Ⅳ). We analyzed heavy metal and C, N, and H contents of dried and milled plant leaves from trees harvested in October using the methods described above. We measured the photosynthetic rates of 4 randomly selected trees in August, using a portable photosynthetic measurement system (Li-6400, Li-cor Biosciences) (30°C, flow rate = 500 μmol/s and 400 ppm CO_2). Needles of the Japanese black pine were arranged in the chamber such that self-shading was minimized and all needles fully covered and were parallel to the plane of the leaf chamber (Zhou & Han 2005). The chlorophyll contents of plant leaves were simultaneously measured by the dimethyl sulfoxide extraction method (Hiscox & Israelstam 1979). The plant height was measured using a Haglöf vertex-b! in May and October 2006 and again in October 2007. Diameter at Breast Height (DBH) was also measured at the same time.

A one-way ANOVA was performed to identify significant difference between treatments. When we detected significant differences, a post hoc Duncan's Multiple Range Test was assessed using SAS 9.1 program (SAS Institute Inc, USA). Differences were considered significant when $p < 0.05$.

RESULTS & DISCUSSION

During composting , the temperature of the biosolid increased up to 69°C after 5 days and remained above 65°C for over one week. The moisture content of the sludge decreased from 64.5% to 52.0%. In April, after composting and just before application, the core temperature of the biosolid was 23°C and the moisture content of the biosolid dropped to 42.0% (Table 1) due to dry weather experienced from fall to spring and compression of the biosolid by its own weight. After composting, the heavy metal content of the sewage sludge was less than 10% of the Korean national standard for compost (KEI, 2003); it also was lower than North American standards as defined in the EPA 503 Sludge rule (Hogg, 2002). The salt content was also below the Korean national limit. Organic matter, moisture, and nitrogen content were higher than national standards. The condition of the reclaimed soils of the landfill was improved by treatment with biosolid (Table 2). Moisture, OM and N contents of the soil in biosolid treatments significantly increased, while the Osmocote treatment showed significant increase only in N, NO_3^- and NH_4^+. Significantly higher soil nitrogen levels were found in the biosolid treatments during the second year. Overall, after being treated with biosolid, soil properties were significantly improved (Table 2).Japanese black pine showed significant growth only in the second year, at the beginning of the growing season in April (Table 3). Likewise, sawtooth oak trees did not show any appreciable increase in growth during the first year but increased in height during the second year. The sawtooth oak trees in Biosolid 1 showed a DBH rate of increase that was more than double that of the control area, in both the first and second years. Biosolid 2, Osmocote, and Reed treatments also showed significant increases in the first year, but Osmocote showed much less of an effect during the second year. A significant increase also was apparent in the Reed treatment. No significant differences of DBH between treatments were found in Japanese black pine trees.

Table 1.Characteristics of biosolid and reclaimed soil in the Sudokwon landfill in Incheon, South Korea

Characteristics	*Quercus acutissima* site	*Pinus thunbergii* site	Biosolid
pH	8.2	8.2	7.8
EC (μS/)	245 ± 12	182 ± 10	8,500 ± 1200
Water (%)	18.5 ± 5.6	10.8 ± 2.1	41.5 ± 8.4
OM (%)	0.8 ± 0.01	0.7 ± 0.08	35.4 ± 6.80
Pb (mg/kg)	28.0 ± 5.30	121.3 ± 10.74	119.9 ± 22.01
Cd (mg/kg)	0.66 ± 0.52	1.08 ± 0.07	0.87 ± 0.18
As (mg/kg)	ND	ND	0.033 ± 0.03
Cr (mg/kg)	8.21 ± 2.10	7.90 ± 0.55	3.5 ± 0.96
Cu (mg/kg)	8.9 ± 1.80	68.2 ± 8.97	31.5 ± 11.95
NaCl (%)	0.01 ± 0.00	0.01 ± 0.00	0.37 ± 0.033
T-N (%)	0.042 ± 0.014	0.036 ± 0.002	1.7 ± 0.050
NH_4^+ (mg/kg)	0.7 ± 0.3	0.1 ± 0.0	44.0 ± 2.2
NO_3 (mg/kg)	2.3 ± 0.6	0.4 ± 0.1	298 ± 8.1

The data are presented as mean ± SE of 3 replicates. (ND: Not Detected,)

Table 2. Soil characteristics at research sites after 5 months of biosolid treatments in the Sudokwon landfill in Incheon, South Korea

	Quercus acutissima				*Pinus thunbergii*			
Parameter	**Biosolid 1**	**Biosolid 2**	**Osmocote**	**Control**	**Biosolid 1**	**Biosolid 2**	**Osmocote**	**Control**
Moisture (%)	26.1 ± 2.37[a]	24.9 ± 3.08[a]	14.6 ± 3.29[c]	17.2 ± 4.04[b]	17.7 ± 0.73[b]	20.3 ± 0.37[a]	15.7 ± 0.28[c]	10.9 ± .29[d]
OM (%)	2.78 ± 0.23[a]	2.39 ± 0.13[b]	1.53 ± 0.10[c]	1.42 ± 0.09[c]	2.78 ± 0.08[a]	2.43 ± 0.07[b]	1.36 ± 0.07[c]	1.27 ± 0.08[c]
C (%)	2.12 ± 0.29	2.05 ± 0.36	1.02 ± 0.12	0.97 ± 0.13	1.82 ± 0.11[a]	1.55 ± 0.12[b]	1.13 ± 0.08[c]	0.46 ± 0.04[d]
N (%)	0.092 ± 0.012[a] (0.089 ± 0.003[a])	0.065 ± 0.008[ab] (0.068 ± 0.004[b])	0.047 ± 0.003[b] (0.051 ± 0.004[c])	0.037 ± 0.004[b] (0.034 ± 0.004[d])	0.075 ± 0.006[a] (0.068 ± 0.004[a])	0.0560 ± 0.006[b] (0.055 ± 0.007[b])	0.045 ± 0.002[c] (0.039 ± 0.004 [c])	0.036 ± 0.001[c] (0.041 ± 0.002[c])
NO_3^- (mg /kg)	16.15 ± 1.99	12.76 ± 2.62	20.40 ± 3.85	4.46 ± 1.56	20.60 ± 3.63[a]	12.65 ± 4.28[ab]	2.34 ± 0.25[bc]	0.39 ± 0.39[c]
NH_4^+ (mg/ kg)	11.24 ± 4.87[a] (14.63 ± 4.92[a])	5.89 ± 1.43[b] (12.00 ± 2.21[ab])	4.3 ± 1.33[b] (3.89 ± 0.19[bc])	1.94 ± 1.29[b] (0.95 ± 0.49[c])	5.64 ± 2.29[ab] (5.48 ± 1.92[ab])	7.95 ± 4.71[a] (8.63 ± 1.45[a])	4.54 ± 0.75[ab] (2.96 ± 0.09[ab])	0.04 ± 0.00[b] (0.04 ± 0.00[b])
Respiration (g/ m² h)	0.74 ± 0.017[b]	1.06 ± 0.049[a]	0.73 ± 0.039[b]	0.60 ± 0.050[c]	0.57 ± 0.09[b]	0.95 ± 0.06[a]	0.86 ± 0.07[a]	0.45 ± 0.03[b]

The data are presented as mean ± SE of 3 replicates
Means within a row followed by the same letter are not significantly different at the 0.05 level.
Parenthesized columns were measured in October 2007, one year later. (ND: Not Detected, NM: Not Measured).
The *Quercus acutissima* and *Pinus thunbergii* data are analyzed separately.

Table 3.Tree growths* with biosolid treatments in the Sudokwon landfill in Incheon, South Korea

		Quercus acutissima		*Pinus thunbergii*	
Characteristics	Treatment	2006	2007	2006	2007
Height(cm)	Biosolid 1	13.3±1.26[b]	12.9±2.81[a]	3.48±0.48[b]	17.95±1.11[a]
	Biosolid 2	12.4±1.53[b]	9.6±3.86[a]	3.10±0.55[b]	19.90±1.16[a]
	Osmocote	21.0±1.36[a]	8.1±4.00[b]	5.10±0.46[a]	13.76±1.31[b]
	Reed	12.9±1.40[b]	8.6±3.11[b]	3.43±0.30[b]	14.19±0.70[b]
	Control	9.5±1.61[b]	7.0±2.28[c]	3.29±0.68[b]	11.70±0.89[b]
Stem diameter (cm)	Biosolid 1	0.30±0.020[a]	0.40±0.024[a]	0.12±0.01	0.21±0.02
	Biosolid 2	0.28±0.032[a]	0.31±0.023[ab]	0.10±0.02	0.22±0.02
	Osmocote	0.25±0.019[ab]	0.20±0.026[c]	0.12±0.01	0.19±0.01
	Reed	0.18±0.024[bc]	0.24±0.033[bc]	0.11±0.02	0.18±0.02
	Control	0.14±0.024[c]	0.18±0.018[c]	0.09±0.01	0.18±0.02

*The Height and diameter (DBH) values indicate increased values for trees.
The data are presented as mean ± SE of twenty replicates.
Means within a column followed by the same letter are not significantly different at the 0.05 level.
The *Quercus acutissima* and *Pinus thunbergii* data are analyzed separately.

Every treatment of sawtooth oak and Japanese black pine showed significantly higher chlorophyll contents than the control (Table 4).The photosynthetic rates of the sawtooth oak trees in the biosolid and reed treatments were significantly higher than controls, but those of the Osmocote-treated trees did not differ from the control [Fig. 1 (a)]. In the Japanese black pine area, the Reed treatment showed a significantly increased photosynthetic rate over all other treatments [Fig. 1 (b)].Biosolid treatments showed significantly increased photosynthetic rates compared to controls, but osmocote treatments did not show any change. The N content of the tree leaves increased significantly with biosolid treatments (Table 5).Osmocote treatments also showed significant increases in N content, while reed treatments showed a significant increase only in the Japanese black pine. Of investigated heavy metals, only Cd significantly increased in the soils of the sawtooth oak area, while no significant increase in Cd was measured in soils of the Japanese black pine area (Table 6).

The accumulation of heavy metals in biosolid treatments was not significantly higher than that measured in the controls (Table 6). Only Cr in needles of Japanese black pine trees significantly increased in response to the biosolid treatment.

The low heavy metal contents and high OM and nutrient contents of the biosolid produced from Sudokwon landfill (Table 1) suggest that it should be an effective fertilizer. As the landfill separates and reclaims toxic materials, levels of toxic contaminants, including heavy metals, are maintained at low levels in the sewage and thus in the biosolid produced from it (Song & Lee, 2010). Our research site was sloped and covered by reclaimed soil, which contained very little OM and high concentrations of heavy metals. Because of this, and also its low moisture holding capacity and increased solidity after reclamation, the reclaimed soil created very poor conditions for the establishment of plants (Song & Lee, 2010). Although the landfill soil had been reclaimed a few years prior to the initiation of our study, its total nitrogen content was low due to slow revegetation, frequent mowing to control weeds, and continual engineering work on the landfill (Lee *et al.*, 2005). These factors resulted in the loss of topsoil and low nitrogen fixation rates, as is apparent at the sawtooth oak site (Table 1). Thus, landfill soils clearly need additional treatment for optimal plant growth and

Table 4.Chlorophyll contents (mg / L) of leaves

	Treatment	Chl-a	Chl-b	Total Chl
Quercus acutissima	Biosolid 1	22.8 ± 1.63	14.4 ± 1.30	36.7 ± 2.90[ab]
	Biosolid 2	19.7 ± 3.28	12.4 ± 2.20	32.1 ± 5.47[ab]
	Osmocote	25.1 ± 1.34	17.3 ± 1.26	42.4 ± 1.57[a]
	Reed	22.9 ± 1.13	15.3 ± 1.62	38.3 ± 2.74[ab]
	Control	17.1 ± 2.36	10.5 ± 1.50	27.6 ± 3.85[b]
Pinus thunbergii	Biosolid 1	3.9 ± 0.35[b]	1.8 ± 0.17[b]	5.7 ± 0.52[b]
	Biosolid 2	3.3 ± 0.18[bc]	1.6 ± 0.08[b]	4.9 ± 0.26[bc]
	Osmocote	5.0 ± 0.69[a]	2.5 ± 0.34[a]	7.5 ± 1.03[a]
	Reed	3.7 ± 0.23[bc]	1.8 ± 0.10[b]	5.5 ± 0.34[bc]
	Control	2.3 ± 0.15[c]	1.3 ± 0.22[b]	4.0 ± 0.72[c]

The data are presented as mean ± SE of 5 replicates.
Means within a column followed by the same letter are not significantly different at the 0.05 level
The *Quercus acutissima* and *Pinus thunbergii* data are analyzed separately.

Table 5. Nutritional status of plant leaves

	Parameter	Biosolid 1	Biosolid 2	Osmocote	Reed	Control
Quercus acutissima	C (%)	46.44±0.25[b]	46.82±0.28[ab]	47.99±0.89[ab]	47.34±0.38[ab]	48.46±0.08[a]
	N (%)	1.89±0.16[a]	1.77±0.11[a]	1.30±0.12[ab]	1.10±0.11[b]	1.08±0.07[b]
Pinus thunbergii	C (%)	48.33±0.09	48.31±0.17	47.35±0.70	47.35±1.08	46.90±0.34
	N (%)	1.12±0.02[a]	1.13±0.00[a]	0.98±0.01[b]	0.91±0.00[c]	0.81±0.03[d]

The data are presented as mean ± SE of 5 replicates.
Means within a row followed by the same letter are not significantly different at the 0.05 level.
The *Quercus acutissima* and *Pinus thunbergii* data are analyzed separately.

restoration. Biosolid can be used as a soil conditioner because it improves the soil in many ways (Hachicha *et al.*, 2008). Our study provides further evidence of its effectiveness (Table 2). Soil nitrogen content increased after treatment with either biosolid or the controlled-release fertilizer. Although controlled-release fertilizer (Osmocote Plus) raised nitrogen content, the release of nitrogen from this fertilizer was less than optimal due to soil dryness (Kochba *et al.*, 1990). To investigate long-term effects of biosolid use, soil nitrogen was measured again 1 year later. The biosolid treatments yielded significantly higher soil nitrogen levels in the second year because of the continuous decomposition of the biosolid (Tester *et al.*, 1977). However, the Biosolid 2 treatment was less effective at increasing soil nitrogen presumably due to its lower biosolid concentration. After being treated with biosolid, soil properties were significantly improved (Table 2). OM from manure acts as a nutrient pool, improving nutrient cycling, reducing compaction, and improving physical properties of the soil (Walker *et al.*, 2004). Reed treatments significantly increased the soil moisture content to 31.4 ± 3.2% at the Sawtooth Oak site and to 23.4 ± 2.5% in the Japanese Black Pine site during the first year, in line with our expectation. The control areas, which had reclaimed soil cover but lacked any canopy cover or vegetation above the soil, had low soil moisture content. While the soil moisture content increased in the biosolid and reed-treated soils, it was not changed by the Osmocote treatment.

Table 6. Heavy metal accumulation in soil and tree leaves after biosolid treatments in a waste landfill

		Soil		Plant leaves	
	Parameter	**Biosolid 1**	**Control**	**Biosolid 1**	**Control**
Quercus acutissima	Cr (mg/kg)	14.98 ± 2.23	9.85 ± 1.28	0.147 ± 0.05	0.180 ± 0.017
	Cu (mg/kg)	99.16 ± 7.41	74.57 ± 5.44	0.397 ± 0.052	0.377 ± 0.049
	Cd (mg/kg)	1.08 ± 0.15[a]	0.57 ± 0.18[b]	0.007 ± 0.003	0.005 ± 0.002
	Pb (mg/kg)	68.07 ± 2.02	56.73 ± 16.68	1.100 ± 0.050	1.037 ± 0.110
	As (mg/kg)	ND	9.85 ± 1.28	ND	ND
Pinus thunbergii	Cr (mg/kg)	7.87 ± 0.32	7.90 ± 0.55	0.29 ± 0.03[a]	0.18 ± 0.02[b]
	Cu (mg/kg)	73.83 ± 4.54	68.2 ± 8.97	0.46 ± 0.11	0.36 ± 0.03
	Cd (mg/kg)	1.04 ± 0.08	1.08 ± 0.068	0.02 ± 0.00	0.01 ± 0.00
	Pb (mg/kg)	121.9 ± 4.86	121.3 ± 10.74	1.00 ± 0.11	0.89 ± 0.05
	As (mg/kg)	ND	ND	ND	ND

The data are presented as mean ± SE of 3 replicates.Means within a row followed by the same letter are not significantly different at the 0.05 level. (ND: Not Detected).

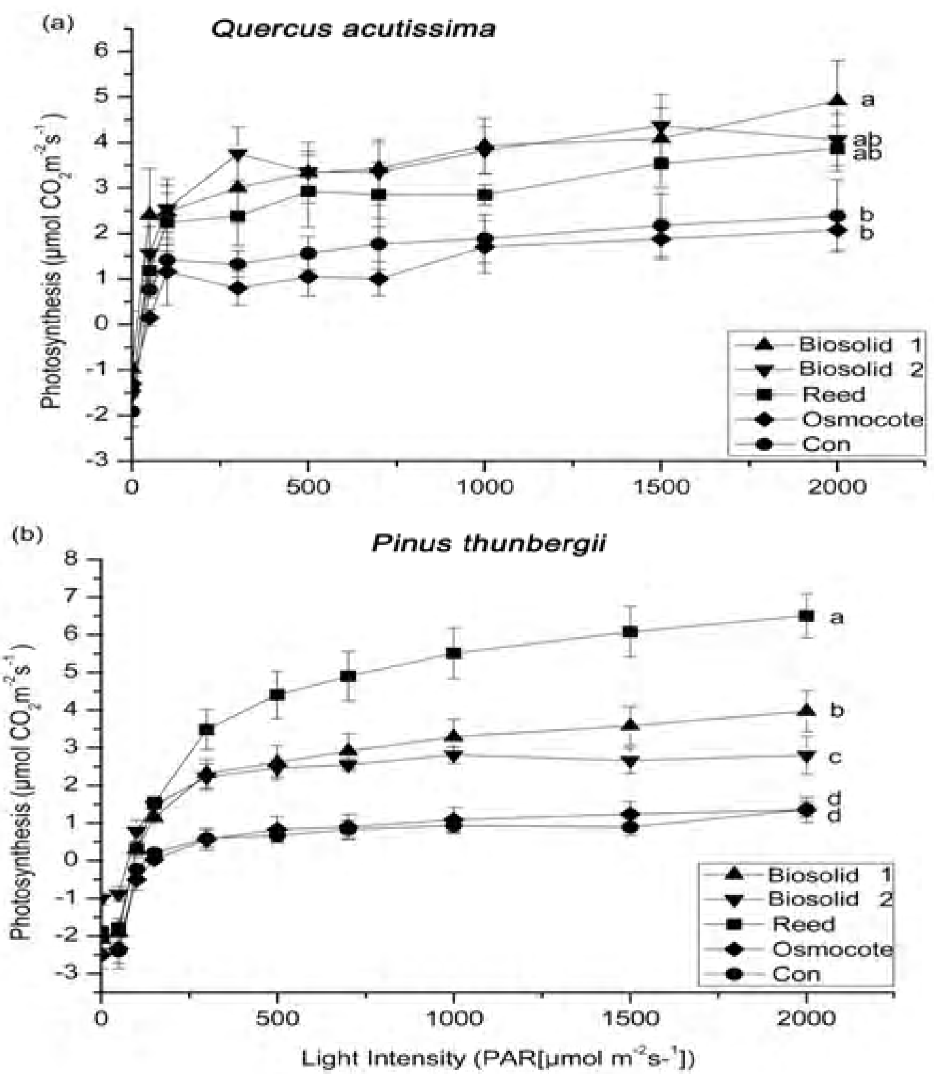

Fig. 1. Photosynthetic performance of (a); *Quercus acutissima* and (b); *Pinus thunbergii* with various treatments (at 30°C, 400 ppm CO_2).

Bars represent mean ± SE of 4 replicates. Symbols having the same letter are not significantly different at the 0.05 level.

Soil moisture is vital to a healthy environment where microorganisms are active (Orchard & Cook 1983). Likewise, the respiration rate of the reclaimed soil was low due to a lack of OM and moisture content, as well as the absence of a source of microorganisms. Biosolid with microbial-nutrient sources improved both soil moisture content and soil respiration (Table 2). While the Osmocote treatment yield increased soil nutrients and the Reed treatments increased soil moisture content,biosolid treatments were able to simultaneously increase both moisture and also enhance OM content as a potential long-term nutrient supply source.

While growth was restricted during the first year due to the stress of transplanting (Kim *et al.,* 2008), Japanese black pine showed significant growth in the second year, apparent at the beginning of the growing season in April (Table 3). Likewise, sawtooth oak trees did not show any appreciable increase in growth during the first year but height increased during the second year.The DBH measurements more clearly reveal different outcomes among the treatments. The DBH rate of increase in Biosolid 1, Biosolid 2, and reed treatments was more than double that of the control area, in both the first and second years, but Osmocote showed much less effect in the second year. The Reed treatment showed better performance than expected, significantly increasing soil moisture, so such treatments can assist plant growth (Stanhill 1957), especially in landfills under dry soil conditions. The effect was larger in the Japanese black pine site because this area suffered a greater deficiency of soil moisture than the sawtooth oak area (Table 2). The overall increase in both height and DBH was very low because of the poor soil condition of the landfill. The DBH of the sawtooth oak trees was only 4.10 ± 0.14 cm despite the trees being 10 to 13 years of age, indicating that the site is not supporting plant growth well. Nevertheless, the increases in DBH in the Japanese black pine plots and the height increase of the sawtooth oak trees demonstrate that the biosolid treatment was very effective. In comparison to the Reed (increased soil moisture only) and Osmocote (increased soil nitrogen only) treatments, biosolid increased both nutrient supply and soil moisture, affecting plant growth positively. Significantly higher chlorophyll contents were observed in every treatment with sawtooth oak and Japanese black pine trees. Since reclamation soil is nutrient and nitrogen deficient (Table 1), fertilizing by biosolid should results in increased chlorophyll contents and photosynthetic rates of trees. Trees in landfill soil had a low maximum photosynthetic rate (Fig. 1) because of the soil's low nutrient and moisture levels, which reduced the trees' ability to manage high intensity light (Kim *et al.,* 2002). The photosynthetic rates of the trees in the biosolid and reed treatments were significantly higher than the controls, but the Osmocote-treated trees did not differ from the controls (Fig. 1) suggesting that soil moisture levels might limit photosynthetic rates in the field. Increasing the soil moisture by treatment with biosolid and reeds then should promote plant metabolism and photosynthetic activities. Biosolid effectively increased soil nutrients as the photosynthetic rate of sawtooth oak trees treated with biosolid was higher than that of trees treated with reed [Fig. 1 (a)], which had the highest soil moisture content. In the Japanese black pine area, the soil moisture was the most important limiting factor for photosynthetic rate as indicated by the Reed treatment, which showed a significantly increased photosynthetic rate over all other treatments [Fig. 1 (b)]. As mentioned above, the Japanese black pine area had very low soil moisture due to the lack of vegetation and canopy cover, so for plants, soil moisture would be more important than soil nutrients, particularly during the hot days of summer. Biosolid treatments, unlike the Osmocote treatment, showed significantly increased photosynthetic rates in comparison to controls. Overall, the biosolid treatment increased chlorophyll contents and photosynthetic rates of the plants transplanted to the landfill slope. The N content of tree leaves increased significantly with biosolid treatments (Table 5). As control soil had poor nitrogen content, the nutrients in the biosolid would be readily taken up by the trees. The sawtooth oak trees were transplanted a few years prior to this study, so we expected the Japanese black pine plantation to more clearly show effects in response to soil nitrogen. However, although the needles of the Japanese black pine trees showed a significant increase in nitrogen, levels of nitrogen in the leaves of the sawtooth oak trees increased even more. This probably reflects the higher soil moisture contents of the sawtooth sites which may have facilitated nitrogen uptake by trees (Dijkstra & Cheng, 2008). Nitrogen supplied via composted sludge greatly affected trees, but Osmocote was less effective than biosolid in increasing the nitrogen content of leaves because of the dryness of soil at the landfill. Since reed treatments resulted in a significant nitrogen increase, soil moisture must be important for plant uptake of soil nutrients. Biosolid treatments resulted in significant increases in nitrogen levels within leaves, which strongly suggest that biosolid can be used as a fertilizer for plants to promote rooting for vegetation restoration in landfill slopes. We measured the concentrations of five heavy metals (As, Cd, Cr, Cu, and Pb), known to be major constituents of sewage sludge and potentially phytotoxic at elevated levels (Song and Lee 2010) in the soil. Of these, only levels of Cd were significantly raised in the sawtooth oak area, while no significant increase occurred in the Japanese black pine area (Table 6). Overall, the values were less than 20% of the national standard for heavy metal contamination in soil. Only the Cr content of the biosolid treated soil was higher than the standard (4 mg/kg) set by the Korean Ministry of Environment (KME, 2008). This cannot be attributable to the biosolid treatment; however, as the Cr content of the biosolid was less than that observed for reclamation soil (Table 1). Indeed, the Cd, Cr, Cu, and Pb contents of the biosolid were lower than the values in the reclaimed soil of Japanese black pine. Mined reclamation soil can contain minerals, and heavy metals can accumulate in the soil through underground water from a leachate channel, or from a buffer lake (Woo and Hong, 1994). Thus, our results suggest that the use of biosolid as a soil conditioner on a landfill slope would not cause significant accumulation of heavy metals.

The heavy metal accumulation in the tree leaves was relatively low compared to that found in previous studies (Wei & Liu, 2005; Casado-Vela *et al.,* 2007). Results of the studies cannot be directly compared, as they involved different species and bed soils, but heavy metal accumulation in our study, measured absolutely or in comparison with the controls, was low (Table 6). Only Cr in needles of Japanese black pine trees significantly increased in response to the biosolid treatment. But as discussed above, the Cr level of the biosolid was lower than that found in the reclaimed soil. Increased growth and plant physiological activities by biosolid would increase plants' uptake from soil and might cause accumulation of Cr already present in the soil before the application of biosolid. The low levels of heavy metal concentration found in sewage sludge are attributable to the separate reclamation and leachate purifying processes (Lee, 2004 *et al.,* SLMC, 2009). Biosolid made from sanitary landfill waste thus can be a useful resource for improving soil conditions and plant rehabilitation after reclamation.

CONCLUSION

Biosolid (Composted sewage sludge) significantly improved the chemical and physical properties of soil at landfill reclamation sites. The biosolid improved the soil nitrogen, moisture, and OM contents of the reclaimed soil. Furthermore, heavy metal concentrations in soils were lower than relevant guideline values and trees treated with biosolid exhibited significantly improved ecological performance in growth and DBH. Plant physiological characteristics, such as chlorophyll content and photosynthetic rates, were significantly improved by biosolid treatments, as was the N content of the plant leaves. The heavy metal accumulation in biosolid-treated tree leaves was not significantly higher than that found in trees grown in control sites on reclaimed soil without sludge. Biosolid potentially can be an important, environmentally friendly solution to disposal problems associated with large volumes of sewage sludge. Further, it can provide a low-cost strategy for restoring soil conditions at waste landfill sites to improve moisture content and promote revegetation.

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