Korean J. Ecol., 22(6): 343~348, 1999

The Effects of Waste Leachate on the Eco-Physiological Characteristics of *Populus euramericana*

Woo, Su-Young

Department of Forest Resources, College of Agriculture, Sangju National University

ABSTRACT: ***Populus euramericana*** **has been identified as a possible species for use for phytoremediation of landfills. To identify the effects of waste leachate on the growth and physiological characteristics of *Populus euramericana*, four different treatments were applied to *Populus euramericana* seedlings: leachate solution (100% leachate), 25% dilution (75% leachate: 25% water, v/v), 50% dilution (50% leachate: 50% water, v/v) and control (100% tab water) were applied to *Populus euramericana*. Treatment with waste leachate significantly stimulated *Populus euramericana* height, diameter at root collar and biomass production relative to the water control. Chlorophyll contents, photosynthesis and transpiration of leachate irrigated-trees were significantly higher than those of water control. These results suggested that poplar could be a suitable species for phytoremediation in landfills because these species showed good growth performance and were capable of taking up waste leachate.**

Key Words: Chlorophyll contents, Growth, Photosynthesis, *Populus euramericana*, Transpiration, Waste leachate.

INTRODUCTION

Waste in the world has enormously increased during the industrial periods in the 20th century with geometrically explosive increase of population. In Korea, industrialization and increase of population in urban area also gave rise to serious waste problems (Ministry of Environment 1997, 1998).

Landfill area near the big cities has been increased to remove municipal and industrial waste in Korea. Serious environmental problems in landfill area could be classified into three general categories: 1) harmful and smelling gases such as CH_4, 2) leachate, and 3) soil contamination due to industrial waste which contains heavy metals (Nutter and Red 1986). Especially, leachate which contains high NH_3 and NO_3 seeps into near river or ocean and gives negative impacts on ground water.

In general, municipal and industrial waste landfill can induce many negative influences on the ecosystems. In contrast, several reports showed that high concentration of NH_3 and NO_3 could be helpful for tree growth in some species. Many studies have shown that waste leachate does not always reduce total biomass (Lee and Woo 1998, Koo *et al.* 1997, 1998). These somewhat conflicting facts indicate that an intensive study of tree species might help to elucidate the nature of these responses.

Phytoremediation is an approach to clean up contaminated soils using plant species. Many countries have been interested in phytoremediation because it appears to be cheaper than chemical and engineering-oriented methods and may also offer a restoration and long-term environmental benefits around contaminated area such as landfills, mining sites, farmland and nuclear waste dumps (Litch and Madision 1995). To absorb gases, leachate and heavy metals, planting of trees in landfill has been often considered. Trees have the potential to remediate or prevent both soil and ground water pollution in waste landfill.

Trees, especially fast growing species such as *Populus* and *Salix*, can take up the toxic materials through their roots and transport them to stems or leaves (Eltrop *et al.* 1991, Kukaszewiski *et al.* 1993). In Korea, poplar species seems to be an outstanding candidate for phytoremediation because of robust growth rate, rapid establishment of many leaves and fast growing characteristic.

The objective of this study was to identify the effects of waste leachate on the growth and physiological characteristics of *Populus euramericana* as a possibility of phytoremediation using poplar species in landfill area.

MATERIALS AND METHODS

Plant materials

This study was conducted at the experimental site of the department of forest resources of the Sangju National University. *Populus euramericana* were collected as 20cm cuttings from the Forest Research Institute clone farm in Suwon, Republic

Table 1. Waste leachate treatments of this experiment

Treatments	Leachate	Water	Periods
100% leachate	100%	0%	March 29~July 4
75% dilution	75%	25%	
50% dilution	50%	50%	
Control	0%	100%	

of Korea in January, 1997. Each cutting was dipped into a root hormone (Indole-3-butyric acid), and then planted into the same area. Five *Populus euramericana* individuals in each leachate treatment were prepared for replication. All the cuttings were made from the same clone.

One year later, these poplars were planted into pots and irrigated daily with different concentrations of leachate (Table 1). NPK fertilizer was applied once a week. Average temperature was between 27 and 29℃ during the experimental period. Relative humidity was between 60 and 80% at seedling height. The midday photosynthetic photon flux density ranged between 1,400 and 1,800 mol m^{-2} s^{-1}.

Elements and treatment of leachate

Waste leachate was collected from Wha-seo waste landfill in Sangju, Republic of Korea. Heavy metals were measured with atomic absorption spectrophotometer (AA-6401 Shimadzu, Japan). Biological oxygen demand (BOD), NO_3, total-P and pH were cited from the data of local government (Ministry of Environment 1997). Waste leachate showed very high BOD and NO_3 concentration (Table 2).

Table 2. Waste leachate collected from Wha-seo landfill at Sangju city (Unit: ppm)

	Legal standard for discharge	Tab water	Leachate solution
pH	8.6	6.9	7.9
BOD	100.0	0.0	4050.0
NO_3	10.0	0.03	1256.0
Total-P	4.0	CD	7.89
K	ND	0.5	124.0
Ca	5.0	0.2	3850.0
Fe	37.0	0.1	89.0
Co	ND	CD	0.8
Cu	3	CD	6.8
Sn	ND	CD	0.44
Na	ND	CD	25.0
Ni	ND	CD	0.6
Mn	2	0.1	105.0
Al	ND	0.1	124.0
Cd	0.1	CD	0.15
Cr	2.0	0.01	2.0
As	0.5	0.01	0.08

CD: could not be detected, ND: No data available

The experimental seedlings were transplanted into 37-liter pots which contained clay and sand in a 1 : 1 ratio. Pots were irrigated daily by leachate. Amount of daily waste leachate absorption was checked everyday and compared with transpiration. Treatments of leachate solution (100% leachate), 25% dilution (75% leachate: 25% water, v/v) and 50% dilution (50% leachate: 50% water, v/v) were applied to identify the effects of leachate on *Populus euramericana* (Table 1).

Growth measurements

Height and diameter at root collar, were measured for each tree. At the end of the experiment, plants were removed from soil. After the roots were washed, plants were separated into roots (excluding the cutting itself), shoots and leaves, then oven-dried at 70℃ for 3 days, and weighed.

Photosynthesis

Net photosynthesis (A_n) was measured with mature leaves of LPI (Leaf Plastachron Index) 11 or 12 on every individual. Net photosynthesis was measured with a broad-leaf cuvette of the Li-Cor 6400 Portable Photosynthesis System (Li-Cor Inc., USA), the leaf was sealed and CO_2 concentration was allowed to be maintained at ambient levels. Air flow through the analyzer was adjusted to maintain leaf cuvette relative humidity near ambient levels (ranged between 60 and 70%) during measurement. The average cuvette temperature was maintained at 25℃. Light intensity (Photosynthetically Active Radiation; PAR) was maintained to 1000 μmol m^{-2} s^{-1}. Net Photosynthesis was calculated by using the following equation.

$$A_n = \frac{U_e(C_e - C_c)}{100s} - C_c E$$

A_n: Net Photosynthesis (μmol CO_2 m^{-2} s^{-1}), U_e: mole flow rate of air entering the leaf chamber (μmol/s), C_e: mole fraction of CO_2 in the leaf chamber(μmol CO_2/mol air), C_c: mole fraction of CO_2 entering in the leaf chamber (μmol CO_2 /mol air), s: leaf area (cm^2), E: transpiration (mmol H_2O m^{-2} s^{-1})

Transpiration

Transpiration was calculated by using the following equation.

$$E = U_e(W_c - W_e)/(S*10^5(1 - W_c/1000))$$

E: transpiration rate (mmol H_2O m^{-2} s^{-1}), U_e: mole flow rate of air entering the leaf chamber (μmol/s), W_c: mole fraction of water vapor in

the leaf chamber (mol H_2O/mol air), W_e; mole fraction of water vapor entering the leaf chamber(mmol H_2O /mol air).

Chlorophyll contents

Chlorophyll contents were measured with SPAD-502 meter (Minolta, Japan) and averaged for 30 measurements. The measurements with the instrument were strongly related to Arnons method (Tadaki and Kinoshita 1988, Wiebel *et al.* 1994, Kim and Um 1996).

Statistical analysis

Analysis of variance was used to evaluate the significance of the treatment effects on biomass, photosynthetic capacity, leachate absorption and transpiration. Duncans multiple range test (< 0.05) was conducted for all variables. All statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS PC$^+$, version 4.0).

RESULTS AND DISCUSSION

Height and diameter growth at root collar

Height and diameter growth at root collar was significantly stimulated by the application of waste leachate compared to the water control for *Populus euramericana*. Fig. 1 illustrates the height growth during experimental period (March 29~July 3). *Populus euramericana* saplings irrigated with leachate grew taller than their water -irrigated counterparts (average 358 cm and 302 cm, respectively). Diameter growth at root collar showed similar trend with height growth changes (Fig. 2). In other words, diameter growth at root collar of *Populus euramericana* saplings increased with increasing the waste leachate concentration levels.

This result was similar to that reported by Cureton *et al.* (1991) who observed that the height and diameter growth at root collar was significantly greater with waste leachate treatments compared to a water irrigation treatment for hybrid poplar (*Populus nigra* × *maximowiczii*). In general, waste leachate gives many negative impacts on tree growth such as reducing height and diameter growth, stimulating leaf senescence and reducing biomass growth due to high BOD and other toxicity in waste leachate inhibiting tree metabolism. In contrast, waste leachate stimulated height and diameter growth at root collar of poplar in this study. This somewhat conflicting result indicates that an intensive study of poplar clones for growth responses to waste leachate might help to elucidate the nature of these responses.

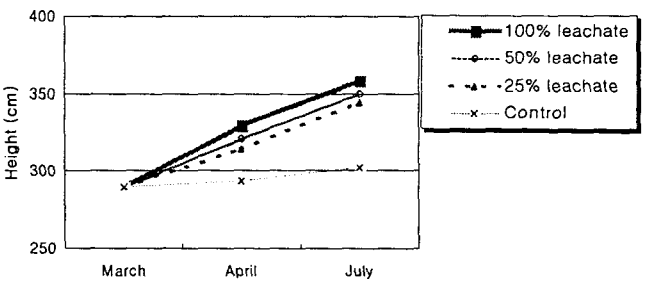

Fig. 1. Changes in height of *Populus euramericana*. Bars indicate standard error.

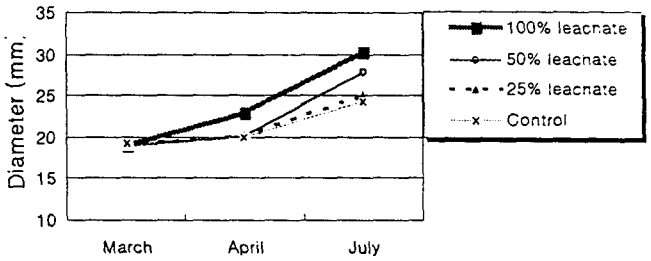

Fig. 2. Changes in diameter at root collar of *Populus euramericana*. Bars indicate standard error.

Soil in the pots could reduce the toxicity of waste leachate (Balsberg 1989). This experiment was conducted during very short periods (March 29~July 4; 95 days during growing season only). Therefore, soil in the pots could immobilize the toxicity of waste leachate during short period. In addition, high NH_3 concentration, probably, could induce the height and diameter growth at root collar as a role of nutrients for fast growing poplar.

Nanjido landfill is a municipal waste deposit area in Seoul, the biggest city in Korea. To test the suitability of poplars for landfill reclamation. *Populus euramericana* was planted on Nanjido landfill in 1994 and 1995 (Koo *et al.* 1997). The growth of *Populus euramericana* in Nanjido landfill was better than that in mountain area. The 3-year-growth of poplar planted in 1994 showed that average height and DBH were 5.9m and 6.2cm, respectively. These impressive growth rates were 1.6 and 1.8 times higher than those in mountain area. Poplar planted at Nanjido landfill in 1995 also showed higher growth than that in mountain area (Koo *et al.* 1997).

High NH_3 and NO_3 concentration in landfill area might help improve tree growth (Nutter and Red 1986). The leachate from landfill or sludge contains high concentration of nutrients. Today, there are numerous examples of the application and treatment of both leachate and sludge on forest and agricultural lands not only to dispose

the waste but also to improve plant growth. In the U.S.A., the growth of Douglas-fir from sludge application was twice as great as when this species was fertilized with urea (Cole and Henry 1986).

Biomass

Poplar grew better when irrigated with 100% leachate solution than with diluted-leachate treatment which in turn was significantly better than the water-irrigated control (Fig. 3). Biomass growth showed a trend similar to the height and diameter growth at root collar (Fig. 1 and 2). Even though root biomass growth by the 100% leachate treatment was slightly smaller than those of the other treatments, the effect of leachate treatment was likely to be positive on the growth of *Populus euramericana* in this study.

Root system of poplar may be beneficial for biomass production. Generally, poplar has a shallow root system. Shallow-rooted tree species may be tolerant of landfill condition because their roots are distributed at shallow depth. Deep-rooted tree species may be more sensitive on landfill soils because they are forced to grow a shallower root system than they normally do (Gilman 1989). This fact suggested that poplar could be a suitable species for planting on landfill area, showing vigorous growth. Landfill areas in Korea have common problems such as low O_2 supply and thin soil cover.

Chlorophyll content

Chlorophyll content is a sensitive indicator of photosynthetic capacity of trees (Grimm and Fuhrer 1992). In this study, chlorophyll contents of the leachate-treated trees were significantly higher than those of control (Fig. 4). It is well known that higher chlorophyll content may help to maintain high photosynthesis rates for stressed trees (Kudson *et al.* 1977, Grimm and Fuhrer 1992).

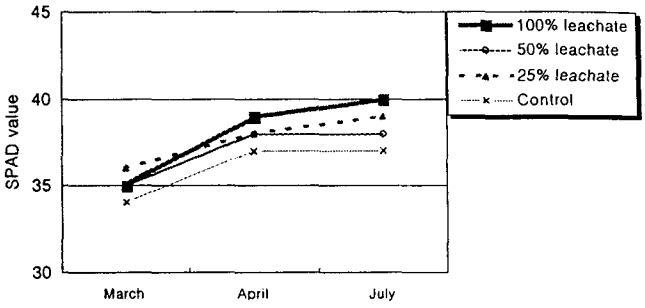

Fig. 4. Chlorophyll contents of *Populus euramericana*. Bars indicate standard error.

Photosynthesis

Photosynthetic capacity of *Populus euramericana* was significantly stimulated by the application of waste leathate (Fig. 5).

Generally, stresses such as waste leachate with high concentrations of heavy metals decrease photosynthetic capacity of many tree species (Cureton *et al.* 1991). In this study, leachate-treated trees have shown higher photosynthetic capacities (Fig. 5). High concentrations of nitrate in leachate may be important in determining the effect of leachate treatments on the photosynthetic capacities of *Populus euramericana*. The leachate was acting as a fertilizer, and the photosynthetic capacity of *Populus euramericana* was accelerated. Furthermore, biomass production is strongly related to photosynthetic capacity (Grimm and Fuhrer 1992). This fact may result in maintaining high biomass production with leachate treatments. In fact, the leachate of municipal waste used in this study has lower concentration of heavy metal than that of industrial waste (Ministry of Environment 1997).

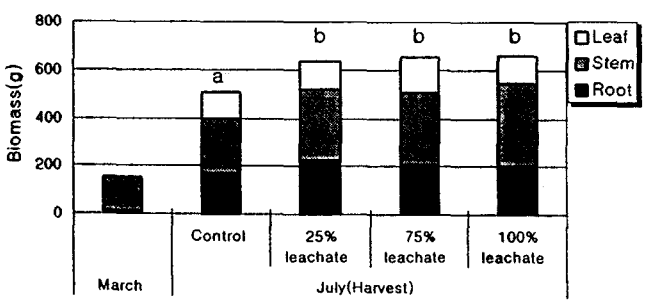

Fig. 3. Biomass changes of *Populus euramericana*. Different letters were statistically different at the 5% significance level (n=5).

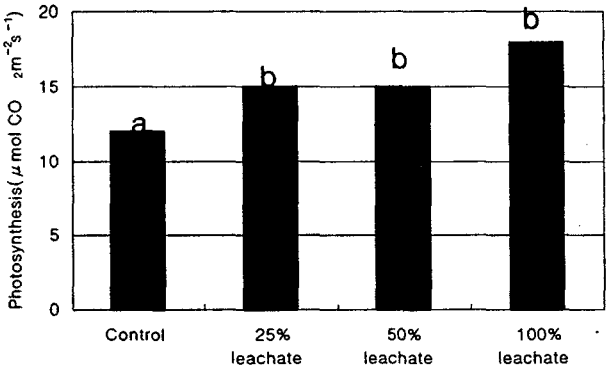

Fig. 5. Photosynthetic capacity of *Populus euramericana*. Different letters were statistically different at the 5% significance level (n=20).

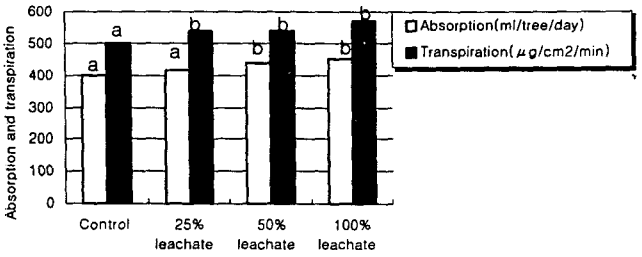

Fig. 6. Comparison of leachate absorption and transpiration in *Populus euramericana*. Different letters were statistically different at the 5% significance level (n=20).

Leachate absorption

The transpiration and the amount of waste leachate absorption of *P. euramericana* showed similar array of responses. Three other leachate irrigated-treatments showed higher transpiration and absorption capacity than those of water control (Fig. 6).

Poplar can immobilize leachate that waste landfill produces. Since fast growing trees utilize large amount of water for transpiration, moisture is extracted from the soil before it percolates beyond the root zone. If poplars produce dense root into the landfill cover soil, they will act as a pump that transpires the soil water back to atmosphere (Schnoor *et al.* 1992). Hybrid poplar trees can remove 600 liters of water from the soil for every kilogram of stem dry matter growth in the U.S.A. (Stomp *et al.* 1994, Licht and Madision 1995).

APPLICATION

In Korea, landfill area has been gradually increased in the past decades. Waste leachate from landfills can be environmentally problematic. The growth of *Populus euramericana* in leachate -irrigated-individuals was better than that in water-irrigated-individuals. Based on this study, using leachate solution to nutrient deficient places can be a useful way to dispose of leachate. It can improve site quality by adding essential nutrients for tree growth. It is hard to say that *Populus euramericana* has good growth performance in landfill area because the effect of leachate application is likely to be cumulative in natural condition. In spite of this fact, the result mentioned above suggested that *Populus euramericana* may be a suitable species for phytoremediation in landfills because this species showed good growth performance and uptake of waste leachate. Therefore, more long-term leachate study would be needed to determine the effect of leachate on the growth of *Populus euramericana*.

CONCLUSION

Height, diameter at root collar and biomass production was significantly stimulated in *Populus euramericana* by the application of waste leathate relative to the water control. Chlorophyll content, photosynthetic capacity and transpiration of the leachate irrigated-trees were significantly higher than those of water control. These results suggest that *Populus euramericana* may be a suitable species for phytoremediation in landfills because of the good growth performance and uptake of waste leachate.

ACKNOWLEDGEMENTS

I thank two anonymous referees for their valuable comments. Dr. Tim A. Martin, Prof. of Univ. of Florida provided excellent proofreading and comments. I also thank Mr. Soon-Mok Kwon for leachate irrigation and for assisting in caring plants, controlling facilities and maintenance. The research was performed under contract 1998 -024-G00002 with the Korea Research Foundation. I wish to acknowledge the financial support of the Korea Research Foundation made in the program year of 1998.

LITERATURE CITED

Balsberg, A-M. 1989. Toxicity of heavy metals (Zn, Cu, Cd, Pb) to vascular plants. Water, Air and Soil Pollution 47: 287-319.

Cole, D.W. and C.L. Henry. 1986. Future directions: Forest sludge application. *In* D.W. Cole, C.L. Henry and W.L. Nutter (eds.). The forest alternative for treatment and utilization of municipal and industrial waste. Univ. of Washington, Seattle. pp. 62-69.

Cureton, P.M., P.H. Groenevelt and R.A. McBride. 1991. Landfill leachate recirculation: Effects on vegetation vigor and clay surface cover infiltration. J. Environ. Qual. 20: 17-24.

Eltrop, L., G. Brown, O. Joachim and K. Brinkmann. 1991. Lead tolerance of *Betula* and *Salix* in the mining area of Mechernich /Germany. Plants and Soil 131: 275-285.

Gilman, E.F. 1989. Tree root depth relative to landfill tolerance. Hortsci. 24: 857.

Grimm, A.G. and J. Fuhrer. 1992. The response of spring wheat (*Triticum aestivum* L.) to ozone at higher elevations. III. Response of leaf and canopy gas exchange and chlorophyll fluorescence to ozone flux. New Phytologist 122: 321-328.

Kim, G.T. and T.W. Um. 1996. Effects of artificial acid mist on leaf injury and surface wettability of several broad-leaved species J. of Kor. For. Soc. 85: 577-585.

Koo, Y.B., S.K. Lee, P.G. Kim, K.O. Byun and S.Y. Woo. 1997. Growth and absorption capacity of heavy

metals of *Populus euramericana* at Nangido landfill. Poplar 14: 25 -32.

Koo, Y.B., E.R. Noh, S.Y. Woo and S.K. Lee. 1998. Using poplar trees as a landfill cover and leachate treatment. Poplar 15: 19-29.

Kudson, L.L., T.W. Tibbitts and G.E. Edwards. 1977. Measurement of ozone injury by determination of leaf chlorophyll concentration. Plant Physiol. 60: 606-608.

Kukaszewiski, Z., R, Siwecki, J. Opydo and W. Zembrzuski. 1993. The effects of industrial pollution on copper, lead, zinc and cadmium concentration in xylem rings of resistant (*Populus marilandica*) and sensitive (*P. balsamifera*) species of poplar. Trees 7: 169-174.

Lee, D.K. and S.Y. Woo. 1998. Status of waste generation, disposal ways and poplar species as a landfill cover in South Korea. *In* K. Sassa (ed.). Environmental Forest Science. Vol. 54. Kluwer Academic Publishers, London, pp. 83-92.

Licht, L.A. and M. Madision. 1995. Using Poplar Trees as a Landfill Cover: Experiences with the Ecolotree Cap. SWANA 11th Annual Northwest Regional Soil Waste Symposium, Portland, Oregon. April, 12-14.

Ministry of Environment. 1997. Environmental Statistics Yearbook. Seoul. 543p.

Ministry of Environment. 1998. Waste landfill facilities. Web site. http://www.moenv.go.kr/pae/pae.htm.

Nutter, W. and J.T. Red. 1986. Future directions: Forest wastewater application. *In* D.W Cole, C.L. Henry and W.L. Nutter (eds.). The forest alternative for treatment and utilization of municipal and industrial waste. Univ. of Washington, Seattle. pp. 55 -61.

Schnoor, J.L., L.A. Licht, S.C. McCutcheon, N. Lee and L.H. Carreira. 1992. Phytoremediation of organic and nutrient contaminants. Environmental Science and Tech. 29: 318-323.

Stomp, A-N, K.H. Han, S. Wilbert, M.P. Gordon and S.D. Cunningham. 1994. Genetic strategies for enhancing phytoremediation. Reprint of Recombinant DNA Technology II Vol. 721 of the Annals of the New York Academy of Sciences.

Tadaki, Y. and M. Kinoshita. 1988. Chlorophyll contents of tree leaves measured with chlorophyll meter SPAD 501. J. Jpn. For. Soc. 70: 488-490.

Wiebel, J., E.K. Chacko, W.J.S. Downton and P. Ludders. 1994. Influence of irradiance on photosynthesis, morphology and growth of mangosteen (*Garciana mangostana* L.) seedlings. Tree Physiol. 14: 263-274.

(Received October 29. 1999)