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Selection of Tolerant Species among Korean Major Woody Plants to Restore Yeocheon Industrial Complex Area

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여천공업단지의 복원을 위한 우리나라 주요 목본식물 중 내성종의 선발

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ABSTRACT

To select tolerant species among the Korean major woody plants for restoring disturbed ecosystems by air and soil pollution, we transplanted the seedlings of 56 species in control and polluted sites within Yeocheon industrial complex area, and compared their aboveground growth characteristics such as total branch length, total leaf weight, and maximum photosynthetic rate.

Tolerant species growing better in polluted site than in control site was *Quercus variabilis, Pinus thunbergii, Q. aliena, P. densiflora, Styrax japonica, Alnus firma, Celtis sinensis, Elaeagnus umbellata, Q. serrata, Eurya japonica, Sorbus alnifolia,* and *Q. acutissimia* in local tree occuring within polluted area group (80%), *Ailanthus altissima* in street tree group (20%), *Populus tomentiglandulosa* and *A. hirsuta* var. *sibirica* in fast growing tree group (50%), *Acer ginala* and *Abies holophylla* in late successional tree group (20%), *Betulla platyphylla* var. *japonica, Acer truncatum, A. palmatum, Syringa dilatata,* and *Rosa multiflora* in garden tree group (38%), and *Q. rubura*, and *Robinia pseudoacacia* in foreign restoring tree group (20%), respectively. The remaining plant species, 37 species (57% of total species), were classified into sensitive species to pollution. Those tolerant species can be utilized for restoration of the degraded ecosystem in this polluted area.

Key words: Korean woody plants, Pollution, Restoration, Tolerant species.

INTRODUCTION

Air pollution, acid rain, and soil pollution have damaged natural ecosystems since industrial development and urbanization. Ecosystems around industrial complex area and metropolitan city were disturbed by air pollution, and these phenomena will be spread over in Korea (Environment Administration 1993, 1996). Thus restoration ecology turning from disturbed ecosystem to natural or semi natural ecosystem is urgently necessary.

Disturbed ecosystems by pollution tend to have poor vegetation, especially in tree layer (Environment Administration 1996). The establishment of vegetation with tree layer is, therefore, crucial for successful restoration in polluted area. Such a restoration is especially critical in heavily disturbed area such as industrial complex area and metropolitan city and might be accomplished by planting the tolerant tree species that grow well in the polluted area. In Korea, however, there is a few researches about restoration ecology and techniques using tolerant trees (Cho and Kim 1995, Environment Administration 1996, Park 1991, Ryu *et al.* 1996).

In this paper, in order to select tolerant species among Korean woody plants for restoring ecosystems degraded by air and soil pollution, we transplanted the seedlings of the 56 species in control site (unpolluted site) and polluted site within Yeocheon industrial complex, and then compared their aboveground growth characteristics.

MATERIALS AND METHODS

Transplanting sites

In order to compare the plant growth characteristics according to intensity of pollution, we selected two sites for planting; one was comparatively unpolluted and the other was severely polluted site, where the concentration of SO_2, F, NH_3 and dust was 26.3 ppm, 2.2 ppm, 6.8 ppm and 11.7 mg/m^3, respectively (referred indirectly from Environment Administration 1996).

The transplanted sites are located at altitude 150 m above sea level, in Yeocheon industrial complex, Yeocheon city, Cheollanam-do. We selected a hill (20 m×30 m) in Homyeong-dong as a control site, comparatively unpolluted site, which is 6 km distant from pollution source, Yeocheon industrial complex. Polluted site was located in the middle of Mt. Jesuk within Yeocheon industrial complex, which have been disturbing severely by air and soil pollution.

When the soil physico-chemical properties were compared organic matter contents, soil pH, Ca, Mg and K were slightly higher in control site than those in polluted one, but the concentrations of the other metals were the reverse excepting for Mn (Table 1). This fact suggested that the cations leached and acid metals accumulated in polluted site.

Preparation of sample plants

We chose the 46 endemic tree species in Korea and 10 introduced species from the foreign country (Table 2). Total 56 species were divided into 7 groups by common usages.

The seeds of plants were collected in Yeocehon industrial complex area for local tree occurring in polluted area (group Ⅰ), in Kwangnung Experimental forest for street trees (group Ⅱ), late successional trees (group Ⅴ), introduced restoring tree (group Ⅶ), fast growing tree (group Ⅲ), and fruit trees (group Ⅳ), and in Seoul National University for garden trees (group Ⅵ), from June to November in 1994.

Viable seeds were selected by means of water washing method and stored in a condition with air, soil, sand or refrigerator (4℃) according to species (Forestry Research Institute 1987). Those seeds were germinated in pots in the greenhouse in Seoul National University in 1995. During winter, the evergreen plants were raised in the greenhouse and the others in the outdoors.

Table 1. Physico-chemical characteristics of soil in control and polluted sites in Yeochon. Data (n=7) showed as mean and standard deviation in parenthesis

Site	Organic matter(%)	pH (water)	Al (mg/kg)	Total-S (μg/g)	Ca (mg/kg)	Mg (mg/kg)	K (mg/kg)	Mn (mg/kg)
Control	25.7 (8.3)	4.7 (0.3)	334.5 (12.1)	37.4 (10.1)	650.4 (16.5)	176.9 (15.7)	162.4 (21.9)	65.2 (48.3)
Polluted	18.2 (5.6)	4.2 (0.4)	484.3 (20.1)	71.0 (8.6)	162.4 (32.5)	24.9 (7.5)	31.7 (14.7)	82.5 (59.3)

Transplantation of plants

We chose properly growing seedlings with similar height and leaf numbers as plant species for transplanting to the field, and acclimated the evergreen plants in field conditions for one month before transplanting.

We transplanted the selected seedlings in polluted site within Yeocheon industrial complex and control site distant from there from April 8 to 13 in 1996. After transplanting, we watered and covered them with soil at root collar height for preventing the loss of water. The number of planted plants was 10~100 individuals/species, and each plant was placed with a spacing of 50 cm in both directions.

Criterion for selection of tolerant species

We selected tolerant species on the basis of the result in field experiment. To select tolerant species, we compared the growth characteristic, such as total branch length, total leaf weight, and maximum photosynthetic rate of each species between two sites. A method to select tolerant species by evaluating the growth characteristics is recognized as appropriate one because growth in seedlings stage reflects well the state of external environments (Turner *et al.* 1991).

Total branch length (cm/tree) was measured by ruler, leaf weight (g/tree) by dry weight after drying at 105℃, and maximum photosynthetic rate by infrared gas analyzer (LCA-2 model, ADC Co.) (Long and Hallgren 1987). 3 individuals per species were adopted for measurement and measurement was carried out on August 20 to 30, 1996.

We considered that tolerant species grew better in polluted site than in control site. We used the ratio of total branch length, total leaf weight, and maximum photosynthetic rate in polluted site to those in control site as the tolerance rato. Tolerance ratio (*Tr*) was determined by the formula, Tr=value of polluted site/value of control site. Also, we calculated the tolerance index of a species (*TI*) by the formula, TI=Sum of tolerance ratio/3.

But for coniferous trees, only two ratios, total branch length and total leaf weight ratios, were used to calculate tolerance index of species.

RESULTS AND DISCUSSION

As is shown in Table 2, in the local trees occurring in polluted area total branch length, leaf weight, and maximum photosynthetic rate were higher in polluted site than those in control site (mean 50.5:45.6, 5.99:5.15, 3.70:3.59). But in fast growing trees (6.72:5.20) and fruiting trees (12.31:11.06), only of total leaf weight was higher in polluted site than in control site. And the introduced restoring trees showed higher total branch length in polluted site (59.8:54.0). All the other values of species were lower in polluted site than in control.

On the bases of aboveground growth characteristics, we estimated tolerance ratio and index of each species (Table 3). Species that better grew in polluted site than in control site were *Q. variabilis, P. thunbergii, Q. aliena, P. densiflora, S. japonica, A. firma, C. sisnensis, E. umbellata, Q. serrata, E. japonica, S. alnifolia,* and *Q. acutissima* in local trees occurred in polluted area (group I) (87% of total species). Percentage of tolerant species among local trees occurring in polluted area (group I) was the highest among seven experimental tree groups. This result suggests that species occurring healthily and frequently in polluted area may be mostly tolerant species to pollution (Environment Administration 1996). But contrary to the report in the laboratory test (Kim 1996), *Q. dentata* was not grew better in polluted site than in control site.

In the street trees (group Ⅱ), only *A. altissima* grew better in polluted site than in control site (20%). This means that present street trees do not proper in polluted condition.

Fast growing trees (group Ⅲ) are important, especially in the polluted sites, because they are able to green earlier than any other plants do. On the other hand, fast growing plants accumulate pollutants as

Table 2. Branch length (cm/tree), leaf weight (g/tree) and maximum photosynthetic rate(μmol $CO_2 \cdot m^2 \cdot sec$) of transplanted woody plants in control and polluted site in August, 1996

Species	Branch length		Leaf weight		Maximum photosynthetic rate	
	Control site	Polluted site	Control site	Polluted site	Control site	Polluted site
Ⅰ. Local trees occurring in polluted region[1]						
Pinus densiflora	24	21	0.65	1.03	–	–
P. thunbergii	9	12	0.67	0.91	–	–
Celtis sinensis	125	172	32.23	35.24	8.5	8.0
Quercus serrata	33	40	2.31	2.46	3.5	3.4
Q. aliena	26	29	4.86	8.96	2.0	1.9
Q. acustissimia	40	43	8.53	8.29	7.7	8.5
Q. variabilis	37	41	6.60	13.2	1.2	1.5
Q. dentata	25	14	0.24	0.19	1.8	1.0
Alnus firma	55	70	8.77	7.74	2.0	3.0
Sorbus alnifolia	42	38	1.14	1.52	2.1	2.0
Styrax japonica	62	80	2.04	2.43	3.5	4.1
Elaeagnus umbellata	83	98	2.52	2.58	4.3	4.5
Euonymas japonica	25	21	1.22	0.58	2.5	2.4
Eurya japonica	14	12	0.88	1.12	1.2	1.3
Ligustrum japonicum	84	66	4.62	3.64	6.4	6.6
Ⅱ. Street trees						
Zelkova serrata	110	74	2.82	2.96	7.2	5.5
Ginko biolova	15	13	1.54	0.62	3.1	2.0
Sophora japonica	43	38	4.22	2.78	6.9	5.5
Platanus orientalis	90	70	26.73	12.87	11.0	10.0
Ailanthus altissima	47	85	19.50	22.50	10.3	12.0
Ⅲ. Fast-growing trees						
Populus tomentiglandulosa	38	78	1.08	2.16	1.3	1.0
Alnus hirsuta	102	64	9.70	8.80	1.2	1.0
Alnus hirsuta var. *sibirica*	90	75	8.80	15.10	2.0	3.0
Firmiara simplex	34	28	1.22	0.82	2.7	1.5
Ⅳ. Fruiting trees						
Castanea crenata	135	120	4.92	4.11	1.9	2.0
Diospyros kaki	59	52	17.20	20.50	7.0	5.3
Ⅴ. Sucessional later trees						
Abies holophylla	29	36	0.54	0.43	–	–
Pinus koraiensis	16	8	0.74	0.66	–	–
Quercus mongolica	36	33	1.52	1.38	3.0	2.8
Carpinus codata	24	22	1.81	1.03	2.5	2.3
Carpinus laxiflora	51	55	3.90	3.46	3.4	3.0
Cornus controversa	86	70	13.73	10.21	2.1	1.8
Acer pseudosieboldianum	23	19	0.81	0.73	2.4	1.6
Acer ginala	79	62	2.72	4.75	5.0	4.6
Acer mono	14	11	0.49	0.39	1.5	1.3
Fraxinus rhynchophylla	28	31	0.88	0.56	3.8	3.0
Ⅵ. Garden trees						
Hibscus syriacus	40	25	2.15	0.74	13.1	10.5
Rhododendron mucronulatum	21	18	0.36	0.31	5.0	3.5
R. yedoense var. *poukhanense*	9	7	0.22	0.19	1.6	1.0
Betulla platyphylla var. *japonica*	54	69	2.09	5.89	1.2	1.0
Acer palmatum	75	58	2.21	3.87	5.2	6.5

Table 2. Continued

Species	Branch length		Leaf weight		Maximum photo-synthetic rate	
	Control site	Polluted site	Control site	Polluted site	Control site	Polluted site
A. rubrum var. *pycnabthum*	71	60	0.54	0.23	10.0	4.0
Wistaria floribunda	160	78	22.50	10.70	2.3	2.5
Syringa dilatata	40	33	1.35	1.76	7.4	7.0
Ligustrum obtusi folium	78	54	2.30	1.25	4.5	4.0
Buxus microphylla var. *koreana*	25	23	1.92	1.99	2.0	1.8
Acer truncatum	28	23	0.43	0.94	1.8	1.9
Magnolia obovata	26	21	5.40	4.20	1.8	1.5
Prunus yedoensis	53	27	1.98	2.57	3.3	3.0
Forsythia koreana	43	50	1.49	1.26	2.8	2.5
Rosa multiflora	115	127	3.98	3.42	5.8	6.1
Parthenocissus tricuspidata	207	193	4.21	4.02	6.7	7.2
Ⅶ. Foreign restoring trees[2]						
Pinus rigida	16	11	0.35	0.42	–	–
Quercus rubra	23	18	1.80	3.60	3.9	4.1
Acer saccharium	60	50	3.74	1.11	1.0	0.8
Robinia pseudoacacia	117	160	3.15	1.45	11.8	11.1

[1];by Environment Administration (1996), [2];from Munshower(1994)

Table 3. Tolerance index of translanted woody plants. Tolerance index was calculated as the mean ratio of value in polluted site to value in control site. Species were rearranged with decreasing of tolerance index

Species	Tolerance ratio			Tolerance index
	Branch length	Leaf weight	Maximumn photosynthetic rate	
Ⅰ. Local trees occurring in polluted region[1]				
Q. variabilis	1.11	2.00	1.25	1.45
P. thunbergii	1.33	1.36	–	1.35
Q. aliena	1.12	1.84	0.95	1.30
Pinus densiflora	0.88	1.59	–	1.24
Styrax japonica	1.29	1.19	1.17	1.22
Alnus firma	1.27	0.88	1.50	1.22
Celtis sinensis	1.38	1.09	0.94	1.14
Elaeagnus umbellata	1.18	1.02	1.05	1.08
Quercus serrata	1.21	1.05	0.97	1.08
Eurya japonica	0.86	1.27	1.08	1.07
Sorbus alnifolia	0.91	1.33	0.95	1.06
Q. acutissima	1.08	0.97	1.10	1.05
Ligustrum japonicum	0.79	0.79	1.03	0.87
Euonymas japonica	0.84	0.48	0.96	0.76
Q. dentata	0.56	0.79	0.83	0.73
Ⅱ. Street trees				
Ailanthus altissima	1.81	1.15	1.17	1.38
Zelkova serrata	0.67	1.05	0.76	0.83
Sophora japonica	0.88	0.66	0.79	0.78
Platanus orientalis	0.88	0.48	0.91	0.76
Ginko biolova	0.87	0.40	0.65	0.64
Ⅲ. Fast-growing trees				
Populus tomentiglandulosa	2.05	2.00	1.15	1.73

Table 3. Continued

Species	Tolerance ratio			Tolerance index
	Branch length	Leaf weight	Maximumn photosynthetic rate	
Alnus hirsuta var. *sibirica*	0.83	1.72	1.90	1.59
Alnus hirsuta	0.63	0.90	0.83	0.79
Firmiara simplex	0.82	0.67	0.56	0.68
Ⅳ. Fruiting trees				
Diospyros kaki	0.88	1.19	0.76	0.94
Castanea crenata	0.89	0.84	1.05	0.93
Ⅴ. Sucessional later trees				
Acer ginala	0.78	1.75	0.92	1.15
Abies holophylla	1.24	0.79	–	1.02
Cornus controversa	0.81	0.74	0.86	0.95
Fraxinus rhynchophylla	1.11	0.64	0.79	0.85
Acer mono	0.79	0.79	0.87	0.82
Quercus mongolica	0.92	0.57	0.93	0.91
Carpinus codata	0.92	0.57	0.92	0.81
Carpinus laxiflora	1.08	0.89	0.88	0.80
Acer pseudosieboldianum	0.83	.90	0.67	0.80
Pinus koraiensis	0.50	.89	–	0.69
Ⅵ. Garden trees				
Betulla platyphylla var. *japonica*	1.28	2.82	0.83	1.64
Acer truncatum	0.82	2.19	1.06	1.36
Acer palmatum	0.77	1.75	1.25	1.26
Syringa dilatata	0.83	1.30	0.95	1.03
Rosa multiflora	1.10	0.86	1.05	1.00
Parthenocissus tricuspidata	0.93	0.96	1.07	0.99
Forsythia koreana	1.16	0.85	0.89	0.97
Buxus microphylla var. *koreana*	0.92	1.04	0.90	0.95
Prunus yedoensis	0.51	1.30	0.91	0.91
Rhododendron mucronulatum	0.86	0.86	0.70	0.81
Magnolia obovata	0.81	0.78	0.83	0.81
R. yedoense var. *poukhanense*	0.78	0.86	0.75	0.80
Ligustrum obtusifolium	0.69	0.54	0.89	0.71
Wistaria floribunda	0.49	0.48	1.09	0.69
Hibscus syriacus	0.63	0.34	0.80	0.59
A. rubrum var. *pycnabthum*	0.85	0.43	0.40	0.56
Ⅶ. Foreign restoration trees2				
Quercus rubra	0.78	2.00	1.05	1.28
Robinia pseudoacacia	1.37	0.88	0.94	1.06
Pinus rigida	0.69	1.20	–	0.95
Acer saccharium	0.83	0.30	0.80	0.64

[1];by Environment Administration (1996), [2];from Munshower(1994)

well as essential nutrients in their body in proportion to high growth rate (Dueck *et al.* 1992, Whangbo 1995). *P. tomentiglandulos* and *A. hirusta* var. *sibirica* among fast growing trees (group Ⅲ) grew better in polluted site (50%). Those species may have physiological mechanisms to counter the side-effect of pollutant (Levitt 1980).

In late successional trees (group V), *A. ginala* and *A. holophylla* grew better in polluted site (20%), but the other species did not so (80%). The lower growth of those tree species group in polluted environment is contrast to that of the early successional species. In our study, most early successional trees, such as *P. densiflora*, *Q. variabilis*, *S. japonica*, *A. firma*, *E. umbellata*, *Q. serrata*, *S. alnifolia*, *Q. acutissimia*, *P. tometigludulosa* and *A. hirsuta* var. *sibirica*, grew better in polluted site. From this result, we can know that early successional species is more tolerant than late successional species to pollution. So, successional tendency of vegetation in polluted area is shown in retrogressive one or remained in dis-climax state (Environment Administration 1996). Those trends were already observed in the area of metropolitan city and industrial complex in Korea (Environment Administration 1996).

In garden trees (group IV), the growth of *B. platyphylla* var. *japonica*, *A. trucatum*, *A. palmatum*, *S. dilatata*, and *R. multiflora* was better in polluted site (38%). *P. tricuspidata* was frequently observed in healthy state around the experimental site. But in our experiments, this species did not grew well. This results may be from that in the field, the environmental factors are very variable at a fine scale level.

In introduced restoring trees (group VII), *Q. rubura* and *R. pseudoacacia* grew better in polluted site (50%). 4 species of group VII have been using for restoration of the degraded ecosystems in USA (Munshower 1994). But it was evaluated that two species, such as *P. rigida* and *A. saccharium*, may inappropriate to restore disturbed ecosystems, at least in polluted area. Especially it was reported that *P. rigida* was the most tolerant to acid Al solution (Ryu and Kim 1996), that species was the most sensitive to pollation among *Pinus* spp. in this experiment.

적 요

대기오염과 토양오염으로 심하게 훼손된 공단지역 생태계에서도 잘 생육하는 내성 식물종을 선발하기 위하여 우리나라 주요 목본 56종의 유식물을 여천공업단지 내의 오염지와 비오염지에 이식하여 그들의 지상부 가지길이, 엽건량과 최대광합성율에 근거하여 지상부의 생육상태를 상호 비교하였다.

비오염지(대조구)보다 오염지에서 더 잘 자람으로써 내성종으로 인정되는 종은, 오염지에서 발견되는 15종 중 굴참나무, 해송, 갈참나무, 소나무, 때죽나무, 사방오리, 팽나무, 보리수나무, 졸참나무, 사스레피나무, 팥배나무 및 상수리나무(80%)이었고, 가로수 5종 중 가죽나무(20%), 속성수 4종 중 현사시나무와 물갬나무(50%), 천이후기 10종 중 신나무와 전나무(20%), 정원수 16종 중 자작나무, 중국단풍나무, 단풍나무, 수수꽃다리 및 찔레꽃(38%), 도입복원수 4종 중 대왕참나무와 아까시나무(50%) 이었다. 나머지 37종(전체의 57%)은 오염지에서 생육이 불량한 예민종이었다. 이러한 내성종을 식재하면 공단지역을 효과적으로 녹화복원시킬 수 있을 것이다.

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