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Relative sensitivities of woody plants to acid deposition in south areas of China

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Abstract— Relative sensitivities of 30 species of common woody plants to simulated acid rain with pH values of 2.0, 2.5, 3.0, 3.5, 4.5 and control were studied. The results showed that 6 species of these plants were sensitive to simulated acid rain. The moderate included 18 species. The resistant included 6. Relative sensitivities to ambient acid rain and air pollutants and visible injury degree of 30 species of common woody plants in Chongqing City were investigated. Results showed that 6 species with foliage lesion rate at above 10 percent were sensitive, that 6 species with no lesion were resistant and that other 18 species with lesion at 10 percent below were moderate. Other 7 cities (Guiyang, Zunyi, Duyun, Changsha, Zhuzhou, Liuzhou and Guilin City) were also investigated and results were consistent with those of Chongqing City. The experimental and investigated results showed relative sensitivities and visible injury degree of woody plants to simulated acid rain were consistent with those of the woody plants to ambient acid rain and air pollutants. The sensitive plants may be used as bioindicators to acid rain or air pollutants. The resistant species can be introduced to acid rain and air pollution areas to substitute damaged sensitive plants in order to improve environment.

Keywords: relative sensitivity; acid rain; woody plant.

STUDY AREAS

The study area located in South China, including Sichuan, Guizhou, Hunan Province and Guangxi Zhuang Autonomous Region (Fig. 1). These areas are the most severe regions of acid rain, SO_2 pollution in China.

MATERIALS AND METHODS

Year-old seedlings of 30 species of woody plants were planted in experiment plots at the Gele Shan Nursery of Chongqing Forestry Institute.

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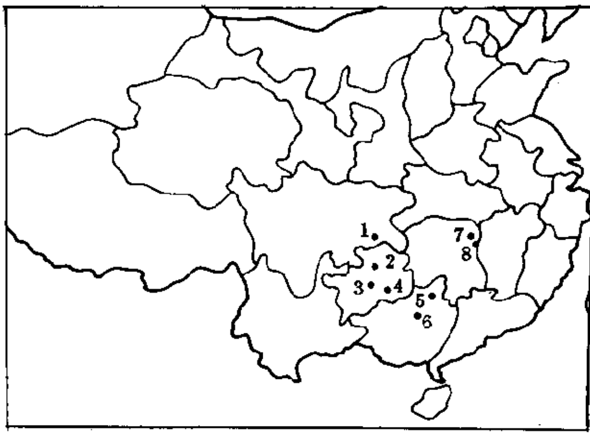

Fig. 1 Map of study areas

1. Chongqing 2. Zunyi 3. Guiyang 4. Duyun
5. Liuzhou 6. Guilin 7. Changsha 8. Zhuzhou

Simulated acid rain solution with 6.6 (control), 4.5, 3.5, 3.0, 2.5, 2.0 were prepared by diluting a mixture of reagent grade sulfuric acid and nitric acid in a 8:1 ratio (by mol concentration) with distilled water. Except rainy days, from August to November 1987 and from April to November 1988, simulated rain was applied to all the experimental plants by spraying upward through a spraying system manufactured from acid proof material for 5 minutes per day.

Determination of biomass at the end of the growing season, biomass of control and treated plant was measured to determine if acid rain treatment had any effect on plant productivity. The roots, stems and foliage of plants were collected, weighed, then oven-dried at 70°C, and weighed again. The ratio of water weight for each plant part was measured, then the dry weight of plant parts could be calculated.

Determination of leaf lesion rate leaves of plant were collected, separated leaf lesion from green tissue, oven-dried at 70°C, and weighed. Leaf lesion rates were calculated by means of formula as follows:

$$r(\%) = \frac{Lls}{Lls + Lgr} \times 100,$$

where r is leaf lesion rate, Lls is leaf lesion dry weight, Lgr is green leaf tissue dry weight.

Dark respiration and net photosynthetic rate were measured by a QGD-07 model portable infra-red CO_2 analyser made in Beijing Analytical Instrument Manufacturer. Cycle and open air pipe was used. Black paper and plastic film were used to shad light. Artificial light density was 20000 lux ($mmolm^{-2}s^{-1}$). Air temperature in leaf chambers was controlled by water bath.

RESULTS AND DISCUSSION

Relative sensitivities of woody plants to simulated acid rain

Relative sensitivities of 30 species of woody plants to simulated acid rain were divided into three groups based on leaf lesion rate, threshold values of simulated acid rain pH and number of exposure to simulated acid rain in that leaf visible injury symptom first appeared (Table 1). The sensitive species exhibited a trend toward higher leaf lesion rates and acid rain threshold values, lower numbers of exposure to acid rain than moderate and resistant species.

Relative sensitivities of root, stem and leaf to simulated acid rain

According to relative sensitivities of 30 species of woody plants to simulated acid rain above, authors selected *S. superba* as sensitive species, *P. massoniana, C. lanceolata* and *C. glauca* as moderate species, and *C. oleifera* and *M. macclurei* as resistant species and measured biomass of these species for comparing the relative sensitivities of root, stem and leaf to simulated acid rain. The results showed root biomass of *P. massoniana*, *S. superba*, *C. lanceolata* and *M. macclurei* were significantly reduced (F-test) by simulated acid rain at pH 2.0 except *C. oleifera.* Simulated acid rain had no significant effects on stem biomass of *P. massoniana, C. lanceolata, C. oleifera* and *M. macclurei*, but significant effects on *C. glauca* and *S. superba*. Leaf biomass of *P. massoniana*, *S. superba*, *C. glauca*, and *C. lanceolata* were significantly reduced (F-test) by simulated acid rain at pH 2.0, but exhibited no significant effects on that of *M. macclurei* and *C. oleifera* (Table 2).

It was found that root was more sensitive than leaf and then leaf was more sensitive than stem based on measure of changes of their biomass.

According to biomass determination in root, stem and leaf, relative sensitivities of 6 species of woody plants were ordered as follows:

In root: *S. superba* > *P. massoniana* > *C. glauca* >
C. lanceolata > *M. macclurei* > *C. oleifera.*

In stem: *S. superba* > *C. glauca* > *P. massoniana* >
M. macclurei > *C. oleifera* > *C. lanceolata.*

In leaf: *S. superba* > *P. massoniana* > *C. lanceolata* >
C. glauca > *M. macclurei* > *C. oleifera.*

Table 1 Relative sensitivities of 30 species of woody plants to simulated acid rain

Plant species	Leaf lesion rate				Threshold of rain pH				Number of exposure				
	<1	1–5	6–10	11–20	2.0	2.5	3.0	3.5	<5	5–10	11–20	21–30	>31
Schima superba				+				+	+				
Pheobe bournei				+				+	+				
S *Metasequoia glyptostroboides*				+				+	+				
Platanus acerifolia				+				+	+				
Sassafras tzumu				+				+	+				
Erythrina indica			+					+	+				
Toona sinensis				+			+		+				
Ligustrum lucidum				+			+		+				
Cyclobalanopsis glauca				+			+		+				
Cryptomeria fortunei				+			+		+				
Camptotheca acuminata				+			+		+				
Melia azedarach				+			+		+				
Cupressus duclouxiana				+			+		+				
Platycadus orientalis				+			+		+				
Phyllostachys pubescens				+			+		+				
M *Cinnamomum wilsonii*			+				+			+			
Cunninghamia lanceolata			+				+			+			
Paulownia tomentosa			+				+			+			
Pinus massoniana			+				+			+			
Broussonetia papyrifera		+					+		+				
Liriodendron chinense		+					+		+				
Cinnamomum camphora		+					+			+			
Aleurites montana		+					+			+			
Salix babylonica		+					+			+			
Michelia macclurei		+				+						+	
Castanopsis sclerophylla	+					+					+		
Citrus reticulata	+					+						+	
R *Osmanthus fragrans*	+					+						+	
Nerium indicum	+					+						+	
Camellia oleifera	+				+							+	

S—sensitive; M—moderate; R—resistant.

Table 2 Effects of simulated acid rain on biomass (g) of 6 species

Plant species		Simulated acid rain control	pH 4.5	pH 3.0	pH 2.0	Significant level
S. superba	root	0.502	0.811	0.583	0.145	F=103.652**
	stem	0.218	0.374	0.289	0.097	F=4.076**
	leaf	0.569	0.747	0.610	0.106	F=16.217**
C. glauca	root	0.527	0.517	0.570	0.297	F =14.011**
	stem	0.284	0.310	0.320	0.243	F =3.261*
	leaf	0.549	0.651	0.615	0.343	F =12.498**
P. massoniana	root	0.104	0.118	0.107	0.040	F =10.127**
	stem	0.133	0.120	0.137	0.084	F=0.386
	leaf	0.238	0.286	0.316	0.143	F=20.426**
C. lanceolata	root	0.873	0.722	1.002	0.342	F=7.238
	stem	0.311	0.382	0.435	0.403	F=0.600
	leaf	0.988	1.100	1.305	0.718	F=2.817*
C. oleifera	root	0.740	0.530	0.360	0.203	F=2.275
	stem	0.356	0.350	0.454	0.349	F=1.262
	leaf	0.533	0.547	0.731	0.460	F=2.110
M. macclurei	root	0.426	0.532	0.360	0.203	F=3.348*
	stem	0.208	0.229	0.237	0.164	F=0.906
	leaf	0.345	0.374	0.320	0.246	F=0.636

* significant at P <0.05; ** significant at P <0.01

As mentioned above, relative sensitive order of the 6 species to simulated acid rain in leaf biomass was consistent with that root biomass, but not consistent with that in stem biomass.

The effect of acid rain on photosynthesis and respiration

P. massoniana and *C. lanceolata* were selected to study physiological responses to acid rain since they are two of the major commercial coniferous species in South China. The experimental results showed that net photosynthetic rate of *P. massoniana* decreased with acidity increase but did not decrease in that of *C. lanceolata*. Analysis of variance indicated no significant effects of acid rian (Table 3). Dark respiration rates of two species were increased significantly at pH 2.0 (Table 4). Ferenbaugh (1976) reported simulated acid rain increased the respiration rate of *Phaseolus vulgaris* L. Therefore, respiration rate increases by acid rain may be a general pattern. So that dark respiration was more sensitive than net photosynthesis to simulated acid rain (Table 3 and Table 4).

Table 3 The effect of simulated acid rain on photosynthetic rate (CO_2 mg/g leaf dry weight/hour)

Plant species	Acid rain treatment ck	pH 4.5	pH 3.0	pH 2.0	Significant level F value	P
P. massoniana	8.577	8.123	7.930	5.796	2.19	—
C. lanceolata	10.230	10.387	11.609	10.316	0.05	—

Table 4 The effect of simulated acid rain on dark respiration rate (CO_2 mg/g leaf dry weight /hour)

Plant species	Acid rain treatment				Significant level	
	ck	pH 4.5	pH 3.0	pH 2.0	F value	P
P. massoniana	1.094	1.143	0.910	1.697	4.09	0.05
C. lanceolata	1.518	1.370	1.728	2.047	3.21	0.05

Relative sensitivities of 30 species of woody plants to ambient acid rain and air pollutants

Table 5 shows status of ambient acid rain and air pollution in investigated areas. It is clear that acid rain and SO_2 were the two main pollutants in the study areas.

Table 5 Status of ambient acid rain and air pollution

Areas	Rain pH	SO_2	NO_2 mg/m^3	TSP	Year
Chongqing	4.09	0.51	0.08	0.64	1985
Guiyang	4.30	0.403	0.04	0.83	1985
Zunyi	4.30	0.193	0.02	–	1985
Duyun	4.80	–	–	–	1985
Changsha	5.27	0.13	0.10	0.30	1983
Zhuzhou	–	0.17	–	0.14	1981
Luizhou	4.38 (1985)	0.194	0.017	–	1982
Guilin	4.83	0.15	0.026	0.478	1981

In combination with simulated acid rain experiment, investigation on damaged status of ambient acid rain and air pollutants to woody plants and their relative sensitivities was performed in some cities in South China, including Chongqing, Guiyang, Zunyi, Duyun, Changsha, Zhuzhou, Liuzhou and Guilin. Leaf lesion rate and frequency of leaf visible injury were used as index of relative sensitivity:

$$r(\%) = \frac{Lls}{Lls + Lgr} \quad \text{and} \quad f(\%) = \frac{n}{N},$$

where f is frequency of visible injury, n is number of city where visible injury of the plant leaf appeared, N is number of city investigated.

It is clear that the sensitive species exhibited a trend toward higher leaf lesion rate and friqurency of leaf visible injury than moderate and resistant species (Table 6).

Comparing Table 1 with Table 6, relative sensitivities of woody plants to ambient acid rain and air pollutants were almost consistent with those to simulated acid rain.

Table 6 Relative sensitivities of 30 species of woody plants to ambient acid rain and air pollutants

Relative sensitivity	Plant species	r, %					f, %				
		0	1–5	6–10	11–17	>17	0	1–25	26–50	51–80	>80
	Metasequoia glyptostroboides					+					+
	Robina pseudoacacia					+					+
	Ormosia hosiei					+					+
S	*Taxodium ascendens*			+							+
	Platanus acerifolia			+							+
	Eucalyptus robusta			+							+
	Cinnamomum platyphyllum			+							+
	Liqustrum lucidum			+							+
	Gleditsia sinensis			+							+
	Melia toosendan			+							+
	Eriobtrya japonica			+							+
	Sassafras tzumu			+							+
	Pinus massoniana		+								+
	Cunninghamia lanceolata			+						+	
	Pinus taeda			+						+	
	Cinnamomum japonicum			+						+	
M	*Paulownia tomentosa*			+						+	
	Cryptomeria fortunei			+						+	
	Cedrus deadara			+						+	
	Cinnmomum camphora			+						+	
	Broussonetia papyrifera			+						+	
	Taxus chinensis			+						+	
	Erythrina indica			+							+
	Camptotheca acuminata		+						+		
	Nerium indicum		+					+			
	Osmanthus fragrans	+					+				
	Citrus reticulata	+					+				
R	*Camellia oleifera*	+					+				
	Cupressus funebris	+					+				
	Magnolia grandiflora	+					+				

Note: S, M, R are the same as to Table 1.

The sensitive plants such as *S. superba, M. glyptostoboides, R. pseudoacacia, O. hosiei, T. ascendens, P. acerifolia* and *E. robusta*, may be used as bioindicators to acid deposition. The resistant plants such as *C. oleifera, O. fragrans, C. sclerophylla, N. indicum, C. reticulata, C. funebris* and *M. grandiflora* may be introduced to acid deposition area to substitute for damaged sensitive species in order to improve environment.

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