Journal of Environmental Sciences (China), Vol. 3, No. 2, pp. 27–36, 1991 ISSN 1001–0742

Effects of acid rain on forest ecosystem in Southwestern China

Chen Chuying[1], Zhang Jiawu[1], Xu Guangshan[1]
Zhou Chonglian[1] and Liao Liping[1]
(Received May 30, 1990)

Abstract—The study of effects of acid rain in Southwestern China on forest ecosystems has been inrestigated since 1984. The results have shown that the ecosystem of *Pinus massoniana* forest has been damaged severely by acid rain. Comparing the areas where the annual mean pH value is lower than 4.5 with that higher than 4.5, the productivity of the ecosystems decreased 50 percent. Both the percentages of the green leaves and the content of chlorophyll cut down; the acidity of soil increased a bit and the fertility showed the tendency to lower. The microbial population components in surface soil were changed and the total number of soil microbes reduced from 63.5 to 92.6 percent. Besides the direct effects of acid rain, the insect pest, especially, *Blastophagus piniperdoz* and *Monochamus galloprovincialis*, seized the opportunity to enter and reproduce in it so as to aggravate the forest dieback of *P.massoniana* in the areas where the annual average pH value is lower than 4.5.

Additionally, the simulation study on the symptoms of main tree species in Southwestern China damaged by acid rain has obtained the results in the resistibility of 30 tree species, which provided a foundation for selecting suitable tree species to cultivate in the polluted areas.
Keywords: acid rain; forest ecosystem; *Pinus massoniana;* forest soil; destructive pest.

INTRODUCTION

Forest ecosystem is the most important component part of terrestrial ecosystems. It not only provides timber which human being needs to live, and variety of forestry by-products, but also has many kinds of ecological effects, which are conserving water, protecting water and soil, wind breaking and dune-fixing, and beautifying the environments. These functions and efficiencies will disappear when forests are suffered to destroy. Thus, it is of importance to study the effects of acid rain on forest ecosystem.

Researches of many scholars in different countries have manifested that acidic rainfall may affect growth and development of trees, diminish biomass production, and even lead to forest

[1]Institute of Applied Ecology, Academia Sinica, Shenyang 110015, China.

death (Zhao, 1984). Our country starts to research the effects of acid rain on forest later. In 1984, Institute of Applied Ecology of Academia Sinica in Shengyang organized a group of professionals from forest ecology, forestry, forest pedology, forest micrology and forest pathoentomology to investigate the effects of acid rain in Southwestern China on forest ecosystems. This paper will show some results of these researches.

METHODS

Comparison of resistance of trees to acid rain

Simulated acid rain is made up according to the ratio of sulfuric acid and nitric acid which is 8:1 in Chongqing area. There are 7 treatments with pH of 2.0, 2.5, 3.0, 3.5, 4.0, 4.5 and 6.5 (as control experiment) respectively. Acid rain is sprayed on the healthy trees with fog-spraying-machine once per day, with exception of natural rain days. In the end, the annual amount of acid rain is equal to the annual precipitation of Chongqing.

Measurement of growing stock of tree layer

In the areas with the rainfall pH 4.5 upper or down, cutting the sample trees according to ages, using $W = a(D^2H)^b$ to fit the regression equation of the growing stock and calculating the growing stocks of each organs in different sample plots.

Soil chemistry analysis

Total of exchangeable base: Ca and Mg are measured by atomic absorption spectrometer. K and Na are measured by flame spectrometer.

Hydrolytic acid is measured by NaAc Hydrolysis-NaOH Titration.

Total of cation is measured by NH_4Ac Exchange-Distill.

Soil microbes are bioassayed by petri dish.

RESULTS AND DISCUSSION

Damage symptoms and susceptibility of trees

The results gained through simulating experiments and field survey have showed that all kinds of symptoms emerged after the acidity of precipitation surpassed the endurance of leaves. They were summed up into four kinds as follows:

Yellowing

Leaves of many tree species first showed clear greensickness. Leaf colours were changed from green to yellow-green or light green.

Necrosis speck

Most trees' necrosis specks appeared on the leaf tips and edges. For palm leaves, they first showed on non-round places. Specks of bigger leaves or thin leaves with fine hair usually emerged on places between leaf veins. The colours of necrosis specks differed with species, which were yellow brown, yellow, red-yellow, brown and greyish white and so on.

Dehydration wilting

Some trees had not prominent greensickness, but often began to dewater and wilt before the necrosis specks appeared, and the leaves' edges rolled into the center or the leaf surfaces folded and lost original lustre.

The cells at the bases of certain trees' petioles separated and produced separation layer. The leaves fallen down too early. Leaves have different capacities of resisting acidic precipitation because of different shapes and structure and different wettability. According to the time when leaves show injury symptoms, the size of injury areas and critical acidity which incurred the damage spots, we have carried out comprehensive and comparative evaluations on 30 tree species in Southwestern China, and divided them into three classes, which were strong, moderate and weak (Table 1). Trees with strong resistance to acid rain were 18 percent of total experiment tree species, who are *Castanopsis sclerophylla, Michelia macclurei*, and *Nerium indicum* and so on. Moderate ones are *Cinnamomum camphora, Cyclobalanopsis glauca* and *Salix babylonica* and so on, which account for 64 percent and susceptable ones are *Metasequoia glyptostroboides, Platanus orientalis* and so on, and amount to about 18 percent. Generally speaking, the resistance of evergreen broad-leaved trees is stronger than that of deciduous broad-leaved and coniferous trees.

Effects of acid rain on the photosynthetic systems of trees

The results of investigation done in regions polluted by acid rain and by artificial acid rain experiments controlled have showed the damage of acid rain to trees first express on the leaves which works as photosynthetic organs. As for *P. massoniana*, one of principal timber trees in Southwestern region, the measurements of 18 analyses of *P. massoniana* showed that the number of green leaves was 98.9 percent of total but in areas where pH value of rain is lower than 4.5, it is only 86 percent, and that the content of chlorophyll in the former areas is 1.4 to 2.1 times larger than that in the latter areas (Table 2).

Effects of acidic wet deposition on forest soil

Forest soil in Southwestern China severely polluted by acid rain is predominantly mountainous yellow soil. The soil-forming rocks are granite and arenaceous shale, and limestone in certain places. In clean regions, generally, the exchangeable base content, base saturation, pH value and hydrolytic acid are 10 meq. per 100g dry soil, 10 to 30 percent, 4.5 to 5.5 and 4 to 8 meq/100g dry soil respectively. And sometimes the last one may be high up to 10 meq. Table 3 shows the basic properties of forest soil in regions with the pH value of precipitation higher than 4.5. It illustrates that pH value, total exchangeable base, hydrolytic acid, total cation and base saturation are 4.55 to 5.69, 1.02 to 3.95 meq/100g dry soil, 6 to 11 meq/100g dry soil, 7 to 12 meq/100g dry soil and 12 to 37 percent respectively. These are almost similar to that of mountainous yellow soil in non-polluted region.

Table 1 Comparison of leaves' resistance of different tree species to acidity

Resistance class	Species	TSO[1], d*	DAL[2] %*	CASO[3], pH
Strong	*Camellia oleifera*	31up	0	
	Nerium indicum	31up	1 down	2.5
	Osmantus fragrana	31up	1 down	2.5
	Citrus reticulata	31up	1 down	2.5
	Castanopsis sclerophylla	21–30	1 down	2.5
	Michelia macclurei	31up	1–5	2.5
Intermediate	*Salix babylonica*	6–10	1–5	3.0
	Vernicia fordii	6–10	1–5	3.0
	Cinnamomum camphora	6–10	1–5	3.0
	Broussonetia papyrifera	5 down	1–5	3.0
	Liriodendron chinense	5 down	1–5	3.0
	Cunninghamia lanceolata	6–10	6–10	3.0
	Pinus massoniana	6–10	6–10	3.0
	Paulownia tomentosa	6–10	6–10	3.0
	Cinnamomum wilsonii	6–10	6–10	3.0
	Phyllostachys pubescens	5 down	6–10	3.0
	Platycladus orientalis	5 down	11–20	3.0
	Cupressus duclouxiana	5 down	11–20	3.0
	Melia azedarach	5 down	11–20	3.0
	Camptotheca acuminata	5 down	11–22	3.0
	Crypotomeria fortunei	5 down	11–22	3.0
	Cyclobalanopsis glauca	5 down	11–22	3.0
	Ligustrum lucidum	5 down	11–22	3.0
	Toona sinensis	5 down	11–22	3.0
Weak	*Erythrina indica*	5 down	6–11	3.5
	Sassafras tsumu	5 down	11–20	3.5
	Platanus acerifolia	5 down	11–20	3.5
	Metasequoia glyptostroboides	5 down	11–20	3.5
	Phoebe bournei	5 down	11–20	3.5
	Schima superba	5 down	11–20	3.5

[1] Time of symptoms occuring; [2] Damaged areas of leaves; [3] Critical acidity of symptoms occurring; * Application of pH 2.5 simulated acid rain for six months

Table 2 Relationship among rainfall pH, leaf colour and chlorophyll content of *P. massoniana*

Acid rain status	Investigation site	Green leaf percentage, %	Chlorophyll content, mg/g		
			a	b	Total
Annual mean rainfall pH lower than 4.5	Nanan district of Chongqing City	86.0	0.6515	0.2745	0.9260
Annual mean rainfall pH higher than 4.5	Ba county	95.5	1.1347	0.4232	1.5579
	Qijiang County	100.0	1.2188	0.4395	1.6583
	Nantong mine area	100.0	0.9600	0.3754	1.3354
	Jiangjin County	100.0	1.4027	0.4977	1.9004
	Mean	98.9	1.1791	0.4340	1.6131

Table 3 Chemical properties of mountainous yellow soil in areas with annual mean rainfall pH higher than 4.5

Profile No.	Depth, cm	pH H_2O	pH KCl	Organic matter, %	Total exchangeable base, meq/100g	Hydrolytic acid, meq/100g	Total cation, meq/100g	Base saturation, %
1	0–3	4.55	3.87	3.13	1.48	10.64	12.12	12.2
	8–22	4.93	4.10	1.54	1.42	8.69	10.11	14.0
	22–31	4.88	4.11	1.07	1.18	6.52	7.70	15.3
	31–45	4.81	4.03	0.88	1.98	5.79	7.77	25.5
2	0–7	4.81	3.86	1.09	1.02	6.01	7.03	14.5
	7–13	4.97	4.25	0.69	2.04	5.76	7.76	26.3
	13–40	5.69	4.39	0.47	2.81	4.57	7.38	38.1
3	0–5	4.71	3.90	3.59	2.06	8.96	12.01	17.1
	5–26	4.81	4.09	1.02	0.62	7.69	8.31	7.5
	26–51	4.80	4.17	0.59	0.86	7.46	8.32	10.3
	51–76	4.74	4.14	0.39	0.90	8.96	9.86	9.2
4	0–7	5.50	4.22	1.63	3.95	6.75	10.70	36.9
	7–17	5.17	4.04	0.99	1.66	5.71	7.37	22.5
	17–31	5.40	4.17	0.66	0.89	4.57	5.47	16.4
	31–60	5.40	4.22	0.62	3.58	4.57	8.16	43.8

However, comparing areas where the annual average pH was larger than 4.5 with that the pH was less than 4.5. Though with similar climate, vegetation, topography and mother material, the soil pH, base content and base saturation existed difference to some degrees between the two areas (Table 4). This manifested that the soil acidity in the latter areas has a little bit increase, and that soil fertility started to decline.

Table 4 Effects of acid rain on soil chemical properties

Acid rain status	Soil pH	Base contents, meq/100g	Base saturation, %	Ca/Al
Annual mean rainfall pH lower than 4.5	4.38–4.57 4.47	less than 1.0	lower than 10	0.32–0.55 0.43
Annual mean rainfall pH higher than 4.5	4.55–5.50 4.90	1.0–4.0	10–30	0.16–4.51 2.25

After acidic precipitation entered soil, it not only raised the soil acidity, but also caused a series of changes on soil properties, and especially, released toxins such as aluminium. The damage of aluminium, however, depended on plants. After researchers (Ulrich, 1980) in Germany studied the resistance of spruce to acid, they considered that the soil pH and Ca/Al ratio lower than 4.0 and 1.0 respectively, which could damage the root systems of spruce trees severely. As for Nanan region of Chongqing City in Southwestern China, which was suffered to most severe acid rain with the pH value of soil (mountainous yellow soil) and the Ca/Al ratio higher than 4.0 and lower than 1.0 respectively. But the relationship among acidification of soil, Al ion and root growth needs further studies

Effects of acid rain on soil microbes in forest

Acid rain directly does harm to plants, in the meantime, affects the microbe population component of surface soil and rhizosphere, and changes the symbiotic relation between plants and microbes, furthermore, reacts by feedback on nutrient cycling of plant-soil subsystem. The results of simulation experiments and field investigation demonstrated that total microbes of soil in areas with pH of rain lower than 4.5 was 7.2 to 36.5 percent of that in areas with pH of rain higher than 4.5. In particular, the number of bacteria and actinomy declined sharply (Table 5). And in bacteria family, chromogenic bacterium and *Bacillus* sp., which are more capable of decomposing organic matter, decreased more pronouncedly (Table 6).

Table 5 Effects of acid rain on microbes in forest soil, thousands/g dry soil

Acid rain, pH	Sampling site	Sampling time	Stand type	Total number	Bacteria	Fungi	Actinomy
AMR lower than 4.5	Nanan district Chongqing City	1985.4	PM	817	271	46	500
AMR higher than 4.5	Dongfeng forest station Pishan County	1985.4	PM	2239	1700	36	503
AMR lower than 4.5	Nanan district Chongqing City	1985.6	PM	3805	3444	151	210
AMR higher than 4.5	Simian Shan Jiangjin County	1985.6	PM	52681	51890	31	760

Note: AMR is short for "annual mean rainfall'; PM is short for "*Pinus massoniana*"

Table 6 Effects of acid rain on bacteria population, thousands/g dry soil

Acid rain, pH	Sampling site	Sampling time	Total bacteria	*Chromogenic bacterium*	*Bacillus* sp.
AMR lower than 4.5	Nanan district	1985.4	271	31	0
AMR higher than 4.5	Dongfeng forest station	1985.4	1700	462	33

The effects of acid rain on microbe population of soil are bound to reflect on the biochemical activity. Ammonification, nitrification and nitrogen-fixation in soil cut down after suffered to acid rain, but decomposition of cellulose and humus tend to get stronger (Table 7). The analytical results on surface soil (0–20cm), for example, demonstrated that ammonia (or ammonium) content also went down to different degrees from 2 to 70 percent, but the decomposition of cellulose became 2 to 7 times stronger. These confirmed that acid rain restrained the decomposition, assimilation and fixation of nitrogen in soil. It can be figured out according to the above data that the content of NH_3−N in surface soil declined by 100kg/ha.

Table 7 Effects of biochemical activity of soil microbes

Acid rain pH	Sampling time	Stand type	Ammonification, mg NH_3/g	Nitrification, mg NO_3/g	Nitrogen fixiation, %	Cellulose decomposition, %	Humus decomposition, %
AMR lower than 4.5	1985.4	PM	0.24	11.30		5.06	7.9
AMR higher than 4.5	1985.4	PM	0.33	11.54		0.63	8.0
AMR lower than 4.5	1985.6	PM	0.68	17.22	0.23	7.60	3.8
AMR higher than 4.5	1985.6	PM	1.40	17.94	0.23	2.30	3.6

Effects of acid rain on the productivity of forest

In the same climatic zone, the growth regime of trees is related not only to site factors such as elevation, slope deposition, aspect of slope, degree of slope, soil thickness and pH value, but also to pollution severity of environment closely. In order to study the relationship between so many factors and tree growth, a quantification theory is to be used for analysing the relations.

The results showed that the growth of *P. massoniana*, the main timber tree species, is related to pH of rainfall which is the principal factor of affecting the growth of *P. massoniana* trees (Table 8).

Table 8 Mark table of coefficients between DBH and height factors

Items	Mark range		Mark percentage in total	
	Height	DBH	Height	DBH
Elevation	0.0093	0.0027	1.36	0.41
Slope direction	0.0811	0.0842	11.89	12.99
Slope position	0.1179	0.1010	17.29	15.57
Slope degree	0.0294	0.0592	4.31	9.12
Rainfall pH	0.3363	0.2891	49.32	44.58
Soil thickness	0.0741	0.0861	10.86	13.28
Soil pH	0.0339	0.0263	4.97	4.05

Table 9 exhibits the preliminary evaluation of productivity loss of *P. massoniana* brought about by acid rain. It can be seen out clearly that the growth of height, DBH, volume, and net production of *P. massoniana* trees growing in areas with the pH value lower than 4.5 was 44.9, 39.9, 59.9 and 56.5 percent less respectively than that in areas with pH of rain higher than 4.5.

Table 9 Preliminary evaluation of *P. massoniana* productivity loss caused by acid rain

Acid rain, pH	Annual mean DBH, cm	Annual mean height, m	Annual mean volume, cm^3/tree	Net production, kg/tree.a
AMR lower than 4.5	0.42	0.38	35.73	0.27
AMR higher than 4.5	0.69	0.69	89.10	0.62
Losses by pH lower than 4.5 acid rain	−39.13	−44.92	−59.89	−56.45

Furthermore, compared the annual periodical growth of *P. massoniana* tree height and DBH in different regions polluted by acid rain, but with similar site condition and same stand ages, and it has been found out that acid rain began to refluence the growth of *P. massoniana* trees at the end of 1960s or the begining of 1970s in areas with the pH value of precipitation lower than 4.5.

Table 10 Investigation of pests damaging *P. massoniana* trees in different acid rain areas

Acid rain, pH	Investigation site	Investigated trees	Mean height, m	Mean DBH, cm
AMR lower than 4.5	Nanan district	60	1.4	2.5
		14	12.9	14.5
AMR higher than 4.5	Ba County	30	3.5	
	Qijiang County	30	5.0	6.9

Acid rain, pH	Pests boring tree tips Infested trees	Ratio, %	*M. galloprovincialis* Infested trees	Ratio, %
AMR lower than 4.5	36	60.0	0	0
	0	0	8	57.1
AMR higher than 4.5	30	100.0	0	0
	7	0	0	0

Table 11 Pests investigation of 17 felled trees in different acid rain areas

Acid rain, pH		AMR lower than 4.5	AMR higher than 4.5			
Investigation site		Nanan district Chongqing	Ba County	Nantong	Qijiang County	Jiang jin
Investigated trees		7	3	2	4	1
Investigated branches		3501	2398	1390	2536	1104
Mean height, m		6.6	15.3	10.6	8.2	7.9
Mean DBH, cm		7.9	12.8	11.1	8.6	11.0
Stand age, a		25	22	27	15	14
Monochamus galloprovincialis	IT	4	1	0	0	
	ITR	57.1	33.3	0	0	0
Blasphagus piniperdoz	IT	6	1	33.3	0	0
	ITR	85.7	33.3	50.0	0	0
	IB	129	2	5	0	0
	IBR	3.7	0.1	0.4	0	0
Coccidea sp.	IT	7	2	0	1	0
	ITR	100	66.7	0	25.0	0
	IB	262	36	0	4	0
	IBR	66.5	24.7	0	5.7	0
Pests damaging tree tips	IB	64	7	0	18	3
	IBR	1.8	0.3	0.4	0.7	0.3

IT: infested trees ITR: infested tree ratio

IB: infested branches IBR: infested branch ratio

As acid rain seriously affected the growth of *P. massoniana*, many insect pests, especially, *Blastophagus piniperdoz* and *Monochamus galloprovincialis*, the destructive pests, caught the opportunity to reproduce so as to aggravate the forest die-back of *P. massoniana* in the heavy acid rain areas (Table 10 and Table 11, Yang, 1989).

CONCLUSIONS

The results of investigation in acid rain areas and simulated experiments demonstrate that the acid rain with pH is higher than 4.5 has no evident injuries to leaves of 30 main tree species in Southwestern China.

The basic soil properties in the areas with rainfall pH higher than 4.5 is similar nearly to that areas without acid rain pollution, but with rainfall pH lower than 4.5, a little lower in soil pH and soil fertility were observed.

The total number of soil microbes in the areas with rainfall pH lower than 4.5 is only 7.2-36.5% of that with rainfall pH higher than 4.5. And in the former soil the ammonification, nitrification and nitrogen-fixation become worse.

In Nanan district of Chongqing City with the rainfall pH lower than 4.5, the productivity of *Pinus massoniana* stands in decline approximately by 50%.

The die-back of large scale *P. massoniana* forest in Nanan district is because that acid rain injuries the tree leaves of *P. massoniana* and make the tree vigor weakly, and destructive pests such as *Blastophogus poniperda* and *Monochamus* alternatus should occur.

REFERENCES

Ulrich, B., Soil and Science, 1980, 130:193

Yang Jinquan and Ji Lanzhu, Acid Rain and Agriculture, 1989, 162

Zhao Dianwu, Outline of acid rain research in China and outside, Beijing: Science Press, 1981:139