模拟酸雨对树木叶片的伤害和树木抗性的研究

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近年来，我国不少地方发现酸性降水，特别是西南重庆、贵阳地区尤为严重[1]．国内外一些文献曾报道：酸性降水能影响生物的生长发育，降低生物产品的产量和质量，甚至引起鱼类和森林的死亡，破坏生态平衡[2,4]．

森林是陆地生态系统中最重要的组成部分，是人类生存和生产的必不可少的物质条件．研究酸雨对森林树木的影响和危害，是保护环境和发展林业生产的一项重要内容．为此，我们在非酸雨区的湖南会同森林生态实验站开展了模拟酸雨喷树试验．本文是试验观察的阶段研究报告，主要是描述了各种树木叶片受酸雨伤害的症状，比较了它们的抵抗酸雨危害的能力，以便为今后进一步研究和防治提供依据．

一、试验材料和方法

选取了亚热带最常见的一些乔灌木树种作为供试材料，包括常绿和落叶的，有用材、经济和绿化观赏树种．供试树种名称详见后面附表．

根据重庆等地酸雨监测分析资料，按 SO_4^{2-}、NO_3^- 4:1 配制 pH 2.0、2.5、3.0、3.5、4.0、4.5 和自然清水（pH 6.5）作对照共 7 个处理，用喷雾器把酸雨喷洒在正常生长树木的枝叶上．除雨天外每天喷洒一次，其喷洒量大致等于重庆历年各月平均降雨量．随时根据叶子发生的变化进行记载，生长期结束时用叶面积测定仪计算叶伤害面积．模拟酸雨 pH 值是用日产 pH-51 型酸度计测定．

二、树木叶片受害症状

试验表明，不同树种叶子对模拟酸雨的敏感性不同．当酸雨酸度超过叶子能忍耐的限度时，常常会出现以下四种伤害症状：

1. 退绿现象　许多树种经模拟酸雨喷洒后，叶子首先出现明显的失绿．叶色变成浅绿色或黄绿色．这是由于叶组织细胞叶绿素含量降低或分解所致．据冯宗炜等在重庆重酸雨区和轻酸雨区分别采集的马尾松针叶分析表明，前者叶绿素含量为 0.9260 mg/g，大大低于后者的 1.6131mg/g[3]．退绿现象出现的早晚和持续时间的长短视树种不同而不同．有的树种酸雨喷洒 3—4 天后，叶片就开始退绿，有的需要 7—8 天或更长时间．退绿部位多在叶上部或叶缘处．一般来说，退绿现象是慢性和轻微的受害症状，一旦停止喷洒酸雨，慢慢还可以恢复．在我们试验和观察的树种中，明显出现退绿的有：苦楝、女真、香椿、马桂木、枇杷、垂柳、檫木、川桂、落羽杉、侧柏和华山松．

2. 坏死斑，酸度较大的模拟酸雨通过气孔进入叶片组织后，能引起细胞中毒死亡，使叶面留下坏死斑点．和退绿现象一样，多数坏死伤斑出现在叶上部和叶边缘；掌状叶先在缺刻处出现．我们观察分析认为这是因为

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这些部位或水膜张力，或叶面粗糙不平之故，容易使酸性雨水蓄集，长时间遭受酸雨浸泡，造成细胞中毒死亡．少数叶子坏死斑出现在叶基部，这是由于此类叶子着生与枝条夹角小，酸雨往叶基部流淌停留之故．坏死斑出现部位很重要，它是区分和识别酸雨和二氧化硫气体危害最基本和有效的方法．二氧化硫伤斑为点状、块状、片状，视植物种类和浓度而异，一般分布在脉间[5]．随着喷洒时间持续延长，坏死斑逐渐增多变大，由叶尖、叶缘向下向内发展，渐渐连成片，有的还穿孔破漏，最后导致叶子枯萎死亡．据观察，不论什么树种，一般都是幼嫩叶坏死斑出现的早，受害重．不同树种坏死斑的颜色也常表现出一些差异．

3. 早落叶，有些树种经模拟酸雨喷洒后，叶柄基部细胞分离，形成离层，叶柄支持力减弱，在重力和风力作用下，叶子很容易过早脱落，影响树木正常生长．在我们试验的树种中，最易表现过早落叶的有：女真、榉树、苦楝、木荷、香椿、枣树、石榴和水杉．

4. 失水萎蔫，模拟酸雨喷洒树木，还能使叶子失水萎蔫，造成叶缘向内卷曲或叶子皱折，失去原有光泽．这种现象多发生在叶表皮薄、具绒毛无腊质层的树木叶子上，如构树、杜仲、柿树等．

三、影响树叶受害的因素

1. 降雨酸度和喷洒时间

降雨酸度和喷洒延续时间不同，树叶受害轻重程度也大不相同．现以榉树、水杉为例说明．从表1中看到榉树和水杉随pH的降低和喷洒时间的延续，树叶伤害情况随之加重和发展．如酸雨pH在4.0以上时，榉树、水杉虽经近半年模拟酸雨喷洒处理，仍不见有伤害症状．pH降到3.5时，喷洒10天后在水杉个别叶子上可见到轻微症状．但pH降到2.5以下，只喷洒几天就可在两树种叶片上出现明显伤斑；喷洒天数延长，叶子受害也日趋严重，pH 2.5的酸雨喷洒头几天，榉树和水杉叶子只有轻微症状，而喷洒一个月后，大部分叶子受害、枯萎，直至枯死脱落．

表1　不同酸度、喷洒天数的树叶伤害状况

树种	喷洒天数	pH				
		2.0	2.5	3.0	3.5	4.0
水杉	5天以下	一部分针叶退绿变黄，叶尖开始枯死	少数叶尖变黄	—	—	—
	6—10天	叶尖枯死增多并向下发展，开始出现落叶	针叶尖开始枯死，约占2%	少数叶尖见黄	—	—
	11—20天	30～40%针叶枯死，落叶严重	10%针叶上部枯死，针尖头部分变黄枯死	针尖变黄增多尖部开始枯死	个别针叶叶尖变黄	—
	21—30天	70—80%针叶枯死	30%针叶上部枯死，落叶现象严重	针尖枯死增多	少数针叶尖部变黄	—
	30天以上	针叶全枯死，并大部分脱落	大量针叶枯死，大量落叶	叶尖枯死向下延长少数叶脱落	叶尖变黄增多	—
榉树	5天以下	叶面退绿，出现小坏死斑点	叶面见少量小坏死斑点	—	—	—
	6—10天	坏死斑点变大、增多，受害叶面积占总喷洒叶面积5%	小坏死斑增多	个别叶缘变黄	—	—
	11—20天	受害叶面积达20%左右，叶缘向内卷曲	坏死斑变大，伤害面积占总喷洒叶面的5%	出现少量小坏死斑点	—	—
	21—30天	叶缘枯萎，严重卷曲	坏死斑连成小片，受伤害面积达10%	坏死斑变大	个别叶见小黄斑	—
	31天以上	叶大部分枯萎，脱落	受害面积扩大，叶缘枯萎向内卷曲	坏死斑继续缓慢变大	少数叶面有小黄斑	—

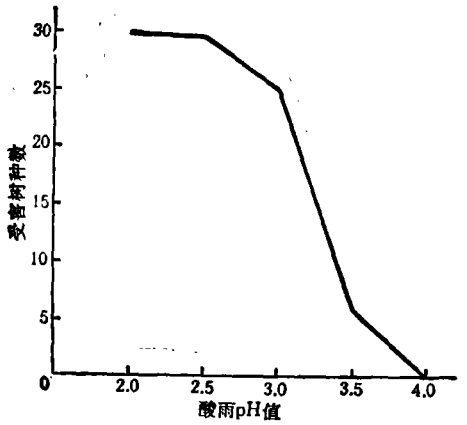

图 1　受害树种数与酸度的关系

其它树种也是这样，如图 1 所示．在供试的树种中，几乎全部受 pH 2.5 以下酸雨危害，pH 升到 3.5 时，受害树种大大减少，只占总数的 20% 以下，而 pH 高于 3.5 以上时，所有树木无一受害．

2. 光照和温度

树叶伤害状况除受雨水酸度和喷洒时间影响外，还随天气温度和光照强度变化而变化．据我们观察，喷洒酸雨后，遇较强光照和较高温度时，能促进和加重叶子的伤害．例如我们对马尾松等十几个针阔叶树种的观察，傍晚喷洒 pH 2.5、3.5 模拟酸雨，连续五个月后，除少数马尾松针叶有退绿现象外，其余树种都不见有任何伤害症状．而在白天和较高的气温下，喷洒等浓度和等量的酸雨，少则几天，多则十几天，树木叶子就陆续出现退绿、变黄和坏死斑等症状．为什么同样树种会出现这种差别呢？我们分析认为，这可能因为傍晚光照弱、气温低，叶子气孔开张度小，同化、蒸腾等生理生化活动低，有害的酸性雨水进入少的缘故．相反，白天光照要相对强得多，气温也较高，树木生命活动旺盛，蒸腾强度大，叶面上停留的酸雨会较快地浓缩并进入叶子细胞里，引起或加重了对叶子的毒害．又如我们在 4 月份做的模拟酸雨喷树试验，其叶子受害症状远比 8、9 月份做的试验出现的晚和轻．按上述情况推测，下过酸雨，天气很快转晴出太阳，要比连续降酸雨和阴雨天危害大．此外光照条件的变化还能引起伤斑色泽的变化．例如榉树、柳杉等一些树种，晴天时喷洒出现的伤斑多呈现棕黄色，而在连阴天是土黄色；香椿、喜树等树种在晴天喷洒后常出现黄褐色伤斑，而阴天为褐色．

四、树木叶片的抗性

由于各树种叶子形态构造和可湿性不同，叶子抵抗酸性降水危害的能力即抗性也有差异．例如降雨酸度、喷洒处理时间都在相同水平上，有些树种叶子对酸性雨水反应很敏感，很快就出现伤害症状，伤害程度也重；而有些树种反应较迟钝，不仅症状出现的时间晚，受害程度轻，而且往往是在较高一级酸度水平上才出现伤害症状．为此，我们根据叶子伤害症状出现早晚、叶受害面积大小和伤斑出现的酸度临界值高低对 30 种树木进行了综合比较，并划分为强、中、弱三类列于表 2．从表 2 看出，多数树种抗性属中等，抗性强的树种中基本上都是常绿阔叶树种．研究和比较树种叶子抗酸性对进一步揭示其受害机理，提出酸雨危害的防治对策有重要的现实意义．

五、小　结

1. 酸性降雨对树木叶子有直接伤害作用，常常会使叶子出现退绿、坏死斑、失水萎蔫和过早落叶等症状，影响树木正常生长．

2. 叶子伤害程度与模拟酸雨的酸度、喷洒日期长短和光温条件有很大关系．酸度高，喷洒延续时间长，叶子受害重，呈正相关关系，雨过天晴要比阴雨天更易受害．

3. 树种抗酸性能不同．有些树种对酸雨抗性强，只在 pH 2.5 以下才受害；有些树种对酸雨较敏感，pH 3.5 就能表现出伤害症

表 2　不同树种叶子抗酸性的比较

抗性等级	树种	症状出现需要的时间 (d)*					叶子受伤害面积(%)*					症状出现酸度临界值 (pH)				
		5 以下	6—10	11—20	21—30	31以上	1 以下	1—5	6—10	11—20	21以上	2.0	2.5	3.0	3.5	4.0
强	油　茶					✓						✓				
	夹竹桃					✓	✓						✓			
	桂　花					✓	✓						✓			
	柑　桔					✓	✓						✓			
	苦　楮				✓		✓						✓			
	火力楠					✓		✓					✓			
中	垂　柳		✓					✓						✓		
	油　桐		✓					✓						✓		
	香　樟		✓					✓						✓		
	构　树	✓						✓						✓		
	马桂木	✓						✓						✓		
	杉　木		✓						✓					✓		
	马尾松		✓						✓					✓		
	泡　桐		✓						✓					✓		
	川　桂		✓						✓					✓		
	毛　竹	✓							✓					✓		
	侧　柏	✓								✓				✓		
	圆　柏	✓								✓				✓		
	苦　楝	✓								✓				✓		
	喜　树	✓								✓				✓		
	柳　杉	✓								✓				✓		
	青　冈	✓								✓				✓		
	女　真	✓								✓				✓		
	香　椿	✓								✓				✓		
弱	刺　桐	✓							✓						✓	
	檫　木	✓								✓					✓	
	法　桐	✓								✓					✓	
	水　杉	✓								✓					✓	
	楠　木	✓								✓					✓	
	木　荷	✓								✓					✓	

* 喷洒 pH 2.5 模拟酸雨，时间六个月.

状．相对来说常绿阔叶树种要比落叶阔叶和针叶树抗性强些．

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附表　树种的拉丁学名

1. 马尾松 *Pinus massoniana*
2. 华山松 *P. armandi*
3. 杉木 *Cunninghamia lanceolata*
4. 柳杉 *Cryptomeria fortunei*
5. 落羽杉 *Taxodium distichum*
6. 水杉 *Metasequoia glyptostroboides*
7. 檫木 *Pseudosassafras tzumu*
8. 楠木 *Phoebe bournei*

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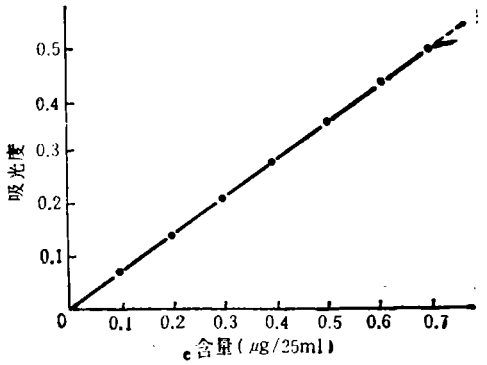

图3 工作曲线

色测定之.

2. 样品的测定

我们对三个水样进行了测定. 结果见表5.

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(收稿日期: 1987 年 8 月 18 日)

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9. 香樟 *Cinnamomum camphora*
10. 川桂 *Cinnamomum wilsonii*
11. 油茶 *Camellia cleosa*
12. 木荷 *Schima confertiflora*
13. 枇杷 *Eriobtrya japonica*
14. 苦槠 *Castanopsis sclerophylla*
15. 青岗 *Cyclobalanopsis glauca*
16. 枣树 *Zizyphus jujuba*
17. 柿树 *Diospyros kaki*
18. 桂花 *Osmanthus fragrana*
19. 女真 *Ligustrum lucidum*
20. 夹竹桃 *Nerium indicum*
21. 油桐 *Aleurites montana*
22. 杜仲 *Eucommia ulmoides*
23. 喜树 *Camptotheca acuminata*
24. 毛竹 *Phyllostachys pubescens*
25. 苦楝 *Melia azedarach*
26. 香椿 *Toona sinensis*
27. 侧柏 *Platycladus orientalis*
28. 圆柏 *Cupressus duclouxiana*
29. 垂柳 *Salix babylonica*
30. 泡桐 *Paulownia tomentosa*
31. 火力楠 *Michelia macclurei*
32. 马桂木 *Liriodendron chinense*
33. 柑桔 *Citrus reticulata*
34. 构树 *Broussonetia papyrifera*
35. 刺桐 *Erythrina indica*
36. 石榴 *Punica granatum*
37. 法桐 *Platanus acerifolia*

(收稿日期: 1987 年 8 月 25 日)

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(收稿日期: 1987 年 5 月 12 日)

The experimantal results show that under the conditions of carbon monoxide below 200 ppm within 16 hours of chambering time, there is no obvious injury on leaves of woody plants. But the ratio of photosynthesis is varied from different biocharacters of woody plants. When 100 ppm CO pollution, the relation of ratio of photosynthesis and the chambering time is exponential function, and $P_t/P_o=5.75$ exp (0.001t) to *Fraxinus chinensis* and $P_t/P_o=7.04$ exp (1.9 10t) to *Puruns davidiana*. (See pp. 27—29)

Injuries to Tree Leaves by Simulated Acid Rain and Resistant Nature of the Trees

Zhang Jiawu, Feng Zongwei et al. (Institute of Applied Ecology, Academia Sinica, Shenyang)

The paper gives a general description of the effects of simulated acid rain on tree leaves. The experiments have been done in Hunan Experimental Station of Forest Ecology. After the simulated acid rain were sprayed upon tree leaves, there appeared some symptoms: discoloration of greens, tissue necrosis, dewatering and early withering. And injurious extents on leaves were fundamentally due to the rain acidity, duration of spraying and conditions of sunlight and temperature. However, because of different tissue structures of the tree leaves, their resistant capacity were varied. (See pp. 30—33)

Toxicity of Floatation Agent S-808 of Phosphatic Ore and Mineral Wastewater to Fishes and Embryos

Zhang Fuying and Yin Yiwa (Institute of Hydrobiology, Academia Sinica, Wuhan)

Toxic test determining larvae of grass carp and guppy for 96-hour LC_{50} was 18 mg/L and 35 mg/L respectively, 10-day LC_{50} of grass carp embryo was 3.69 mg/L. For fish embryos in 1 mg/L, there appeared deformation. Deformation percentage and concentration were of positive correlation. In fish toxic test, deformed index was more sensitive than dead index. The toxic test showed that, according to classfication standard, S-808 was a "poisonous grade" of fish toxicity. S-808 in floating process was treated with physiochemical method and toxicity of dressing mineral wastewater decreased, so the value of LC_{50} in the test could not be determined, and there didn't appear deformation of fishes. (See pp. 34—37)

Tests on the Residues of 5% *Bestox* in Cotton Fields

Zhou Hou'an et al. (Institute of Zoology, Academia Sinica, Beijing)

Experiments on the residual kinetics of *Bestox* emulsion (5%) were carried out in the cotton fields. The results showed that the half-life of *Bostox* emulsion (5%) was 23 to 25 days in soil, and 3 to 5 days on leaves. The residues were not observed in cotton seeds even by using dosages 1.5 to 2.0 times of the conventional ones. *Bestox* is low toxic to mammals and there is no systemic action. The results can give a reliable basis for rationalizing the use of *Bestox* in the cotton field and limting MRL value in cotton seeds. (See pp. 38—41)

Ascertainment of Main Factors for Biological Denitrification System Using Orthogonal Test

Du Shelin et al. (Institute of Environmental Pretection, Shanghai Petrochemical Complex, Shanghai)

Hydraulic retention time (HRT), ratio of the volume of anaerobic tank to the volume of aerobic tank (I: R) and reflux ratio (r) have been established as three main factors in a biological denitrification system by using mathematically the orthogonal test method of Lg (3^4). Thus, in such a system for the treatment of a combined wastewater containing nitriles and sodium thiocyanate in high concentration, it was determined that HRT, I: R and r are 24 hours, 1:3 and 5.5 respectively, and they would be more favourable process parameters. In addition, an analysis of the whole system is made in this paper. (See pp. 42—46)

Removal of Mercury from Wastewater with Maize-Starch Dregs

Liu Manying and Kang Weijun (Hobei Medical College, Shijiazhuang, Hobei Province)

This paper deals with removal of mercury from wastewater by using maize-starch dregs. The experimental result shows that the rate of removal is 99.9%, and Saturated capacity is 45 mg/g. The method seems to be a cheap and efficient one for treating mercury-contained liquids. (See pp. 47—48)

Method for Determination of Twelve Phthalate Esters in Natural Water

Kang Junxing (Research Center for Eco-Environmental Sciences, Academia Sinica, Beijing) *Hing-biu Lee* (National Water Research Institute, Canada Center for Inland Waters)

An Analytical method was developed and validated, which permits determination parts per billion levels of twelve phthalate esters in natural water. Water sample was extracted with methylene chloride, and the extract was cleaned up by using silica gel liquid chromatographic column prior to determination of the phthalate esters by capillary column ECD-GC, (See pp. 49—54)

Spectrophotometric Determination of Trace Beryllium in Water and Wastewater after Adsorption concentration by Activated Carbon

Qiu Xingchu, Cheng Jun and Zhu Yingquan Ganzhou Institute of Environmental Science, Ganzhou, Jiangxi Province)

In this paper the optimum conditions of colour reaction of Be-CAS-CPC and adsorption concentration by activated carbon has been studied. In the buffer solution of urotropine pH 5.0. The adsorption maximum of the complex is near 605 nm. Beer's law is obeyed for 0-0.70 g *Be*/25ml (2cm cell) ranges. It is applied to determine the trace Be in Water by spectrophotometric method, which is simple exact and rapid. (See pp. 55—58)