

酸雨和 SO₂ 复合污染对几种农作物的影响*

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摘要 采用模拟酸雨喷雾和 SO₂ 开顶式熏气, 研究了酸雨和 SO₂ 复合作用对西红柿、胡萝卜和棉花等农作物产量的影响及其机理。通过模拟试验, 发现酸雨和 SO₂ 使农作物生长受阻, 产量降低, 其二者的复合作用明显高于单一因素的作用, 但其交互作用不显著。并通过模拟相关方程计算出农作物产量损失的污染物阈值。

关键词 酸雨, SO₂, 复合污染, 农作物。

本研究的目的是通过模拟试验, 获得农作物产量损失与污染物剂量之间的关系, 估算酸雨和 SO₂ 复合污染对几种农作物产量影响及其机理。

1 试验材料和方法

1.1 模拟酸雨

以我国酸性降水较为严重的浙江地区天然降水的离子构成(表1)、降水总量和降水频率为依据(表2), 用蒸馏水配制模拟酸雨母液, 然后根据 S/N 比, 配制混合酸母液, 混合酸的体积比为 H₂SO₄/HNO₃=3.316, 以此混合酸调节酸雨母液的酸度, 配制成试验用模拟酸雨, 其 pH 值分别为 5.6(对照)、4.6、4.1、3.6 和 2.8, 用喷雾器浇灌模拟酸雨, 每次降水持续时间为 11—15 min。

表1 模拟酸性降水的离子构成

离子构成	SO ₄ ²⁻	NO ₃ ⁻	NH ₄ ⁺	Ca ²⁺	Mg ²⁺
离子浓度(μeq/L)	112.3	13.5	68.2	59.9	7.6

表2 模拟酸性降水总量及降水频率

月 份	5	6	7	8	9	10
降水总量(mm)	179.9	196.2	126.5	136.5	177.6	77.9
降水频率(次)	16.8	14.9	12.3	12.5	13.3	9.7

1.2 SO₂ 熏气装置

采用开顶式野外动态模拟熏气装置, 每种

作物分为 5 个熏气罩, 其 SO₂ 浓度分别为 0(对照), 0.143、0.286、0.429 和 0.714 mg/m³, 用美国 UV-480 紫外荧光分析仪随时监测罩内 SO₂ 浓度, 以确保罩内浓度稳定。开始熏气后, 每周熏气 6 d, 每天从上午 9:00 至下午 4:00, 熏气 7 h。

1.3 植物暴露

采用盆栽方式, 定苗以后开始熏气、浇酸雨, 每个罩内分 5 组, 分别用不同 pH 值的模拟酸雨浇灌, 每组 4—6 盆做为重复, 熏气、浇酸雨同时进行, 直至植物成熟。

1.4 生理代谢功能测定

- (1) 叶绿素 丙酮提取, UV-260 测定。
- (2) 膜透性 HG-3 型火焰光度计测定 K⁺ 浓度。
- (3) 丙二醛 三氯醋酸法, UV-260 测定。
- (4) 产量 称重法。

2 试验结果

2.1 伤害症状

3 种作物在试验前期均未表现出伤害症状, 随着酸雨浇灌和 SO₂ 熏气的不断进行, 在第 5 周时西红柿和胡萝卜的叶片逐渐出现伤害症状。对于西红柿, SO₂ 浓度为 0.286 mg/m³ 的罩子

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内 pH2.8、pH3.6 酸雨处理有明显伤害症状,表现为叶脉间不规则的组织坏死;SO₂ 浓度 0.429 mg/m³ 罩内, pH2.8、3.6 和 4.1 时出现伤害症状;SO₂ 浓度为 0.714 mg/m³ 的罩内,所有处理都出现伤害症状。到了后期甚至整株西红柿萎蔫,叶片小,叶色浅,而且随着 pH 值的降低,伤害症状加重,并严重影响果实生长。

胡萝卜的伤害症状不如西红柿明显,第 5 周开始某些处理表现出伤害症状,主要是在 SO₂ 0.714 mg/m³ 的熏气罩内,各 pH 值酸雨处理的叶片均受到可见伤害,且随着 pH 值的降低伤害更加明显,叶片先变为黄褐色,后从叶缘开始干枯。在 SO₂ 0.429 mg/m³ 的熏气罩内也有轻微伤害症状,其它处理均无明显症状。由此可见,对胡萝卜叶片的伤害作用。SO₂ 表现的更为明显,而酸雨则加重了伤害作用;这是 SO₂ 和酸雨复合作用的结果。

3 种作物相比,棉花的伤害症状最不明显,在第 6 周开始某些处理表现出伤害症状,主要是在 SO₂ 为 0.714 mg/m³ 的熏气罩内,叶片变黄,伤害严重的从叶尖叶缘开始干枯,叶片较对照小,在 SO₂ 为 0.429 mg/m³ 的熏气罩内也有轻微的伤害症状。

2.2 对光合色素的影响

以西红柿和棉花为例,试验中期采集同位叶片测定其叶绿素含量,结果见表 3、表 4。

表 3 西红柿苗期叶片中叶绿素含量(mg/g)

pH	SO ₂ (mg/m ³)				
	0	0.143	0.286	0.429	0.714
5.6	3.049	2.060	2.521	2.034	1.863
4.6	2.657	2.010	1.890	2.221	1.797
4.1	2.169	2.362	2.094	2.361	1.738
3.6	2.248	2.339	1.635	1.782	1.818
2.8	1.798	1.681	1.711	1.879	1.693

表 4 棉花苗期叶片中叶绿素含量(mg/g)

pH	SO ₂ (mg/m ³)				
	0	0.143	0.286	0.429	0.714
5.6	1.973	1.561	1.590	1.550	1.051
4.6	1.942	1.569	1.410	1.564	1.040
4.1	1.902	1.344	1.295	1.309	1.015
3.6	1.732	1.304	1.251	0.917	0.934
2.8	1.626	0.869	0.823	0.639	0.476

由此可见酸雨和 SO₂ 的复合作用将导致光合作用强度降低。

2.3 对细胞膜透性的影响

植物受到污染后,细胞膜是污染物首先作用的部位,膜受到伤害后,细胞内的 K⁺ 大量外渗,通过测量细胞外渗液的 K⁺ 浓度即可知膜受损的程度。

以西红柿和胡萝卜为例,试验中期取同位新鲜叶片,用 HG-3 型火焰光度计测定 K⁺ 渗透率,结果见表 5 和图 1。

表 5 西红柿叶片质膜差别透性[K⁺(%)]

pH	SO ₂ (mg/m ³)				
	0	0.143	0.286	0.429	0.714
5.6	6.48	6.60	8.84	6.46	6.29
4.6	6.87	5.16	9.02	10.93	8.96
4.1	7.13	6.90	10.70	10.76	10.38
3.6	7.78	11.37	10.83	10.19	13.92
2.8	8.40	8.88	11.66	17.43	16.11

随着 SO₂ 浓度和模拟酸雨酸度的增加, K⁺ 渗透率呈增加趋势,尤其是 pH2.8 的酸雨, SO₂ 浓度 0.286 mg/m³ 以上的处理,渗透率增加更显著,说明 SO₂ 和酸雨的复合作用破坏了质膜的结构和功能,必然会使代谢功能紊乱。

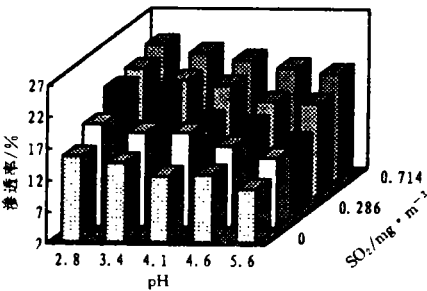


图 1 酸性降水和 SO₂ 对胡萝卜叶片细胞膜透性的复合影响

2.4 对丙二醛含量的影响

丙二醛是叶片细胞代谢过程中的脂类过氧化产物,丙二醛的增加可作为叶片衰老程度的指标,植物衰老进程的改变在一定程度上表示了植物受害的轻重。

以西红柿和胡萝卜为例,熏气、浇酸雨 4 周

后，分别取同位、同叶龄的新鲜西红柿、胡萝卜叶片，用三氯乙酸法测定叶片中丙二醛的含量，结果见表 6 和图 2。

表 6 西红柿叶片中丙二醛的含量(μmol/g)

pH	SO ₂ (mg/m ³)				
	0	0.143	0.286	0.429	0.714
5.6	8.77	13.42	12.39	13.16	11.10
4.6	12.90	14.49	13.16	14.71	11.10
4.1	14.97	14.45	13.68	15.23	15.48
3.6	13.42	13.16	12.65	14.19	15.48
2.8	15.48	14.97	16.77	15.48	18.32

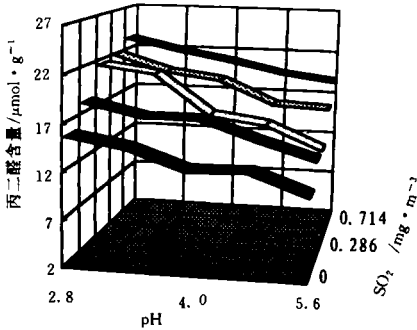


图 2 酸性降水和 SO₂ 对胡萝卜叶片
丙二醛含量的复合影响

以 pH5.6, SO₂ 为 0 mg/m³ 的处理作为对照，所有处理的叶片丙二醛含量都比对照明显增加，而且酸雨 pH 值越低，SO₂ 浓度越大，则叶片中丙二醛含量越高。

2.5 对产量的影响

对产量影响结果见表 7—9。

2.5.1 西红柿减产量的对比

各处理与对照相比的减产幅度见表 10。

2.5.2 胡萝卜减产量的对比

表 7 酸雨 SO₂ 复合作用对西红柿
产量的影响(g/株鲜重)

pH	SO ₂ (mg/m ³)				
	0	0.143	0.286	0.429	0.714
5.6	94.8	88.0 ¹⁾	81.9 ²⁾	73.4 ²⁾	70.6 ²⁾
4.6	90.4	86.2	80.7	74.1	69.0
4.1	88.1 ¹⁾	85.8	80.5	73.9	67.3
3.6	84.4 ²⁾	84.2	79.5	71.7	67.2
2.8	84.9 ²⁾	81.9	74.4	70.9	59.2

1) af<0.05 2) af<0.01

表 8 收获后胡萝卜单体鲜重(g/株)

pH	SO ₂ (mg/m ³)				
	0	0.143	0.286	0.429	0.714
5.6	112.1	95.9	82.0 ¹⁾	78.8 ¹⁾	69.5 ¹⁾
4.6	98.6	87.4	81.2	72.3	64.5
4.1	90.4	84.2	83.1	70.4	65.0
3.6	88.1	83.2	77.2	67.5	64.6
2.8	85.8	78.2	73.6	65.8	60.6

1) af<0.01

表 9 棉花单株皮棉干重(g/株)

pH	SO ₂ (mg/m ³)				
	0	0.143	0.286	0.429	0.714
5.6	32.9	27.0	25.9	22.9	20.4
4.6	31.1	25.8	23.7	21.9	19.2
4.1	28.7	24.5	20.9	17.7	15.0
3.6	28.1	19.7	19.2	16.2	12.0
2.8	21.7	16.7	16.6	13.2	10.9

表 10 西红柿各处理与对照相比减产量(%)

pH	SO ₂ (mg/m ³)				
	0	0.143	0.286	0.429	0.714
5.6	0	7.71	13.61	22.57	25.53
4.6	4.64	9.07	14.87	21.84	27.22
4.1	7.07	9.49	15.08	22.05	29.01
3.6	10.97	11.18	16.14	24.30	29.11
2.8	10.44	13.61	21.52	25.21	37.55

各处理与对照相比的减产幅度见表 11。

表 11 胡萝卜块根产量与对照相比减产量(%)

pH	SO ₂ (mg/m ³)				
	0	0.143	0.286	0.429	0.714
5.6	0	14.45	26.85	29.71	38.00
4.6	12.04	22.03	27.56	35.50	42.46
4.1	19.36	24.89	25.87	37.20	42.02
3.6	21.41	25.78	31.13	39.79	42.37
2.8	23.46	30.24	34.34	41.30	45.94

2.5.3 棉花减产量的对比

各处理与对照相比减产幅度见表 12。

表 12 各处理棉花产量与对照相比减产量(%)

pH	SO ₂ (mg/m ³)				
	0	0.143	0.286	0.429	0.714
5.6	0	17.93	21.28	30.40	37.99
4.6	4.86	21.58	27.96	33.43	41.64
4.1	12.76	25.53	36.47	46.20	54.41
3.6	14.59	40.12	41.34	50.76	63.52
2.8	34.04	49.24	49.54	59.85	66.87

由表 12 可以看出, 单一酸雨 pH2.8 的处理棉花减产 34.04%, 单一 SO₂ 0.714 mg/m³ 的处理减产 37.99%, 二者复合作用减产 66.87%, 复合作用的结果几乎是二因素结果之和。

2.5.4 相关分析

通过线性相关分析, 分别计算出西红柿、胡萝卜、棉花产量损失与 SO₂ 浓度、酸雨 pH 值的相关关系方程式见表 13。

表 13 农作物产量与 SO₂ 浓度、pH 值的相关关系

作物名称	相 关 方 程	R	n
西红柿	$Y_{\text{产量损失(g)}} = -3.02 \times 10^{-7} - 37.42X_{\text{SO}_2(\text{mg/m}^3)}$	-0.96	5
西红柿	$Y_{\text{产量损失(g)}} = -22.55 + 4.03X_{\text{pH}}$	0.95	5
胡萝卜	$Y_{\text{产量损失(g)}} = 9.67 \times 10^{-6} - 53.99X_{\text{SO}_2(\text{mg/m}^3)}$	-0.94	5
胡萝卜	$Y_{\text{产量损失(g)}} = -48.77 + 8.71X_{\text{pH}}$	0.96	5
棉花	$Y_{\text{产量损失(g)}} = -7.15 \times 10^{-6} - 52.74X_{\text{SO}_2(\text{mg/m}^3)}$	-0.95	5
棉花	$Y_{\text{产量损失(g)}} = -63.17 + 11.28X_{\text{pH}}$	0.94	5

可见, 西红柿、胡萝卜、棉花产量损失与 SO₂ 浓度、酸雨 pH 值均具有很好的相关性, 相关系数均达到 0.94 以上。

酸性降水和 SO₂ 复合污染对农作物产量的直接影响阈值以减产 5% 来确定, 根据试验结果, 用二元线性回归方法建立供试农作物产量与 SO₂ 暴露浓度和酸性降水酸度之间回归方程, 获得 3 种农作物减产 5% 时的降水 pH 值和 SO₂ 浓度, 作为其产量的影响阈值, 见表 14。

表 14 酸性降水和 SO₂ 复合污染对产量的影响阈值

农 作 物	酸性降水 pH	SO ₂ 浓度(mg/m ³)
西红柿	4.63	0.079
胡萝卜	4.46	0.120
棉花	4.63	0.176

由 3 种作物的试验结果可以看出, 酸雨和 SO₂ 这 2 种因素对农作物的生理指标具有不利影响。国外也有一些报道指出了酸雨加 SO₂ 对植物营养生长的影响^[1,2], 本研究结果与这些结果基本一致。酸雨和 SO₂ 的复合作用影响了植物的正常生长, 进而必然导致产量的降低, 而二者复合作用的影响大于单一因素的影响, 这是二因素叠加的结果

3 小结

(1) 酸雨和 SO₂ 的复合影响对植物生理代

谢功能具有不利的影响, 使叶片中叶绿素含量降低, 细胞膜透性增加, 使细胞代谢过程中的脂类过氧化产物丙二醛含量增加, 加速了植株的衰老进程。

(2) 在复合作用下, 使西红柿减产 5% 的 SO₂ 浓度为 0.079 mg/m³, 酸雨 pH 值为 4.63; 使胡萝卜减产 5% 的 SO₂ 浓度为 0.120 mg/m³, 酸雨 pH 值为 4.46; 使棉花减产 5% 的 SO₂ 浓度为 0.176 mg/m³, 酸雨 pH 值为 4.63。随着 SO₂ 浓度和酸雨的增加, 农作物减产幅度增大。

(3) 复合作用对产量的影响明显大于单一因素的影响, 导致产量显著降低, 这是二因素叠加的结果, 经统计检验, 二者的交互作用不显著。

(4) 西红柿、胡萝卜和棉花的产量损失与 SO₂ 浓度、酸雨 pH 值均具有很好的相关性, 根据其相关方程可以计算出酸性降水和 SO₂ 及复合污染对产量的影响阈值。

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A Research on the Ecological Effect of the Soil Animals Community by the Heavy Metal Pollution. Deng Jifu et al. (Zhuzhou Institute of Environ. Sci., Zhuzhou 412000); *Chin. J. Environ. Sci.*, 17(2), 1996, pp. 1-5

The research results show that there are 31 soil animal species in the polluted area, in which *Acarina* and *Collembola* are dominant population. The species and quantities of the soil animals are decreased with the aggravation of pollution, which can be found mainly from the growth and decline of the dominant population and decrease and disappearance of the polluted sensitive species. The big animals, such as earthworm and spider, have a strong ability to acculate heavy metal elements. The content of Cd, Pb, As in these animal's body relates proportionally to the metals in soil, but the centipede's ability in accumulating the heavy metal elements is obviously weaken.

Key words: heavy metal pollution, soil animal, ecological distribution, accumulation.

Microbial Degradation of Regenerated Cellulose Film. Zheng Lianshuang et al. (Dept. of Environ. Sci. Wuhan University, Wuhan 430072); *Chin. J. Environ. Sci.*, 17(2), 1996, pp. 6-8

The biodegradability of regenerated cellulose film was tested by soil-burial test in field, culture-dish test and CO₂ evolution test respectively. The results of test are as follows: (1) The mass loss of the film increased with the extension of soil-burial test; (2) Test strains had different abilities to degrade the film, and the order of their abilities was strain T-311 > strain A-305 > strain P-307; the biodegradation rate of the film might exceed 70% during 42 days after the film had been buried or inoculated with strain T-311; (4) In the process of biodegradation, mass loss, visible growth of test strains on the film and CO₂ evolution are both relative and different indexes for assessing biodegradation degrees of the film.

Key words: regenerated cellulose film, biodegradability, CO₂ evolution.

Adsorption Behavior of Ammonium Ion in Saturated Silty Sand and Sandy Loam. Zhu Wapeng et al. (Dept. of Environ. Eng., Tsinghua University, Beijing 100084); *Chin. J. Environ. Sci.*, 17(2), 1996, pp. 9-11

The adsorption characteristics of ammonium ion in saturated silty sand and sandy loam were studied by means of dynamic soil column experiments. The transportation of ammonium ion in soil were modelled with a combined equilibrium and kinetic adsorption model (Cameron's model). The coefficients (K_1 , K_2 and K_3) under different soil and NH₄⁺ concentration in water were obtained. The distribution curves of ammonium ion in soil were drawn. The results indicate that the longitudinal dispersion coefficients (D) in silty sand and sandy loam are 0.175 cm²/min and 0.0093 cm²/min respectively. The dynamic adsorption capacity of silty sand are 0.156 mg/g when concentration of NH₄⁺ in water is 13.7 mg/L and

0.400 mg/g when concentration of NH₄⁺ in water is 41.0 mg/L; the dynamic adsorption capacity of sandy loam is 1.33 mg/g when concentration of NH₄⁺ in water is 51.0 mg/L. Above results can be used to determine the suitable thickness of protective soil in land treatment system of wastewater.

Key words: ammonium ion, saturated silty sand, saturated sandy loam, transportation, dynamic soil column experiment.

Study on the Adsorption Mechanism of Mercury (I) with Prime Amine N₁₉₂₃ Levextrel Resin. Cheng Deping and Xia Shijun (Dept. of Chem., Hangzhou University, Hangzhou 310028); *Chin. J. Environ. Sci.*, 17(2), 1996, pp. 12-15

The adsorption mechanisms of mercury (I) with prime amine (N₁₉₂₃) levextrel resin were studied when it doesn't form salt or it is in salt forming condition. The adsorption compounds have been determined and the different mechanisms have been analysed from the results obtained by using constant mole method, slope method, saturated capacity method, IR and NMR spectra, and also discussed the different mechanism in low or high concentration of [HCl] on the theory.

Key words: mercury, mechanism, levextrel resin, primary amine N₁₉₂₃.

A Study on Effects of Simulated Acid Rain and Sulphur Dioxide on Crops. Liu Liangui et al. (Chinese Research Academy of Environmental Sciences, Beijing 100012); *Chin. J. Environ. Sci.*, 17(2), 1996, pp. 16-19

The effects of acid rain and sulphur dioxide alone and in combination on tomato, carrot and cotton was studied by simulated acid rain irrigating and SO₂ exposure. It was found that the simulated acid rain and sulfur dioxide could inhibit the growth of crops in a degree and reduce the productivity. The synthetic effect of acid rain and sulfur dioxide was more notable than alone, but their mutual effect was not marked.

Key words: simulated acid rain, sulfur dioxide, crop, inhibition, synthetic effect.

The Fluxes of Volatile Mercury over Soil Surface in Guizhou Province. Feng Xinbin et al. (State key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang, 550002); *Chin. J. Environ. Sci.*, 17(2), 1996, pp. 20-22

After summing up the work of former researchers, the authors set up a instrument which can be used to measure the fluxes of volatile mercury over soil in field. From Aug. to Oct. in 1993, the authors studied the fluxes of volatile mercury over soil at five sites of three different areas (high mercury contented area, mercury polluted area and reference area). Studies showed that soil release more volatile mercury in day than at night, and that the fluxes of volatile mercury over soil has relationship with both the total mercury content of soil and air temperature.

Key words: mercury, fluxes, flux chamber, Guizhou