

硅对酸性土壤铝毒的缓解作用*

黄巧云 李学垣 胡红青

(华中农业大学土化系, 武汉 430070)

摘要 铝毒是酸性土壤限制作物生长的主要因素, 寻找缓解甚至消除土壤铝毒的措施是合理开发利用酸性土壤、提高作物产量的重要途径。本试验选取湖北温泉第四纪母质发育的酸性红壤(pH 值 4.8), 作了加硅处理的小麦土培和根际培养试验, 测定了麦苗植株生长量、部分矿质元素含量以及根际土壤活性铝的含量。结果表明, 加硅 0.3 mmol/kg 即可促进麦苗根系对钙、镁等元素的吸收, 增加植株的生长量。硅加入量达到 0.9 mmol/kg 时, 对麦苗生长和矿质养分吸收的促进作用更加明显。加硅处理还在一定程度上减缓了麦苗根际土壤 pH 值下降和活性铝增长的幅度。本文讨论了酸性土壤上施用含硅物料缓解铝毒的作用及其应用的前景。

关键词 硅、酸性土壤, 小麦铝毒, 根际培养。

施用石灰改良酸性土壤的施用技术以及施用石灰对土壤养分有效性和农作物的产量与品质的影响等已有相当多的研究报道^[2,4,7,12]。有研究表明, 硅能增强某些植物对病虫害的抗性, 抑制铁、锰的毒害^[5]。施用 CaSiO_3 可以提高灰土和氧化土的 pH 值, 在土壤中形成稳定的非晶形铝硅酸盐^[7]。最近, Galvez 等在溶液培养试验中, 通过加硅酸钠来提高溶液的 pH 值, 缓解了铝离子对高粱的有害作用^[6]。Li 等(1989)认为, 在不改变培养液酸度的情况下, 硅在抑制铝离子对棉花的毒害作用上因棉花品种的不同而不同^[10]。在南方酸性土壤地区, 有大量含硅工业废弃物如炉渣、煤灰、尾矿等以及农业的有机

残茬, 均有待合理地开发利用。因此, 笔者在水培试验的基础上^[11], 研究了矿质酸性红壤上施用硅酸对小麦生长、对土壤活性铝类型、数量, 特别是根际土壤铝的形态的影响, 以探讨硅是否具有缓解酸性土壤铝毒的作用为含硅工农业废弃物的开发利用寻找途径和提供科学依据。

1 材料与方法

- (1) 供试小麦品种 鄂恩一号。
- (2) 供试土壤 采自湖北咸宁温泉杨下村荒地。前期工作表明^[8], 此土壤种植小麦铝毒明显。土壤的基本性状见表 1。

表 1 供试土壤的基本性状

地点	层次 (cm)	pH (H ₂ O)	有机质 (g/kg)	<2 μ m 粘粒 (g/kg)	速效磷 (mg/kg)	交换性(cmol(+)/kg)						铝饱和度 (%)	主要粘粒矿物
						H	Al	Ca	Mg	K	Na		
温泉													高岭、水云母
杨下村	15—50	4.80	7.06	520	3.4	0.25	7.24	1.05	0.48	0.21	0.13	77.3	1.4 nm 过渡矿物

(3) 土培试验 土样风干后过 2 mm 筛, 每 kg 土加入下列营养成分:
150mg N $[(\text{NH}_4)_2\text{SO}_4]$, 44mgP (KH_2PO_4) , 140mg K (KCl) , 175mg Ca (CaCl_2) , 85mg Mg $(\text{MgSO}_4 \cdot 7\text{H}_2\text{O})$, 0.5mgB (H_3BO_3) , 1.5mg Zn $(\text{ZnSO}_4 \cdot 7\text{H}_2\text{O})$, 2mg Cu $(\text{CuSO}_4 \cdot 5\text{H}_2\text{O})$ 和 0.2mg Mo $[\text{NH}_4\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}]$ 。设以下 7 个处

理: 处理 1 为对照, 不加硅; 处理 2、3、4、5、6、7 分别加入 0.1, 0.3, 0.6, 0.9, 1.2 和 1.5 mmol \cdot kg⁻¹ Si (pH4.8 的硅酸钠溶液)。各处理均重复 4 次。具体步骤如下: 土样加入各种试剂

* 国家自然科学基金资助课题
收稿日期: 1995-06-12

后,充分混匀,置于塑料袋内,加去离子水平衡 7 d,风干过 2 mm 筛。将土样分装于 250 ml 的塑料杯中,播入精选的已催芽的小麦种子,进行温室培养,每天浇水至田间持水量的 70%—80%。几天后间苗使每杯苗数为 5 杯,生长 45 d 收获。植株收获后,洗净根系上的泥土,与地上部分分开,在 60℃ 下烘干、称重。植株样用硝酸-高氯酸消化,在直流等离子体上测定根系和茎叶中钙、镁、磷、钾和铝的含量。

(4) 根际培养试验 试验设 5 个处理,3 次重复。处理 1 为对照(CK),处理 2、3、4、5(Si-1, Si-2, Si-3, Si-4)分别加 Si 0.4, 0.8, 1.2 和 1.5 mmol/kg。土壤中添加量同上述土培试验。具体操作如下:将与各处理溶液充分混匀后的土样,装入小号盆钵(1 kg 土/钵),中间放入 300 目、直径为 3.5 cm 的圆柱状网袋,袋内装有同样处理的土样(100 g/袋)。每袋播入 12 粒已催芽的小麦种子,温室培养,浇水方法同(3)、50 d 后收获。此时,尼龙网袋内土

壤基本充满根系,作为根际土,外面的土壤为非根际土。用离心法提取根际土和非根际土的土壤溶液^[8]。土壤凉干后,取部分样品过 60 目筛,测定土壤的 pH 值,用 0.02 mol · L⁻¹CaCl₂ 和 1 mol · L⁻¹KCl 溶液提取土壤水溶态铝和交换态铝。

(5) 铝的测定 土壤溶液铝、水溶态铝及交换态铝含量均用直流等离子体测定。

2 结果与讨论

2.1 加硅处理对麦苗生长的影响

供试土壤加硅处理的小麦土培试验结果(表 2)表明,每 kg 土加入 0.3 mmol Si 的处理 3,麦苗根系的干物重显著高于对照处理,比对照增加 27%。当 Si 的用量增加至 0.9 mmol 以后,根系干物重又有明显的增加。从茎叶干物重的情况来看,加 0.3 mmol 以上 Si 的处理均比对照有显著的增加。加 0.1 mmol 硅的处理 2,其根系和茎叶的生长量与对照无明显差异。

表 2 加硅处理的土壤上麦苗的生长量和部分元素的含量

处理 (mmolSi/g 土)	根 系 (mg/kg)						茎 叶 (mg/kg)					
	干物重 (mg/5 株)	Ca	Mg	K	Al	P	干物重 (mg/5 株)	Ca	Mg	K	Al	P
CK	181.2 d ¹⁾	0.73 c	1.04 c	13.58 b	13.70 a	2.12 a	158.3 c	8.78 b	4.50 a	14.18 a	1.11 a	2.45 a
0.1	193.8 cd	0.93 bc	1.36 c	14.73 ab	14.27 a	1.97 ab	173.0 bc	9.18 ab	4.68 a	14.26 a	1.17 a	1.96 b
0.3	228.9 bc	1.17 ab	1.95 b	14.07 ab	15.44 a	2.05 ab	193.4 ab	9.98 a	4.75 a	14.77 a	0.96 ab	2.05 b
0.6	234.8 ab	1.04 bc	1.86 b	15.64 a	15.58 a	2.03 ab	192.8 ab	9.91 a	4.87 a	15.68 a	0.47 b	1.98 b
0.9	257.3 a	1.19 ab	2.19 a	15.59 a	15.32 a	1.92 ab	227.4 a	10.18 a	4.77 a	15.43 a	0.48 b	2.01 b
1.2	263.8 a	1.28 a	2.11 a	15.71 a	15.38 a	1.88 b	228.1 a	10.23 a	4.79 a	15.38 a	0.48 b	1.99 b
1.5	260.5 a	1.26 a	2.17 a	15.67 a	15.40 a	1.86 b	219.6 a	10.25 a	4.76 a	15.50 a	0.48 b	1.96 b

1) 标有相同字母的处理之间,其差异未达到 5% 的显著性水准(邓肯检验法)

对各处理的小麦植株元素含量的测定结果表明,加硅的处理,根系钙、镁的含量增加,钾的含量有增加的趋势,磷的含量有所下降,铝含量变化不明显;加硅处理使麦苗茎叶含钙量增加,铝和磷的含量比对照降低,镁和钾的含量与对照的差异不明显。可见,加硅处理可以在一定程度上增加麦苗根系和茎叶的生长量,促进植株对某些营养元素的吸收,降低地上部分铝的含量。

2.2 麦苗根际和非根际土壤的 pH 值与活性铝

由表 3 可见,与非根际土壤比较,各处理的根际土壤都有一定程度的酸化,如对照处理土壤的 pH 值从 4.32 下降到 4.12, Si-1、Si-2、Si-3 和 Si-4 处理的根际土壤 pH 值从 4.33 分别降至 4.19、4.22、4.25 和 4.29。对照的根际土壤 pH 值下降 0.2 个 pH 单位,其他处理下降 0.05—0.1 单位。可见,加硅处理对根际土壤的酸化有一定的缓解作用。

表 3 各处理根际与非根际土壤的活性铝

处 理	CK	Si-1	Si-2	Si-3	Si-4
土壤 pH 值	4.12	4.19	4.22	4.25	4.29
根 土壤溶液 pH	3.98	4.05	4.07	4.09	4.12
际 土壤溶液铝 ($\mu\text{mol/L}$)	305	290	288	286	280
土 水溶态铝 ($\mu\text{g/g}$)	231	231	222	215	205
交换态铝 ($\mu\text{g/g}$)	529	518	506	493	482
非 土壤 pH 值	4.32	4.33	4.32	4.32	4.33
根 土壤溶液 pH	4.11	4.10	4.09	4.09	4.08
际 土壤溶液铝 ($\mu\text{mol/L}$)	127	170	175	180	182
土 水溶态铝 ($\mu\text{g/g}$)	173	175	177	180	181
交换态铝 ($\mu\text{g/g}$)	396	394	411	427	426
差 Δ 土壤溶液铝 ($\mu\text{mol/L}$)	178	120	113	106	98
Δ 水溶态铝 ($\mu\text{g/g}$)	58	56	45	35	24
值 Δ 交换态铝 ($\mu\text{g/g}$)	133	124	95	66	56

由表 3 可知,加硅处理的根际土壤中几种活性铝的含量比对照处理的低。从不同处理的根际土壤与非根际土壤活性铝含量的差值还可看出,在小麦生长的 50 d 内,加硅处理在土壤溶液铝、水溶性铝和交换性铝等活性铝的数量增加上均远小于对照处理。这些结果说明,在小麦生长期间,植株根际的土壤溶液铝、水溶性铝、交换性铝等的含量都在增加,但不同处理的增加幅度不一样。加硅处理虽不能完全阻止麦苗根际土壤活性铝含量的增加,但却可使得它的增加幅度大为降低。可见,向酸性土壤中施用硅,除使小麦根系对某些养分的吸收增加,生长量增大,增强其克服土壤铝毒的能力外,还可起到减缓土壤酸化的作用。

考察本试验中硅的加入量与麦苗植株的生长量和部分元素含量,以及麦苗根际土壤某些活性铝含量的情况,可以认为,在供试的土壤中加入 0.3 mmol/kg 左右的硅,即在提高麦苗生物量方面有较明显的作用。增加硅的用量至 0.9 mmol/kg,麦苗植株的生长量及部分营养元素含量仍有继续增加的趋势,但硅的加入量超过 1.2 mmol/kg 以后,对麦苗的生长再无显著的促进作用。而且,所加入的硅量均在一定程度上起到抑制小麦根际土壤活性铝含量的增加,减缓根际土壤 pH 值下降的作用。因此,在酸性土壤中适当提高土壤的可溶性硅的含量有利于

减轻土壤铝的毒害,提高作物产量。从本试验结果看,在加硅于土壤后,土壤的 pH 值并没有得到提高,这可能也在一定的程度上影响植物的生长和矿质营养的吸收。因此,在生产实践中,在施用硅肥的同时,可以根据具体土壤情况,适当配合施用其它的土壤改良剂如石灰、有机物等,来提高土壤的 pH 值,这样效果会更好。

参 考 文 献

- 1 黄巧云,徐凤琳,李学垣,杨金安. 土壤资源的特性与利用. 北京:北京农业大学出版社,1992: 274
- 2 秦遂初. 中国农业科学. 1988, 21(4): 68
- 3 黄巧云,李学垣,徐凤琳. 华中农业大学学报. 1995, 14(2): 147
- 4 Adams F. Soil Acidity and Liming(2nd Ed.). American Society of Agronomy, Madison, WI. 1984
- 5 Ahmad F and K H Tan. Soil Sci. Soc. Am. J.. 1986, 50: 656
- 6 Galvez L et al.. J. Plant Nutr.. 1987, 10(9—16): 1139
- 7 Haynes R J. Soil Sci.. 1984, 138(1): 8
- 8 Huang Q et al.. Second Workshop on Material Cycling in Pedosphere. Nanjing, China, 1993: 32
- 9 Hue N V and I Amien, Commun. Soil Sci. Plant Anal.. 1989, 20(15—16): 1499
- 10 Li Y C et al.. J. Plant Nutr.. 1989, 12(7): 881
- 11 Marschner H. Plant and Soil. 1991, 134: 1
- 12 Robson A D. Soil Acidity and Plant Growth. Marrickville, Australia; Academic Press, 1989

Abstracts

Chinese Journal of Environmental Science

Microbial Purification and Recovery of Pu-239 from Nuclear Industrial Wastewater. Li Fude et al. (Chengdu Institute of Biology, Chinese Academy of Sciences, Chengdu 610041); *Chin. J. Environ. Sci.*, **16**(6), 1995, pp. 1-3

From Pu-containing wastewater from nuclear industry, 13 strains of bacteria were isolated and screened out, and observed for their abilities of enriching Pu-239. One of them, called strain OR, was found to be one which can efficiently accumulate Pu-239 and to have the highest capacity of accumulating Pu-239 as compared to *Desulphovibrio* sp., *S. cerevisiae*, *Actionmycetes* sp., and *Rhizopus* sp.. The optimum conditions under which strain OR can efficiently accumulate Pu-239 were pH6, 30°C, and a dosage of 0.05 g wet culture per ml of solution to be treated. Under these conditions, a Pu-239 removal of 99% was given by reacting for 5 min. and up to 97% of Pu-239 were recovered by desorbing 2 times with 0.5 mol/L of NaHCO₃. Alpha-energy spectrometric detection showed the presence of Pu-239 in the cells of strain OR. The analysis using scan electronic microscope in combination with transmission electronic microscope showed that the adsorption of Pu-239 onto strain OR occurred mainly due to the surface adsorption and flocculation of cell walls.

Key words: microbe, Pu-239, purification, recovery.

Study on the Photooxidation of Brominated Alkanes. Zhong Jinxian et al. (Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085), Chen Dazhou (Chinese Research Center for Certified Reference Materials, Beijing 100013); *Chin. J. Environ. Sci.*, **16**(6), 1995, pp. 4-6

Under simulated atmospheric conditions, the photochemical reactions were studied in the four systems of CH₃Br + H₂O₂ + O₂, CH₃Br + O₂, CHBr₃ + H₂O₂ + O₂, and CHBr₃ + O₂. Irradiated by UV at 253.7 nm, H₂O₂ in these systems was decomposed to give OH radical which then reacted with CH₃Br and CHBr₃. The products of these reactions were determined with a Fourier Transform Infrared Spectroscopy in a 20 m long

path cell. As the products of photochemical reactions, CO, CO₂, CH₂O and H₂O were detected in both systems of CH₃Br + H₂O₂ + O₂ and CH₃Br + O₂; CO, CO₂ and H₂O were detected in the system of CHBr₃ + H₂O₂ + O₂; and CO and CO₂ were detected in the system of CHBr₃ + O₂. Based on these products, the photochemical reactions which possibly occurred were suggested and reasonable explanations were given.

Key words: photochemical oxidation, OH radical, brominated alkanes.

Biotechnological Removal of Sulfides in the Effluent from Sulfate Reducing Reactors. Zuo Jian'e et al. (Dept. of Environ. Eng., Tsinghua University, Beijing 100084); *Chin. J. Environ. Sci.*, **16**(6), 1995, pp. 7-10

Studies have been carried out on the possibility of converting sulfides directly by colourless sulfur bacteria into elemental sulfur in the treatment of effluent from sulfate reducing reactors. The treatment was conducted in an upflow biofilm reactor packed with Raschig rings at an ambient temperature (18-22°C). The results show that sulfides were removed at a rate of over 90% and almost all of sulfides removed were converted into elemental sulfur while organics being removed at a rate of about 10% only, when the treatment was conducted with a sulfide volumetric loading of 12 kg H₂S/(m³ · d), a hydraulic retention time of 22 minutes and a dissolved oxygen (DO) concentration of 5.0-5.5 mg/L and at a pH value of 7-8. The results also show that the DO concentration required in the biofilm reactor and the increase in pH value were linearly correlated to the sulfide loading in the influent and to the amount of sulfides removed, respectively.

Key words: aerobic microbial desulfurizing process, upflow aerobic biofilm reactor, colourless sulfur bacteria, elemental sulfur.

Alleviating Effect of Silicon on Aluminum Toxicity to Wheat Growth in Acid Soil. Huang Qiaoyun et al. (Dept. of Soil Science, Huazhong Agricultural University, Wuhan 430070); *Chin. J. Environ. Sci.*, **16**(6), 1995, pp. 11-13

Pot culture experiments were carried out to study the effect of silicon application in acidic soil on the

alleviation of aluminum toxicity to wheat. Silicon was added as solutions of sodium silicate with a pH value of 4.8 and the unamended soil was used as control. Plant biomass and contents of some elements in wheat seedlings were measured. The concentrations of some species of active aluminum in rhizosphere soils were also determined. It was found that the biomass of wheat seedlings increased and the uptake of Ca, Mg etc. by wheat seedlings was improved with 0.3 mmol/kg of Si added. When the amount of Si added reached 0.9 mmol/kg, more significant effects can be observed for the growth and uptake of nutrients by wheat seedlings. Moreover, silicon treatments slowed down the pH decline and the increment of soluble and exchangeable aluminum content in rhizosphere soils. Considering the resources and the effects for mitigating aluminum toxicity, application prospect of silicon materials such as some industrial waste products and crop residues in acid soils were discussed.

Key words: silicon, acid soil, aluminum toxicity, alleviating effect, wheat, rhizosphere.

Study on Degradation Mechanism of Organophosphorus Pesticide Isocarboxophos by Immobilized Microorganism. Luo Qifang et al. (Institute of Environmental Medicine, Tongji Medical University, Wuhan 430030); *Chin. J. Environ. Sci.*, **16**(6), 1995, pp. 14—16

Gas chromatography/mass spectrometry and other analytical methods were applied in this study. The test has given a mass-spectrum of refined isocarboxophos. Analytical results demonstrated that the cyclic structure of isocarboxophos might be broken into simple inorganic compounds such as CO_2 , H_2O , NH_3 , H_2S and H_3PO_4 by immobilized microorganism. Organic compounds such as isopropyl salicylate were products of degradation process by inference. The primary research on the degradation mechanism of isocarboxophos has also been done.

Key words: immobilized microorganism, isocarboxophos, degradation mechanism.

Comparison of the Mutagenicity of Water Samples Disinfected with Several Disinfectants.

Tang Fei et al. (Inst. of Environ. Med., Tongji Medical University, Wuhan 430030), Cheng Maoyi et al. (Shashi Station of Sanitation and Antiepidemics, Shashi 434000); *Chin. J. Environ. Sci.*, **16**(6), 1995, pp. 17—20

In this study, the mutagenicity was detected and compared after treatment of the Wuhan East Lake water with chlorine, chlorine dioxide or ozone. The concentrates of untreated and ozone-treated water at all sample collection dates were nonmutagenic in the Ames test. Both chlorine and chlorine dioxide treatment of the water resulted in increases of TA98 mutagenicity. Comparative analysis of these treated waters for mutagenicity showed a consistent pattern of mutagenic potency, with decreasing activity in the order: chlorine > chlorine dioxide > ozone. The study also found that pretreatment of water with potassium permanganate prior to chlorination was effective in reducing the level of mutagenicity which formed during chlorination.

Key words: chlorine, chlorine dioxide, ozone, mutagenicity of drinking water.

Biological Control of Nitrite in Fish Farming Ponds by Photosynthetic Nonsulfur Bacteria.

Liu Shuangjiang et al. (Institute of Microbiology, Chinese Academy of Sciences, Beijing 100080), Sun Yan et al. (Institute of Water Research, Chinese Academy of Environmental Science, Beijing 100012); *Chin. J. Environ. Sci.*, **16**(6), 1995, pp. 21—23

Nitrite, a toxic factor for most aquatic animals and causing a great loss for fishery if it was kept at a higher level in water, was found to be utilized and removed screened and isolated strains of photosynthetic nonsulfur bacteria. Experiments indicated that the isolated strains removed nitrite by more than 80% when the nitrite in the bulk ranged from 0.01 to 5.0 mmol/L, regardless they were cultured under illumination or in dark. Results also show that acetate and lactate were the optimal C sources for nitrite removal. Field surveys on the nitrite concentration in fish farming ponds in Beijing area found that it was about 0.006—0.008 mmol/L. By using the isolated strains in the ponds, their nitrite concentrations decreased by 50%—80%.

Key words: photosynthetic bacteria, nitrite, fishery.

Study on the Motor Soot Combustion Performance over Different Catalysts. Chen Min et al.

(Catalytic Institute, Hangzhou University, Hangzhou 310028); *Chin. J. Environ. Sci.*, **16**(6), 1995, pp. 24—25

In this paper, the soot collected from automobile