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La(Ⅲ)与酸雨对大豆幼苗生长的复合影响

范金凤,曾淑平,梁婵娟,周 青

([1] 江南大学工业生物技术教育部重点实验室,江苏 无锡 214122;[2] 江南大学环境与土木工程学院,江苏 无锡 214122)

摘 要:为探索稀土元素镧和酸雨对大豆幼苗生长的复合影响,采用模拟酸雨和镧处理大豆(*Glycine max*),研究了La(Ⅲ)与酸雨(AR)复合处理对大豆幼苗地上、地下器官生长的影响。结果表明:稀土镧(RE_1/20 mg·L^{-1}、RE_2/60 mg·L^{-1}、RE_3/100 mg·L^{-1}和RE_4/500 mg·L^{-1})单独作用时,RE_1对大豆幼苗生长有促进作用,RE_2、RE_3和RE_4表现为抑制作用,且$RE_4 > RE_3 > RE_2$。在酸雨(AR_1/pH2.5、AR_2/pH3.5 和 AR_3/pH4.5)单独作用和 RE +AR 复合作用影响下,大豆幼苗生长均受到抑制;而且 AR 的 pH 越低,RE 的浓度越高,抑制作用越明显。RE_1和 AR 复合对大豆幼苗的抑制程度低于 AR 单独作用,其它浓度 RE 和 AR 复合抑制程度高于各自单独作用。

关键词:La(Ⅲ);酸雨;复合处理;大豆幼苗;生长

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Effects of La(Ⅲ) and Acid Rain on Growth of Soybean Seedling

FAN Jin-feng,ZENG Shu-ping,LIANG Chan-juan,ZHOU Qing

(Key Laboratory of Industrial Biotechnology,Ministry of Education,Jiangnan University,Wuxi 214122,Environment and Civil Engineering,Jiangnan University,Wuxi 214122,Jiangsu,China)

Abstract:In order to explore combined effects of growth of soybean seedling to acid rain and rare earth,soybean seedling were subjected to Lanthanum (Ⅲ) and simulated acid rain. Response of growth of soybean seedling's underground and above-ground organs to combined treatments of Lanthanum (Ⅲ) and acid rain were studied. The results indicated that RE_1 (20 mg·L^{-1}) promoted soybean seedling growth,but that RE_2(60 mg·L^{-1}),RE_3(100 mg·L^{-1})and RE_4(500 mg·L^{-1}) inhibited growth of soybean seedlings. The sequence of inhibition degree was $RE_4 > RE_3 > RE_2$. Under acid rain (AR_1/pH2.5,AR_2/pH3.5 and AR_3/pH4.5) stress alone,all growth indices were lower than those of the control. With RE and AR combined treatments,growth of soybean seedling were all inhibited. The degree of inhibition of growth was larger when the pH value of AR was lower and the concentration of RE solution was higher. Moreover,the degree of decrease of growth index in RE_1 and AR combined treatment was lower than that in AR or RE_1 treatment alone,while RE_2,RE_3 and RE_4 are opposite.

Key words:Lanthanum (Ⅲ);Acid rain;Combined treatment;Soybean seedling;Growth

酸雨(Acid rain,AR)是公认的全球性环境污染问题之一。研究显示,AR 对陆生植物危害巨大[1-3]。稀土环境生态研究结果显示,适宜浓度的稀土(Rare earth,RE)对植物生长发育有促进作用[4],但长时间和大面积施用稀土会造成稀土元素在土壤表层持留。自然条件下,外源稀土很难发生迁移,以交换态存在的活性稀土占土壤中稀土总量的比例很低[5]。在酸雨多发农业区,土壤 pH 值随酸性降水而降低[6],土壤中稀土离子淋溶加强,赋存状态发生改变[7],解吸量升高,植物可利用性增加[8],稀土农用环境安全风险加大。国内外有关 RE 或 AR 胁迫对植物生理、生态的影响,已有很多报道[4,9-10],但涉及 RE 与 AR 复合作用对植物影响的研究,尚未见有文献报道。环境污染物对植物的复合污染常表现为相加、独立、协同或拮抗等作用方式。以大豆幼苗为试材,探讨 La(Ⅲ)和 AR 对植物生长的复合影响,旨为客观、综合评估酸雨对植物的危害及 RE 农用的环境安全性等问题提供参考。

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作者简介:范金凤(1987-),女,学士。研究方向为环境生态学。
通讯作者:周青,教授。E-mail:zhouqeco@ yahoo. com. cn. 。

1　材料与方法

1.1　酸雨与稀土溶液配制

配制 $LaCl_3$ 梯度溶液(20、60、100、500 mg·L^{-1})[11]。模拟酸雨(AR)配制参照文献[12],先配制 pH 1.0 的酸雨母液,其中硫酸根和硝酸根的体积比为 4.7:1。以去离子水作为稀释液,将酸雨母液和配制好的 $LaCl_3$ 梯度溶液(20、60、100、500 mg·L^{-1}) pH 分别调制为 2.5、3.5、4.5,并经 PHS-29A 酸度计(上海精密科学仪器有限公司校准)。

1.2　试材培养与处理

大豆(*Glycine max*)“垦农 18”种子用 0.1% $HgCl_2$ 消毒 5 min,去离子水冲洗后,置 3 层纱布培养皿中,于恒温培养箱(25±1.0)℃中萌发。胚根长至 2 cm 移入盛有 Hoagland[11] 营养液的塑杯(Φ=15 cm)中培养,每杯 3 株,日换水 1 次。室温 25±5℃培养,每日光照 12 h (光强 8klx),早晚通气各 1 次,并用去离子水维持溶液体积,3 d 换 1 次营养液,至第 3 片真叶展开后用于处理。用配制好的稀土溶液浸泡大豆幼苗根部,每天处理 6 h,持续处理 7 d,对照植株(CK)用等量营养液浸泡。分别在第 3、6 d,用喷雾器向叶片喷施不同 pH 值酸雨溶液,以滴液为限,CK 喷等量蒸馏水。设置为:CK、RE_1(20 mg·L^{-1})、RE_2(60 mg·L^{-1})、RE_3(100 mg·L^{-1})、RE_4(500 mg·L^{-1}),AR_1(pH2.5)、AR_2(pH 3.5)、AR_3(pH 4.5),RE_1+AR_1、RE_1+AR_2、RE_1+AR_3、RE_2+AR_1、RE_2+AR_2、RE_2+AR_3、RE_3+AR_1、RE_3+AR_2、RE_3+AR_3、RE_4+AR_1、RE_4+AR_2、RE_4+AR_3。以上各处理均 3 杯,3 次重复。

1.3　生长指标测定

根系生长指标测定参照文献[13];用直尺测量茎长、株高及主根长;叶面积以透明方格纸法计算而得[14]。以单株为单位,分别测出每株大豆幼苗的叶片鲜重,茎鲜重,根鲜重。之后,于电热恒温干燥箱中 100℃杀青 10 min,80℃烘 12 h 至恒重,分别称其干重。

2　结果与分析

2.1　La(Ⅲ)与酸雨对大豆幼苗地上器官生长的复合影响

表 1 显示,与 CK 比,AR_1 ~ AR_3 组大豆幼苗地上部各项指标均下降,AR_1 降幅 > AR_2 > AR_3。与 CK 相比,RE_1 组大豆幼苗地上部各项指标上升 2.56% ~14.14%,RE_2 ~ RE_4 组各指标均下降,RE_2 降幅 < RE_3 < RE_4。RE 浓度越大,差异越明显。复合实验中,与 CK 比,处理组大豆幼苗地上部各指标均下降,其中 RE_1+AR_1 降幅 > RE_1+AR_2 > RE_1+AR_3,RE_2+AR_1 降幅 > RE_2+AR_2 > RE_2+AR,RE_3+AR_1 降幅 > RE_3+AR_2 > RE_3+AR_3,RE_4+AR_1 降幅 > RE_4+AR_2 > RE_4+AR_3。AR 的 pH 越低,RE 的浓度越高,降幅越明显。

表 1　La(Ⅲ)与酸雨复合作用对大豆幼苗地上器官生长的影响

Table 1　Effects of La(Ⅲ) and acid rain on the growth of above-ground organs of soybean seedling

处理 Treatment	株高 Plant height/cm	叶面积 Leaf area/cm^2	茎鲜重 Shoots fresh weight/g	茎干重 Shoots dry weight/g	叶鲜重 Leaf fresh weight/g	叶干重 Leaf dry weight/g
CK	45.25±0.62b	101.77±1.70b	1.597±0.027b	0.173±0.001b	0.888±0.021b	0.129±0.011b
RE_1	46.41±0.34a	105.31±1.68a	1.767±0.006a	0.184±0.005a	0.964±0.036a	0.147±0.004a
RE_2	42.40±2.15c	79.57±2.89f	1.532±0.036c	0.171±0.003b	0.728±0.002e	0.103±0.003ef
RE_3	41.23±0.04de	73.10±1.14g	1.385±0.009ef	0.160±0.003cd	0.689±0.007fg	0.092±0.003gh
RE_4	35.97±0.20gh	69.71±0.31h	1.266±0.004g	0.150±0.003ef	0.586±0.022i	0.084±0.002ij
AR_1	34.65±1.49jk	80.93±1.42f	1.091±0.065h	0.123±0.006hi	0.658±0.049h	0.099±0.004fg
AR_2	35.70±1.68hi	87.80±0.79e	1.336±0.006fg	0.135±0.017g	0.687±0.006fg	0.107±0.004de
AR_3	37.63±0.0.70f	91.18±0.35d	1.442±0.050d	0.156±0.003de	0.762±0.054d	0.116±0.009c
RE_1+AR_1	37.15±0.69f	87.13±3.00e	1.228±0.048gh	0.136±0.008g	0.703±0.020ef	0.110±0.009cd
RE_1+AR_2	40.31±0.03e	90.87±1.15d	1.394±0.002de	0.155±0.005def	0.730±0.007e	0.115±0.009c
RE_1+AR_3	41.72±0.58cd	94.45±2.50c	1.505±0.049c	0.165±0.002bc	0.815±0.055c	0.125±0.003b
RE_2+AR_1	33.61±0.36l	42.58±0.70l	1.070±0.045i	0.119±0.002ij	0.230±0.018m	0.068±0.007m
RE_2+AR_2	34.74±1.01j	62.88±0.74j	1.252±0.055gh	0.131±0.006gh	0.559±0.005ij	0.080±0.002jk
RE_2+AR_3	36.88±0.35fg	70.44±0.66gh	1.371±0.010ef	0.147±0.006f	0.671±0.035gh	0.095±0.012gh
RE_3+AR_1	31.75±0.36mn	32.06±2.73m	0.911±0.029k	0.117±0.004ij	0.179±0.003n	0.061±0.005n
RE_3+AR_2	33.78±0.40kl	58.15±2.21k	1.200±0.008h	0.123±0.006hi	0.501±0.008k	0.077±0.003kl
RE_3+AR_3	34.95±0.44ij	66.42±2.20i	1.265±0.004g	0.129±0.007gh	0.558±0.002j	0.089±0.003hi
RE_4+AR_1	30.60±1.17o	30.59±0.76m	0.848±0.058l	0.108±0.011k	0.151±0.005o	0.059±0.003n
RE_4+AR_2	31.47±1.16no	57.86±2.67k	0.981±0.015j	0.113±0.006jk	0.465±0.024l	0.073±0.005lm
RE_4+AR_3	32.51±0.10m	60.74±0.42jk	1.207±0.058h	0.116±0.015ijk	0.511±0.046k	0.084±0.006ij

表中数据为平均值±标准差;不同字母表示同列中各处理间差异显著($P<0.05$),下同. The data in the table are average values ± standard deviation. Values followed by a different letter within the column are significantly different at 0.05 probability level. The same as below.

2.2 La(Ⅲ)与酸雨对大豆幼苗地下器官生长的复合影响

表2数据显示,与CK相比,AR_1 ~ AR_3组大豆幼苗主根长、根鲜重、根干重均下降,其中AR_1降幅) > AR_2 > AR_3。AR酸度越低,降幅越大。与CK相比,RE_1组大豆幼苗主根长、根鲜(干)重均上升3.75%,6.42%,7.01%,RE_2 ~ RE_4组各指标均下降。其中RE_2降幅 < RE_3 < RE_4。RE浓度越大,各指标降幅也越大。复合试验中,与CK相比,处理组大豆幼苗地上部分各项指标均下降,其中RE_1+AR_1降幅 > RE_1+AR_2 > RE_1+AR_3,RE_2+AR_1降幅 > RE_2+AR_2 > RE_2+AR_3,RE_3+AR_1降幅 > RE_3+AR_2 > RE_3+AR_3,RE_4+AR_1降幅 > RE_4+AR_2 > RE_4+AR_3。AR的pH越低,RE的浓度越高,降幅越明显。

表2 La(Ⅲ)与酸雨复合作用对大豆幼苗地下器官生长的影响

Table 1 Effects of La(Ⅲ) and acid rain on the growth of underground organs of soybean seedling

处理 Treatment	主根长 Main root length/cm	根鲜重 Root fresh weight/g	根干重 Root dry weight/g
CK	12.60 ±0.35b	0.921 ±0.053b	0.058 ±0.007b
RE_1	13.07 ±0.24a	0.980 ±0.004a	0.062 ±0.001a
RE_2	12.42 ±0.06b	0.887 ±0.009c	0.056 ±0.002b
RE_3	12.06 ±0.01c	0.841 ±0.003d	0.049 ±0.001c
RE_4	11.72 ±0.15d	0.803 ±0.004e	0.046 ±0.001d
AR_1	9.59 ±0.60i	0.605 ±0.055kl	0.033 ±0.007hi
AR_2	10.47 ±0.40fg	0.664 ±0.024hi	0.037 ±0.009g
AR_3	11.07 ±0.76e	0.732 ±0.053f	0.045 ±0.011d
RE_1+AR_1	10.50 ±0.03fg	0.670 ±0.005hi	0.040 ±0.001f
RE_1+AR_2	10.84 ±0.10e	0.703 ±0.016fg	0.044 ±0.0.01de
RE_1+AR_3	11.71 ±0.43d	0.781 ±0.043e	0.049 ±0.001c
RE_2+AR_1	9.40 ±0.06i	0.267 ±0.0080n	0.021 ±0.001j
RE_2+AR_2	10.19 ±0.09gh	0.621 ±0.003jk	0.035 ±0.001gh
RE_2+AR_3	10.95 ±0.09e	0.682 ±0.034gh	0.043 ±0.001ef
RE_3+AR_1	9.30 ±0.09 ij	0.231 ±0.013o	0.016 ±0.002k
RE_3+AR_2	9.97 ±0.11h	0.588 ±0.021lm	0.033 ±0.001hi
RE_3+AR_3	10.79 ±0.18ef	0.675 ±0.012gh	0.041 ±0.002f
RE_4+AR_1	8.97 ±0.11j	0.108 ±0.030p	0.011 ±0.001l
RE_4+AR_2	9.59 ±0.67i	0.572 ±0.020m	0.031 ±0.002i
RE_4+AR_3	10.42 ±0.24g	0.644 ±0.014ij	0.037 ±0.001g

3 结论与讨论

自然环境中,多种污染因子常共同作用于植物,以协同效应方式抑制植物。考察La(III)和AR复合作用对大豆幼苗生长的影响。结果显示,AR对大豆幼苗生长有抑制作用,其抑制程度随AR酸性增强而增大;适宜浓度La(III)(本试验为20 $mg \cdot L^{-1}$)促进大豆幼苗生长,高浓度La(III)则产生伤害作用,且浓度越大,伤害越严重[4],呈现明显的低促高抑现象。20 $mg \cdot L^{-1}$ La(III)与AR对大豆幼苗的复合作用低于AR单独伤害,两者呈现拮抗效应;高浓度La(III)(60 ~ 500 $mg \cdot L^{-1}$)与AR对大豆幼苗的复合伤害,大于AR和高浓度La(III)对大豆幼苗的单独伤害,大豆幼苗生长明显受到抑制,且随AR pH降低,RE浓度增加,抑制作用越明显,两者呈协同效应。推测其原因,可能AR、高浓度La(III)降低植物体内活性氧清除酶系(超氧物歧化酶、过氧化氢酶、过氧化物酶)活性及含量,导致活性氧生成量增加,植物体内自由基反应增强,继而导致细胞膜脂过氧化加剧,膜透性增加,电解质渗漏上升,细胞电化学平衡破坏,代谢紊乱,从而抑制大豆幼苗生长[4]。

综合上述,得到如下结论:La(III)对大豆幼苗生长具有"低促高抑"的hormesis效应;AR对大豆幼苗生长各指标的影响存在明显的"剂量 – 效应"关系;AR与低浓度La(20 $mg \cdot L^{-1}$)对大豆幼苗生长的复合作用呈拮抗效应,与高浓度La(60 ~ 500 $mg \cdot L^{-1}$)复合,则呈协同效应。

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素含量的估计都将有较好的预测效果。因此，mSR_{705}、mND_{705}是预测叶片叶绿素含量的最好的植被指数。

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