学校编码：10384　　　　　　　　　　分类号________密级________
学号：200226086　　　　　　　　　　UDC ____________________

厦 门 大 学

硕 士 学 位 论 文

重金属 Cd 对红树植物木榄幼苗生理生态效应研究

The Ecophysiological Effect Research of Heavy Metal Cd on Mangrove Species *Bruguiera gymnorrhiza* Seedlings

孙 娟

指导教师姓名：郑 文 教 教授
专 业 名 称：生 态 学

论文提交日期：2 0 0 5 年 7 月
论文答辩日期：2 0 0 5 年 8 月
学位授予时间：2 0 0 5 年 　 月

答辩委员会主席：严重玲 教授
评　　阅　　人：黄维南 研究员
　　　　　　　　严重玲 教授

2004 年 8 月

厦门大学学位论文原创性声明

兹呈交的学位论文，是本人在导师指导下独立完成的研究成果。本人在论文写作中参考的其他个人或集体的研究成果，均在文中以明确方式标明。本人依法享有和承担由此论文而产生的权利和责任。

声明人（签名）：

年　　月　　日

目　录

CONTENT

摘 要

采用砂基栽培，研究红树植物木榄（*Bruguiera gymnorrhiza*）在不同 Cd 浓度梯度系列和不同暴污处理时间条件下幼苗的萌发生长以及生理生态效应的影响。设置 Cd 胁迫浓度系列为 0.1、0.5、2.5、5、25、50、100mg/L，以不加 Cd 为对照，培养基海水盐度均为 15‰，培养期 180d。试验期间，全过程计录及观测各暴污级木榄种苗的萌发及生长状况，定期记录幼苗的高度生长、叶片大小、根系生长、幼苗各组分生物生长量，以及幼苗含水量以及光合生理、抗氧化酶系活性、膜脂过氧化、盐分代谢等指标参数。研究结果表明：

1. 在 Cd 浓度达 100mg/L 培养 30d 时，木榄的吐芽速率仍与对照组相当，这表明受 Cd 污染的胁迫（0.1-100mg/L）木榄繁殖体在露芽上与对照组相比未明显受影响，且表现出一定的 Cd 浓度有一定的促进作用，但对幼叶萌生则有一定的迟滞作用。从培养开始 30d 之后，木榄幼苗的成活率都为 100%，未发现幼苗死亡现象。

2. Cd 浓度 2.5mg/L 组以上浓度对红树植物木榄幼苗茎高生长有抑制作用；而低浓度（0.1-0.5mg/L）则不同暴污时间表现不同，较短时间受抑制后随着时间的延长则表现为平缓至促进作用。

3. 受 Cd 污染胁迫，木榄幼苗叶片面积在暴污时间相对较短时间（60d）受 Cd 的抑制，但随着暴污时间的延长，在低 Cd 浓度组 0.1-0.5mg/L 则反而表现略有促进作用，而中高浓度（≧2.5mg/L）则显抑制作用。

4. 中低浓度Cd（0.1-0.5mg/L）污染胁迫对木榄幼苗根系生长影响不明显，但高浓度（25-100mg/L）幼苗根系生长则明显受抑制。

5. 中高浓度 Cd 污染胁迫对木榄幼苗各组分生物量和总生物量有显著的抑制作用，且随着污染胁迫时间延长而加剧，其中抑制程度依次为茎生物量

＞根生物量＞总生物量＞叶生物量。结合 Cd 不同浓度和胁迫时间对种苗的萌生、幼苗叶片大小、苗高生长及根系生长与外部形态特征表现，可以推断红树植物木榄幼苗对 Cd 的耐性与抗性生长的浓度范围在 2.5mg/L 以下水平，临界浓度上限在 5 mg/L 左右。

6. 随着暴污时间延长，Cd污染胁迫对木榄幼苗叶片叶绿素含量具有一定的抑制作用；叶片胞间CO_2浓度随生长基Cd浓度的提高均呈逐步下降的趋势；叶片的净光合速率均表现为低浓度（80d为 0.1-0.5mg/L，180d为 0.1- 2.5mg/L）略为促进，而后则随生长基Cd浓度的提高而逐步降低。

7. 根尖蛋白含量在 80d 时受 Cd 不同浓度处理的变化不显著，整个处理系列的根尖蛋白含量处于比较稳定的状态；而到 180d 时，根尖蛋白含量随 Cd 浓度的增加有稳步上升的趋势。暴污处理 80d 时，木榄幼苗叶片可溶性蛋白含量随 Cd 处理浓度的增加表现为先下降后上升的趋势，在 0.5mg/L 处叶片蛋白含量最小；当 Cd 暴污时间达 180d 时，叶片蛋白含量呈随 Cd 处理浓度的增加而逐步上升的变化，并且在 25、50、100mg/L 组与对照组间差异极显著。

8. 随着暴污时间的延长，培养 80d 和 180d 时不同 Cd 浓度处理下，根系（包括主根和侧根）的含水量在三次不同的取样时间有表现出随时间延长，相同浓度的幼苗含水量明显下降的趋势。暴污培养 80d 和 180d 时 Cd 对木榄叶片的气孔导度影响与蒸腾速率相似，均表现出低浓度促进而后高浓度降低的趋势。

9. 暴污培养 180d 时，木榄幼苗根系 Cl 含量随 Cd 处理浓度的增加表现为降低的趋势。木榄幼苗原胚轴的 Cl 含量在 0.1 至 0.5mg/L 之间保持比较稳定，与对照组相比均无显著差异，而从 2.5mg/L 开始，随 Cd 浓度的增加原胚轴 Cl 含量逐步增加。木榄幼苗茎的 Cl 含量随生长基质 Cd 浓度提高而逐步升高。木榄幼苗叶的 Cl 含量变化规律与原胚轴和茎的类似，即在 0.1 至 0.5

mg/L 之间保持比较稳定，而从 2.5mg/L 开始，随 Cd 浓度的增加叶的 Cl 含量逐步增加。

10. Cd 暴污培养 40d 时，根尖 SOD 活性与 Cd 胁迫影响的变化无规律可循，但 0.5、25 和 50mg/L 组与对照组相比有显著的提高。当暴污培养 80d 时，随着 Cd 浓度的提高根尖 SOD 活性表现为先下降后上升的趋势，在中低浓度 0.1、0.5 和 2.5mg/L 组与对照组差异显著。当暴污时间延长到 180d 时，此时根尖 SOD 活性基本无变化，暴污组与对照组之间均无显著差异。

11. Cd 暴污处理培养 40d、80d 和 180d 的木榄幼苗根尖 POD 活性变化趋势基本一致，都表现为随着 Cd 处理浓度的增加而逐步上升的趋势。叶片 POD 活性随时间推移表现出明显的下降趋势。培养 80d 和 180d 时，随 Cd 处理浓度的提高，叶片 POD 活性而呈先上升后下降的趋势。

12. 不同浓度的 Cd 处理对叶片中 MDA 含量影响较大，而根系 MDA 含量则保持相对的稳定，并且叶片 MDA 含量高于根尖中 MDA 含量。这表明重金属 Cd 胁迫处理对叶片的膜脂过氧化程度大于根尖。

关键词：红树植物；木榄；Cd；生长；生理生态

Abstract

In this paper, mangrove species *Bruguiera gymnorrhiza* hypocotyls were cultivated in sand and treated with 15‰ seawater for 180 days in a greenhouse under laboratory conditions. The influence of increasing concentrations of Cd (0, 0.1, 0.5, 2.5, 5, 25, 50, 100mg/L) on hypocotyls germination and seedlings growth, photosynethesis metabolism, water metabolism, salt contents and membrance protection system were observed to inquire into the ecophysiological responses of mangrove *B. gymnorrhiza* to Cd phytotoxicity. The results showed:

1. Effect of Cd different concentration on hypocotyl germination of *B. gymnorrhiza* seedlings in sand culture in different development period is obvious. The sprout rate of viviparous propagules in Cd different treatment concentration were all above 90.0% in 30 days, and there was no significant difference from control group. The survive rate of *B. gymnorrhiza* seedlings in different Cd concentration was 100%. The series of different Cd concentration have an obvious different effect on the sprout of the first leaves. Concretely, all of the Cd treatment group have passive impact comparing with the control group, but the impact to the middle and high Cd concentraton groups is more obvious.

2. The height growth of stem of *B. gymnorrhiza* seedlings was restrained when the Cd concentration was above 2.5 mg/L; while under lower Cd concentration (0.1-0.5 mg/L) it was restrained in shorter treatment time and was promoted in a way in longer time.

3. The area of leaves in different Cd concentration of *B. gymnorrhiza* seedlings was reduced step by step when seedlings were treated for 60 days, 150 days and 180 days. When the concentration of Cd were above 25 mg/L, the treatment groups showed significant difference between the control group. With increasing concentrations of Cd, a decrease in the width and length of mature leaves were observed, and 100 mg/L group decreased at the least level. There

were extraordinary significant difference in 25, 50, 100 mg/L group when they compared with the control group. The ratio of the width and length showed no significant difference.

4. Effect of different concentration Cd on the roots growth of *B. gymnorrhiza* seedlings was obvious. The number and length of taproot showed more significant antiblastic influence above 25 mg/L concentration. Some phenomena were observed, for example, the number of slender radicels reduced markedly and the roots growth showed obvious lignification, and so on.

5. Different Cd concentration showed significant antiblastic influence on the biomass of *B. gymnorrhiza* seedlings, including the total biomass and each part biomass of seedlings such as roots, stems and leaves. The falling extent is the biaomass of stems more than the biomass of roots, the total biomass, and the biaomass of leaves in turn. It can be concluded that the endurant range of *B. gymnorrhiza* seedlings to Cd pollution is under 2.5 mg/L, and the critical concentration is about 5 mg/L.

6. The changes of the contents of chlorophyll a, chlorophyll b and total chlorophyll in leaves of *B. gymnorrhiza* seedlings with increasing concentration of Cd is approximate, and they increased slightly at lower concentration firstly and then decreased significantly with higer Cd concentration. The three kinds of contents all represent the maximal level in 0.1 mg/L group. The CO_2 concentration of the cell interspace of leaves in *B. gymnorrhiza* was decreased stage by stage with increasing Cd concentrations after 80 days and 180 days. Comparing with the control group, 0.1 and 0.5 mg/L groups showed no significant difference, while the groups from 2.5 to 100 mg/L showed extraordinary significant difference. The net photosynthetic rate of mature leaves of *B. gymnorrhiza* increased slightly at lower concentration and then decreased significantly with the Cd concentration increasing after 80 days and 180 days. But the maximal level in different treatment time was 0.5 mg/L and 2.5 mg/L group, respectively.

7. The content of soluble protein in roots of *B. gymnorrhiza* didn't change obviously with the different Cd concentration after 80 days, but showed a steady climb after 180 days, which is similar with the leaves. The content of soluble protein in leaves of *B. gymnorrhiza* showed an drop firstly, and then an obvious climb after 80 days. But when treatment time prolonged to 180 days, the content of soluble protein in leaves showed a steady climb with the increasing Cd concentration.

8. The changes of the transpiration rate of mature leaves of *B. gymnorrhiza* is consistent in 80 days and 180 days, and both showed an trend which revealed a increase in lower Cd concentration and a climb in higer Cd concentration. The stomatal conductance of mature leaves of *B. gymnorrhiza* showed homologous changes with the transpiration rate of them.

9. The Cl contents of hypocotyls, stems and leaves in *B. gymnorrhiza* seedlings were increased steadily with increasing Cd concentrations, otherwise the Cl content of roots decreased on the contrary after 180 days.

10. The SOD total activity of root tips *B. gymnorrhiza* seedlings showed a decline first and then a climb with the increasing concentration of Cd after 80 days, while after 180 days the SOD total activities of root tips showed no much difference because of the different Cd concentration. The SOD total activity of leaves is similar with the change of root tips after 80 days, and after 180 days it reached the max in 0.1 mg/L group but have no significant different when comparing with the control group.

11. The change trend of the POD total activities of roots tips were the same after 40 days, 80 days and 180 days, which showed a steady climb with the increase of Cd concentration. The POD total activities of leaves of *B. gymnorrhiza* seedlings showed a decline first and then a climb with the increasing concentration of Cd after 80 days and 180 days.

12. The contents of MDA of leaves of *B. gymnorrhiza* seedlings were greatly influenced by the different concentration of Cd, nevertheless those of root tips

keep steady. The contents of MDA of leaves were always higher than those of root tips, and this meaned that Cd did more harm to leaves than root tips.

Keywords: mangrove speices; *Bruguiera gymnorrhiza*; Cd; growth; ecophysiology

1 前言

1.1 土壤中 Cd 污染及其植物效应

1.1.1 土壤中 Cd 污染来源及 Cd 对土壤的影响

1.1.1.1 土壤中 Cd 污染来源

自然界中镉污染主要来自铅、锌、铜的矿山和冶炼厂的废水、尘埃、废渣和电镀、电池、颜料、塑料稳定剂、涂料工业废水等工业生产以及大气中Cd粉尘的沉降等[1-4]。镉在自然界中虽然分布很广，但是其含量微小。镉在地壳中的含量为 0.15～0.20mg/kg，镉在海水中的浓度为 0.11μg/kg，河流与湖泊的水体浓度为 1～10μg/kg，最大的镉浓度可达 130μg/kg。空气中的镉含量为 0.002～0.005μg/m^3，土壤中镉含量为 1mg/kg以上。在正常情况下，Cd在土壤中应为痕量元素[5-8]。据不完全统计，我国目前受镉污染的农田已有 18 万hm^2，其中大部分分布在南方粮油产区[9,10]。

1.1.1.2 土壤对 Cd 的吸附效应

土壤对重金属镉有较强的富集作用，即土壤对镉的吸附、固定作用，其中也包括植物吸收与凋落物聚集于土壤中等作用过程。相应地，镉能与土壤中有机质和矿物质相结合而固定或累积于土壤中。Cd在土壤中一般以+2 价形式存在，主要有矿物态、有机络合态和土壤吸附态。Cd的络合物主要以腐殖酸-Cd络合物形式存在，土壤有机质的含量和性质都会影响土壤中Cd的形态和含量[9,11,12]。

影响土壤吸附镉的因素还有土壤本身的物理化学性质，主要包括土壤的有机质、pH值、Cl^-等。当土壤pH值保持在 4～7.7 时，每增加一个pH单位，沙土和壤土对镉的吸附量增加 3 倍[13]。Cd在pH值较高，尤其是含有较多$CaCO_3$的碱性土壤中活性低，不易移动，而在酸性条件下则易迁移，毒性