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不同高程下白骨壤+秋茄人工红树林生长、生理及其更新能力的比较研究

Comparisioms on growth, physiology and generation of *Avicennia marina* + *Kandelia candel* mangroves restored at different tidal elevations

胡倩芳

指导教师姓名：　叶 勇　教授

专 业 名 称：　环 境 科 学

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答辩委员会主席：卢昌义 教授

评　　阅　　人：卢昌义 教授

黄维南 研究员

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摘 要

以厦门市曾营海岸的三个人工填土相差 0.5 m，有相同底质背景的三个滩涂样地（厦零高程 3.35、3.74、4.15 m）人工种植的白骨壤+秋茄红树林为研究对象，造林 4 年后，探讨白骨壤和秋茄生长、生理及后代更新的差异。

三个样地红树幼林均密闭成林。从生长上看，白骨壤幼树树高、基径、分枝数、冠幅均为中样地最高，高样地白骨壤树高显著低于低样地，高样地和低样地上的其它指标无显著差异；中样地秋茄幼树树高、基径、分枝数、冠幅最高，高样地上树高和分枝数显著高于低样地，高样地和低样地秋茄幼树基径和冠幅则差异不显著性。中样地白骨壤和秋茄全树年平均生长量及整个样地群落年均增长量最高。从生长的优势上可以推测，中样地（厦零高程 3.74 m）是白骨壤和秋茄的最佳造林高程。

从生理上看，不同高程并没有对这两种红树幼树叶片的光合色素含量产生差异，三个样地上白骨壤的光合速率没有显著差异，但是低样地秋茄叶片光合速率低于中、高样地。白骨壤在光照强度为 600 $\mu mol \cdot m^{-2} \cdot s^{-1}$ 时，三个样地成熟叶片都达到了光饱和点，光合速率差异不大。低样地秋茄在光照强度 600 $\mu mol \cdot m^{-2} \cdot s^{-1}$ 时就达到光饱和点，中、高样地在 1000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ 才达到光饱和点，且三个样地的光合速率差异显著，低样地光合速率始终低于另外两个样地；在相同条件下，光合速率白骨壤>秋茄。低样地上两种红树成熟叶片中超氧化物歧化酶（SOD）、过氧化物酶（POD）活性显著高于中、高样地，白骨壤和秋茄长期在水渍环境中，已经发展出一套完备的防护机制，从而免于被活性氧伤害，这两种红树植物具有一定的抗淹水能力。白骨壤成熟叶中丙二醛（MDA）三个样地上未达到显著性差异，秋茄在低样地高于另外两个样地。两个物种脯氨酸（Pro）含量在高程上都没有显著差异。两种红树叶片可溶性蛋白含量随高程升高而降低。白骨壤可溶性糖也有相似的规律，但秋茄在中样地上含量最高。淹水胁迫对红树的恢复起到一定的限制作用，秋茄的限制大于白骨壤，说明了白骨壤的耐淹性比秋茄强。

从后代的更新情况看，淹水对白骨壤+秋茄红树林的白骨壤果实和秋茄胚轴

的发育起一定作用。中样地白骨壤果实重量、大小及每株平均个数都大于另外两个样地。高样地秋茄胚轴重量及长度大于中样地，而低样地幼树尚未发育出胚轴。

从林缘、林内白骨壤幼苗的数量来看，三个样地没有显著差异，但是林内幼苗数量大于林缘。

从林缘、林内 2 月生白骨壤幼苗的生长和生理情况来看，林缘白骨壤幼苗单叶面积、基径、茎高，叶生物量、茎生物量和总生物量的最大值都出现在中样地的林缘滩面。在林缘，低样地幼苗叶片较厚，肉质化程度高，叶片数最多；三个样地根生物量差异不显著；林内不同样地幼苗生长差异主要体现在叶片和茎高上，低、中样地差异不大，比高样地叶片厚、肉质化程度高，叶片数多；除茎高外，林缘低、中、高样地的其它指标都明显高于林内，且光照对幼苗的影响大于高程的影响。

不同高程白骨壤幼苗某些生理的变化规律和幼树不同。低样地幼苗叶绿素含量最高；根系活力并没有受到淹水胁迫的影响；SOD 活性、POD 活性、MDA 含量、Pro 含量在白骨壤幼苗三个器官中不同，但在不同高程中有着相似的变化规律：MDA 含量随高程升高而降低，低样地的 SOD、POD 活性最高，质膜过氧化程度最高，需要更多活性氧清除剂；Pro、可溶性蛋白和可溶性糖在低样地含量最高，三者之间的相互作用，提高细胞的渗透势减少植株水分的流失。

从光照水平上看，林内光照强度低于林缘，根系活力比林缘低，但叶绿素含量和叶绿素 a/b 比值比林缘高，这是植物提高光合能力以适应隐蔽的条件；三个器官中中 MDA 含量在光照水平上未达到显著性差异；根中、林缘的 SOD 、POD 活性明显高于林内；根和茎 Pro 含量在光照上存在差异，林内根的 Pro 含量极显著高于林内，水分胁迫及缺少光照劣势生长环境下，林内白骨壤根系呼吸困难，水肥吸收受阻，增加 Pro 使细胞的保水和正常的代谢进行，增加抗逆性；光照有利于可溶性蛋白和可溶性糖的累积，尤其是可溶性糖。

关键词：红树　高程　人工造林

Abstract

After 4 years' reforestation, differences in growth and physiological responses of *Avicennia marina* and *Kandelia candel* and the next generation updating were studied at three tidal elevations （3.35，3.74，4.15 m of Xiamen sea-level respectively）with 0.5 m intervals，the same sediment background at coastal flat of Zengying, Xiamen.

These two mangroves at three tidal elevations were closed 4 years after reforestations. In terms of growth, stem heights, stem basal diameters, branches and crowm breaths of *A. marina* were highest at middle tidal elevatdion. Stem heights of *A. marina* at high tidal elevation were significantly lower than those at low tidal elevation, the other indexes at those two elevations had no significant difference. Stem heights, stem basal diameters, branches, crown breaths of *K. candel* were also highest at middle tidal elevatdion. Stem heights, branches at high tidal elevation were significantly higher than those at low tidal elveation. There was no significant difference in stem basal diameters and crown breaths between these two elevations. It was estimated from the growth advantages that middle tidal elevation (3.74 m) above the lowest sea level of Xiamen) was the best reforeataion elevation for *A. marina* and *K. candel*.

In terms of physiological responses, tidal elevation did not cause any differences in contents of chlorophyll in mature leaves of those two mangroves at three elevations. The photosynthesis rate of *A. marina* did not significantly differ among the elevations, but that of *K. candel* decreased at lower elevation. When light intensity was 600 μmol·m^{-2}·s^{-1}, *A. marina* reached the light saturation poin and photosynthetic rate showed no significant difference in elevations. When light intensity is 600 μmol·m^{-2}·s^{-1}, *K. candel* at low tidal evelation come to the light saturation poin, as the others at middle and high tidal elevations were 1000 μmol·m^{-2}·s^{-1}, there were also significantly different photosynthesis rate at three

elevations. Under the same conditions, photosynthetic rate was *A. marina* > *K. candel*. Superoxide dismutase (SOD), peroxidade (POD) activities in mature leaves of the two mangroves at low elevation were higer than those at other two elevations. *A. marina* and *K. candel* had developed a set of comprehensive protection mechanisms from the long-term floodinig environment to escape the hurt from reactive oxygen species (ROS). It showed the two mangroves had some resistances to hypoxia. Contents of malondiaidehyde (MDA) of *A. marina* did not reached significantly different at the three elevations, as *K. candel* showed less at low elevation than the other two; contents of proline (Pro) of the two mangroves showed no differ among the elevations. contents of soluble protein of the two mangroves were decreased by the elevations; Contents of soluble sugar of *A. marina* had the same rule, but that of *K. candel* was highest at middle elevation. Flooding threat had more limition on *K. candel* than *A. marina*. Therefore we concluded that *A. marina* had stronger waterlogging resistance.

In terms of generation updating, flooding had some influences on fruits of *A. marina* and hypocotyls of *K. candel* of the *A. marina*+ *K. candel* mangroves. Heights, sizes, numbers of per tree of fruits of *A. marina* at middle elevations were more than at the other two. Heights and lengths of hypocotyls of *K. candel* at high elevation were more than middle elevation, as there was no hypocotyls at low elevation.

In terms of number of *A. marina* seedlings under two light levels at three tidal elevations, there was no differ among the elevations, while there was significant difference between the two light levels: number of *A. marina* seedlings under mangrove canpoy was more than it under light gap.

Differences in growth and physiological responses of 2-month old *A. marina* seedlings were investigated under the forest canopy and in light gap of artificially planted mangroves at three tidal elevations. The maximum of area per leaf, stem basal diameter, stem height, leaf biomass, stem biomass and total biomass occurred in light gap of the middle elevation. In light gap, *A. marina* seedlings of the low tidal elevation had the highest leaf thickness, succulence and leaf number, but there was no significant difference in root biomass among these three tidal elevations. Under

mangrove canopy, there were no differences in growth parameters except for those of leaf characters and stem height. Seedlings of the low and middle elevations had higher leaf thickness, succulence and leaf number than those of the high tidal elevation. Except for the stem height, the growth parameters at the three tidal elevations in light gap were much higher than those under mangrove canopy. Effects of light level on growth of *A. marina* seedlings were much more serious than tidal elevation.

There were some different physiological responses between 2-month old *A. marina* seedlings and *A. marina* saplings. The seedlings had more chlorophyll contents at low elevation. Root activities were not affected by flooding. There were different SOD and POD activities, MDA and Pro contents in roots, stems and leaf numbers, but they had the same elevation tendency. MDA contents decreased with the elevation. There were high SOD, POD activities at low elevation to clear ROS. Contents of Pro, soluble protien, soluble sugar which had interations were highest at low elevation to enhance enzyme osmotic potential to avoid losing water.

In terms of light level, root activity under mangrove canopy was lower than that at light gap, but chlorophyll contents and Chl.a/b were in contrast because the plant needed to boost photosynthetic responses to adopt the shadow condition. MDA in three organs did not show significant difference between the two light levels. Activities of SOD, POD in roots at light gap were higher than those under mangrove canopy. Content of Pro in root and stem was significant different form that at light level. Under the water and light stresses, it was hard to respiration for roots which hampered to absorb water and nutrition. Therefore, the seedlings at mangrove gap need more Pro to protect enzyme from losing water and ensure normal metabolization. Light had advantages to acccumulate soluble protien and soluble sugar, special soluble sugar.

Key words: Mangrove; tidal elevation; reforestation

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