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厦门大学

博 士 学 位 论 文

九龙江口秋茄红树林生态系统的碳吸存与碳平衡

Carbon Sequestration and Balance in *Kandelia candel* Plantation Ecosystem in Jiulongjiang Estuary

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摘　要

本文选择福建九龙江口不同发育阶段（中龄林、成熟林）的秋茄红树林为研究对象，通过测定秋茄红树林林木层各器官、凋落物层和土壤层含碳率，结合各组分生物量和年净生产量，计算了秋茄红树林生态系统的碳储量和不同发育阶段秋茄林的年净固碳量。于 2010 年 5 月至 2011 年 4 月，采用 LI–8100 全自动土壤 CO_2 通量测定系统，研究了不同林龄秋茄林的土壤呼吸的日动态、月动态与季节差异，及其土壤水热因子对土壤呼吸的影响。通过测定样地的土壤含碳率和碳储量，以及秋茄林生态系统地上部分的年固碳量，分析评价了秋茄红树林生态系统的碳源-碳汇能力，以期为准确评估我国东南沿海秋茄红树林生态系统的碳汇能力提供科学依据。主要研究结果如下：

（1）秋茄林林木层、凋落物层和土壤层含碳率在不同发育阶段以及同一发育阶段不同器官间存在显著差异，各器官含碳率随发育阶段而有所变化。其中，中龄和成熟秋茄林生态系统碳储量分别为183.31和244.45 $t·hm^{-2}$，随林龄升高而升高，植被层碳储量分别为162.45和222.95 $t·hm^{-2}$；凋落物层碳储量则表现出不同的变化规律，分别为15.05和16.99 $t·hm^{-2}$；土壤层和林木层碳储量在生态系统碳储量中的比例随林龄增大而升高。

（2）凋落物作为土壤呼吸的地上部分的主要碳源，是红树林生态系统初级生产力的重要组成部分。秋茄中龄林和成熟林年凋落物量分别为10.08和13.02 $t·hm^{-2}$，不同发育阶段间存在显著差异。年凋落物量中叶占60.69%，枝占23.64%，花占8.22%，果实占7.45%。凋落量的峰值出现在台风多发季（7～9月），以9月份凋落量最大。凋落物碳素含量的季节变化为夏季>春季>秋季>冬季。

（3）随着林龄的增大，土壤中可溶性有机碳（DOC）含量升高，中龄林的43.92 $mg·kg^{-1}$升高到成熟林的51.60 $mg·kg^{-1}$。两种林分0～10 cm土层中微生物生物量碳（MBC）平均含量分别为37.31和42.58 $mg·kg^{-1}$。

（4）以秋茄中龄林为例，土壤呼吸通量在 2010 年 7 月、10 月和 2011 年 1 月、4 月的日均值分别为 6.18、2.24、0.55 和 0.85 $\mu molCO_2·m^{-2}·s^{-1}$。2010 年 10 月和 2011 年 4 月的土壤呼吸速率日动态表现为单峰型，日最高值出现在 14:00，最低值出现在 00:00；而 2010 年 7 月和 2011 年 1 月的日动态则显示出不同的趋势，最大值出现在 08:00 和 10:00 而最低值分别出现在 22:00 和 04:00，样地土壤

呼吸的日均值出现在 08:00。秋茄红树林土壤呼吸速率的季节动态表现为单峰曲线，最大值出现在 7 月，最小值出现在 12 月；这与林地的生态因子（主要是 5 cm 深处土壤温度）有着相似的变化动态；秋茄中龄林土壤呼吸速率和呼吸速率的月际变化幅度都高于成熟林，其中中龄林和成熟林土壤呼吸速率月际变化幅度分别为 5.82 和 4.92 $\mu molCO_2 \cdot m^{-2} \cdot s^{-1}$，土壤呼吸速率分别为 1.72 和 1.70 $\mu molCO_2 \cdot m^{-2} \cdot s^{-1}$。

（5）本研究主要从温度方面来探讨土壤呼吸速率的影响因子并构建相关呼吸模型。土壤呼吸速率与气温、5 cm 土温和 10 cm 土温 3 个指标均有较好的指数关系，其中拟合度最好的是 5 cm 土温，中龄林和成熟林中的 R^2 分别为 0.672 和 0.588，基于 5 cm 土温的 Q_{10} 值（温度每升高 10℃，土壤呼吸速率所增加的倍数）分别为 3.706 和 2.858。研究数据表明：土壤含水量与土壤呼吸无显著关系，在样地未淹水的情况下，土壤含水量不会成为土壤呼吸的限制性因子；而水位的变化对土壤呼吸起着重要的影响，土壤呼吸的日最高值一般在当天的最低潮时左右出现。凋落物量的变化对土壤呼吸速率的变化无显著影响。

（6）秋茄中龄林和成熟林均表现出了碳汇功能，其中中龄林（18.51 $t \cdot hm^{-2} \cdot a^{-1}$）年净固碳量较大，而成熟林（7.01 $t \cdot hm^{-2} \cdot a^{-1}$）的碳汇功能较低。

关键词： 碳储量，红树林，秋茄，土壤呼吸，碳平衡

Abstract

The carbon storage and net carbon sequesation of different ages plantations was studied at a subtropical *Kandelia candel* mangrove wetland in Jiulongjiang Estuary. The carbon content of organs and soil in tree, litterfall and soil layers was measured, and then carbon storage and net carbon sequesation were calculated by carbon content and biomass or net productivity of plantations. The diurnal, monthly and seasonal dynamics of soil respiration were studied from May 2010 to April 2011 by LI-8100 Automated Soil CO_2 Flux System.

(1) There were significant difference for carbon content in tree layer (leaf, branch, stem, bark and root), litter layer and soil layer of *K. candel* mangrove at different development stages, so the carbon content of different organs. The carbon storage of *K. candel* mangroves increased with forest ages and were 183.31 and 244.45 $t\cdot hm^{-2}$ in middle-aged and mature plantations, respectively. The carbon storage of tree layer in middle-aged and mature plantations were 162.45 and 222.95 $t\cdot hm^{-2}$, respectively. But litter layers showed different pattern, the carbon storage were 15.05 and 16.99 $t\cdot hm^{-2}$, respectively. The proportion of tree layer and soil carbon storage in total carbon storage increased with forest ages.

(2) As the main carbon source of the aerial parts of soil respiration, litter is an important part of the primary productivity of mangrove ecosystem. There were significant difference for litter biomass between different ages and were 10.08 and 13.02 $t\cdot hm^{-2}$ in middle-aged and mature plantations, respectively. 60.69% of annual litter production was leaf, 23.64% were branch and 8.22% were flower. The peak value of litter biomass occurred in May and from July to September with the maximum in September. The carbon content of litter in different seasons followed the order: summer > spring > autumn > winter.

(3) DOC Concentration of soil increased with increase of forest ages, and were 43.92 and 42.58 $mg\cdot kg^{-1}$ in middle-aged and mature plantation, respectively. The average of MBC concentration of soil in 0-10 cm soil layer in middle-aged and mature plantation were 37.31 and 42.58 $mg\cdot kg^{-1}$, respectively.

(4) The soil respiration of middle-aged plantation in July and October of 2006, January and April of 2007 were 6.18、2.24、0.55 and 0.85 $\mu mol\ CO_2\cdot m^{-2}\cdot s^{-1}$. Similar patterns in the diurnal variation of soil respiration were found on 2 October and 11

April, with the maximum values at 14:00 and the minimum at 00:00. The diurnal patterns on 8 July and 15 January were completely different, with the maximum values appearing at 08:00 to 10:00 and the minimum at 22:00 and 04:00, respectively. The daily mean values of soil respiration were close to the measurements taken at 08:00. Soil respiration fluctuated with distinct seasonal patterns. The seasonal variation was characterized by a mono-peak pattern, with the highest rate (6.18 μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$) in July, and the lowest rate (0.36 μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$) in December. The monthly dynamics of soil respiration rates were similar, which were also similar with meteorological factors (mainly soil temperature at 5 cm depth and water content). The change extent of soil respiration rates in middle-aged plantation (5.82 μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$) were higher than in mature (4.92 μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$) plantations.

(5) The factors, which impacted soil respiration rate, were researched from temperature and the amount of soil respiration on the basis of modeling by this factor was estimated. The relationships between soil respiration rate and temperature, soil temperature at 5 cm depth and soil temperature at 10 cm depth were analyzed based on multiple regressions. The correlations of them both were power exponent ($R = ae^{bT}$). There was the most significant correlation between soil respiration rate and soil temperature at 5 cm depth, and R^2 were 0.672 and 0.588, Q_{10} were 3.706 and 2.858 in middle-aged and mature plantations, respectively. The result showed that the variation of soil respiration in mangrove wetland was mainly controlled by soil temperature, and there was no significant correlation between soil respiration and soil water content. The daily maximum value of soil respiration occurred around the lowest tide time. Therefore, the water level may have an important influence on soil respiration. There was no significant correlation between soil respiration and litter fall.

(6) The net amount of carbon storage was higher middle-aged (18.51 $t \cdot hm^{-2} \cdot a^{-1}$) than in mature plantations (7.01 $t \cdot hm^{-2} \cdot a^{-1}$), which indicated that the *K. candel* mangrove ecosystem acted as a carbon sink.

Key words: Carbon storage, Mangrove, *Kandelia candel*, Soil respiration, Carbon balance

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