毛竹新竹爆发式生长期的碳输入及其水驱动机制研究

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摘　要：【目的】毛竹（*Phyllostachys edulis*）是我国分布面积最广、人工栽植面积最大的竹种，具有生长快、用途广泛等特点，其生态和经济效益突出。毛竹高速生长（即“爆发式生长”）的特点是这些效益的保障。然而新竹在完成高生长前几乎没有叶片，缺少叶片意味着此时的新竹为非自养型，其生长所需的非结构性碳（Non-structural Carbohydrate，NSC）可能依赖外部提供。前人研究认为母竹储存碳是新竹生长的碳来源，然而并未明确母竹叶片在“爆发式生长”期间新产生碳的贡献及外部碳源进入新竹的驱动力问题。【方法】（1）利用高清摄像头连续动态监测“爆发式生长”期竹笋高度，获取小时尺度的高生长数据；（2）在“母竹-竹鞭-新竹”实验体上，通过断鞭、去叶处理，检测母竹茎秆非结构性碳含量在新竹生长期的动态，探索母竹茎秆储存碳以及母竹叶片光合固定的新碳向新竹的转移；（3）使用 TDP+技术监测竹鞭液流，研究新竹高生长期间的水分利用特点；（4）综合分析新竹高生长特点、同步监测的竹鞭液流特点、以及新竹非结构性碳含量动态，探索碳水协同运输及碳水对新竹高生长的影响机制。【结果】（1）新竹在“爆发式生长”期，其日平均高生长量呈现慢-快-慢格型，到 4 月 25 日左右达到高生长的最大值（约 70 cm），高生长量在夜间（30.13±8.21 cm）明显高于白天（20.64±5.97 cm），夜间平均高生长量比白天多 9.5 cm。（2）在母竹转移给新竹的碳中，储存的老碳约占 50% - 55%，叶片光合产生的新碳约占 45% - 50%，表明母竹叶片光合产生的新碳对新竹生长的重要意义，且母竹的新、老碳可能存在交替供应新竹生长的现象。研究发现在新竹展业前期，母竹供应新竹生长碳的类型存在大小年现象，小年以淀粉为主（57%），大年以可溶性糖为主（64%）。伴随高生长，新竹茎秆 NSC 含量下降，其中可溶性糖约占下降 NSC 总量的 90%，淀粉约占 10%，新竹在“爆发式生长”期间以消耗可溶性糖为主。（3）母竹液流日动态格型呈现典型的单峰格型，新竹展叶前呈现“昼低夜高”的相反格型，展叶后与母竹液流格型相同。竹鞭液流在新竹展叶前呈现与新竹相同的日格型，白天液流从新竹流向母竹，夜间液流从母竹流向新竹（“昼出夜入”）。表明在新竹爆发式生长期间，竹林水分资源白天更多的分配给母竹，夜间分配给新竹。（4）母竹在爆发式生长期向新竹转移碳，但新竹在此期间所需的碳高于母竹转移给新竹的量（137.63 mg.g-1 vs. 30.21 mg.g-1），研究表明母竹并不是新竹唯一的碳来源，可能还包括新竹地下根鞭系统储存的碳、新竹茎秆和笋箨光合产生的碳。研究发现竹鞭正向液流日累积量（母竹流向新竹）和新竹 NSC 含量呈现显著正相关，暗示了新竹获取碳的过程可能存在水的协同。【结论】毛竹新竹爆发式生长期的研究结果表明，新竹的碳来源不仅仅是母竹的储存碳，还包括母竹叶片光合作用产生的新碳。同时，研究结果还揭示了碳进入新竹与水分存在协同作用的机制。研究为理解毛竹爆发式生长的生理机制提供了重要线索。

关键词：毛竹；爆发式生长期；非结构性碳；液流；碳水协同转运

Study on Carbon Uptake and Water-Driven Mechanism during the Explosive Growth Period of Newly Sprouted Moso Bamboo

Abstract: 【Objective】 Moso bamboo (*Phyllostachys edulis*) is China's most widely distributed and artificially

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planted bamboo species, characterized by fast growth, versatility, and outstanding ecological and economic benefits. The high growth rate, or "explosive growth," guarantees these benefits. However, the lack of leaves means the new bamboo is non-autotrophic and may rely on external sources of non-structural carbon (NSC) for growth. Previous studies suggested that stored carbon in the mother culm is the carbon source for newly sprouted culm growth. However, the contribution of newly produced carbon from the mother culm leaves during "explosive growth" and the driving force of external carbon sources into the newly sprouted culm remain unclear.【Methods】 (1) Continuous dynamic monitoring of bamboo shoot height during the "explosive growth" period using thermal infrared cameras to obtain hourly scale height growth data; (2) Examining the dynamics of non-structural carbon content of mother culm stalks during the growth period of new culm by breaking the whip and removing leaves in the "mother culm- rhizome -new culm" experiment, and exploring the carbon stored in the mother culm and the transfer of new carbon fixed by photosynthesis in mother leaves to the newly sprouted culm; (3) Monitoring bamboo rhizome sap flow using TDP+ technology to study the water use characteristics of new bamboo during culm growth; (4) Exploring the synergistic carbon and water transport mechanisms and the influence of carbon and water on the growth of newly sprouted culms by combining the characteristics of growth of newly sprouted culms, the simultaneous monitoring of bamboo rhizome sap flow, and the dynamics of non-structural carbon content of newly sprouted culms.【Results】(1) During the "explosive growth" period, the average daily height growth of newly sprouted culms showed a slow-fast-slow pattern, reaching maximum height growth (about 70 cm) around April 25. Height growth was significantly higher at night (30.13±8.21cm) than during the day (20.64±5.97cm), with average height growth at night being 9.5 cm higher than during the day. (2) Among the carbon transferred from the mother bamboo to the newly sprouted culm, stored old carbon accounted for about 50%-55%, and new carbon produced by leaf photosynthesis accounted for about 45%-50%. This indicates the importance of new carbon produced by leaf photosynthesis of the mother culm for the growth of the newly sprouted culm and the possible existence of an alternating supply of new and old carbon from the mother culm to the newly sprouted culm. It was found that the type of carbon supplied by the mother culm to newly sprouted culm differed between on-year and off-year, with starch dominating in the off-year (57%) and soluble sugars in the on-year (64%). Soluble sugars accounted for about 90% of the total NSC content, and starch accounted for 10%. Soluble sugars were mainly consumed during the "explosive growth" period. (3) The daily dynamic pattern of sap flow in the mother culm showed a typical unimodal pattern, while the newly sprouted culm showed the opposite pattern of "low day and high night" before leaf development and the same pattern as the mother culm after leaf development. The flow pattern of the bamboo rhizome before leaf development showed the same daily pattern as that of newly sprouted culms, with flow from the newly sprouted culm to the mother culm during the daytime and from the mother culm to the newly sprouted culm during nighttime ("day-out and night-in"). This indicates that during the explosive growth of newly sprouted culms, bamboo forest water resources were allocated more to the mother bamboo during the daytime and to the newly sprouted culm during nighttime. (4) The mother culm transferred carbon to the newly sprouted culm during the explosive growth period, but the newly sprouted culm required more carbon during this period than the mother culm transferred to the newly sprouted culm (137.63 mg.g-1 vs. 30.21 mg.g-1). This suggests that the mother culm is not the only carbon source for the newly sprouted culm but may also include carbon stored in the underground rhizome system of the new culm and carbon produced by photosynthesis of the newly sprouted culm stems and culm sheaths. A significant positive correlation was found between the daily accumulation of positive sap flow from the bamboo rhizome (mother culm to new culm) and the NSC content of newly sprouted culms, suggesting a possible water synergy in the acquisition of carbon by newly sprouted culms.【Conclusion】The findings from this study on the "explosive growth" phase of moso bamboo shoots indicate that the carbon source for new shoots includes not only stored carbon from mother bamboo but also newly fixed carbon from mother bamboo foliage. Additionally, the results reveal water's collaborative role in the carbon influx into new shoots. These findings provide valuable insights into the physiological mechanisms underlying the explosive growth of moso bamboo and have significant implications for the efficient cultivation and management of this species.

Keywords: Moso bamboo; the explosive growth period; non-structural carbohydrate; sap flow; Synergistic transport of carbon and water.