

施氮对毛竹林土壤胞外酶活性的影响

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摘要:【目的】以中国重要的经济和生态资源竹种毛竹 (*Phyllostachys edulis*) 为研究对象, 在全球氮沉降加剧的背景下, 通过设定不同施氮水平的田间实验, 系统探讨施氮对毛竹林土壤碳、氮、磷相关的胞外酶活性的影响, 并阐明土壤胞外酶在毛竹林土壤养分循环中发挥的关键作用, 进一步深入理解施氮对土壤养分循环的综合效应。【方法】使用随机区组设计, 包含四种施氮处理 (0、242、484、726 kg N·ha⁻¹·yr⁻¹), 试验自 2021 年 10 月开始。每个处理在 3 个 15m×15m 的样地内重复, 并在样地间设置 5m 的缓冲区; 试验所施氮肥为尿素 (N 46.4%), 各处理配施磷、钾肥 (过磷酸钙、氯化钾)。土壤样品按年份从样地中用土钻采集, 样品过 2mm 筛后, 储存在 4℃ 下以备分析。土壤胞外酶 β -1,4-葡萄糖苷酶 (BG)、N-乙酰- β -D-葡萄糖苷酶 (NAG)、亮氨酸氨基肽酶 (LAP) 和酸性磷酸酶 (ACP) 使用酶标仪法测定; 土壤 pH、有机碳、全氮和有效磷等遵循标准方法。采用单因素方差分析 (ANOVA) 评估施氮对土壤性质和土壤胞外酶活性的影响, 采用 Pearson 相关分析研究了土壤胞外酶和土壤性质之间的关系, 使用 R 软件对土壤性质和土壤胞外酶活性进行冗余分析 (RDA) 分析, 确定影响土壤施氮最显著因素。【结果】研究结果表明, 适量施氮 (242kg N·ha⁻¹·yr⁻¹) 能够显著提高土壤胞外酶活性, 尤其是亮氨酸氨基肽酶 (LAP)、N-乙酰- β -D-葡萄糖苷酶 (NAG)、亮氨酸氨基肽酶 (LAP) 和酸性磷酸酶 (ACP), 进而促进土壤碳氮磷的转化与矿化过程, 表明适度施氮有助于增强土壤微生物的分解能力和养分释放效率。然而, 高剂量施氮 (726 kg N·ha⁻¹·yr⁻¹) 抑制了部分胞外酶活性, 导致土壤养分有效性下降, 可能对生态系统产生负面影响。冗余分析结果进一步表明, 胞外酶活性与土壤有机碳、有效氮等养分含量存在显著相关性。【结论】本研究揭示了施氮对毛竹林土壤胞外酶活性和养分循环的复杂影响, 适量施氮不仅促进了土壤养分的转化与可用性, 还有助于维持土壤生态系统的健康。而过量施氮则可能引发负面反馈, 降低土壤微生物活动和胞外酶活性, 从而影响养分循环的效率。因此, 为了促进土壤健康和毛竹林生产力的可持续发展, 建议施氮量应控制在中等水平。此外, 未来的研究可以进一步探讨不同施氮策略对胞外酶活性的长期影响及其在不同土壤类型中的适用性, 以提供更具有针对性的管理建议。

关键词: 毛竹林; 施氮; 胞外酶活性; 土壤养分循环; 氮沉降

The effect of Nitrogen Application on Soil Extracellular Enzyme Activity in *Phyllostachys edulis* Forests

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Abstract: 【Objective】 This study focuses on the economically and ecologically significant bamboo species, *Phyllostachys edulis*, against the backdrop of increasing global nitrogen deposition. We systematically investigate the effects of nitrogen fertilization on soil extracellular enzyme activities related to carbon, nitrogen, and phosphorus in bamboo forests, aiming to elucidate the critical role of soil extracellular enzymes in nutrient cycling and further deepen our understanding of the comprehensive effects of nitrogen application on soil nutrient dynamics. 【Methods】 A randomized block design was employed, comprising four nitrogen treatment levels (0, 242, 484, 726 kg N·ha⁻¹·yr⁻¹). The experiment commenced in October 2021. Each treatment was replicated in three 15m × 15m plots, with a 5m buffer zone between plots. Urea (N 46.4%) was applied as the nitrogen source, alongside phosphorus and potassium fertilizers (calcium superphosphate and potassium chloride). Soil samples were collected annually using soil augers, passed through a 2mm sieve, and stored at 4℃ for analysis. The activities of soil extracellular enzymes, including β -1,4-glucosidase (BG), N-acetyl- β -D-glucosaminidase (NAG), leucine aminopeptidase (LAP), and acid phosphatase (ACP), were measured using a microplate reader; soil pH, organic carbon, total nitrogen, and available phosphorus were determined following standard methods. One-way ANOVA was conducted to assess the effects of nitrogen application on soil properties and extracellular enzyme activities. Pearson correlation analysis was employed to explore the relationships between soil extracellular enzymes and soil properties, while redundancy analysis

(RDA) using R software was performed to identify the most significant factors affecting soil nitrogen application. **【Results】** The results indicate that moderate nitrogen application ($242 \text{ kg N} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$) significantly enhances soil extracellular enzyme activities, particularly LAP, NAG, and ACP, thereby promoting the transformation and mineralization of soil carbon, nitrogen, and phosphorus. This suggests that appropriate nitrogen application can enhance microbial decomposition capabilities and nutrient release efficiency. Conversely, high nitrogen application rates ($726 \text{ kg N} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$) inhibited certain enzyme activities, leading to decreased nutrient availability in the soil, which could have negative implications for the ecosystem. RDA results further revealed significant correlations between extracellular enzyme activities and nutrient contents, such as soil organic carbon and available nitrogen. **【Conclusion】** This study uncovers the complex impacts of nitrogen application on extracellular enzyme activities and nutrient cycling in bamboo forests. Moderate nitrogen application not only facilitates the transformation and availability of soil nutrients but also helps maintain the health of the soil ecosystem. In contrast, excessive nitrogen application may induce negative feedbacks, reducing microbial activity and extracellular enzyme function, thereby affecting nutrient cycling efficiency. Therefore, to promote soil health and the sustainable productivity of bamboo forests, nitrogen application rates should be maintained at moderate levels. Future research should further explore the long-term effects of different nitrogen strategies on extracellular enzyme activities and their applicability across various soil types to provide more targeted management recommendations.

Key words: *Phyllostachys edulis*, nitrogen application, extracellular enzyme activity, soil nutrient cycling, nitrogen deposition