

## 不同火烈度下油松林植物细根功能性状-土壤理化性质耦合关系研究

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**摘要:** 植物功能性状可以反映植物对外部环境的适应对策, 细根在植物养分获取中发挥着关键作用。不同火烈度条件下植物通过调整其功能性状以适应火环境, 细根对林火的响应较为迅速, 因此研究油松林植物细根功能性状及土壤理化性质在不同火烈度条件下的变化特征, 探讨二者之间的耦合关系及关键影响因子, 为火烧迹地的生态恢复提供理论基础。我们以油松林火烧迹地为研究对象, 根据不同火烈度(低、中、高烈度)及未过火共设置 12 块样地。通过植物细根调查和土壤理化性质实验, 分析了不同火烈度下细根功能性状和土壤理化性质的差异性和变化趋势。采用耦合协调度模型(Coupling Coordination Degree Model, CCDM)评价二者间的耦合协调度, 并利用偏最小二乘路径模型(Partial Least Squares Path Modeling, PLS-PM)进一步明确耦合协调度的影响机制。不同火烈度下油松林植物细根功能性状与土壤理化性质均存在不同程度的显著差异性( $P < 0.05$ )。细根功能性状-土壤理化性质的耦合协调度在不同火烈度下均处于中级(0.4~0.6), 具体表现为对照(0.491) > 中烈度(0.484) > 高烈度(0.449) > 低烈度(0.438)。火烧对油松林植物细根-土壤耦合协调度产生间接的负作用, 耦合协调度主要受细根形态性状(由比根长等反映)和土壤养分(由 N、AP 等表示)的直接正效应。中烈度下油松林植物细根-土壤的协同恢复水平较高, 二者具有较好的耦合协调程度; 低烈度条件下建议采取土壤增温等措施重点改善细根的形态特征, 高烈度下建议施加适量的氮肥等土壤肥料重点改善土壤环境。

## Effects of Fire Severity on the Coupling Relationship Between Fine Root Functional Traits and Soil Physicochemical Properties in *Pinus tabulaeformis* forest

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**Abstract:** Plant functional traits are key for understanding the adaptive strategies to environments, and fine roots play a crucial role in nutrient acquisition. Examining the variation of functional traits of fine root and soil physicochemical properties, and investigating their coupling relationships and dominating factors, could provide a theoretical foundation for ecological restoration in the burned forest. We established 12 plots within *Pinus tabulaeformis* forests subjected to light, moderate, and severe fire severities. Through

detailed analysis of fine roots and soil physicochemical properties, we evaluated the variations and coupling effects in fine root functional traits and soil properties using the Coupling Coordination Degree Model (CCDM) and Partial Least Squares Path Modeling (PLS-PM). Our results showed significant differences in the functional traits of fine root and soil physicochemical properties across fire severities ( $P < 0.05$ ). The coupling coordination degrees between fine root functional features and soil physicochemical properties ranged from 0.4 to 0.6, with the following order: unburned, moderate, severe, and light severity. Forest fire negatively impacted the coupling coordination degree indirectly, primarily influenced by the direct positive effects of fine root morphological traits (e.g., specific root length) and soil nutrient properties (e.g., nitrogen, available phosphorus). The synergistic recovery of fine root-soil systems in *Pinus tabulaeformis* forests was most pronounced following moderate fire severity, showing a medium-level coordination degree. For light-severity fires, enhancing fine root morphological characteristics through soil warming is recommended. In contrast, it is suggested to apply appropriate nitrogen and soil fertilizers for improving soil conditions after severe fire.