望天树人工林根际土壤微生物群落随林龄变化特征及其对磷限制的影响

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摘　要:【目的】本研究旨在分析亚热带龙脑香科濒危树种人工林根际土壤养分现状和微生物群落特征，明确林龄对土壤真菌和细菌群落结构及功能的影响，以及根际微生物在磷素转化过程中发挥的关键作用，并揭示微生物群落与磷素有效性和磷限制的相关关系。【方法】以 6 个林龄的望天树人工纯林为研究对象，采集根际土壤，通过分析微生物群落多样性与磷组分的动态转化特征，揭示它们之间的相互影响及随年龄的变异特征。【结果】（1）6 个林龄的林地根际土壤处于强酸性和缺磷状态，Fe^{3+}对磷的强吸附作用和高含量稳定态有机磷严重制约着土壤磷供应；（2）在长时间尺度上，根际土壤酸性磷酸酶活性和微生物量磷是难溶性磷活化的主要驱动因子，pH、有效磷、酸性磷酸酶活性和铵态氮是驱动微生物群落多样性变异的关键因子；（3）随着林龄增加，多数土壤理化和养分指标呈先升后降的趋势；到造林后期，各形态磷向有效磷的转化由易变难，磷有效性下降，土壤肥力开始衰退；但是细菌群落仍能够维持稳定的物种丰度和多样性，真菌群落的均匀度有增加趋势；（4）真菌群落的结构组成和功能多样性变异比细菌更显著，真菌比细菌更能适应低磷环境；优势真菌的生长比细菌更有利、能更好地指示土壤磷有效性和土壤质量。【结论】随林龄增加，根际土壤酸性磷酸酶活性降低减缓了有机磷向生物有效性无机磷矿化的过程，全磷向有效磷的转化能力逐渐减弱，土壤有机质和有效态氮、磷、钾含量降低，导致养分限制。然而，望天树根际可以形成耐酸耐低磷的微生物群落从而保证较高的微生物群落丰度和均匀度，在一定程度上可以维持磷的有效性并缓解磷限制。同时，我们建议在望天树人工造林后，适当延长追肥期将有利于维持土壤磷供应能力，保证有益微生物和树木的正常生长发育。该研究有助于提高人们对酸性低磷红壤区人工林地力维持机制的理解，也可为濒危植物的迁地保护和人工造林等过程中的土壤适配、施肥期限和根际菌群结构维持等工作提供科学参考。

关键词: 望天树；亚热带濒危树种；低磷限制；磷有效性；磷形态转化；根际微生物多样性

中图分类号 Q958.15；S154.5　　**文献标识码：** A　　**文章编号：**1001-7488（）-0000-00

Variation characteristics of microbial community in rhizosphere soil of *Parashorea chinensis* plantations with stand age and its effect on phosphorus limitation

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Abstract:【Objective】The aim of this study was to analyze the current status of rhizosphere soil nutrients and microbial community characteristics in plantations of endangered tree species of Dipterocarpaceae in the

subtropics, to clarify the effects of stand age on the structure and function of soil fungal and bacterial communities, and the key role played by rhizosphere microorganisms in the phosphorus (P) conversion process, and to reveal the correlation between microbial communities and P availability and P limitation.【Method】Six stands of pure *Parashorea chinensis* plantation were collected from rhizosphere soils, and the dynamic transformation characteristics of microbial community diversity and P fraction were analyzed to reveal the interaction between them and the variation characteristics with stand age.【Result】(1) The rhizosphere soils of six stands were in a strongly acidic and P-deficient state, with strong P sorption by Fe^{3+} and high levels of steady-state organic P severely constraining soil P supply; (2) On long time scales, acid phosphatase activity and microbial biomass P were the main drivers of insoluble P activation, and pH, available P, acid phosphatase activity and ammonium nitrogen were key factors driving variation in microbial community diversity; (3) With the increase of forest age, most of the soil physicochemical and nutrient indicators showed a trend of increasing and then decreasing; at the later stage of silviculture, the conversion of other forms of P to available P became increasingly difficult, P availability decreased, and soil fertility began to decline; however, the bacterial community was still able to maintain stable species abundance and diversity, and the evenness of the fungal community tended to increase; (4) the variation of structural composition and functional diversity of the fungal community was more significant than that of bacteria, and fungi were better adapted to the low P environment than bacteria; the growth of dominant fungi was more favorable than that of bacteria, and could better indicate soil P effectiveness and soil quality. 【Conclusion】With the increase of stand age, the decrease of acid phosphatase activity in rhizosphere soils moderates the process of mineralization of organic P to bioeffective inorganic P, the conversion of total P to available P gradually weakens, and the content of soil organic matter and available state N, P, and K decreases, leading to nutrient limitation. However, the rhizosphere surroundings of *Parashorea chinensis* can form acid-tolerant and low P-tolerant microbial communities, thus ensuring higher microbial community abundance and homogeneity, which can maintain P effectiveness and alleviate P limitation to some extent. At the same time, we suggest that an appropriate extension of the fertilization period after the plantation of *Parashorea chinensis* will be beneficial to maintain the soil P supply capacity and ensure the normal growth and development of beneficial microorganisms and trees. This study helps to improve our understanding of the mechanisms of soil maintenance in plantations in acidic low P red soil areas, and may also provide scientific reference for soil suitability, fertilization duration and maintenance of rhizosphere microbial community structure during the relocation of endangered plants for conservation and plantation, etc.

Key words: *Parashorea chinensis*; subtropical endangered tree species; phosphorus limitation; phosphorus effectiveness; phosphorus form transformation; rhizosphere microbial diversity