国家自然科学基金研究专著
NATIONAL NATURAL SCIENCE FOUNDATION OF CHINA

杉木人工林长期生产力保持机制研究

盛炜彤　范少辉　等　著

Long Term Productivity of Chinese Fir Plantations

科学出版社
www.sciencep.com

国家自然科学基金研究专著
NATIONAL NATURAL SCIENCE FOUNDATION OF CHINA

杉木人工林长期生产力保持机制研究

Long Term Productivity of Chinese Fir Plantations

盛炜彤　范少辉 等　著

科学出版社
北京

内 容 简 介

杉木人工林长期生产力保持机制研究，分别在福建南平、福建尤溪与江西分宜三种不同自然和岩性条件下进行。重点研究了杉木及其人工林自身对土壤肥力的影响，杉木人工林育林干扰对土壤养分损耗和土壤功能的影响，杉木人工林的土壤变化，杉木营养特性与人工林生产力和碳分配，连作对杉木人工林生产力、碳分配及养分生物循环的影响，连作对杉木生长影响机制探索等 6 个方面，并提出了杉木人工林立地生产力下降原因机制和保持长期生产力途径。本书是作者长期深入系统研究的成果综合，资料丰富翔实，对人工林长期生产力保持在理论与实践上有指导价值。

本书适于林业科研和教学工作者阅读，也可供林业行政部门的技术干部和从事林业第一线工作的技术人员参考。

图书在版编目(CIP)数据

杉木人工林长期生产力保持机制研究/盛炜彤，范少辉等著. —北京：科学出版社，2005

ISBN 7-03-015733-8

I. 杉… II. ①盛… ②范… III. 杉木-人工林-生产力-研究 IV. S791.27

中国版本图书馆 CIP 数据核字(2005)第 065127 号

责任编辑：莫结胜 李久进/责任校对：刘小梅

责任印制：钱玉芬/封面设计：耕者设计工作室

科学出版社 出版

北京东黄城根北街 16 号

邮政编码：100717

http://www.sciencep.com

中国科学院印刷厂 印刷

科学出版社编务公司排版制作

科学出版社发行 各地新华书店经销

*

2005 年 12 月第 一 版 开本：787×1092 1/16

2005 年 12 月第一次印刷 印张：17 插页：4

印数：1—1 200 字数：403 000

定价：68.00 元

(如有印装质量问题，我社负责调换〈科印〉)

前　言

1997~2001 年，我们承担了国家自然科学基金重点项目“杉木、桉树人工林长期生产力保持机制的研究”，经过 5 年在三个点上的系统研究，完成了预定的研究任务，于 2002 年 3 月 23 日通过了国家自然科学基金委员会生命学部组织的专家验收，取得了总评价为“A”的成绩。出版本书的目的在于反映我国对人工林长期生产力的研究成果，促进学术交流，为维护和提高人工林生产力做出贡献。

人工林的稳定性问题是一个世界性问题，1997 年出版的《欧洲人工林培育》(牛津大学出版社)一书在人工林长期生产力的论述中认为关于与单作相联系的人工林生物稳定性和潜在问题仍有许多需要研究。自 20 世纪 80 年代以来，长期生产力保持成为人工林生态学重要问题而被广泛关注。1990 年的国际林业研究联合会第十九届世界大会及 1991 年第十届世界林业大会都将人工林长期生产力作为重要议题加以讨论。1993 年美国林业协会提出了“森林健康及生产力长期保持”的特别报告，1995 年世界林业研究中心(CIFOR)实施了“热带人工林长期生产力研究”项目。这些都反映了人工林长期生产力保持已成为世界人工林发展中的一个重要问题。人工林长期生产力保持主要存在三个问题：一是人工林气候适应能力差，易引起大面积的风倒雪压，对酸雨反应也较敏感；二是由于人工林树种单一易遭病虫害袭击；三是由于树种单一性，特别是针叶树和育林实践干扰易引起地力退化。目前在地力退化问题上研究较多，有着许多报道，但迄今为止由于人工林连作代尚未大量形成或者由于育林措施影响和树种本身影响难于分开，还由于缺乏长期观测的试验基地与网络，如树种本身是否会导致地力衰退，是否存在第二代效应等也还存在争论。再如当前实行人工林的集约栽培及利用范围扩大对土壤养分带来什么后果，各种育林措施(包括收获)干扰对土壤肥力及林木生长产生什么影响，这些问题都还在研究探索之中，有些问题还需要科学地设置试验地，对人工林生态系统的基本过程加以长期观测研究，才能做出科学的解释和结论。

我国杉农很早就发现杉木林地力退化问题。20 世纪 60 年代初由中国科学院沈阳林业土壤研究所在湖南会同进行研究，证明了杉木人工林地力衰退的存在，并对连作杉木人工林土壤肥力和中毒问题进行了多年探索。以后，中国林业科学研究院林业研究所，在研究杉木人工林速丰产林过程中，也深切地认识到因地力衰退严重影响了杉木人工林生产力的保持，各地杉农迫切要求尽快为他们提供技术支持。为此，在“七五”国家科技攻关专题“杉木人工林集约栽培技术研究”中，将“提高与维护杉木林地土壤肥力”作为一个重要研究内容列入攻关；同时在与杉木人工林地力衰退有关的问题研究中也连续多次获国家自然科学基金的资助，并取得了“杉木人工林地力衰退及防治技术研究”成果。在此期间，南京林业大学等单位也进行过相关研究。但上述这些研究，由于人力和经费所限，研究地点比较分散，内容不够系统，未能从地力衰退的机制上加以深入研究。因此，1997~2001 年笔者又获得国家自然科学基金对本研究项目的资助，本书就是在此项目的基础上结合以往的研究写成的。

杉木人工林长期生产力保持机制研究，分别在下面3个不同自然地理条件下进行：①福建南平花岗岩山地；②福建尤溪粉砂岩山地；③江西分宜板页岩山地。在上述3个地点进行了杉木及其人工林自身对土壤肥力影响，杉木人工林育林措施干扰对土壤养分损耗和土壤功能影响，杉木人工林的土壤变化，杉木营养特性与人工林生产力和碳分配，连作对杉木人工林生产力、碳分配及养分生物循环影响，连作对杉木生长影响机制探索等5个方面的研究，并提出了如下基本研究结论和维护地力的途径：

(1) 杉木叶寿命长，枯死枝叶有宿存的特性，凋落物发生晚；并且杉木的凋落物养分含量与分解速度均低，因而杉木人工林养分归还慢(养分归还速率在 40%左右)，这与杉木早期速生所需养分量较多是矛盾的。

(2) 杉木人工林与天然的常绿阔叶林相比，不论在树种组成、群落结构、物种的多样性上均存在很大差别，例如，树种组成与群落结构单一，生物多样性低，加上杉木人工林通常造林密度偏大，因而维护地力的能力差。

(3) 传统的杉木人工林经营人为干扰严重，如炼山、全垦整地、幼林的频繁抚育以及收获时的皆伐作业等，导致比较严重的水土流失，大量生物量外移或被焚烧，每一个轮伐期的营林过程都要损失大量养分和有机质，且杉木营林过程中又不施肥，从而使土壤养分库入不敷出，肥力不断下降。

(4) 上述 3 个方面的因素影响，使杉木人工林土壤综合功能退化。土壤容重增加，透水性下降，物理性质变劣；土壤 pH 值降低；土壤生物性质恶化、土壤微生物数量和土壤酶活性下降，土壤养分亏缺，多代连作人工林的土壤中有效 P 和 N 下降幅度较大，这更加剧了南方原本缺 P 少 N 的林地 P、N 养分的不足。

杉木是速生树种，5~15 年前是生长量最大的时期，年生长量每公顷可达 22~35m^3。这一时期，土壤综合功能的退化，特别是 P、N 养分供应的不足，将对杉木人工林生产力保持产生严重影响。为此，本项研究从 5 个方面提出了保持杉木人工林长期生产力的途径：①要避免炼山、全垦整地、皆伐并火烧清理林场等强烈的干扰措施，要保留采伐剩余物于林地，尽可能减少人工林生态系统受到的强烈干扰，以使其在短期内得到恢复。②采取科学的植被管理措施，改善杉木人工林的群落结构。如通过降低林木密度发展林下植被，提倡培育混交林等，以避免人工林组成结构的单一性，增加生物多样性。③减少连作代数，实行轮作。在杉木的造林区域，按照立地条件和已有人工林和天然林的分布情况进行多种不同森林群落的景观配置，优化区域景观结构，而不是大面积的单一树种的造林和连作。④采取培肥措施，以补充杉木林土壤的养分。⑤加强遗传控制，选择生长量大、适应能力强、特别是比较耐瘠的优良种植材料，减少因连作地力下降而带来的生产力损失。

本书分为两大部分，第一部分为总论共分 9 章，分别就人工林生产力研究进展，研究技术路线和方法，杉木及其人工林自身特性对土壤肥力的影响，杉木育林干扰对土壤养分损耗及功能的影响，杉木人工林土壤变化，杉木营养特性与人工林生产力和碳分配，连作对杉木人工林生产力、碳分配及养分生物循环的影响，连作林地土壤抑制幼林生长机制探索和杉木人工林生产力下降原因机制及保持长期生产力的途径等问题进行了综述。第二部分分 3 章，分别论述 3 种不同地理与岩性条件下杉木人工林长期生产力的保持机制，阐述的具体内容为不同立地不同代不同发育阶段杉木人工林的生长规律与生产

力变化，林下植被变化，凋落物及其分解，林木及其生态系统生物量与养分积累和分配，营养元素生物循环，土壤肥力变化，在不同岩性条件下长期生产力保持机制等。

杉木人工林长期生产力保持机制是一个新的研究课题，许多问题尚需讨论和进一步研究，限于作者研究水平，书中难免出现一些不适当的意见和结论，热切盼望读者指正。

盛炜彤

2005.03.04

Preface

During 1997~2001, we conducted a project on "Maintenance of long-term productivity of Chinese fir and Eucalypt plantations" funded by the National Natural Science Foundation of China. The project was completed after 5 years of systematic studies at 3 sites, all project goals were achieved. The project was reviewed by an expert panel organized by the Life Science Division of the National Natural Science Foundation on March 23rd , 2002 and was rated 'A' class. This book is intended to publish the research results of studies on Chinese fir obtained by the project, in order to reflect the studies of long-term productivity of plantations in China and to disseminate research achievements. The monograph will facilitate academic exchanges and promote studies on long-term productivity of plantations, which would contribute to maintain and increase plantation productivity.

Plantation stability is a global issue. The book "Plantations in Europe" published in 1997 suggested that many studies be needed on monoculture-related biological stability of plantation and potential problems. Since the 1980's, maintenance of long-term productivity became a widely concerned key issue of plantation ecology. The 19th IUFRO World Congress held in 1990 and the 10th World Forestry Congress held in 1991 have taken long-term plantation productivity as an important issue for discussion. In 1993 the American Foresters Association published a special report on "Forest health and maintenance of long-term plantation productivity"; in 1995 the Center for International Forestry Research (CIFOR) implemented a project on "Studies of long-term productivity of tropical plantation". All these reflected that maintenance of long-term productivity has been taken as a key issue of world's plantation development. There are three main concerns regarding maintenance of long-term productivity, firstly, plantations are poorly adaptable to climate conditions, susceptible to large-scale wind blown-down and snow pressure as well as acid rains; secondly, the mono-species composition of plantation makes it susceptible to attacks by diseases and pests; thirdly, mono-species composition, particularly for conifer plantation and silvicultural activities, can easily cause soil fertility degradation. Many studies have been carried out on fertility degradation, and many research papers have been published. However, whether tree species itself could lead to fertility degradation and whether the second rotation effect exists are still under debating, because up to date advanced rotations of plantations are still not established yet, or because of the difficulty to separate the effects of silvicultural measures from the effects of tree species itself, and also because of the lack of experimental bases and networks for scientific and long-term observations. Furthermore, what impacts of current practices of intensive cultivation and expansion of the utilization scope of plantations will be on soil nutrients, what impacts of various silvicultural interventions (including harvesting) will

be on soil fertility and the growth of trees? All these questions are still being studied, to obtain scientific interpretation and conclusion, and it requires to establish field experiments for long-term observation of plantation ecosystem process.

Growers of Chinese fir in China have found the problem of fertility degradation of Chinese fir forest long time ago, during the 1960's studies in Huitong County, Hunan Province carried out by Shenyang Institute of Forest Soil of the Chinese Academy of Sciences proved the existence of fertility degradation of Chinese fir plantation, many years of studies on soil fertility and toxicosis of multi-rotation Chinese fir plantations. Later, during the studies of fast-growing and high-yielding Chinese fir plantations by the Institute of Forestry, Chinese Academy of Forestry, it was clearly recognized that soil fertility degradation severely affected the maintenance of productivity of Chinese fir plantation. To solve this problem has been urgently requested by Chinese fir growers in different regions. For this reason, a study on "Improvement and maintenance of soil fertility of Chinese fir plantation" was included as a key component of the 7th national priority research project "Intensive cultivation of Chinese fir plantation", meanwhile, studies on fertility degradation of Chinese fir plantations and related problems have been continually supported by the National Natural Science Foundation. The achievement of "Chinese fir plantation fertility degradation and its prevention" was obtained. During the same period, Nanjing Forestry University and other organizations have also conducted studies on similar issues. However, due to the limitation of funding and human resources, these studies were scattered at different places, the research components of different projects were not in systematic way. Nonetheless, Insightful studies were not conducted on the mechanisms of fertility degradation. As a result, the study on long-term productivity of Chinese fir and Eucalyptus plantations was funded again as a key project by the National Natural Science Foundation from 1997 to 2001. This book mainly synthesizes the research results on Chinese fir plantation and some previous studies.

The study on long-term productivity of Chinese fir plantation was carried out at three different sites: ① Granite mountainous area in Nanping, Fujian Province; ② Silt-rock mountainous area in Longyan, Fujian Province; ③ Shale mountainous area in Fenyi, Jiangxi Province. Studies were conducted at the above three sites in the following 5 aspects: impacts of Chinese fir and its plantation itself on soil fertility; impacts of silvicultural interventions of Chinese fir plantation on soil nutrition consumption and soil functions; changes in soils of Chinese fir plantation; nutritional characteristics, plantation productivity and carbon distribution of Chinese fir plantation; impacts of multiple rotation on Chinese fir plantation productivity, carbon distribution, biological cycling of nutrients, and growth mechanism. Following conclusions and approaches to maintenance of soil fertility were proposed:

(1) The leaves of Chinese fir have long lifespan, and wilted leaves remain on trees, litters occur late; nutrition contents in the litters is low and decomposition of litters are slow, therefore the return of nutrients to soil is slow (return rate is about 40%), this is in conflict with its fast early growth and high consumption of nutrients.

(2) By comparing Chinese fir plantation with natural evergreen broadleaved forest, they differ largely in species composition, community structure and species diversity. In addition, Chinese fir plantation usually has high stocking density, simple species composition and community structure, leading to low biodiversity and poor capacity of maintaining soil fertility.

(3) Traditional management of Chinese fir plantation imposes heavy artificial intervention, such as site clearance by burning, site preparation by complete ploughing, frequent tending for young plantations and clear-cut at harvesting, leading to severe soil erosion, large amount of biomass being moved away or burnt. Large amount of nutrients and organic matters were lost during silvicultural activities of each rotation, and no fertilization was applied, making imbalance between input and uptake of nutrients, fertility therefore declines continuously.

(4) The above three factors working together have caused degradation of the comprehensive soil functions of Chinese fir plantation. Soil volume weight increases, water permeability declines, physical properties becomes poor; soil pH decreases, soil biological properties deteriorates, and the number of soil micro organisms and activity of soil enzymes were significantly lower for multiple rotations than for single rotation; soil nutrition gets insufficient, available soil P and N of the multi-rotation plantation largely declines, further worsening the insufficiency of P and N of forest soil in the south of China where is already lacking of P and N.

Chinese fir is a fast-growing species, 5~15 years of age is the period with largest growth rate, annual growth can reach 22~35m^3/hm^2, during this period, degradation of comprehensive functions of soil, particularly insufficient supply of P and N, produces serious impacts on maintenance of productivity of Chinese fir plantation. The project proposed 5 approaches to the maintenance of long-term productivity of Chinese fir plantation: ① Avoid heavy intervention activities such as site clearance by burning, site preparation by complete ploughing, clear cut and burning clearance of harvesting sites, retain harvesting residues at the logging site, reduce as much as possible disturbance to the plantation ecosystem and restore the ecosystem in a short time. ② Take scientific vegetation management measures to improve the community structure of Chinese fir plantation. For example, by reducing stocking density to develop under forest vegetation; advocate development of species mixture forest to avoid the mono-species composition of plantation and to increase biodiversity. ③ Reduce the number of successive rotations, and adopt the alternative species rotation system. In Chinese fir planting areas, according to site conditions and the distribution of existing plantations and natural forests to deploy different forest community landscapes, and optimize regional landscape structure, rather than planting large areas of single tree species for multiple rotations. ④ Apply fertilizer to supplement nutrients to the soil for nutritional consumption by Chinese fir. ⑤ Strengthen genetic control, select plant stocks with large growth and high adaptability, especially tolerant to poor soil to reduce the productivity loss due to fertility degradation

caused by multi-rotation.

This book is divided into two parts, the first part is the generals comprised of 9 chapters, respectively describe: progress in plantation productivity studies; approaches and methodology of studies; impacts of properties of Chinese fir and its plantation on soil fertility; impacts of silvicultural interventions of Chinese fir on soil nutrition and functions; changes in soil of Chinese fir plantation; nutritional properties of Chinese fir and its plantation productivity and carbon distribution; impacts of multi-rotation Chinese fir plantation on productivity, carbon distribution and nutrition cycling; mechanisms of suppression of multi-rotation plantation soil on the growth of young trees; causes for productivity decline of Chinese fir plantation and approaches to maintenance of long-term productivity. The second part consists of three chapters, respectively describe the mechanisms of maintaining long-term productivity of Chinese fir plantations at three different geographic and rock conditions, specifically, growth patterns and productivity changes of Chinese fir plantations at different development stages at different rotations at different site conditions, changes in under-forest vegetation, litters and their decomposition, accumulation and allocation of biomass and nutrients of trees and ecosystem, cycling of nutritional elements, soil fertility changes, and mechanism of maintaining long-term productivity under different rock conditions.

Long-term productivity of plantation is still a new topic that needs more discussions and further studies. It is unavoidable that some opinions and conclusions presented in this book may no be appropriate. Your comments for improvement are very much appreciated.

Sheng Weitong
March 4, 2005

目　录

第二部分 不同地理与岩性条件下杉木人工林长期生产力的保持机制

Contents