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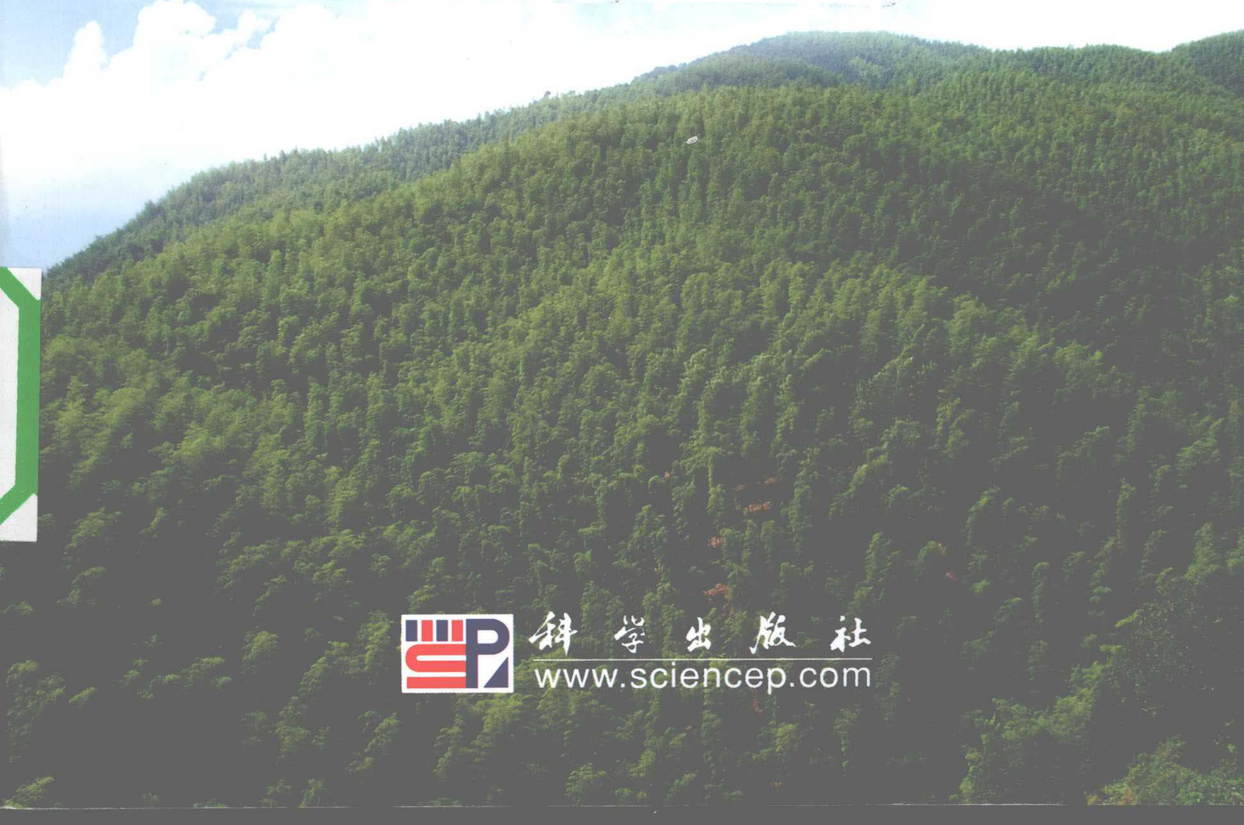

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内 容 简 介

本书是依据国家自然科学基金(NO. 30771715、NO. 30271072)和浙江省自然科学基金(NO. 300209)等项目的研究成果撰写而成的。

全书共分两部分：第一部分以英文详尽地综述了竹林生态系统中碳固定和转化的研究结果。第二部分共分 11 章。第 1 章综述了森林生态系统的碳库、碳循环与碳平衡的最新研究进展；第 2 章综述了毛竹林栽培管理及生物量研究进展；第 3 章、第 4 章探讨了毛竹林碳储量的空间分布，并估算了浙江省毛竹林的总生物量和碳储量；第 5 章、第 6 章揭示了不同经营模式和不同经营年龄的毛竹林碳素的积累和动态变化；第 7 章探讨了施肥和覆盖雷竹林土壤有机碳的演变；第 8 章比较了亚热带毛竹林与其他林分的土壤活性有机碳库；第 9 章探讨和比较了毛竹、杉木和马尾松林土壤的固碳能力；第 10 章研究了冬季覆盖雷竹林土壤的呼吸；第 11 章系统总结了竹林生态系统中碳固定和转化的研究成果。

本书可供林业科学、生态科学、土壤科学以及有关方面的科技工作者和高等院校有关专业的师生参考，也适合于各级政府部门从事领导农村农业生产可持续发展工作的干部阅读。

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前　言

当前，地球气候正经历一次以变暖为主要特征的显著变化，这种气候变化主要是由工业发展排放大量的二氧化碳（CO_2）等温室气体所致。联合国政府间气候变化专门委员会（IPCC）于2007年发布的第四次评估报告显示，1906～2005年：全球地表平均温度上升了0.74℃，海平面上升了17cm，全球大气CO_2浓度已从工业化前的约280ppm①增加到了2005年的379ppm。全球变暖已是不争的事实，对自然生态和人类生存环境产生了显著的影响，成为全世界共同面临的严峻挑战。

国际社会在应对全球气候变化中，主要是采取直接减排（减少工业温室气体排放）和间接减排（森林吸收CO_2）两大措施。作为陆地生态系统主体的森林，在调节全球碳平衡、减缓大气CO_2等含碳温室气体浓度上升，以及调节全球气候方面具有不可替代的作用。发挥森林生态系统的独特功能是应对全球气候变化最经济、最有效、最直接、最可持续的途径。

竹子是重要的森林资源，且竹林固碳具有一般森林所没有的优势和特点。第一，世界竹林面积不断扩大，全球有竹类植物70余属、1200余种，竹林面积约2200万hm^2，广泛分布于亚洲、非洲和拉丁美洲的热带、亚热带地区，在全世界森林面积急剧下降的今天，竹林面积却以每年3%的速度递增，这就意味着竹林是一个不断扩大的碳汇。第二，竹林的生长速度明显超过一般森林，其固碳速率也同样高于一般森林。第三，竹林采伐期短、利用率高，一般4～5年就成林，碳元素转化率和利用率高，而且大量碳元素被转化到竹林产品中。根据推算，中国竹林生态系统的竹林植被、土壤和凋落物固定的碳量分别为3.19×10^{14}g、1.66×10^{15}g和4.5×10^{13}g，合计2.024×10^{15}g，占中国整个森林碳储量的5.1%，而毛竹林年固碳量分别是杉木林和马尾松林的1.68倍和2.33倍。我国是竹子大国，竹类资源丰富，现有竹林面积约720万hm^2，其中，毛竹林面积约300万hm^2，占竹林总面积的2/3以上，是我国分布面积最大、范围最广、开发利用程度最高，集生态、经济和社会效益于一体的竹种。当前，为不断提高应对气候变化的能力，我国正在大力实施林业碳汇项目，而研究和利用毛竹林的碳汇能力则在其中具有重要的意义。

浙江是中国竹林面积最大的省份之一。全省竹林总面积80万hm^2，其中毛

① 1ppm$=10^{-6}$，后同。

竹林60万hm^2，几乎每个县（市、区）都有竹林分布或栽培，这为研究毛竹林碳汇提供了广阔的空间和良好的平台。近年来，浙江林学院在研究毛竹林碳汇方面起步较早，发展迅速，学校从2002年开始进行毛竹林碳汇能力的研究，是国内外最先开展该领域研究的院校。2002年12月，由国家林业局植树造林司、中国科学院农业政策研究中心主办的全国“造林绿化与气候变化”研讨会在浙江林学院举行，会议介绍了森林的储碳作用及其相关科研进展与成果，并对清洁发展机制（CDM）、造林绿化与气候变化的关系等进行了广泛的研讨。2003年，浙江林学院在对竹林生态系统中碳的固定与转化的研究过程中，得到了国家有关部委和浙江省科技厅的大力支持，先后获得国家自然科学基金（NO. 30771715和NO. 30271072）和浙江省自然科学基金（NO. 300209）等项目的资助。2008年4月，由浙江林学院实施的全国也是全球首个毛竹林碳汇项目——中国绿色碳基金临安毛竹林碳汇项目正式启动，该项目在浙江临安藻溪镇营造50hm^2毛竹碳汇林，并从毛竹林碳汇计量技术研究、毛竹采伐利用的碳平衡及碳转化研究等多个方向开展研究。该项目的研究不仅可以更准确地计算我国的竹林碳汇，也为计算全国竹林乃至森林生态系统对全球碳平衡的贡献量、中国森林资源碳汇情况提供重要的资料和数据，对我国参与碳交易的国际谈判具有重要的参考价值。

本书展示了近年来浙江林学院在竹林生态系统碳汇能力方面研究的最新成果。全书通过对浙江省竹林生态系统的碳储量、固定、空间分布、碳积累动态以及不同经营措施、经营历史的竹林生态系统中土壤活性有机碳的研究，探明竹林不但具有很好的经济效益，而且有着良好的环境效益和生态效益。竹林生态系统强大的固碳能力，使之可在全球气候变化中发挥重要作用。这些研究成果，为在竹林经营实践中，如何全面考虑和平衡竹材生物量、土壤肥力、生物多样性等几方面关系提供了理论依据，也为未来进行毛竹林碳汇交易提供了基础数据。

在本书出版之际，谨向所有关心和支持本书出版的领导、专家、学者和朋友表示衷心的感谢！尽管近年来我们在竹林生态系统碳汇能力研究上取得了一定的进展，但基础理论研究还较薄弱，很多方面尚处于初始阶段，有待进一步深化和探索，加之客观条件和作者水平的局限，书中存在一些不足和疏漏，恳请读者批评指正。

周国模　姜培坤　徐秋芳

2009年夏于浙江临安

缩 写 语

AC	active carbon	活性碳
AK	available K	速效钾
AOC	active organic carbon	活性有机碳
AP	available phosphorus	有效磷
CF	chemical fertilizer	化肥
DOC	dissolved organic carbon	溶解（性）有机碳
DOM	dissolved organic matter	溶解（性）有机质
GPP	gross primary productivity	总初级生产量
EM	extensive management	粗放经营
EOC	easy oxidation carbon	易氧化碳
IM	intensive management	集约经营
NPP	net primary productivity	净初级生产力
MC	mineralize carbon	矿化态碳
MBC	microbial biomass carbon	微生物量碳
NN	hydrolyzable nitrogen	水解氮
OF	organic fertilizer	有机肥
SOC	soil organic carbon	土壤有机碳
SOM	soil organic matter	土壤有机质
TN	total nitrogen	全氮
TOC	total organic carbon	土壤总有机碳
UAC	un-active carbon	非活性有机碳
WSOC	soluble organic carbon	水溶性有机碳

目　录

CONTENTS

Advance in study of carbon fixing and transition in the ecosystem of bamboo stands

Carbon dioxide (CO_2) in the atmosphere has been increasing steadily since at least 1958. Carbon dioxide is one of the so—called 'greenhouse gases' which are responsible for absorbing energy from the sun, leading to warming of the earth's atmosphere——the 'greenhouse effect'. Forest ecosystems have been increasingly paid more and more attentions due to the roles in sequestration and storage of carbon with an increase in greenhouse gas concentration in the atmosphere for the last decades. For forest ecosystems, the carbon storage and the cycling of carbon are common indicators to assess the CO_2—fixation capacity. Selection and development of tree species with high fixing CO_2 capacity is an increasing problem worldwide.

Because of the relation between forests and atmospheric carbon dioxide, there are opportunities to manage forests in ways that would result in storage of additional carbon and thus reduce atmospheric carbon dioxide. Major forestry opportunities include increasing forest area, increasing the productivity of existing forest lands, reducing forest burning and deforestation, increasing biomass production and utilization, planting trees in urban environments, and increasing use of wood in durable products.

Forest development influences a variety of ecosystem processes including carbon exchange with the atmosphere. Carbon dioxide is a dominant greenhouse gas. Increased atmospheric CO_2 is attributable mostly to fossil fuel combustion (80%～85%) and deforestation worldwide. Of all the plant kingdom, forests provide the most long-lived storage sink in the carbon cycle. Forests store 86% and 73% of carbon pool of vegetation and soils (Brown et al., 1993), thus they play very important impact on C balance of global.

In south China, bamboo is an important forest resource which can be widely utilized as materials, energy etc., and is also an essential income source of the local farms. Bamboo has a high potential in fixing CO_2 from the atmosphere. This paper summarizes our study results on carbon fixing and transition in the ecosystem of bamboo stands.

1 Effects of different management models on ecology and environment of bamboo stands

1.1 Distribution and cultivars of bamboos

1.1.1 Distribution of bamboos

Bamboo stands are an important composition part of forest ecological system. Bamboos are widely distributed on tropics and subtropics zones in Asia, Africa, Latin America. There are 1200 varieties of bamboos in all over the world and its planting area was 2.2×10^7 hm^2, which accounting for 1% of total forest area in all over the world (Guo et al, 2005). In Recent years, forest area has been reducing rapidly, whereas bamboo stand area has been increasing yearly by 3% in all over the world and by 6.0×10^4 hm^2 in China (Jiang, 2002).

China is a country with abundance bamboo resources, the pioneer country of utilizing bamboos, and the maximal country of producing bamboos in all over the world. There are 38 genera and more than 500 species of bamboo in China. Bamboo stands are widely distributed in south China, especially in Zhejiang, Fujian, and Jiangxi provinces, and their area was 5.0×10^6 hm^2.

1.1.2 Cultivars of bamboos

Phyllostachys pubescens Mazel ex H. de Lehaie (See in Photo. 1) and *Phyllostachy praecox* (See in Photo. 2) are the two varieties of the largest planting area in South China.

Phyllostachy pubescens is a cultivar of *Phyllostachys heteroclada*. It is suitable for growth on central subtropics regions, and are naturally distributed on 23°23′~32°20′N, 104°30′~122°00′E in China.

Phyllostachy pubescens has a long cultivation history in China. Since 1950s, the area of *Phyllostachy pubescens* has been increasing rapidly in China, and its area has been rapidly increased up to 2.62×10^6 hm^2 in China (Zhang and Miao, 2000). At present, planting area and production values of *Phyllostachy pubescens* has reached 4.5×10^6 hm^2 and 3.85×10^{10} yuan in China, respectively.

According to investigation of forest resources in 1994~1998, the volume of *Phyllostachy pubescens* was 8.766×10^7 t and accounting for 79.07% of total volume of bamboo forests (Chen, 2003). The cutting volume of *Phyllostachy pubescens* increased from 8.6×10^7 plant in 1980s to 6.68×10^8 plant in 2002. The yields of woods and bamboo shoot of *Phyllostachy pubescens* were 1.286×10^7 t and 4.0×10^6 t in 2005, respectively, and increased by 2.75 and 8.5 times as compared to 1980 (Chen, 2003).

Phyllostachy pubescens is one of the most important economic forests. It possesses some advantages such as wide distribution, rapid growth, high production, and wide purposes. Furthermore, it is also a bamboo species with the largest plating area, and high economic values. Its advantages are as follows:

① It is an excellent tree species for conservation soil and water in South China due to high crown density and developed underground stem and roots.

② It could restore the destructed soils induced by excess graze and unreasonable cultivation ways.

③The end use of timber harvested from forests is an important factor in evaluating the contributions of forestry to the global carbon cycle. If the end uses of forest products are in long-term durable goods such as furniture or timber bridges, the carbon is stored in those materials. If the end use is for paper products that are rapidly used and discarded to decay, then the carbon is released to the atmosphere. Bamboo trunks can be used in architecture, bamboo implements, furniture, paper making, and so on, thus the carbon is stored in those materials.

④It is a cultivar of producing both bamboo woods and bamboo shoots, and has advantages with sustained utilization and naturally renewed, therefore, it has very high economic benefits.

⑤ It has a higher potential in absorbing CO_2 from the atmosphere. The study results of Japan and other countries showed that the amount of absorbing CO_2 was $12t \cdot hm^{-2} \cdot a^{-1}$.

⑥ It has high carbon translation rate. Cutting period of bamboo stands is short. The biomass of bamboo is almost translated into forest products.

Phyllostachys praecox is an excellent bamboo species for producing edible bamboo shoots, and has been planted in many areas of southern China, with a total of $6 \times 10^4 hm^2$ in Zhejiang Province.

In order to gain high yield of bamboo shoots (about 30 000kg $\cdot$ hm^{-2}) and higher income, a new technique has been developed that allows shoots to emerge in winter season by mulching a thick layer of organic material to elevate the soil temperature (See in Photo. 5). This technique, together with an increased fertilization, results in both an earlier harvest/market for much higher price and a higher yield than that of normal practice.

1.2 Growth characteristics of bamboos

①Rapid growth, short becoming timber time (3～5a), high yield, very strong capacity of propagation and renew, easy to plantation, producing bamboo shoots and becoming timber every year once plantation;

②Generally, the time from sprouting bamboo shoots to cut down for bamboo trees is 6 years. The rapidest growth period is 1～6 weeks after sprouting bamboo shoots. Bamboos are mainly propagated by ground stems. The growth of bamboos is greatly different from the arbors species, and the growth of increasing diameter and height is accomplished in 35～40d and then is a slow course of accumulation of dry matter. It is a fast-growing plant species and grows in uneven stands which can be harvested every 2 years in a repeating manner.

③The timber of bamboo stands is in dynamic balance. It has been suggested that the biomass from cutting once is 1/3 of the biomass in the stock. Therefore, the biomass of tree-layer in bamboo forest is 1/6 of biomass in the stock.

1.3 Management practices of different models

1.3.1 Management practices of different models for *Phyllostachy pubescens* stands

In recent 20 years, management of bamboo stands has been converted from conventional practice to intensive one because of its high economic effect. At present, there are 2 major management practices in bamboo plantations in south China, namely about 60% in extensive management (EM) with no fertilization or tillage, and a newly developed intensive management (IM) with heavy application of chemical fertilizers, removal of shrubs and weeds, and deep plowing of the surface soil layer.

Intensive management (IM) (See in Photo. 3): Fertilization and deep-plough were conducted in May every year under bamboo stands with IM (the growth density of bamboos is 3000～4500plant • hm^{-2}). Therefore, there were no shrubs and weeds under bamboo stands with IM N, P, and K as composed fertilize ($N : P_2O_5 : K_2O = 15 : 15 : 15$) and urea were broadcasted at the rates of 400～600kg • hm^{-2}, 150～200kg • hm^{-2}, and 200～250kg • hm^{-2} in the middle of May. After fertilization, the surface soil was ploughed down to depth of 30cm. Bamboo plantations under IM have higher yields of bamboo wood and shoots.

Extensive management (EM) (See in Photo. 4): Shrubs and weeds were