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中国竹类

文化 / 资源 / 培育 / 利用

CHINA'S BAMBOO

CULTURE / RESOURCES / CULTIVATION / UTILIZATION

International English Edition *国际英文版本*

Original Chief Editors *主编*
Yang Yuming, Hui Chaomao *杨宇明，辉朝茂*

Contributing Editor English Edition *英文编辑*
Adam Turtle FLS *龟亚当*

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The International Network for Bamboo and Rattan is an independent, non-profit intergovernmental organisation established in 1997. INBAR is dedicated to improving the social, economic, and environmental benefits of bamboo and rattan. INBAR plays a unique role in finding and demonstrating innovative ways of using bamboo and rattan to protect environments and biodiversity, alleviate poverty, and facilitates fairer pro-poor trade. INBAR connects a global network of partners from the government, private, and not-for-profit sectors in over 50 countries to define and implement a global agenda for sustainable development through bamboo and rattan.

国际竹藤组织(INBAR)成立于1997年，是一个独立的、非赢利的政府间国际组织，致力于促进竹藤的社会、经济和环境效益。INBAR在探索和示范竹藤创新利用，从而保护环境和生物多样性、消除贫困和为有利于贫困人群的公平贸易提供支持方面发挥着独特的作用。INBAR的全球网络成员来自50多个国家的政府部门、私有部门和非赢利机构，共同为通过竹藤的有效利用实现可持续发展而努力。

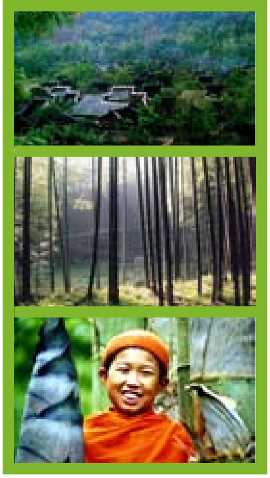
The Bamboo and Rattan Research Institute (hereinafter called the institute) of the Southwest Forestry University was founded in 1997 under the leadership of China's renowned bamboo expert, Prof. Xue Jiru. It is the only bamboo and rattan oriented professional institute for both scientific researches and industrial technology development in Southwest China. Currently, it has a crew of 35 full and part time researchers. Since 1999, the institute's leading members are: Prof. Yang Yuming (director, student of Prof. Xue Jiru), Prof. Hui Chaomao (executive vice director), Prof. Dong Wenxuan and Xue Jiarong (vice directors). By far, the institute has held over 30 fundamental research projects and over 50 technology extension & enterprises-funded projects, objects of which are mainly large sympodial bamboos and rattans widely distributed in the tropical and subtropical areas. Bamboo species and bamboo forest resources of Yunnan were systematically surveyed, identified, classified, mapped and documented. Many rare and eximious bamboo germplasm resources were collected, selectively bred and successfully cultivated. The directive breeding and intensive management techniques of bamboo plantations were developed. The institute's pioneer works on large sympodial bamboo researches and intensive management have inaugurated a new era in the field and defined itself a leading role in China and an advanced position internationally.

中国西南林业大学竹藤研究所，是在我国著名竹类学家薛纪如教授领导下于1997年组建成立的，是中国西南地区唯一的最具科技实力专门从事竹藤研究和竹藤产业技术开发的专业科研机构， 现有专兼职竹类研究人员35人，1999年由薛纪如教授之学生杨宇明教授担任所长，辉朝茂担任常务副所长，董文渊，薛嘉榕担任副所长。研究所成立以来，先后主持竹藤方面基础研究项目30余项，技术推广项目和横向合作项目 50余项。主要针对全球热带亚热带广泛分布的大型丛生竹和棕榈藤为主要研究和开发对象，对云南的竹类资源进行了系统全面和调查整理，基本查清了云南的竹种和竹林资源，从珍稀优良竹种种质资源收集和选育，到优良竹种的集约经营和定向培育技术研究方面取得了丰硕的成果。特别是在大型丛生竹的基础研究和经营培育方面的工作尤具开拓性，目前该所在丛生竹研究领域已处于国内领先和国际先进水平。1998年被中国国家林业局授予“全国农业科技推广先进集体”称号，2008年遴选为云南省科技创新团队。

Yang, Yuming Professor/Doctor, born in 1955. Vice-president of Southwest Forestry University, president of Yunnan Bamboo and Rattan Association,standing member of the Council of Chinese Bamboo Industry Association, and director of the National Plateau Wetland Research Center of China. He has begun a survey of forests and bamboos since 1970's at the Forestry Survey and Plan Institute of Yunnan. He graduated with a Bachelor from Biology Department of Yunnan Normal University in 1982, a Master from Southwest Forestry University in 1988, and Doctorate from the Department of Environment Science and Engineering of Tsinghua University in 2003 and has been engaged in forestry research for 40 years.

Hui, Chaomao Professor/Doctor, born in 1962. Director of Bamboo Institute of Southwest Forestry University, vice-president and secretary-general of Yunnan Bamboo and Rattan Association (YNBAR), chief of Yunnan Bamboo and Rattan Research & Development Center (YBRC). Graduated Bachelor and Master from Southwest Forestry University from 1980 to 1987, and received Doctorate from the Department of Environment Science and Engineering of Tsinghua University in 2003. He has been engaged in scientific research on bamboo for 18 years.

The two authors have published nearly 100 scientific research papers as well as the following monographs on bamboos: The Research of Bamboo from Nujiang (1994), Bamboo Cultivation and Utilization (1995), Bamboo Resources In Yunnan and Their Utilization (1996), Industrial Utilization of Culm-producing Bamboos (1997), Industrial Exploitation of the Quality Shoot-Producing Bamboos (1998), The Prevention and Control of Moth and Mildew for Bamboo Timber (1999); The General Planning of Bamboo Industry Development of Yunnan Province(2000), A Hand-book of Bamboo Cultivation and Utilization in China (2002) ; Study on Valuable and Rare Bamboo Species of Dendrocalamus sinicus(2005)..



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本书谨献给敬爱的导师、著名林学家和竹类学家薛纪如教授
This book is a memorial for Prof. Xue Jiru, the honourable teacher of the authors of the book

The authors of this book, Hui, Chaomao; Yang, Yuming; Du, Fan; together with their late teacher, Xue, Jiru, the world renowned bamboo expert and forestry professor of Southwest Forestry University, China

竹

PREFACE

Yunnan province is China's most bio-diverse region. With over 250 bamboo species throughout its tropical, sub-tropical, temperate and montane forests, it is one of the foremost bamboo biodiversity hotspots in the world. It is also China's most ethnically diverse area, and bamboo is an essential component of many of its ethnic groups' ways of life. More recently bamboo plantations have been established, as well as factories producing bamboo paper and pulp, and the province is gradually trying to develop a modern bamboo sector – an often difficult task, in part due to the terrain and physical isolation of much of the province.

INBAR recently ran a project that developed new sustainable methods of managing and using the knobbly-noded bamboo, Qiongzhuea tumidinoda, with communities in northeastern Yunnan. With its bamboo biodiversity, bamboo history, bamboo culture and modern bamboo factories, Yunnan is unique, and what better place could there be from which to produce a comprehensive guide to these most versatile of plants. Both professors Yang and Hui have been based in Yunnan for decades, researching and supporting bamboo-based development both as part of their research programs and as part of the Yunnan Bamboo Society, and their experience is second to none. Adam Turtle has rendered even complex technical matters into lively and readable English, and enabled the non-Chinese speaking world to share in the authors' considerable knowledge and experience. It is INBAR's great pleasure to partner them all in this important work.

This excellent university-level introductory text to bamboo and the principles that underline the practice of using it to help the environment and alleviate poverty is packed with useful information for students and enthusiasts alike, not only those interested in bamboos in China, but in bamboos all over the globe. It will be a fitting addition to any library collection and will enthuse and enthrall new generations of bamboo practitioners.

Coosje Hoogendoorn
Director General of the International Network for Bamboo and Rattan (INBAR)
July 21, 2010

竹

FOREWORD

According to archeological discoveries, bamboo research and utilization in China has a history 5,000~6,000 years old. There was a bamboo managerial body called "Sizhujian" at each government level from the Central to local ones since the Han Dynasty (206 BCE~220 CE). It had been in operation for 2,000 years until it was abolished in the Qing Dynasty (1616~1911). Bamboo planting in ancient China started over 2,440 years ago and long-distance introduction was carried out 2,260 years ago, as verified by many treatises created on Bamboos. Bamboo accounts appeared in The Book of Songs, the earliest and most complete collection of Chinese poetry. Bamboo Chart by Dai, Kaizhi (317~420CE) in the Jin Dynasty was the first monograph in the world that included records of morphological features, production nature, and distribution range of over 70 bamboo species. Paper Manual by Su, Yijian (976~997) and Shoot Illustration by Zan, Ning (the later half of the 10th century) a monk in the Song Dynasty, as well as Detailed Bamboo Chart written in 1312 by Li, Kan during the Yuan Dynasty were also among the earliest research works on bamboos in Chinese history. By the Qing Dynasty (1616~1911) there had been as many as 24 works published that contained detailed records and accounts of bamboo concerning classification, distribution, characteristics, cultivation, and utilization. Together they describe and recall the very rich experience in Chinese bamboo production.

Adding to the abundant accounts of bamboo in ancient books, modern scholars started their scientific research on bamboos in the early 1930's. The late professor Keng, Yili (1897~1975) was the first Chinese scholar to have published a new species of bamboo in 1936 and then in 1940 two new genera, one of which, Brachystachyum is in current use. Following this example, a large number of scholars, such as the late Dr. F. A. McClure an American scholar working at Lingnan University, have contributed to bamboo study in China and much has been accomplished. Illustration of Major Plants in China (Gramineae) chief-edited by Professor Keng, Yili in 1959, made an initial and systematic study of bamboo genera and species in China, inclusive of 71 species and varieties in 20 genera. Volume 22 in Flora of China, (English edition) published in 2006 as a result of joint efforts by many scholars throughout the country, contains a record of over 500 species and varieties in 37 genera of Bambusoideae. Publication of this monograph has greatly enriched China's as well as the world's treasure of scientific bamboo literature.

Taxonomic study of the Bambusoideae started abroad in 1788 when A. J. Retzius, a Swedish scholar, first published Bambos as a pioneer scientific name for what is now *Bambusa*. For the past 200 years scholars from different countries have published over 120 genera in Bambusoideae in many monographic documents. With more and more weight lent to bamboo research in recent years, a great number of countries, Japan and India particularly, have invested large sums of money and assembled powerful research forces. Incomplete statistics show that organizations in over thirty countries are engaged in bamboo research. For example All-Japan Society for Bamboo Research and the American Bamboo Society in the US both publish professional journals on bamboos. In other countries including China, Japan, Thailand, Myanmar, the Philippines, Malaysia, Sri Lanka, and Indonesia, institutions of forestry and higher learning treat bamboo research as a major field of study. Great importance is attached to bamboo research and development programs, to preservation and development of bamboo resources, and to comprehensive utilization of bamboos by international NGO organizations such as IFOA, ITTO, INBAR, GTZ and IDRC. International academic conferences on bamboo have been held almost every year since 1976, and are strong stimuli to bamboo research and exchange. Advances have been made in various aspects of bamboo research including taxonomy, growth habits, propagation, flowering, anatomy, resistance, physiochemical properties, exploitation, and utilization for many years. Scientific study of bamboo has extended into various fields such as biology, ecology, biochemistry, genetics, cultivation, management, and utilization. It is a cross disciplinary approach that is being systematically perfected.

China is known as a "Country of Bamboo Civilization" by the West and the Chinese people have been very fond of bamboos since ancient times. Being upright and modest, bamboos offer people an excellent subject for poetry, painting, and gardening. Bamboos have made major contributions to the development of the historical culture of China, and advances in science and technology are in return constantly pioneering new fields for bamboo utilization. Remarkable achievements have been made in bamboo research, education, and production in the past score of years since political reform and the open-door policies were adopted. For a wider view, experts, institutes, units, and departments that carry out research, production, and management in bamboos are readily available throughout the country. Substantial work has been done by various organizations such as the Office for Management of Bamboo Industry and Bamboo Research and Development Center attached to the Forestry Ministry of China, Bamboo Branch of the Chinese Forestry Society, China Association of Bamboo Industry, as well as local bamboo industry associations. The bamboo area continues to expand as new technologies and findings arise, and various new and novel bamboo products are being offered for sale at home and abroad. All of these indicate that China is gaining a lead in the world of bamboo research, management, production, and development. Bamboo courses are currently offered at quite a few universities and colleges, and bamboo subjects for undergraduates and MS degree students are set up at Nanjing Forestry University, Southwest Forestry College, and Zhejiang Forestry College. Bamboo study serves bamboo production, and the bamboo industry in return, promotes development in bamboo education.

Publication of this book is then, of great significance in such a historical perspective. The editors, my promising postgraduates, have achieved some initial successes in their cause through assiduous toil. Their extensive publication of theses has gained professional acknowledgement and their achievements in scientific research have won repeated awards. Monographs under their general or joint editorship have come into existence successfully and some are listed among important works of contemporary sciences in China. But most essential and encouraging are their steps taken in bamboo resource exploitation and utilization, as well as in industrial application of R&D achievements of bamboo research through a combination of teaching, research, and production. As a substantial bamboo textbook in 8 chapters, this book is fairly complete in content and system. On one hand it offers an introduction to historical and cultural situations in bamboo research and production in China as well as other countries, and offers strategies for development in the bamboo industry. It also draws relevant information from historical works on bamboos, absorbs recent achievements of bamboo research in China and other countries, and lays a basis for first-hand data from the editors' own practices in research and exploitation.

Now at this time of spring, birds keep singing, flowers are blooming, and new greenery is being added to emerald culms that have endured through bitter frosts. New bamboos after rain are shooting taller than the old culms. What an inspiring sight this is! Things are changing, China is opening up further, and the world is making progress each passing day. So unite, all friends who are concerned with the bamboo cause! Let us work hard and combine our efforts for a quicker development of bamboo industry.

Xue Jiru (Hesuh)

Internationally renowned bamboo expert and professor of SWFU

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中文版序言

根据考古学证明，我国竹类研究和利用已有6000多年的历史。自汉代开始，从中央到地方有一个“司竹监”的竹子管理机构，一直到清代才废止，延续了近2000年之久。中国祖先种竹已有2440年历史，作长距离引种已有2260年，并有许多竹类研究的专著。《诗经》中已有竹子的记载。晋代戴凯之（317~420）所著《竹谱》是世界上第一部竹类专著，记述了70多种竹子的形态特征、生产习性和分布范围。宋代苏易简（976~997）撰《纸谱》，宋僧赞宁（10世纪后期）撰《笋谱》，元代李衎著有《竹谱详录》等，也是我国历史上较早的竹类研究著作。至清代为，记述竹类的菱达24种之多，对竹子的分类、分布、习性、栽培技术及用途等，都有较详尽的记载和论述，积累了丰富的经验。

我国除古藉中有大量有关竹类的著述外，本世纪30年代始有学者对竹类进行科学研究，已故耿以礼教授（1897~1975）于1936年发表竹类一新种为其开端，1940年又发表了短穗竹属（Brachystachyum keng）等两个新属为我国学者最早发表的新属。此后包括前岭南大学美籍学者E. A. McClure博士在内的大批学者投身于我国竹类学研究，取得了很大成就。1959年，耿以礼教授主编的《中国主要植物图说·禾本科》对我国竹亚科的属种进行了初步的系统整理，当时收入了20属71种（含变种和类型）。《中国植物志》第九卷第一分册（竹亚科）已在全国各地竹类研究者共同努力下于1991年底交稿付印，该专著一共记录了竹亚科37属500多种（含变种和变型），其出版发行将极大地丰富我国乃至世界竹类学宝库。

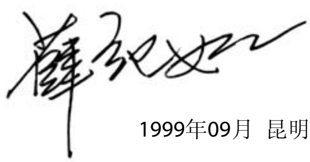
国外竹子分类研究始于1788年瑞典人A. J. Retzius发表的簕竹属先驱名称Bambos。200多年来，世界学者发表的竹亚科属名达120个之多。此后发表了不少专题研究文献。近年来，竹子研究日益受到重视，世界上许多国家都投入大量资金，组织很强的科技力量进行研究，这方面日本和印度尤为突出。据不完全统计，现在进行竹子研究的有30多个国家，如日本有“全日竹业研究会”，美国有“竹子学会”，他们都出版竹类专业刊物。中国、日本、印度、孟加拉、泰国、缅甸、菲律宾、马来西亚、斯里兰卡、印尼等国的林业机构以及高等院校都把竹子研究和开发作为重点课题之一。此外，还有不少国家建立了竹类植物园和标本馆，搜集竹类标本，开展各学科专题研究。国际林业组织协会（IFOA）、国际热带木材组织（ITTO）、国际竹藤联络网（INBAR）、加拿大国际发展研究中心（IDRC）等国际组织都十分重视竹子研究和开发项目，强调保护、发展竹林资源和开展综合利用。自1976年开始，国际性竹子学术讨论会几乎每年都有，极大地推动了竹子研究与交流。多年来，在竹类植物分类、生长、习性、繁殖、开花、解剖、抗性、理化性质、开发利用等领域都取得了进展。竹类学研究已深入生物学、生态学、群落学、生物化学、遗传学、栽培学、经营学、利用学等各个领域，成为一门体系逐步完善的交叉学科。

中国被西方称为“竹子文明的国度”。中华民族自古喜爱竹子，因为它刚强正直、实节虚心，成为诗歌、绘画和园林的绝好题材。竹子在我国光辉灿烂的历史文化发展中立下了不可磨灭的功勋，科技的发展又不断开拓出新的利用领域。纵观全国，仅是改革开放以来的十多年间，我国的竹类研究、教学和生产取得了显著的成就，从事竹类研究的学者和研究机构、

从事竹业生产和管理的单位和部门已遍及大江南北。国家林业部成立了“竹产业管理办公室”和“竹子研究开发中心”，中国林学会成立了“竹子分会”，“中国竹产业协会”及各竹产区地方性竹业协会、竹类研究开发机构和企业也相继成立并开展了大量工作。我国竹林面积不断扩大，新技术、新成果不断问世，各种竹产品不断推向国内外市场。这一切，显示了我国在竹类研究、竹林经营和产品开发领域已居于世界领先地位。目前，许多大学都开设了竹子方面的课程，在南京林业大学、西南林学院和浙江林学院等还设立了大学本科教育或硕士研究生专业。教学为生产服务，竹业促进了教学的发展。

在这一历史背景下，本书出版具有重要意义。编者是我的3位优秀研究生，经过刻苦钻研和勤奋耕耘他们在事业上已经初见成效。他们的学术论文广泛发表得到同行专家肯定，他们的研究成果屡屡获奖，由他们主编或参加编写的专著也相继问世，有的被列入当代科技重要著作。更重要的是他们把教学、科研和生产有机结合，在推动竹类资源开发利用、实现竹类科技成果产业化方面所迈出的步伐更为可喜。本书是目前内容较为全面具体的竹类学教科书，共分8章，介绍了国内外竹类研究和竹业生产的历史和现状以及中国竹文化等内容，系统论述了竹类植物的形态解剖特征、分类与分布、竹林群落结构和类型、竹林营造和丰产技术、经济价值和开发利用、竹类多样性及其保护等，既融合了过去各种竹类研究的有关内容，又广泛吸收了近期国内外研究成果，更注入了编者自己研究和开发实践的第一手资料，系统完整，内容详赡。本书适用于竹类、经济林、林业、园林、木材加工、森林旅游、森林保护、森林资源开发和林业经济管理等专业，亦可为其它有关专业参考使用，同时也是广大竹业工作者较好的工具书。

春天来临，百鸟争鸣、百花齐放，经霜不凋的翠竹又添新绿，雨后破土而出的新竹高于老杆。事物在发展，中国在开放，世界在前进，让我们一切关心竹类事业的朋友们，团结协作，共同努力，为加快我国竹产业发展而奋斗。



1999年09月 昆明

本书谨献给敬爱的导师、著名林学家和竹类学家薛纪如教授

This book is a memorial for Prof. Xue Jiru, the honourable teacher of the authors of the book

The authors of this book, Hui, Chaomao; Yang, Yuming; Du, Fan;
together with their late teacher, Xue, Jiru, the world renowned bamboo expert
and forestry professor of Southwest Forestry University, China

Dendrocalamus sinicus is the biggest bamboo that can be found in literature. It can grow to more than 30m tall by 30cm in diameter.

Photographs by Hui, Chaomao and Yang, Yuming From southwest Yunnan, China.

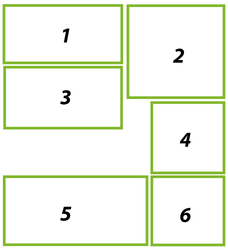
Bamboo culture

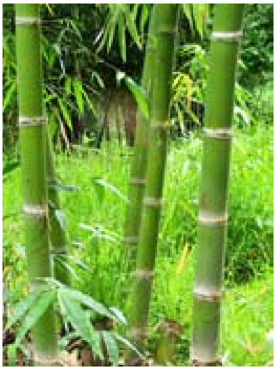
Bamboo is closely related to every aspect of people's lives including clothing, foodstuff, lodging, traveling, and appliances in China. Lower left: The fossil of bamboo dug from Longling, Yunnan, China. Photo by Hui, C.M., Yang Y.M., Pu C.Y.; the lower right is introduced from Yunnan China, 1999

Timber Bamboos

1. *Phyllostachys edulis* grove
2. *Dendrocalamus sinicus*
3. *Schizostachyum funghomii*
4. *Fargesia* yuanjiangensis
5. *Dendrocalamus* giganteus
6. Indosasa sinica

Photos by Hui,Chaomao and Yang,Yuming

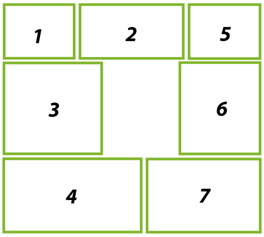




Shoot Producing Bamboos

1,2. *Dendrocalamus* brandisii
3. *Chimonocalamus delicatus*
4. *Fargesia* yunnanensis
5. *Cephalostachyum pergracile*
6. *Phyllostachys* praecox cv. prevernalis
7. *Dendrocalamus latiflorus*

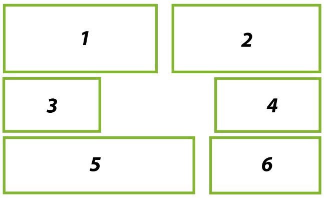
Photo by Hui, Chaomao (1,2,3,4,5,7)



Ornamental Bamboos

1. *Bambusa* vulgaris cv. vittata
2. *Bambusa* vulgaris cv. wamin
3. *Phyllostachys edulis* f. heterocycla
4. *Phyllostachys nigra*
5. Indosasa amara f. striata f. nov.
6. P. aureosulcata cv. spectabilis
   (七彩红竹)

Photograph by Hui, Chaomao



Some of the valuable and rarity bamboos

1. Dinochloa multiramora
   (Photo by Liu Jiazhu, 1998)
2. *Dendrocalamus sinicus*
   (by Gu, Zhongming, 2004)
3. Qiongzhuea tumidinoda
   (Photo by Dong, Wenyuan)
4. Gaoligongshania megathyrsa
   (by Xue Jiarong, 1998)
5. Cephalostachyum scandens
   (by Hui Chaomao, 1992)
6. *Schizostachyum* pingbianensis
   (by Hui Chaomao, 1992)

The natural bamboo forest of *Dendrocalamus membranaceus*, which distributed in the lower reaches of Lantsang river. Photo by Hui Chaomao, 2006

This is a village of the Dai people: bamboo houses dotted in bamboo forests form a special ethnic bamboo culture. From Xishuangbana, Yunnan. Photo by Yang, Yuming, 1996

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The project has been contributed, supported or assisted by the State Forestry Administration of China, the Provincial Government, the Provincial Scientific and Technological Department, and the Provincial Forestry Department. The authors are particularly grateful to the late Professor Xue, Jiru (1921-1999), who was our teacher and a former president of Yunnan Bamboo and Rattan Association (YNBAR). He was a world-renowned bamboo expert and professor at the Southwest Forestry University. We thank him for prefacing the book and devoting his attention to direct our work.

The authors have benefited greatly from the advice, concern and support of Professor Li, Dezhu and Pei, Shengji, research fellows of Kunming Institute of Botany Chinese Academy of Science. Professor Jiang, Hanqiao; Jin, Zhenzhou; Sun, Bixing and Yang, Yiguang of Yunnan University; Professor Chen, Yongsen of Yunnan Normal University; Professor Chen, Hairu of Yunnan Agricultural University; Professor Chen, Baokun; Liu, Huimin and Xie, Kaili et. al. of Southwest Forestry University; Professor Zhang, Qisheng; Zhou, Fangchun and Din, Yulong of Nanjing Forestry University; Professor Zhang, Guangchu of the Guangdong Provincial Forestry Academy; and Professor Yi, Tongpei of Sichuan Provincial Forestry School. The illustrations/plates were drawn by Mr. Wang, Hongbing; Li, Nan; Zhou, Dongning; and Liu, Jiazhu. The authors are grateful to the concerned graduates of Southwest Forestry University for their participation in part of the field work, and also grateful for permission to quote some reference data and illustrations/plates from the experts (for details, see the Bibliography).

In preparation for the International English Edition, the second principal author, Yang, Yuming traveled to Earth Advocates Research Farm near Summertown, Tennessee in U.S.A. to collaborate with bamboo researcher, Adam Turtle, on updating, internationalizing and making available to English readers this important modern bamboo book. Two visits and a lot of e-mails were necessary to create the final form. While they were editing the manuscript, Sue Turtle not only entered most of the text changes but also fed them well from her vegetable garden and generally kept things flowing.

The authors wish to express their thanks to all the above mentioned persons and departments, and to others too numerous to mention here, who have contributed to the preparation of this book. The authors invite the readers to put forward your proposal concerning any questions. All comments or suggestions will be appreciated.

竹

INTRODUCTION TO THE INTERNATIONAL ENGLISH EDITION

This important new look into the world of bamboo in its cultural and historic context as seen through the eyes of several Chinese academics began as doctoral work in the early 1990's under my friend and colleague the late Professor Xue, Jiru – the world renowned bamboo expert and head of the Bamboo Institute of Southwest Forestry University in Yunnan – to whom it is respectfully and affectionately dedicated.

This work was first published in Chinese in 1996 under the title (ISBN: 7-5038-1628-7) as a text for agriculture and forestry students. A rough English translation entitled China Bamboo was subsequently produced, but unfortunately such archaic English forms and terms were used that when coupled with the many unique spellings and typos, the resulting manuscript was intriguing but nearly incomprehensible. In the autumn of 2003 I had the honor of being invited to present a paper before the embassy level conference held in conjunction with the 4th China Bamboo Festival in Xianning, Hubei province. While there, I met and spent time with Jin, Wei and many of the INBAR staff. On learning more about INBAR and its important bamboo work, I offered, as a longtime bamboo scholar, to help however I could. Previously with my wife and research partner Sue we had edited and published the illustrated international journal "Temperate Bamboo Quarterly".

The following year Jin, Wei sent the rough translation and asked if we would consider "proof reading" the book. After accepting, it quickly became evident that this was very important and timely information as the west is just beginning to appreciate bamboos' future role as a major agro-industrial material. But it was also evident that transliterating as well as updating and a fair amount of editing would be required to achieve the book's international potential. After several months of effort using every bit of my then 25 years of bamboo research experience as well as near constant back-and-to for reference in our extensive bamboo library, it became evident that we needed some face-to-face discussion with one or both of the principle authors to resolve ambiguities and/or clarify intent on a number of passages.

To harmonize the botanical Latin bamboo names, we used Ohrnberger, D. The Bamboos of the World 1999 edition, ISBN: 0-444-50020-0 where possible. This was supplemented by reference to Volume 22 (The Poaceae) of the Flora of China ISBN: 1-930723-50-4. Also included are several newly described but not yet internationally published species. Fortunately Yang, Yuming was able to come to our bamboo farm in Tennessee in August of '05 for a couple weeks of intensive collaboration. We successfully resolved many of the puzzling aspects while establishing a firm mutual respect and friendship before running out of time. In the intervening two years we worked sporadically, as best we could, but found that attempting a complex scientific/literary discussion with language complications via e-mail – and amidst other responsibilities was proving both slow and difficult. Professor Yang was able to arrange another visit to our farm in July '08 with his assistant Dr. Wang, Juan and the four of us were able to more-or-less finalize the International English Edition of China's Bamboo.

Wherever possible we have retained both the flavor and the sense of the original aiming only for clarity rather than polished English prose. For instance we chose to keep most land measurements in the traditional units, the Mu which is equivalent to 1/15ha. It has been a tremendous undertaking on the part of both the Chinese and the American collaborators. It is our hope that this new (to the western world) bamboo book will not only help provide historical and cultural insights into the complex relationships between this unique plant and the Chinese people, but also furnish useful and practical information based on their thousands of years of experience as well as many decades of modern scientific study into selecting, growing, and utilizing bamboo's many beneficial attributes and applications.

We especially hope it will appeal to young people and encourage them to consider bamboo as a field of study … to the benefit of all people.

Adam Turtle FLS
Contributing Editor
Summertown, Tenn. U.S.A.
August, 2008

Photo by Jin Wei, 2003

Introduction to Contributing Editor

Ethnobotanist, Adam Turtle FLS, is the Co-director of Earth Advocates Research Farm where he grows and studies approximately 300 species and forms of temperate bamboos as well as many other useful but underappreciated plant taxa. As a bamboo farmer/researcher with nearly 30 years of experience, he lectures, writes and consults worldwide on various aspects of bamboo. He is a strong proponent of widespread use of bamboo as an agro-industrial feedstock with multiple social as well as environmental benefits.

E-mail: bambooconsultant@aol.com

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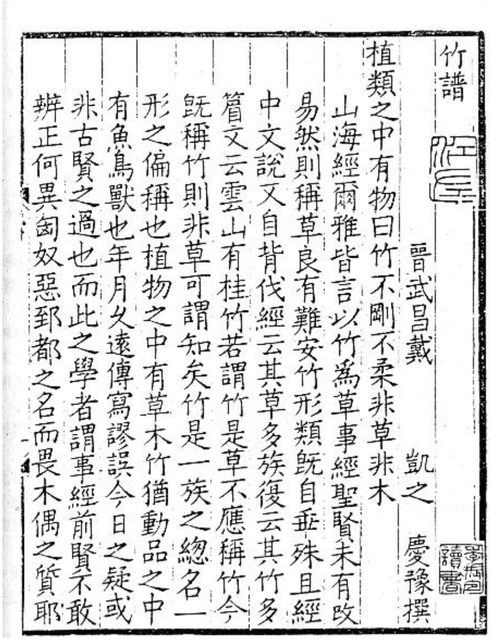
CHAPTER 1

A SURVEY OF CHINESE BAMBOO CULTURE

Through the ages the Chinese people have always been fond of bamboo and China is believed to be the first country in the world to have carried out formal bamboo research on cultivation and utilization. Bamboo has played an immense role in the development of Chinese historical culture and the formation of Chinese ideology. In fact bamboo is very closely linked with the people. The long-standing relations between bamboo and Chinese poetry, calligraphy, painting, and landscape construction goes back to ancient times. When viewed from this perspective, it is not difficult to conclude that China deserves to be known as a "Country of Bamboo Civilization".

1.1 Bamboo and Chinese History

Though bamboo utilization is reflected in tales and legends of ancient China, reliable records of bamboo started in the time of the Yangshao Culture. The Chinese character "竹" (bamboo) can be clearly discerned on pottery unearthed as relics of the Yangshao Culture found in Banpo Village near Xi'an (capital city of Shaanxi Province) in 1954 and dating back some 6,000 years. This shows that bamboo had been a subject of research and utilization even before recorded history. Bamboo research and utilization dates back to the Neolithic Age some 5,000~6,000 years ago. It is believed that Chinese characters resulted from the Yangshao Culture, which followed the collapse of a more primitive society, so the original sign, "竹" may have appeared earlier. Bamboo was also found in Hemudu relics of the primitive society which dates 7,000 years back, in Yuyao County of Zhejiang Province. It is evident that bamboo already shared a close and important relationship with people's lives in the primitive society, as a symbol or character for bamboo only became necessary when the plant was actually used by humans. (Xiong, Wen-Yu 1983; He, Yang-Ming 1982)


竹譜

晉武昌戴凱之 慶豫撰

植類之中有物曰竹不剛不柔非草非木
山海經爾雅皆言以竹爲草事經聖賢未有改
易然則稱草良有難安竹形類既自乖殊且經
中文說又自背伐經云其草多族復云其竹多
箘文云雲山有桂竹若謂竹是草不應稱竹今
既稱竹則非草可謂知矣竹是一族之總名一
形之偏稱也植物之中有草木竹猶動品之中
有魚鳥獸也年月久遠傳寫謬誤今日之疑或
非古賢之過也而此之學者謂事經前賢不敢
辨正何異匈奴惡郅都之名而畏木偶之質耶

Fig. 1-1 The book **Bamboo Chart**, was written i n the Jing Dynasty of China by Dai, Kaizhi

Research demonstrates that different uses of bamboo were known in the Shang Dynasty (c.17~11th BCE) one of which was to make inscribed bamboo books. That means to have Chinese characters inscribed on bamboo slips (though also on wooden slips sometimes) before they are bound together into a "book" and that is where the Chinese character "册" (volume) originated. A large number of precious documents dating prior to the East Han Dynasty (25~220CE) were preserved in the form of bamboo or wooden slips. These included the **Book of Esteems**, the **Book of Rites**, and the **Book of Debates**. In the Shang Dynasty books inscribed on bamboo slips were called "bamboo books" while messages written on bamboo slips were known as "bamboo messages". The invention of the bamboo writing brush was also regarded as something original in the cultural history, and writings in Chinese ink done with a bamboo brush were discerned on bones, tortoise shells, jade bars, and pottery unearthed from cultural relics of the Shang Dynasty. Evidence was also found in cultural relics from the "Spring and Autumn Period" and the Warring States Period (770~221 BCE) unearthed from Zenghou, Yi's tomb and other tombs in Ting'e of Hubei Province. Another important result of bamboo utilization was bamboo paper. Bamboo was initially used to make paper in China beginning in the 9th century, nearly 1,000 years earlier than in Europe, though the boom didn't come until long afterwards. The techniques for making bamboo paper were maintained with illustrations in the **Thien Kung Khai Wu** (1640), a book written in the Ming Dynasty. Bamboo paper making, a mark of significant advance and achievement in paper making technology of ancient China, made a tremendous contribution to prosperity in the Chinese culture. Tools for paper making were also made from bamboo even before bamboo paper came into being. So from bamboo slips for inscription to the invention of bamboo paper, bamboo occupied an important position in the history of cultural development. It played direct and indirect roles in conservation of human knowledge as well as in the formation of a time-honored and brilliant historical culture.

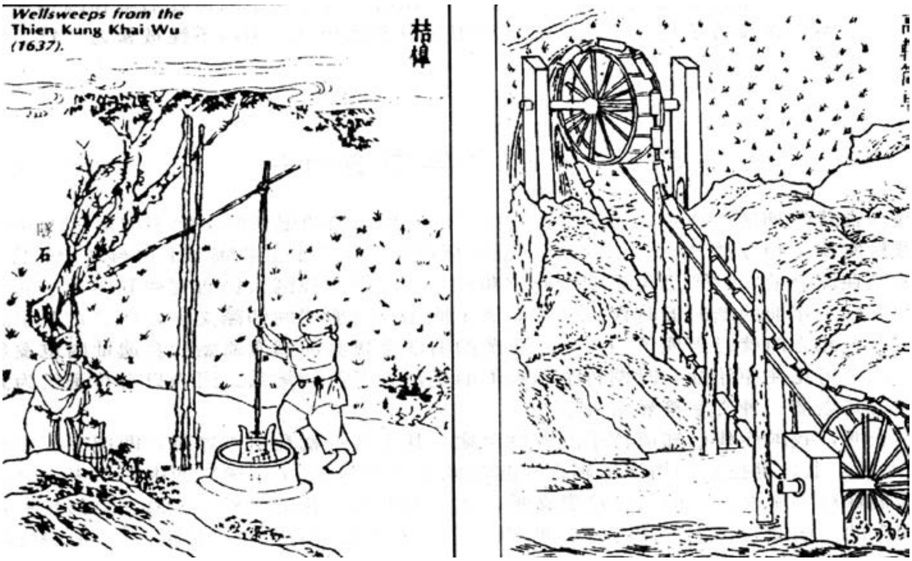


Fig. 1-2 Ancient Chinese Irrigation Devices (from the Thien Kung Khai Wu, China)

There were many other ways of bamboo utilization in ancient China. During the Spring and Autumn and the Warring States Periods, for instance, our ancestors invented "wellsweep", a bamboo tool for lifting water from a well and "high-wheeled turning tube", an irrigation device composed of linked rotating bamboo tubes. (See Fig. 1-2) Bamboo also contributed much to the development of ancient weapons, from primitive bows and arrows to stone-throwers of the Spring and Autumn Period to gunpowder filled bamboo arrows and even bamboo-barreled firelocks of the Song Dynasty (960~1279).

The ancient history of bamboo civilization can also be reckoned from analysis of bamboo-based characters. Our forefathers called bamboos the plants that were neither hard nor soft and neither grass nor trees but alike in internodes and nodes with minor differences only in hollowness and stiffness. To start from morphological knowledge, they processed bamboos into articles and derived bamboo-based characters from the same root "竹". Bamboo utilization was expanded and the number of bamboo-based characters were increased accordingly as human knowledge about bamboo grew. A total of 209 characters were included in the **Complete Collection of Characters** (1979). Many more were included in other dictionaries in different Dynasties (Table 1-1) (Xiong, Wen-Yu 1983). Many idioms were laden with interesting allusions to bamboo, such as "an all-well home letter", "a bamboo-stick horse for childhood game", and "a late morning when the sun three-pole high". Involving almost all walks of life, these characters and idioms reflect on one hand man's deep ongoing understanding and utilization of bamboo and on the other, their significant roles in many time-honored fields in Chinese history, i.e. agriculture, industry, literature, art, as well as in daily life.

Table 1-1 A Statistic Table of Bamboo-based Chinese Characters

Date	Source	Total Characters	Bamboo-based Characters
Shang Dynasty (c. 16-11 th BCE)	On bone or tortoise shells	21,700	6
Zhou Dynasty (c. 11-3 th BCE)	On ancient bronze objects	–	18
Eastern Han Dynasty (25-220 CE)	Explanation of Characters	9,353	151
Liang Dynasty (502-557 CE)	A Treasure of Characters	16,917	506
Ming Dynasty (1368-1644 CE)	A Collection of Characters	33,179	573
Qing Dynasty (1616-1911 CE)	Kang Xi Dictionary	47,035	960

1.2 Bamboo and Chinese Spiritual Life

Throughout the long history of Chinese culture, bamboo has been praised as one of "the three good friends withstanding severe cold" together with pine and plum. Like plum, orchid, and chrysanthemum, it was also personified as one of "the four upright gentlemen of honor". It is seen from these descriptions that bamboo occupies a place in people's hearts because of its tall and graceful culms, natural branches and leaves, varied forms and postures, evergreen features, and specific charms of interest. When people stroll in the shadows of green bamboo, a feeling of boundless comfort and pleasure wells up in their hearts, their fatigue and vexations melt away. No wonder Su, Dongpo, a famous poet in the Song Dynasty (960~1279CE) once declared: "I'd rather eat without meat than live without bamboo". In parks or around villages large patches and clusters of bamboo not only beautify people's lives but also purify their temperament. It is true that the peony is more gorgeous, pine and cypress are more magnificent, and blossoms of peach and plum are more charming. Bamboo's modest and elegant characteristics and qualities are, however, much more often extolled by the people. It can be proudly said that bamboos are selfless, unadorned, and uncritical of the environment. Instead of showing off, they silently dedicate their shelter to the land and their wealth to the people.

During the Chinese people's long course of production and cultural activities, biological features of bamboo have been associated with spiritual features such as modesty and integrity. They are treated as a part of noble personalities whose connotation stands as a symbol of the virtues, natural endowments, and aesthetic essence of the Chinese. When in the presence of bamboo, one can't help thinking of its noble character of being straight and unyielding, as well as defying difficulties and adversity. This is bamboo's inexhaustible spiritual wealth in which lies its aesthetic value. In people's spiritual lives, bamboo culture imparts a rich, unique connotation that exerts influences on the aesthetic viewpoint, sense, and morality of Chinese literature, painting, handicraft, gardening, music, religion, and folklore as well.

Through all ages since the **Book of Songs** came into being, bamboos have been a resource rich theme for literature. Numerous excellent literary works have been created in the forms of poem, prose, and fu (a literary style in ancient China) singing praise of bamboo. Together they constitute a distinctive, unique, and brilliant section of Chinese literature(He, Yang-Ming 1982).

Fig. 1-3 Larvae of some insects are delicacies. Photo by Xue, Jiarong, 1998

As products of science and art, handicrafts are born out of the marriage of aesthetics and the needs of life. Bamboos provide an important part of the materials for making handicrafts. In the long process of thousands of years, the meaning of bamboo culture has been enriched by a large variety of charming handicrafts woven and carved by the Chinese ancestors from bamboo. Archaeological studies indicate that bamboo implements were woven at the beginning of the Neolithic Age, and that bamboo weaving techniques were already highly developed by the Spring and Autumn Period and the Warring States Period. Bamboo implements in the State of Chu, particularly, were renowned for ample variety, superb skills, and unique styles. Bamboo carving technology started to take form in the Shang Dynasty, bamboo carving works were preserved for the first time in the Han Dynasty, and accounts of artistic bamboo works were kept in documents of the Six Dynasties (222~589). Renowned experts of bamboo carving kept coming forth after the Tang Dynasty (618~907). There were Zhancheng in the Song Dynasty, the Jiading School represented by the three generations of Zhu, Songlin's family, and bamboo carving master Li, Wenfu in Jinling (today Nanjing) in the Ming Dynasty (1368~1644). Bamboo inner-skin carving of the Qing Dynasty (1616~1911) developed respectively in Shaoyang of Hunnan, Jiang'an of Sichuan, and Huangyan of Zhejiang. In early years of the Republic of China (1912~1949) there appeared the North School of bamboo carving pioneered by Zhang, Zhiyu in Beijing. In handicrafts bamboos were woven into various patterns to express all good wishes such as blessing, prosperity, wealth, happiness, high position, good luck, plain sailing, and long life. Bamboos have also been popular with decorative folk arts for thousands of years and used extensively in carving, embroidery, dyeing, pottery, weaving, and cut paper silhouettes.

Sharing a close relationship with the Chinese musical culture, bamboo provides an important material for the making of musical instruments. In fact, the traditional Chinese wind and stringed instruments are virtually all made of bamboo. Historical documents and archaeological findings indicate that bamboo contributed much to the formation of the Chinese tonality, and that tones have been set with bamboo flutes through all ages since the Zhou Dynasty (c. 11th~256 BCE). That is why the term "string and bamboo" has been applied as another name for "music" since the Jin Dynasty (265~420 CE), and circulated the proverb "music of string is inferior to that of flute". In the Tang Dynasty (618~907), artisans who played the musical instruments were called "bamboo men". All these illustrate that bamboo was a bearer of material irreplaceable in the Chinese musical culture.

Bamboo also had great influences on religious culture in China. Our forefathers in ancient times believed in totemism and worshiped bamboo as a totem. They treated bamboo as a tool for sacrificial offering or even as the offering itself. For the sake of doctrine, Taoism and Buddhism adorn bamboo and seek after a bamboo-structured environment.

Bamboo has played a major part in Chinese folklore. Linked with oral literature, art, entertainment, beliefs, as well as habits, bamboo culture has become a part of human rites such as memorial ceremonies, weddings and funerals, social intercourses, festivals, and pilgrimages. These, in return, make up the essence of bamboo culture in folklore.

1.3 Bamboo and Chinese Poetry and Painting

From ancient times countless men of letters and writing have shown great interest in bamboos. They expressed their feelings with good reasons and created thousands of tales, poems, paintings, and calligraphy featuring bamboo. These constitute an essential part of bamboo culture in China.

Of all bamboo poems included in the **Book of Songs**, the earliest and most complete of its kind in China, five dealt directly with bamboos while dozens made indirect allusions. Qi'ao in the Wei Section said, for example, that "Behold Qi'ao please, and so green are bamboos there". 'Ballad of Wei', another poem in the same section, chanted that "with tenacious bamboo culms they fish on the Qi River". Though different ideas have been expressed in history about bamboo records in the **Book of Songs**, it is doubtless a fact that they refer to bamboos. The second line, for instance, unmistakably means to fish on the Qi River with bamboo culms. Here "bamboos" cannot be substituted with other plants. Composed during the Spring and Autumn Period, the **Book of Songs** was followed by various documents in later dynasties with records of bamboo poems and paintings.

When we talk about bamboo poems and paintings, we should never fail to mention a few touching stories of loving bamboos. According to **Imperial Reading at Time of Leisure**, Wang, Ziqiu, a great calligrapher in the Jin Dynasty, once lodged in an empty house and had bamboos planted. When asked why he bothered, he reflected a while before he replied by pointing directly to the plant: "How can I bear to live a day without this gentleman?" For all his life he had loved bamboo as an appreciated friend. Su, Dongpo in the Song Dynasty also sang high praise of bamboo. In his poem 'Green Bamboo Gallery of a Hermit' he declared that "I'd rather eat without meat than live without bamboos. For one grows weak without meat but vulgar without bamboos. A weak person may grow strong again but a vulgar man is beyond any cure..." Zheng, Banqiao, an outstanding painter among the Eight Eccentrics of Yangzhou in the Qing Dynasty, was especially fond of and good at painting bamboos. He had hundreds of his colorful and unmatched bamboo poems inscribed on his bamboo paintings. On his 'Bamboos and Rocks' he inscribed a poem reading "Tight to the green mountain you hold, in stone cracks your roots manage to pierce. Firm you stand through untold hardships; does it bother how winds may blow?" This is indeed a high praise to bamboo's temperament of defying adversity.

Among the forerunners who wrote poems and painted pictures during the Chinese revolution (1921~1949), the most representative was Fang, Zhimin. To encourage himself, he put up a self-composed couplet on the wall of his bedroom: "The three loves dear in heart are rare book, gallant horse, and wonderful view; the four plants grown in yard include pine, bamboo, plum, and orchid." He even named his sons and daughters after pine, bamboo, plum, and orchid. These showed how much bamboo dwelled in his heart. Having experienced a difficult time in the revolution, he wrote an epic imbued with soaring resolve: "Under a snowfall bamboo lowers its head, till the muddy ground it almost touched. But whenever the red sun shines high, stands that sturdy bamboo against the sky."

Thousands upon thousands of Chinese bamboo poems through the past ages involve Chinese myths and folklore, eulogize the moral character of bamboo, express one's emotions and record the utilization of bamboo, etc. Their contents are very rich and interesting.

It is no accident that the art of traditional painting in China has emphasized bamboo painting, for the spiritual outlook and special aesthetic value of bamboo not only arouse creative inspiration in the artists but also serve as esteemed models for their conduct.

From ancient times the art of bamboo painting has been regarded highly in traditional Chinese painting. In the middle of the Tang Dynasty bamboo became a specialized subject; in the Northern Song Dynasty (960~1127) Wen, Tong, who pioneered "the Huzhou School of Bamboo Painting", was regarded as the originator of bamboo painting in Chinese ink. Great masters of bamboo painting with distinctive styles include Ke, Jiusi; Gao, Kegong; and Nizan in the Yuan Dynasty (1206~1368), Wang, Fu; Xia, Chang; and Xu, Wei in the Ming Dynasty, Shi, Tao; Zheng, Banqiao; Pu, Hua and Wu, Changshuo in the Qing Dynasty. Each of them made a contribution to the shared development and perfection of techniques and theories in bamboo painting and even now bamboo painting still prevails in China as an important cultural phenomenon.

Bamboo painting became popular in the Tang Dynasty when bamboos were originally painted in Chinese ink. Greater achievements were made in the Song Dynasty when masters of bamboo painting kept appearing one after another. The great poet Su, Dongpo was an artistic giant of bamboo painting. His second son Su, Guo was a famous bamboo painter, and his close friend Wen, Yuke was also a bamboo painting master with excellent skills. Su, Dongpo's theory of "conceiving an image of bamboo before painting" was embraced and observed by bamboo painters in Chinese ink through all ages in their creation of traditional painting. With elegant postures, boundless beauty, and vivid styles, the charming figure of his Bamboos in Chinese Painting was wonderfully displayed. In his **Account of Wen, Yuke's Painting of Yanzhu at the Valley of Flute Appreciation**, an excellent piece of writing read through all ages, he pointed out that "before you paint you should visualize bamboos in your mind".

Su, Dongpo, who was versatile and good at writing poems and painting pictures, loved bamboo so much that he "would rather eat without meat than live without bamboo". His bamboo pictures in Chinese ink, mostly with upturned branches and drooped leaves, were done with vigorous strokes in dense ink. His painting of Tree, Rock, and Bamboo was a masterpiece that has been passed down through ages. In the picture he drew a dead tree that had a solitary trunk and aloof branches, a gigantic rock that occupied the center, and a few thin-leaved bamboo culms that expressed a strong will for life through concessions. The dead tree and gigantic rock were, consequently, endowed with life.

With distinctive features of their own, masters of bamboo painting in all ages created different schools through their painting practice. To sing high praise of their expressive paintings, Bai, Juyi, a well-known poet in the Tang Dynasty, acclaimed that "at first glance they look unlike paintings, yet on lending ears we seem to hear sounds".

Bamboo painting continued to prosper and grow in the Qing Dynasty as emergence of the Eight Eccentrics of Yangzhou brought about a new situation. To reflect natural things as they really are is a conventional requirement of the Chinese painting. What Zheng, Banqiao expressed in his paintings, however, were not merely inborn features of natural objects but also his personality, ideas, and attitudes toward society. He also left for us 69 pieces of painting inscription in addition to many excellent bamboo paintings. He praised "bamboo as a gentleman, rock as his Highness, pine as an eternal friend, and orchid as a lasting spring". On one of his paintings he wrote: "When Wen, Yuke drew bamboos he had bamboo images in his mind, but when Zheng, Banqiao drew bamboos he bore no such images". This is a good revelation of his viewpoints on society and art (Guan, Chuan-You 1994; Zhou, Fang-Chun; Hu, De-Yu 2001).

1.4 Bamboo and Chinese Gardens

Bamboo has been a plant indispensable to Chinese gardens of classical style. The history of garden building in China started during the reign of Emperor Wen in the Zhou Dynasty (c. 11th~256 BCE) when "Lingtai, Lingzhao, and Lingyou", three of the earliest imperial gardens were built. After Emperor Qin, Shihuang (246~209BCE) in the Qin Dynasty united the other six states; he went for a large-scale construction. In order to build Shanglin Yuan, he had bamboo introduced from Yungang of Shanxi to Xianyang of Shaanxi according to the **Book of Anecdotage**. This is the earliest record of bamboo utilization in garden building. Confined mostly to the construction of game lands and bases for strategic supplies, bamboo cultivation or bamboo garden building of that time was still at a very primitive stage.

During the periods of Wei and Jin (265~420) and the Southern and Northern Dynasties (420~589), Chinese gardens underwent changes from the early primitive to the more developed stage. Under influences of political turmoil and religious criteria concerning social behavior, some literati and many officials at that time advocated metaphysics, abandoned themselves to nature, and visited famous mountains and rivers as a fashion. Their poems and prose, which eulogized natural views, rural scenery, and the newborn art of landscape painting, provided great stimuli to the development of gardens. Bamboos were included and merged into garden building immediately after "natural landscape gardens"came into existence and due developments of bamboo views were made in both imperial and private gardens. The book **Notes to Water Channels** holds an introduction to Hualinyuan, a famous garden in Northern Wei (386~534): "Shading the rocks are bamboos and cypresses, clustering by the fountains are flowers and grass". It was recorded in **Account of Galan** in Luoyang that private gardens of high officials and noble families were "unexceptionally green in summer with peaches and plums, and in winter with bamboos and cypresses".

There were famous bamboo views such as "Jinzhu Mount" and "Zhuli Hall" in the garden of Wangchuan Bieye which was designed by Wang, Wei, a poet in the Tang Dynasty. From **Account of Genyue** by Huizong (1101~1119), the 8th emperor of the Northern Song Dynasty who took a personal interest in designing his imper ial garden Shoushan Genyue, we know it was a landscape garden typical of bamboo views at that time. When the Southern Song (1127~1279) renamed Hangzhou as Bianliang for its capital city, noblemen, officials, and rich merchants began to settle south of the Changjiang River. Imperial palaces and private gardens of that time laid a solid foundation for later development of gardens there. Bamboos were widely used in the dynasties of Tang and Song. The book **Famous Gardens in Luoyang** gave commentary on 19 private gardens, of which 10 received special description on bamboo views including Guirenyuan, Western Garden of the Dong Family, Fuzheng Park, and Miaoshui Garden. From **Gardens in Wuxing**, a book written by Zhoumi in the Southern Song Dynasty, it is learned that bamboos were planted in "every private garden" in Wuxing. Bamboo gardens, hereafter, entered their final period of full glory.

With a tradition inherited from the Tang and Song dynasties and local styles gradually formed, gardens south of the Changjiang River in the Ming and Qing dynasties, as represented by private gardens, stood at the peak of development at this later stage in Chinese feudal society. A combination of bamboos with water, rockery, garden walls, and bamboo views is characteristic of gardens south of the Changjiang River and south of the Five Ridges. The six famous gardens in Suzhou such as Pavilion of the Surging Waves and Lion Grove, Ge Garden in Yangzhou, and Xiaoyaotang in Huizhou were all regarded as successful examples of bamboo application to garden building, many of whose architectural skills are still adopted by modern people. (Guan, Chuan-You 1994)

Quite a number of booklets on theories and techniques for garden construction were printed in the Ming and Qing dynasties, such as Wang, Xiangjin's **A Guide to Flora**, Tulong's **Casual Notes in a Mountain House**, and Liyu's **Living Room (Volume of Little Pleasures in Sustenance)**. The most influential of all, however, were Jicheng's **Garden Management** and Wen, Zhengheng's **Annals of Growing Plants**. They made exhaustive and brilliant expositions on bamboo application to garden construction and were highly praised and followed by later generations. By then the development of gardens, particularly bamboo gardens in the Ming and Qing dynasties, had entered the stage of maturity. (Jin, Sha; Lan, Xio-Buang 1993).

With developments in poetry, calligraphy, painting, and landscape gardening, people were no longer contented with courtyard views and started to create miniatures of natural views, i.e. potted-landscapes (known as Penjing in the West) that could be appreciated anytime at home. Potted-landscapes in China, according to research, came into being during the Tang Dynasty. Bamboo-based landscapes can be seen in many painting rolls by famous painters of the Song Dynasty, and those with the theme of "the three good friends withstanding severe coldness" became extremely popular during the Ming and Qing dynasties. Both **Kaopan Yulu** and **A Guide to Flora** made introductions to the making and appreciation of bamboo potted-landscapes. A stand of bamboo potted landscape made of jadeite is kept in the Palace Museum in Beijing. This potted-landscape was a treasure dedicated to Emperor Qianlong of the Qing Dynasty on his 80th birthday by his ministers. After many years' development, many wonderful works of bamboo potted landscape have been created, and the representatives include Seven Virtuous Men in Bamboo Forests, Delights from Bamboos, Running Waters in Bamboo Forests, Green Wildness, Seclusion in Bamboo Forests, and Influences Left Over by Dongpo.

Potted landscapes of bamboo are another traditional utilization in China. Praised as "silent poems and stereo pictures", potted landscapes of China are of great interest to Western people to whom they are known as Penjing.

1.5 Bamboo and People's Lives

Owing to fast growth, strong adaptability and extensive uses, bamboo is closely associated with every aspect of people's lives such as clothing, food, lodging, traveling, and appliances. Bamboo has been used in construction from times immemorial. It played an important part in people's evolution from living in trees and caves to living in grounded houses. Bamboo material for construction was found at the Straw Sandal Mountain in Wuxian County of Jiangsu Province, the cultural relics belonging to a late stage of the Neolithic Age. Bamboo Hall in the Sweet Spring Palace in the Han Dynasty, and Huanggang Bamboo Tower in the Song Dynasty were both made of bamboo and enjoy a famous reputation.

Regarding clothing, bamboo exercised important influences on the start and development of Chinese clothing. In the Qin and Han dynasties bamboo was used to make cloth, head-coverings, and rain gear. Bamboo shoes, bamboo hats, and bamboo umbrellas are still in use today. In some prefectures and counties south of the Five Ridges bamboo cloth used to be a major tribute to the imperial government in the Tang Dynasty. Bamboo was also used as a decorative material by the ancients. All these are concrete examples of bamboo's contribution to man's culture of costume.

To examine as foodstuff, bamboo shoots and fungus are people's favorite delicacies from land and bamboo seed has for centuries been an important relief to famines. According to documents of the pre-Qin period, bamboo shoots were served as a fine dish 3,000 years ago. When cooked in different ways, it can be made into thousands of tasty dishes for the table. Bamboo is also medically valuable and records of bamboo's uses in disease treatment were recorded in China's earliest medical documents. Every part of bamboo, in fact, is a treasure. Bamboo leaf, seed, root, tabasheer, fungus, as well as chips of fine inner skin and juice from bamboo culms are all efficacious medicines for many diseases.

In the history of Chinese civilization, the origin and development of means and devices of transportation in ancient China was closely related to bamboo. The ancients used bamboos to build carts, rafts, and bridges, and created "many a first" in the history of world transportation. In a word, bamboo made a great contribution to the birth and development of world transportation means and devices.

Fig. 1-4 Traditional tools in a rural area of China
Photograph by Hui, Chaomao, 2003

Archaeological findings prove that bamboo ware was made by our ancestors in the late Paleolithic and early Neolithic periods. The impression mark of a bamboo braid was found on the bottom of pottery excavated at Banpo Village near Xi'an. Much bamboo ware stamped pottery was found at Liangzhu in the South, and over 200 pieces of similar bamboo ware were found at Qianshanyang of Wuxing County in Zhejiang Province. Bamboo ware increased in variety with advances in society and culture. By the Spring and Autumn Period and the Warring States Period, the making of bamboo ware had grown to be an important sector of social production, and bamboo ware had become indispensable to people's daily lives, nourishing the living and burying the dead. There were some 60 kinds of bamboo articles for daily use in the Han Dynasty, over 100 in the Jin Dynasty, about 200 in the Tang and Song dynasties, and over 250 in the Ming and Qin dynasties. Currently over 1,000 uses are known! For example: cooking utensils such as, ladles, plates, and steamers; goods-holders such as carrying baskets, hand baskets, and chests; furniture such as beds, couches, mats, chairs, pillows, teapots, screens, tables, cases, and shelves; calculating devices such as counting rods and abacus; measuring tools such as bamboo rulers and bamboo tubes; lighting devices such as lanterns and torches; sanitation appliances such as brooms and smokers; ornaments such as curtains and vases; handy toys such as fans and canes; gambling tools such as bamboo chips; and coffins for burying … were all daily essentials frequently homemade and based on bamboo for material.

Fig. 1-5 Bamboo bridge in a rural area. Photograph by Yang, Yuming, 1989.

Bamboo also contributed much to people's living environment. Its special protective function was discovered by our forefathers in ancient times and it was used as a protective screen or hedge for a house against thieves and burglars, or as a wall for a city against enemies. It is still used as a climate regulator, water purifier, soil preserver, noise reducer, air purifier, and wind-break. Bamboo has been held in people's hearts since ancient times and used to protect and beautify their living surroundings.

From these examples we can see that bamboo has contributed much to the daily life of the Chinese people and revealed an elegant demeanor of bamboo civilization. The relationship between bamboo and man, therefore, is a close one just as Su, Dongpo wrote: "We have bamboo shoots for food, seek shelter under bamboo tiles, ride on bamboo rafts to cross a river, cook with bamboo as firewood, make clothing with bamboo skin, write on bamboo paper, and wear bamboo shoes. Indeed we cannot last for a day without this gentleman."

The Chinese civilization is characterized by agriculture, and bamboo has served as a major contributor to agricultural development in China. Archaeological and national archive data indicate that bamboo utilization began with primitive societies, and remains can still be found in some ethnic minorities at the developing stage. Many tools for agricultural production in the civilized societies were made of bamboo. For example: threshing tools such as flails, rakes, sieves, winnowing baskets, winnowing fans, and tanning plates; irrigation devices such as dunking bird, water pipes, linked-tubes, and turning tubes; strainers, poles, weirs, and trunks. Bamboo was also important to the construction of water conservation projects. For instance, a large amount of bamboo was used in Dujiangyan Irrigation System in Sichuan over 2,000 years ago and a method was then invented to cut off and divide water with stones held in huge and long bamboo baskets. This method was successfully utilized in fighting against floods, particularly in closing up bank collapses of the Huanghe River since the Han Dynasty, and in building sea embankments in coastal areas against tide damage from the Five-dynasty Period (907~960). Known in the West as "gabions", the technique of using caged stones is still employed today.

The fields of bamboo use and utilization have been expanded continuously by the Chinese in their long association. Developments in science and technology have led to strong efforts in the further development of bamboo utilization. Besides innumerable traditional uses, bamboo has been adapted to produce laminated artificial boards, weave beautiful handicrafts, and be processed as high-quality food. It is still finding more and more profound and extensive uses in many fields such as light industry, construction, and agriculture that, in return, continually increase bamboo's economic value (Lan, Xiao-Guang 1990).

Bamboo is closely associated with the national culture. Xishuangbana, a low-altitude river valley where the Dai people live in compact communities, is famous for its charming natural scenery and unique regional flavor, and attracts tourists at home and abroad with its distinctive bamboo-based culture. Having a tradition of loving, planting, and using bamboo, the Dai people live in bamboo cottages, sleep on bamboo mats, have bamboo shoots for food, cook with bamboo as firewood, build bridges with bamboo instead of wood, and cross rivers on bamboo rafts. In fact almost all of their household appliances are made of bamboo, such as pails, baskets, tables, and stools. Their bamboo lunch-boxes, bamboo smokestacks, and "bamboo rockets" are rich with national features. The Dai countryside is so colorfully embellished that the villages would lose much of their brilliancy if they were not surrounded with green bamboos. Natural scenery of bamboo in the border areas is a very precious resource for tourism.

In short, bamboo culture in China is rich and profound in its content. Bamboo exerts a tremendous influence on Chinese history and culture, literature and art, poetry and painting, craft, horticulture, music, religion, folk customs, etc. It is a material as well as a spiritual treasure in which the Chinese people take great pride. This chapter has given a summary of the study of the present condition of China's bamboo culture.

Fig. 1-6 The new style of Dai people bamboo house designed by YNBAR and YBRC

This thesis will bring to our attention a larger view. It will include: the conservation development of the ethnic minority bamboo cultures, the research of bamboo culture which must be integrated with tourism development, the typical regions of bamboo culture and the program of tourism development, such as the Region of Maozhou (*Phyllostachys edulis*) Culture in East Asia (south of the Yangtze River of China), the Region of Ethnic Minority Bamboo Culture in Southeast Asia (Yunnan, China), the Region of Alpine Bamboo Culture in The Himalayas, the Region of Guadua Bamboo Culture in Latin America, and the general and ongoing increase in bamboo use and appreciation worldwide (Hui, Chaomao; Du, Fan; Yang, Yuming 1997).

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CHAPTER 2

MORPHOLOGY AND ANATOMY OF BAMBOO

2.1 Morphological Features of Bamboo

Bamboo is known to share certain common features with other members of the grass family. It presents itself as a particular type, however, with all its peculiarities in external morphology of vegetative organs, structure of reproductive organs such as flower and fruit, as well as regulations of growth and development. These peculiarities can be discussed under various aspects including culm, rhizome, branch, sheath, flower and inflorescence, together with fruit and seed.

2.1.1 Culm

As the essential part of bamboo, the culm is divided downward into three sections, namely culm (cane), culm base, and rhizome neck (Fig. 2-1, 2-2).

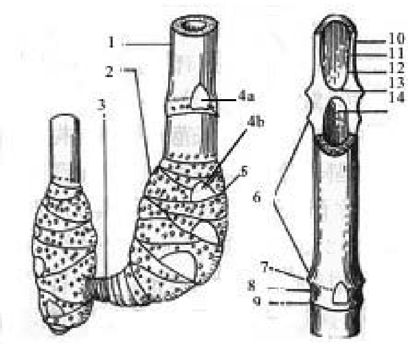

Fig. 2-1 Structure of culm
(1. culm; 2. culm-base; 3. rhizome-neck; 4a. branch bud; 4b. shoot bud; 5. root bud; 6. internode; 7. nodal ridge; 8. intranode; 9. sheath scar; 10. culm skin; 11. culm wall; 12. culm cavity skin; 13. diaphragm; 14. culm cavity)

Fig. 2-2 Culms of Dendrocalamus giganteus from Xinping, Yunnan. Photograph by Sun, Maosheng, 2003

• Culm (cane)

The culm (cane) is the aerial stem and has distinctive nodes and generally hollow internodes. Each node has two rings: the lower and the upper. The lower is the sheath scar, a mark remaining after the culm sheath has come off while the upper is the supranodal ridge, a spine-like trace left over when the intercalary meristem has ceased growing. The part between two adjacent nodes is known as the internode, formed inside is a woody septum or diaphragm and on the outside is the branch bud. Striking differences exist between species as to the form and length of nodes, intranodes and internodes respectively. The internodes generally take the form of a round green pipe, but can be oval, squareish or tortoise-shell shaped in some other instances. In some species the internodes may be purple to black, or yellowish, or even striped or spotted. *Schizostachyum funghomii* has relatively long internodes, commonly 70~80cm, with an extreme of over 100cm. These special morphological features lend themselves considerably to the landscape value of bamboo.

• Culm base

As the bottom, the culm base is normally subterranean and thicker, made up of several to some dozens of nodes exceedingly shortened and thickened. Shoot buds (known as eyes) and roots grow at these nodes. For some species, buds on the culm base can directly grow into culms; but for others, long thin rhizomes have to be formed first before new culms can grow out from lateral buds on these stems.

• Rhizome Neck

The rhizome neck is the gradually thinning end of the culm base. It is connected to the rhizome or to the parent bamboo, and has neither buds nor roots. It is formed of ten or more nodes varying in length from several to a dozen centimeters. In certain species, the rhizome neck can extend to over one meter and hence form a "pseudo-rhizome", typically exemplified in *Fargesia and Pseudostachyum*, or even as much as 3 meters in the South American genus *Guadua*. Growth habit of the culm can also differ considerably between species with four normal patterns being differentiated: erect, assurgent, climbing, and gramineous.

The erect culm type is typified by *Thyrsostachys siamensis*. With very graceful upright culms, bamboos of this genus branch comparatively high and clustered. Others of this type may bend or hang down at the top, for example *Bambusa emeiensis*. Species of *Dendrocalamus* are typical representatives of the assurgent type. Their culms tend to be slanting, neither climbing nor erect. With extremely long culms, some bamboos have their main branches so well developed as to even take the place of the culms themselves. They either take the liana form of rattan climbing into trees or grow similar to tendrilled vines. Representatives of this kind are found in *Dinochloa and Melocalamus*. Certain species of *Indocalamus*, however, are graminaceous with rather short and slender culms.

2.1.2 Rhizome

The rhizome is the primary structure through which bamboos reproduce themselves and expand their growing territory. A grove or forest arising from the same rhizome system can be viewed as virtually the same "individual" although actually a colony. We may regard the rhizome as the main stem and culms as its branches. Bamboo can be roughly classified into the following types according to the growth habit of the rhizomes (Fig. 2-3).

• Sympodial (or Pachymorph)

Rhizomes of this type are considered the earliest to evolve, i.e. the oldest type. They consist only of culm neck and culm base. Shoot buds on the culm base of clumping bamboos are capable of sprouting directly into young culms. Generally these rhizomes do not grow a long distance underground. New culms join their parents closely with short and thin necks so that dense clumps are produced. Bamboos with these reproductive features, such as *Dendrocalamus giganteus*, are known as sympodial. But for other bamboos, their long culm necks can extend into pseudo-rhizomes and their terminal buds shoot up in places far from the parents. These culms in scattered positions are termed sympodial scatterers or open clumpers. With no roots or buds growing at the nodes, such pseudo-rhizomes are commonly solid and wrapped in leaf-like sheaths, as those of some *Fargesia* spp. and *Pseudostachyum polymorphum*.

• Monopodial (or Leptomorph)

Rhizomes of this type are more recently evolved and have a long relatively thin rhizome, a shorter culm neck, and a culm base. There are no shoot buds on the culm base, all shoot buds are on the rhizome proper. Some of these buds activate to become new culms and a few activate to become branching rhizome. .Rhizome extension occurs first, from its growing tip. Both lateral buds and adventitious roots grow from nodes on the rhizome. Although terminal buds on the rhizomes generally don't grow out as shoots, most of the lateral buds do while others may branch and form new rhizomes. Therefore, despite the fact of being distantly spaced and scattered, culms aboveground can be expected to grow steadily into a forest. Rhizomes of monopodial bamboos have both roots and buds which can hopefully develop into either shoots or new rhizomes. They differ essentially from the budless and rootless pseudo-rhizomes of the sympodial types. They are correctly called true rhizomes, in contrast with pseudo-rhizomes. Bamboos with such reproductive properties are known as monopodial runners, such as *Phyllostachys edulis* and most *Indosasa* spp.

• Amphipodial

These share features of both the sympodial and monopodial rhizome types. They are intermediate in their evolution. Stems of this type can either germinate buds on the culm base directly into new culms, or extend into rhizomes from which buds may shoot into culms. Therefore, compound groups are formed above the ground, as found in *Indocalamus longiauritus* and *Pleioblastus amarus* for example.

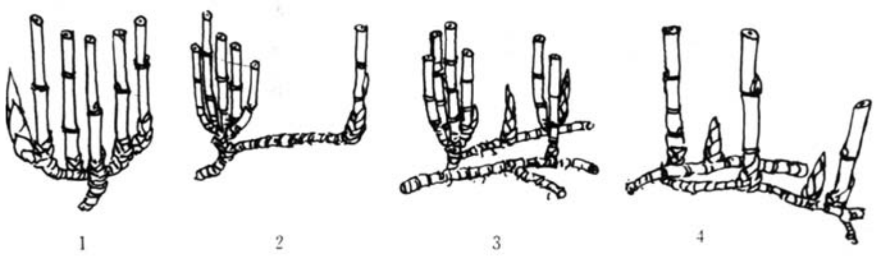

Fig. 2-3 Structures of Subterranean Stems
1. Sympodial Clustered; 2. Sympodial Scattered; 3. Amphipodial Compound; 4. Monopodial Running.

2.1.3 Branching

Arising from buds on the bamboo culms, branches are the structures to which leaves are attached. As mentioned above, bamboo culms can be regarded as immediate or primary branching of the rhizomes. Bamboo branches then can be taken as the second or upper branching. They also are usually made up of hollow internodes and nodes with similar septa inside and a nodal ridge outside. In some tropical bamboos at the base of the branches certain swollen nodes and shortened internodes combine into knobs where adventitious roots are apt to grow. These knobs can be used in place of culms as propagules to increase bamboos. Since each is notably different and unique to specific genera, branching type is a principal factor for bamboo identification and classification at the genus level. Four branching types are generally recognized as follows (Fig. 2-4): Note: In some genera young culms show one branching type while older culms may show a different, more complex pattern – i.e. *Semiarundinaria* (a provisional genus of hybrid origin).

• Monoramose (1 branch)

Ferrocalamus and *Indocalamus* are of this type. Generally only 1 branch grows at each node but sometimes 3 or more may appear at upper nodes.

• Bioramose (2 branches)

Phyllostachys and *Metasasa* are typical of this type. Each node has 2 usually subequal branches, i.e. one thick and the other thin.

• Trioramose (3 branches)

This type includes, *Chimonobambusa* (including section *Qiongzhuea*), *Chimonocalamus*, *Indosasa*, and *Sinobambusa*. Three branches similar in thickness grow at each node but sometimes 5 to 7 are possible for each of the upper nodes.

Fig. 2-4 Branching Types
1. Monoramose; 2. Bioramose; 3. Trioramose; 4. Multiramose (axial); 5. Multiramose (non-axial).
Photo: The branches of *Cephalostachyum pergracile*. From Simao, Yunnan.
Photograph by Hui, Chaomao, 1999

• Multiramose (4 or more branches, axial and non-axial)

In this type many branches may crowd around a node. According to the development of the axial branches this type can be further divided into:

a. Non-axial: With aborted axial and equally thin laterals, *Bambusa emeiensis* serves as a typical example of this kind. No sharp differences in size can be found between the axial and lateral branches.
b. Mono-axial: The axial branches of this kind are fairly well developed; as in *Dendrocalamus giganteus* and *D. latiflorus* for example. But as in *Melocalamus*, the axial branch is often so well developed that on some occasions it can even grow larger than the culm itself.
c. Tri-axial: Representatives of this kind are *D. membranaceus* and certain species of *Bambusa*. Besides the many thin laterals, this kind of bamboo can produce three well-developed axial branches.

2.1.4 Leaf and Sheath

Bamboos have two types of leaves: true leaves and culm sheathes (Fig. 2-5). A normal leaf, is usually distichous and persistent on nodes of the final branchlets. It is composed of blade, pseudopetiole, sheath, ligule, and auricle (if any). The leaf blade is oblong or lanceolate, with a raised midrib. Joined by small transverse veins, pairs of lateral veins lie parallel to the midrib so that a grid or net is formed. The leaf petiole (actually a pseudopetiole) is often short, only 3~10mm long. The leaf sheaths cover each other in sequence and finally wrap up the branchlets. Between the sheath tip and petiole is a joint where the blade and petiole emerge. Normally on the inner side of the sheath tip, in the middle, stands a membrane known as the ligule. This may, however, be nonexistent or replaced by cilia. On one or both sides of the sheath tip at the blade base one may find two earlike bumps technically known as auricles, which may have margins covered with fimbriae called oral setae.

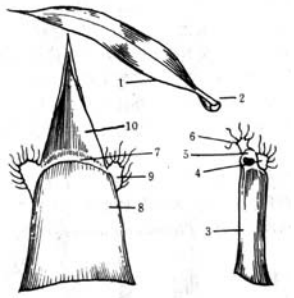

Fig. 2-5 Structure of leaf and sheath (McClure, F. A. 1966)
1. Leaf blade; 2. Leaf petiole; 3. Leaf sheath; 4. Leaf auricle; 5. Leaf ligule; 6. oral setae;
7. Sheath ligule; 8. Sheath vagina; 9. Sheath auricle; 10. Sheath blade.
Photo: The culm sheath of *Dendrocalamus* giganteus. Photo by Hui, Chaomao, 1998

The culm sheath or shoot sheath is in fact a kind of specialized leaf. Growing at the nodes of the culm or of the axial branches, culm sheaths function as protector to shoots and tender internodes. They are usually deciduous and fall off when the internodes finish growing, but a minority may be persistent for years. Similar to the leaf, the culm sheath is made up of blade, vagina, ligule and auricle, but lacking a petiole. Usually short and wide, the sheath blade is connected with the sheath vagina by a joint at the conjunction where it is liable to come off. For a small number of species the sheath blade can be degenerated into a cone, such as in *Chimonobambusa*. The sheath vagina is often a hard skin enclosing shoots or young culms. The middle part of its tip is a vertical lamina called the sheath ligule and the lateral earlike projections (when present) are called sheath auricles. The characteristics of the culm sheaths, particularly at nodes of the lower part of the culm, are a highly relevant vegetative factor by which some bamboos can be identified on the species level even when flowers are not present.

In fact the form of the culm sheath experiences a gradual change on the same culm. From the base to the top, as the internodes become increasingly thinner, the sheath vaginas also get narrower, and the sheath blade gets thinner and longer. Color of the sheath also changes from non-green to green until finally, at the apex, the culm sheath has almost turned into a leaf. So, from a dynamic perspective, sheath and leaf are only comparatively differentiated. When applied as a principle for species identification, its relative position has to be clearly stated. The general practice is to take the sheaths growing on the lower part of the culm as the basis for a taxonomic description.

2.1.5 Flower and Inflorescence

• Flower

The morphological structure of a bamboo flower is approximately the same as for other members of the grass family. Each flower produces 1 lemma and 1 glume, which are equivalent respectively to bract and bractlet. Being multi-veined the lemma holds the glume; and the glume with two vertebrae at the back, encircles the other parts of the flower. Normally bisexual, the flower itself is composed of lodicule, stamen, and pistil. As equivalents for perianth lobes, the lodicule, normally 3, have transparent

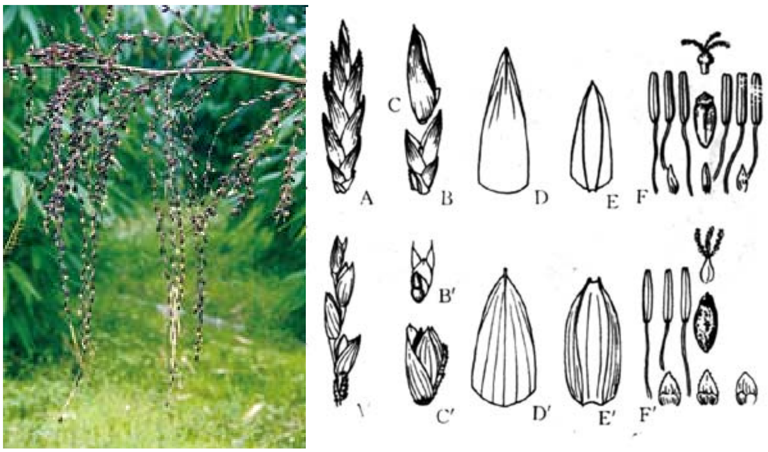

Fig. 2-6 Structure of Flower

A. Branching of indeterminate inflorescence, i.e. Pseudospikelets; A'. Branching of determinate inflorescence, i.e. Spikelets; B. Base of A, indicating prophyll, caulome, and hollow glume; B'. Base of A', indicating prophyll; C. & C'. Florets; D. & D'. Lemmas; E. & E'. glumes; F. & F'. Constituents of flower; lodicule, stamen, pistil, & seed. Photo: The inflorescence of *Dendrocalamus latiflorus*, from Kunming, Yunnan. Photograph by Hui, Chaomao, 2001

and fleshy membranes and often irregularly cut edges. Stamens 3 or 6, but sometimes with dozens sparsely arranged; filaments linear, distinct or partially coalescent at the base. Superior ovary, 1 chamber with 1 ovule inside; styles thin yet conspicuous, stigmas commonly 2~3, with rare exceptions of only 1 or as many as 4~5. Stigmas vary tremendously on the surface, with either capillary or smooth or papillose or plumelike (Fig. 2-6).

• Spikelet

The spikelet is composed of 1 to several flowers and glumes at the base. The glumes are basal bracts; a common number is 2, the lower outer glume while the upper inner glume, sometimes 1, or many, or none. Flowers on the spikelet are alternate on different nodes of the axes, with internodes usually more or less elongated and readily seen. Along the spikelet, flowers may fall off successively upwards; but that is not the case for a small number of genera, such as *Dendrocalamus and Bambusa*, with internodes exceedingly contracted. For some bamboo species, the spikelets may bear some latent buds (capable of developing into new spikelets) inside their axils which are termed pseudospikelets.

For the convenience of distinction, spikelets without such buds can be labeled genuine spikelets in which flowers bloom successively upwards.

• Inflorescence

In bamboo flowers the formation of the inflorescence is preceded by that of the spikelet. That is to say, spikelets are fundamental units of the inflorescence. According to occurrence and morphological structure, inflorescences of bamboo can be roughly classified into two types, i.e. determinate and indeterminate.

In the determinate inflorescence the peduncle extends upward to form a general rachis which is usually solid. At each apex of graded branches stands a genuine spikelet. As formed in one-time development, the determinate inflorescence reserves no more meristem in the form of latent buds. So this type of inflorescence can also be called a one-time genuine inflorescence, or simply a genuine inflorescence. This feature is commonly shared by certain bamboo species and other monocots outside the ***Bambusoideae*** and is a more evolved inflorescence type within the grass family.

The indeterminate inflorescence is composed of pseudospikelets adherent to graded foliage branches. With hollow internodes, these foliage branches are essentially different from rachis of the genuine inflorescence. Furthermore, a young pseudospikelet may arise from the latent bud dormant in the glumal axil of the pseudospikelet base. This new pseudospikelet itself, in return, may give birth to a newer pseudospikelet. Consequently the formation and development of the inflorescence actually becomes a long process, lasting sometimes for several years. This type is known as an indefinite recurrent pseudo-inflorescence or pseudo-inflorescence. Being stalkless, the pseudospikelet seldom extends to more than 3cm long. So with the gradual increase of stages on the pseudospikelet, a densely comate or spherical cluster of pseudospikelets is produced at the node of the foliage branch. As a primitive type of inflorescence, this type of pseudo-inflorescence in the grass family has only been found in some few bamboos.

2.1.6 Fruit and Seeds

Bamboo fruit is generally an indehiscent caryopsis, with only 1 seed inside as in *Phyllostachys* and *Dendrocalamus*. The pericarp is thin and coalescent with an episperm, the shape of an enlarged and elongated wheat grain, the endosperm is starchy, embryo in the lower part of endosperm and porrect, the opposite side is the grooved hilum (Fig. 2-7).

For some species the fruit is baccate, such as *Ferrocalamus strictus*, *Chimonobambusa yunnanensis*, C. *(Qiongzhuea) tumidissinoda*, *Melocanna baccifera*, etc. The pericarp is thick and somewhat fleshy, spherical or oval; normal length 8~12cm, width 4~8cm. But the fruit of *M. baccifera* is able to grow to a length of over 10cm, a diameter of 7~8cm, pyriform, fresh weight 47~180g. The fruit is baccate and the hilum is invisible from outside.

The fruit of still other species is pyriform, for instance *Cephalostachyum fuchsianum*, *Dinochloa* spp., and *Melocalamus compactiflorus*. It has a thicker pericarp of over 1mm, is hard and definitely separated from the episperm. The fruit can be spherical or oval, the diameter 1cm or longer, and the hilum also invisible from outside. At the apical point of the bamboo fruit stand snouts derived from styluses, either long or short or thick or thin, varying considerably between species.

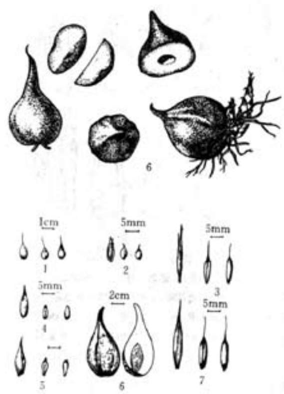

Fig. 2-7 Shapes of bamboo seed
1. *Dendrocalamus latiflorus*; 2. *D. strictus*; 3. *Phyllostachys edulis*; 4. *Pseudosasa amabilis*; 5. *Bambusa* lapidea; 6. *Melocanna baccifera*; 7. *Phyllostachys bambusoides*.

Photo: The seeds of Cephalostachyum scandens.
From Longchuan, Yunnan. Photograph by Hui, Chaomao, 1993

Bamboo seed, whether of caryopsis or non-caryopsis form, are without exception thin-coated with only one layer of cells. But because of complete coalescence of episperm and pericarp, seed of caryopsis types have lost the usual form and function of the common episperm. Seed of non-caryopsis types, on the other hand, face no direct exposure problems owing to their comparatively thicker pericarps. Since protection is completely provided by the pericarp, the episperm is also thin without any appendages.

Regarding the endosperm, bamboo seed can also be differentiated into two patterns: endospermic and non-endospermic, just as with seeds of other plants. Generally speaking seed of the caryopsis type have conspicuous blastopores while some nuts and berries do not. Examples of the former are too numerous to list, but examples of the latter include *Melocalamus compactiflorus*, *Dinochloa* spp., *Melocanna baccifera* and *Ochlandra* spp.

The embryo of bamboo seed is consistent in general structure with other monocots such as wheat and corn, comprised of a notable scutum (well developed cotyledon), a small epiblast (obsolete cotyledon), a germ, hypocotyl and radicle (with radicle sheath). But certain distinct differences exist between bamboo species as well as between bamboos and other herbaceous plants when micro morphology is considered. These include trend of vascular bundle in the embryo, coalescent degree of scutum and coleorhiza, vascular bundle number of euphylla in the embryo bud, and overlapping state at both ends of the euphylla. These differences result in distinct micro morphology patterns which relate to phylogeny and speciation. Since 1994 more detailed studies have been done in this field by successive specialists (Wang, Shi-Jin. 1983).

Chinese specialists isolated the component ingredients in bamboo fruit (seed) near the end of the 1980's (He, Xiao-Ling 1988). Their studies show bamboo seeds contain as many as 18 proteolytic amino acids, basically of the same in type as in the shoots, but in higher concentrations with an average of 11.588g/100g. Among the 18 amino acids, glutamic acid stands out at 2.106g/100g followed by an average for aspartic acid of 1.56g/100g, with pozzuolite the lowest with an average of 0.223g/100g. The content ratio of each amino acid to the total volume of acids is rather similar between different species. The total quantity of these acids certainly exerts some influence on germination, growth, and adaptability of bamboo seed. As bamboos rarely bloom and seed-collecting is difficult, knowledge about bamboo seed is comparatively incomplete and superficial, with certain basic problems remaining unsolved.

2.2 Anatomic Properties of Bamboo

2.2.1 Anatomic Structure of the Rhizome

Without exception adventitious with no secondary growth or structure, anatomically bamboo rhizomes consist of: epidermis, cortex, and vascular cylinder (Hu, Chen-Hua 1990) (Fig. 2-8).

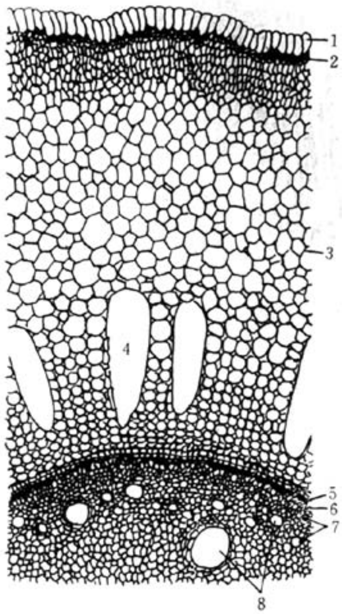

Fig. 2-8 Rhizome Transection of *Phyllostachys edulis*
1. Epidermis 2. Sclerenchyma 3. Cortical parenchyma 4. Air cavity 5. Endodermis 6. Pericycle 7. Sieve tubes 8. Vessels

• Epidermis

Forming the outmost layer of the rhizome, the epidermis consists of large continuous parenchyma cells which may be round or irregular in form. Epidermal cells in juvenile rhizomes usually emerge as root hairs or feeder roots to absorb water and mineral nutrients. Later on the epidermis becomes obsolete and gradually sloughs off, leaving the exodermis and parietal fibre to continue its protection.

• Dermis

All tissues between the inner side of the epidermis and stele are collectively known as dermis. According to its position and structural characteristics, the dermis can be further divided as follows:

a. **Exodermis**: The exodermis refers to the layer of cells on the inner side of the epidermis. Although walls of the exodermic cells are not thickened in clumping bamboos, they are strongly thickened in running bamboos with the only exception on the inner tangential wall, i.e. to form an endocentric "C" of thickening.
b. **Parietal Fibre Tissue**: As a kind of mechanical tissue, parietal fibre refers to the one (1) or several layers of cells at the inner side of the exodermis, with clearly thickened walls.
c. **Cortical Parenchyma Cells**: Forming the vast majority of cells in the dermis, they connect outside with parietal fibres and inside with annular endodermis. They have large thin-walled cells that function as storage and for horizontal conduction.
d. **Air Cavity**: A ventilating tissue formed by parenchymatous schizogenesis in the dermis, the air cavity is a response to the humid habitat of bamboos.

e. **Annular Endodermis**: Refers to the one or more layers of cells that border outwardly with cortical parenchyma cells and encircle inward the endodermis. The cells of the annular endodermis gradually become smaller from outside, shapes may be spherical, oblate, polyhedral and so on. With intercellular space, these cells are thickened on the walls with the only exception being on the outer tangential section.
f. **Endodermis**: As the innermost layer of the dermis, the endodermis is structurally characteristic of the particular thickening which relates to the selection and absorption of mineral salts by the root. Degree of thickening differs slightly between clumping and running bamboos. Cell walls of the former are entirely thickened while the latter are not on the outer tangential inwall. No thickening occurs in a juvenile root on the endodermal cell walls at the apex of pro-deutoxylem, where passage cells are formed through which water is conducted in and out. With a gradual loss of root absorption, these passage cells become progressively thickened on the walls and eventually become identical with other cells in the endodermis.

• Vascular Cylinder

The vascular cylinder occupies the entire inside of the endodermis. Its proportion to the total transection may differ considerably between genera and species. It is bigger in clumping bamboos and smaller in running bamboos. Outside the vascular cylinder 1or 2 layers of compact cells called pericycles are arrayed in an orderly fashion. When young pericycle cells are parenchymatous and potentially meristematic, they are able to produce lateral roots. But as they mature, the walls of pericyclic cells become gradually thickened as the mitogenetic capacity ceases to function. Inside the pericycle are scattered vessels which increase sequentially in aperture. Vessels of small aperture are proto-vessels while those of large aperture are meta-vessels. Between vessels on the periphery are distributed some sieve tubes. In the central part of the vascular cylinder is the medulla, usually having no cavity, with exceptions only in a small number of species such as *Phyllostachys edulis*. In medulla cells the walls are thin when young but steadily thicken afterwards.

Such is the general make-up of bamboo rhizomes although varying exceptions still exist in certain species which will not be discussed further here.

2.2.2 Apical Meristem and Intercalary Meristem

• Apical Meristem

Bamboo shoots develop from buds on the rhizomes. Their bodies are enclosed in progressive layers of culm sheaths. The region of apical meristem or division, including a vegetative cone and a derivative zone, lies near the apex of the shoot. The lower limit of this region is anatomically marked by the appearance of a node. Composed of proto-meristem the vegetative cone stands as a typical structure of tunica-corpus. The two outmost layers being tunicae, cells of the vegetative cone are neatly arranged as they undergo anticlinal divisions that increase only in area but not in layers. Inside the tunicae resides the corpus, a mass of disorderly arranged cells that are capable of enlarging volume through anticlinal and periclinal divisions. With very exuberant cell divisions, the tunicae and corpora of the vegetative cone can divide in coordination to ensure a balance between its surface growth and volume growth. Yet at this time the cells still remain undifferentiated (Fig. 2-9).

But below the vegetative cone cell differentiation has already begun in the derivation region (known also as the differentiation region or sub-apical meristematic region). In the middle of this region are medullary meristems which will afterwards develop into medullas. On the outer ridge are lateral meristems which will differentiate into skin, leaf, sheath, protomeristem, and ground tissue primordium, and still further into epidermis, culm sheath, vascular system, and ground tissue accordingly. When the sheath primordia begin their development (now called young sheaths), papillary lateral-bud primordia, an embryonic form of the nodes, consequently appear in the axils.

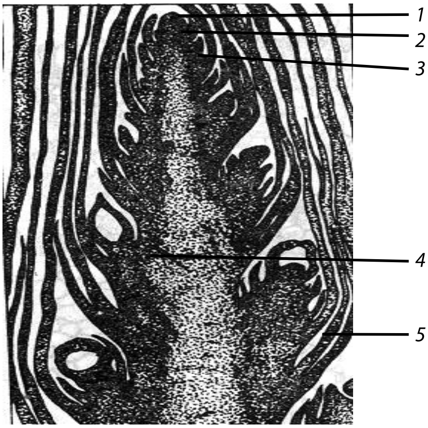

Fig.2-9 Structure of Shoot Tip
1. Apical meristem; 2. Sheath primordium; 3. Lateral primordium; 4. Embryonic form of the node; 5. Young sheath

• Intercalary Meristem

At the place of attachment of the culm sheath, immediately after the formation of the sheath primordia, node-septa take form when vascular bundles bend inward and medullary cells develop horizontally. The number of septa begins to multiply while cells in the apical meristem continue differential division. Beginning from the bottom, these septa divide the meristem into many sections, each of which becomes an internode. These short internodes on the tender shoot are all meristems that are capable of cell division. But eventually as the internodes elongate, division of the upper cells gradually ceases. Then meristem tissue becomes confined to the lower part of each internode until finally stopping all division. As division span of the lower part is longer in a given internode, the aging order is up from the bottom; but when the whole shoot is taken into consideration, internodes at the base become mature first, then those upwards. Mitoses plays a leading role during prophase and metaphase of the fission, but amitoses prevails at anaphase. Having much to do with fast growth, amitosis is the type of fission that best suits the rapidly extending shoot. Amitoses dominates in the fission of girdles at the nodes, septa, and internodes, which causes an early maturing of cells at these points.

In the intercalary meristem, timely formation of new vascular bundles is made possible by the simultaneous occurrence of cell division and differentiation. Therefore, water and nutrient conduction will not be obstructed even though tissues may vary in degrees of aging at different parts on the shoot.

Like many other monocots, bamboo has a very short period of active growth. Activities of the apical meristem have virtually ended as soon as the shoot emerges. By this time differentiation of the nodes and internodes is already complete so any later growth of the shoot will come from intercalary meristem extension. But because of the lack of secondary meristems, no thickening can occur in bamboos after the culms establish their final diameters during the shooting period.

Among all internodes of a shoot (before height increase stops) there is one particular internode which is undergoing the most vigorous division and elongation. Below this active internode, expansion has ceased and above this internode, division and elongation of the other internodes are successively weaker. This most vigorous division or elongation, however, transfers progressively upward node by node. In general, division or elongation is weak in the sprouting period, strongest in the mid-term and weakest again until it stops at the final stage of height increase. That is to say, many intercalary meristems simultaneously undergo degrees of cell division or elongation in a bamboo shoot. This is the property which ensures the shoot a fast realization of its final height. Occurring mostly at night, the average height increment in a given 24-hour period for most species is 8~15cm. For some other species, their fastest height increment of a day and a night can reach tens of centimeters or even one meter or more (Xiong, Wen-Yu 1980; 1982).

2.2.3 Anatomic Structure of the Culm

The bamboo culm has distinct nodes and internodes. The usually empty inside is called medullary cavity and the walls surrounding are called culm walls. The developing bamboo wall is divided beginning outside into: bamboo outer-skin, bamboo pulp, and bamboo-inner skin. But from an anatomic point of view it is divided into epidermis, derma, ground tissue, vascular bundles, and cavity wall (Grosser, D; Liese, W. 1982; Fang, Wei 1989; Wen, Tai-Hui; Zhou, Wen-Wei 1984).

• Epidermis

As the outmost cell layer of the bamboo wall, the epidermis or cortex is formed by longitudinal alternation of long cells with short cells. To fortify surface hardness, the outer tangential wall is of cutin formed by mineral uptake. Short cells are separated into cork cells and silica cells, with walls respectively suberized and silicic. In the longitudinal arrangement of epidermal cells, a long cell usually connects with a silica cell and a cork cell. A small number of stomata may also appear on the surface of the epidermis.

• Derma

The section without the vascular bundles of the epidermis is termed the derma. Formed of 3~7 layers, the cells are cylindrical and longitudinally arranged, and the traverse section is oval or rectangular. When young, derma contains chloroplasts that make the culm green. No clear line exists between derma and the ground tissue inside. In some species, the outmost 1~2 layers of cells are technically called hypodermis when the walls thicken. The outer skin of developing bamboo culms includes both epidermis and derma.

• Ground Tissue

Ground tissue refers to the parenchyma cells inside the derma where vascular bundles are diffused. On the surrounding ridge, ground tissues naturally connect with derma at the parts between vascular bundles, and no clear boundary is identifiable. On the traverse section of the bamboo wall, cells of ground tissues from outer-skin to inner-skin are in a small--big--small arrangement.

• Vascular Bundles

Diffused in ground tissues, vascular bundles consist of outer vascular bundle sheaths, inner xylems, and phloems (Fig. 2-10).

The xylem is arranged in the form of letter "V" near the inner-skin, with a large vessel called the deutoxylem on both sides. The base of the "V" is protoxylem, which is formed earlier than deutoxylem. In protoxylem air cavities are often produced if vessel cells have been destroyed, and sometimes one or two smaller annular vessels or threads can be found there. The phloem, close to the outer skin, consists of sieve cells with large apertures in which are inserted companion and parenchyma cells of small aperture. Walls of these sieve cells are not thickened. With walls somewhat thickened, parenchyma cells in vascular bundles are obviously smaller than those in ground tissues. These parenchyma cells separate all vessel cells from one another, and xylem cells from phloem cells. No cambium is found between xylem cells and phloem cells.

Commonly made up of 3~6 layers of fibrous cells encircling the xylem cells and phloem cells, vascular bundle sheaths are mechanically important tissues in the bamboo wall. Their cell cavities are tiny, for the cells are highly lignified with a very small cross-section. From their placement they are respectively called external vascular bundle sheath (outside phloem, near the outer skin), flank vascular bundle sheaths (on the lateral sides of the two large vessels), and internal vascular bundle sheaths (outside protoxylem, close to the inner skin).

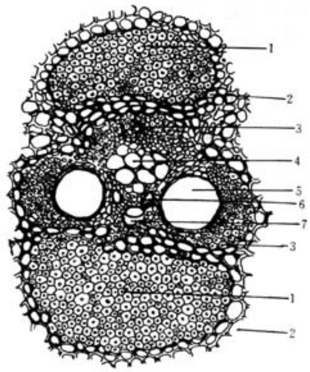

Fig. 2-10 Structure of Vascular Bundles
1. Fibre strand; 2. Parenchyma cell;
3. Sclerotic tissue sheath;
4. Phloem; 5. Deutoxylem vessel;
6. Small deutoxylem molecule;
7. Intercellular space.

Some species have many fibre bundles on the inner and outer sides of the vascular bundles. They, too, are mechanically important tissues in the bamboo wall. Those on the outer side are known as external fibre strands (or phloem fibre strands), separated from external vascular bundles by 2~4 layers of big parenchyma cells. Those on the inner side are known as internal fibre strands (or xylem fibre strands), also separated from flank and internal vascular bundle sheaths by 2~4 layers of big parenchyma cells. In this case the vascular bundles themselves may be called central vascular bundles.

The arrangement of fibre strands and vascular bundle sheaths may vary between different species, between sections on the same culm, or between regions on the same bamboo wall section. This bears important implications for phyletic classification of bamboo and evaluating the physio-mechanical properties of bamboo timber. This is one of the fields that has received much research in recent years.

According to the forms of all vascular bundles, bamboo vascular bundles fall into one of the following five types. Identification of these types is based on the forms of central vascular bundles on the traverse section in the middle part of the culm. There are representative vascular bundles in different species and each type is found in one or more genera (Fig. 2-11).

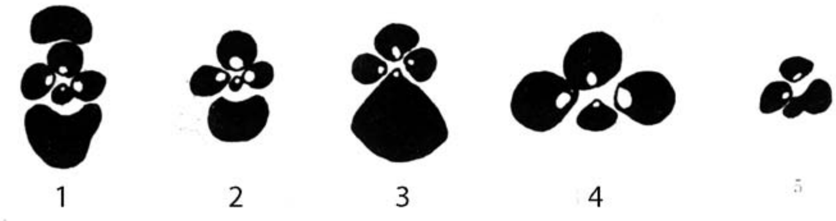

Fig. 2-11 Types of Bamboo Vascular Bundles
1. Double-broken; 2. Broken; 3. Binding; 4. Open; 5. Semi-open.

1. Double-broken Type: This type possesses both internal and external fibre strands. Bamboos with this vascular bundle type are all clumpers, such as *Thyrsostachys*, *Oxytenanthera*, *Dinochloa*, *Dendrocalamopsis*, *Dendrocalamus*, and a few species of *Bambusa*.

2. Broken Type: With only internal fibre strands, this type has an internal vascular bundle sheath smaller than other vascular bundle sheaths. Bamboos with this type are sympodial and include some species in *Bambusa*, *Ampelocalamus*, *Dendrocalamopsis*, *Dendrocalamus*, *Drepanostachyum*, *Gigantochloa*, and a small number of *Schizostachyum*. Broken type and double-broken type are often found in combination on the same culm.

3. Binding Type: or "tight-waist type" -- Without fibre strands, the internal vascular bundle sheath notably larger than the other three vascular bundle sheaths, this type extends fan-shaped to the left and right. Bamboos with this vascular bundle type can include some species in the genera *Schizostachyum*, *Melocanna*, and a few species of *Cephalostachyum*.

4. Open Type: Without fibre strands, this type has four vascular sheaths of approximately the same size. Bamboos that share this type may be monopodial or amphipodial, i.e. *Phyllostachys*, *Pleioblastus*, *Shibataea*, *Bashania*, *Brachystachyum*, *Cephalostachyum*, *Chimonobambusa* (including section *Qiongzhuea*), Chimonocalamus, *Racemobambos*, *Melocalamus*, *Pseudosasa*, *Indosasa*, *Acidosasa*, *Oligostachyum*, and *Sinobambusa*.

5. Semi-open Type: This type has no fibre strands, but its flank and internal vascular bundles are linked together. This type can include some species of *Sasa*, *Yushania*, *Fargesia*, as well as some species of *Chimonobambusa* in section *Qiongzhuea* and also some in *Indosasa*.

A clear regularity manifests itself on the same traverse section of bamboo wall concerning the form, size and density of vascular bundles. The longitudinal length of vascular bundles changes inward from longer to equal or slightly shorter than traverse width. Volume (area) changes from small to large and back to small again near the inner skin. Density also changes from thick to thin and back to thick again near the inner skin and the difference in density between internal and external vascular bundles of the bamboo wall may be 3~5 times as big. For example, when the culm wall on the lower section of *Dendrocalamus giganteus* is 17.7mm thick, the density of vascular bundles near the outer skin is 473/ cm^2 and near the inner skin is 115/cm^2, about a four fold difference. Instead of xylems or phloems, there are only a mass of dense fiber cells in the outer most 1~2 layers of the vascular bundles (close to the outer skin). These fiber cells are closely arranged or even connected. From here on inward vascular bundles gradually become normal, but those innermost near the inner skin are often muddled or reversed. Some may have comae only, others may turn about to form internal ligamentous vascular bundles.

As the bamboo wall becomes thinner from base to top, density of the vascular bundles also undergoes changes. Again, using *D. giganteus* as an example, when thickness of the bamboo wall in the lower section is 17.7mm, average density of vascular bundles is 187/cm^2. When the thickness in the middle is 8.33mm, average density of vascular bundles rises to 262.7/cm^2. But when thickness in the upper culm wall drops to 5.9mm, average density of vascular bundles increases to 322.3/cm^2.

• Bamboo Cavity Wall

Bamboo cavity wall refers to the innermost part of the bamboo wall, i.e. what is generally addressed as bamboo inner-skin. Composed of several to about ten cell layers of hard lithocytes that are highly lignified and densely arranged, it is about 0.3~1.0cm thick.

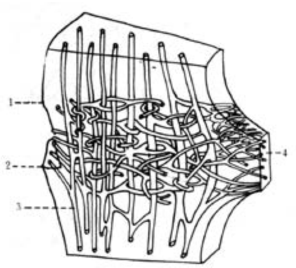

Fig. 2-12 Structure of Node
1. Supranodal ridge; 2. Sheath scar; 3. Vascular bundle; 4. Septum.

2.2.4 Anatomic Structure of the Node

The structure of the node is a distinctive feature that separates bamboos from other plants. A bamboo node consists of supranodal ridge, sheath scar, intranode and a septum or diaphragm, with a structure anatomically much more complex than the internode. This is mainly because the sheath grows from the sheath scar and over the supranodal ridge, buds germinate at the intranode, and the septum occurs inside. The most striking difference is that vascular bundles curve, cross, and interlink at the node (Ding, Yu-Long 1995) (Fig. 2-12).

a. Vascular bundles start forking at least 5mm below the node and continue to above the supranodal ridge. That means a node anatomically includes the part between supranodal ridge and sheath scar.

b. Most of the longitudinal vascular bundles in the culm wall go directly through the node, where they are mutually twined and joined by forking traverse or nearly traverse vascular bundles. Peripheral vascular bundles in the culm wall bend more or less outward and fork into the culm sheath and lateral buds. Vascular bundles inside the culm become thick and bend clearly inward. Similarly, they also fork into the diaphragm and finally join those from the other side.

c. At the node, fibrous tissues encircling vascular bundles are very reduced in number. Various changes take place inside vascular bundles for torsion, all concerning position of xylems and phloems.

d. Following the example of vascular bundles, vessels and fibres also fork, and the cell shape of ground tissues becomes crooked and irregular.

e. The length and diameter of vessel cells are far shorter and thinner than those in an internode. In

Phyllostachys edulis, for instance, the average length of deutovessels in the internode and at the node is 6.79 mm to 2.1 mm; average diameter of vessels in the intranode and at the node is 1.4 mm to 1.1 mm. At the node, the length of sieve cells is much greater than that of vessel cells. For example, length of sieve cells in *P. edulis* is 7.6 mm, with a massive sieve area on the flank walls. This has much to do with horizontal transport of materials at the node. Fibre length is also shorter than that in the internode. Length-width ratio of fibre in the internode is 70:1~150:1 while at the node it is only 40:1~60:1.

Due to mutual separation between vascular bundles and lack of a vascular ray system like that in dicots, horizontal transport of materials is difficult at the intranode. But repeated forking and connection between vascular bundles and the massive sieve area on flank walls of sieve cells enables the horizontal transport of internal materials to different areas at the node. Although fibres here are reduced in number and length, the node still possesses great mechanical strength and a particularly increased cleavability because fibres fork, vascular bundles bend and intertwine, and cells of ground tissues in irregular forms get mutually inlayed. This is indeed necessary for bamboo which usually has a thin, hollow, and rather cleavable culm.

2.2.5 Anatomic Structure of the Leaf

The three parts: epidermis, mesophyll, and vascular bundle (vein) can be discerned on a traverse section of leaf (Chen, Shou-Liang 1986; Qian, Ling-Yuan; Fang, Wei 1986; Liu, You-Quan 1986) (Fig. 2-13).

• Epidermis

Regularly arranged with epidermal cells and stomata, the epidermis is divided into epicuticle and hypodermis, with cuticles covering the outside. Epidermal cells are differentiated into long cells and two types of short cells. Short cells include silica cells and suberin or cork cells that have walls respectively silicified and suberized. Beams of long cells are vertically arranged. Silica cells often bulge out and make the leaf surface hard and coarse.

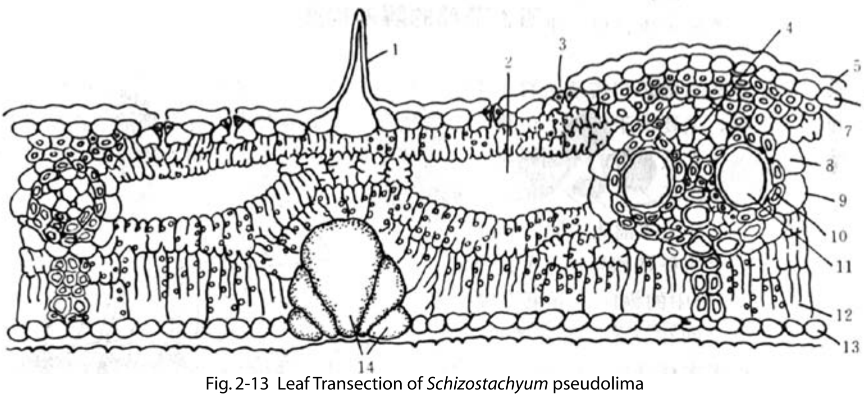

Fig. 2-13 Leaf Transection of *Schizostachyum* pseudolima
1. Epidermal hair; 2. Air cavity; 3. Stoma; 4. Phloem; 5. Cuticule; 6. Epicuticle; 7. Mechanical tissue; 8. Primary lateral-vein; 9. Exotheca; 10. Endotheca; 11. Xylem; 12. Mesophyll; 13. Hypodermis; 14. Bulliform cell.

Epicuticles in the middle part between two neighboring veins are replaced by some special large-size parenchyma cells. Often with extremes cuticularly thickened and large vacuoles inside, they are known as motor cells and longitudinally positioned to parallel the veins. On the traverse section there are 4~7 motor cells between two adjacent veins, the largest residing in the middle and the rest tapering bilaterally. As dehydration contraction and absorptive expansion of motor cells co-relate directly to curling and uncurling of the leaf, they are also known as kinetic cells.

Stomatal apparatus are also orderly ranked, and their guard cells assume the form of a "dumb-bell". The globularly swollen parts on both sides of the stomatal apparatus are thin-walled, but the straight central part is thick-walled. Their hydration and dehydration respectively control opening and closing of stoma. There is also an assistant guard cell on either side of the guard cell.

• Mesophyll

The form of a bamboo leaf is more or less isolateral. The mesophyll produces no differentiation of grid tissues or spongy tissues, but the cell walls all fold inward to increase area for chloroplasts. Bamboo leaves have very big stomatal chambers on the inner side of stoma, though its cell gap is narrow. Different species may vary in form, size, and number of cell layers.

• Veins

Arranged in a parallel manner and embedded in mesophyll tissues, main veins and lateral veins are combined with stringer veins. Composed of vascular bundles and their surrounding sheaths, a vein is connected with the epicuticle and hypodermis through strands or slices of sclerenchymatous fibres. Vascular bundle sheaths are commonly distinguished into two layers of cells. The inner is thick-walled and the outer is thin-walled having no chloroplasts. This structure reveals that bamboo is a plant of typically inefficient C3 photosynthesis. These vascular bundles are closed and made up of xylems and phloems, the former near the epicuticle and the latter near the hypodermis. In most species, gaps of varying degrees are symmetrically produced on both sides of a vein. Formed by large parenchyma cells whose walls get broken during the growing process, these gaps or cavities function as a kind of ventilating structure.

2.2.6 Chromosomes of Bamboo

As carriers of hereditary DNA, chromosomes are a special structure visible only under a microscope. They are formed by chromatins that are collected, shortened, and thickened during mitotic and reductional divisions of cells. Because the number and form for every living being is fairly stable, they become fundamental features in cytology and are of great significance to phyletic classification, community evolution, and cross-breeding of living things. So far more than 200 species of Bamboo have been cytologically studied. The chromosome numbers of 42 major bamboo species are found in Tab. 2-1 (Zhang, Guang-Chu 1985).

Numerically Bamboos are of two basic chromosome types: 2n=72 and 2n=48. Altogether these represent 83.7% of all species that have so far been cytologically studied. The two types are more or less evenly represented. For a few species their chromosome counts are 2n=24, 2n=40, 2n=46, and 2n=64.

• Chromosome Base Quota

Of all bamboos for which chromosome numbers are known, the lowest is 2n= 24 (in at least 4 species), the most common two types are 2n = 72 and 2n = 48. Therefore, x = 12 is generally believed to the base ploidy number of Bamboo. That is to say, 2n = 24 is diploid, 2n = 48 is tetraploid, and 2n = 72 is hexaploid. 2n = 46 is still tetraploid, but known as nulliploid derived from the 2n =48 type with certain chromosomes eliminated.

Chromosomes of the South American genera *Swallenochloa* and *Chusquea* are mainly 2n=40, also a tetraploid whose base quota x=10 is the reduced form of the type x=12. For a small number of bamboos, their base quotas of chromosomes can be x=8 and x=9. This case, however, is rare in bamboos and awaits further study pending new data.

• Chromosome Ploidy

Tetraploid and hexaploid are the basic types of chromosome ploidy found in most bamboos, diploid forms have so far been discovered only in 4 species. A large body of statistics indicates that most pseudanthial sympodial bamboos are of hexaploid chromosome types (diploid for a few), with no exceptions at least in Asia and Africa–two of the chief distribution regions of bamboos. Yet tetraploidy is also found in some species of *Guadua* in South America, a very significant exception. On the other hand, tetraploidy is found in almost all pseudo-inflorescence non-sympodial and genuine inflorescence bamboo (diploid for a couple though), but hexaploidy has not been found so far. A combined analysis of chromosome numbers and ploidy with geographical distribution, inflorescence, and types of rhizomes of bamboo will likely lead to a better understanding of many interesting phenomena concerning the origins and evolution of bamboo. But we will not discuss it here, since it is beyond the scope of this book.

• Chromosome Morphology

At present little is known about the morphology of bamboo chromosomes, i.e. nuclear types of chromosomes. This is mainly because bamboo chromosomes are tiny and their centrometres are difficult to identify. It is not easy, therefore, to obtain a cell film of clear chromosomes with little or no overlapping.

Tab. 2-1 Chromosome Numbers of some Major Bamboo Species

Species	Chrom. (2n)	Species	Chrom. (2n)
Bambusa blumeana	24	*D. latiflorus*	72, 64, 48
B. chungii	72,64	*D. minor*	72
B. emeiensis	72	*D. strictus*	72, 70
B. intermedia	72	*Fargesia porphyrea*	48
B. lapidea	78,64	*F. yunnanensis*	48
B. multiplex	72	*Ferrocalamus strictus*	48
B. oldhamii	N=12	*Gigantochloa nigrociliata*	72
B. pervariabilis	64	*Indocalamus longiauritus*	48
B. sinospinosa	64	*Indosasa crassiflora*	48
B. textilis	64, 56, 72	*I. glabrata*	48
B. tuldoides	72	*Melocanna baccifera*	72

Species	Chrom. (2n)	Species	Chrom. (2n)
Cephalostachyum pergracile	72	*Phyllostachys edulis*	48+B
Chimonobambusa microfloscula	48	*P. makinoi*	48, n=12
Chimonobambusa (Qiongzhuea) tumidissinoda	48	*P. mannii*	48+B
Chimonocalamus pallens	48	*Pleioblastus amarus*	48
Chusquea longiligulata	48	*P. simonii*	24, 48
Dendrocalamus bambusoides	72	*Pseudostachyum polymorphum*	72
D. barbatus	72	*Schizostachyum chinense*	72
D. brandisii	70	*Shibataea chinensis*	48
D. giganteus	72	*Thyrsostachys oliveri*	n=20
D. hamiltonii	72, 70	*Yushania polytricha*	72

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CHAPTER 3

CLASSIFICATION AND DISTRIBUTION OF BAMBOOS

3.1 World Bamboos and Their Origins

3.1.1 World Bamboos and Their Distribution

Relationships between the genera and species in sub-family ***Bambusoideae*** have long remained a most confusing part in phytotaxonomy. In 1788 A. J. Retzius, a Swede, first issued *Bambos* as a pioneer scientific name for *Bambusa*. Since then, scholars in different countries have given names to more than 1,400 species in 80+ genera over the past 200 years or so. But some genera and species have been merged to correct obvious misunderstandings or were untenable due to noncompliance with international regulations for plant naming. Only some 1,000 or so species in 70~80 genera now have worldwide acceptance from the majority of scholars. In China there are about 400~500 species in 40 genera, though no single taxonomic system has been fully accepted up to now. One reason for this lies in difficulties of taxonomic studies caused by the lack of a complete comparative collection of bamboo's reproductive and vegetative organs due to long and irregular flowering intervals.

Although originating from the tropics, bamboos have evolved to cover a wide range of climates from tropical areas to temperate ones, from plains to high mountains. Some species even occur in the cold temperate zones or on mountains as high as 4,500m above sea level. Most species are concentrated in tropical areas and damp, warm districts of the subtropical zone, though natural distribution has been found on every continent except Europe. Geographic distribution of bamboo worldwide may fall into three major regions; namely, the Asian-Pacific Region, the Americas Region, and the African Region. (Fig. 3-1)

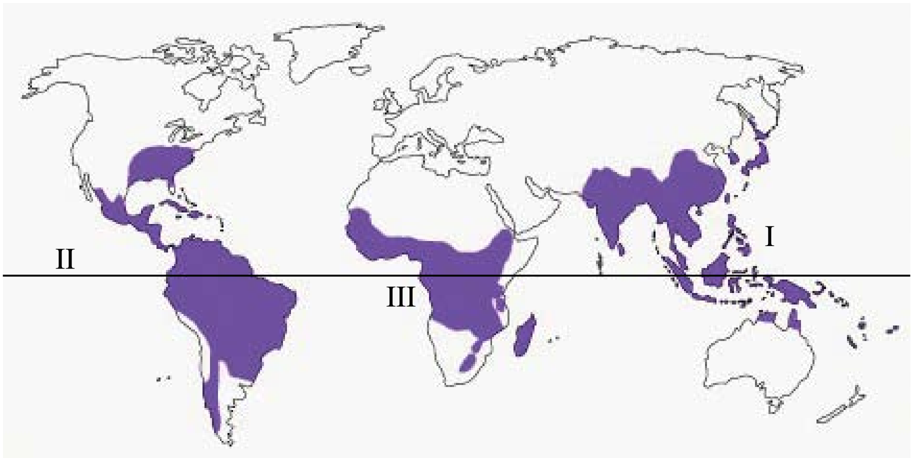

Fig 3-1 A Sketch Map of World Bamboo Distribution
I. The Asian-Pacific Region; II. The Americas Region; III. The African Region.

• The Asian-Pacific Region

This bamboo region covers a wide area reaching south to Singapore at 42ºS in Asia and north to Sakhalin Island at 51ºN, east to the Pacific Islands, and west to the southwestern part of the Indian Ocean with a major distribution of 900+ species in 40~50 genera. Southeast Asia is regarded as the center of origin of world bamboos as well as one of the modern distribution centers. The middle and southern parts of Yunnan, a south-border province of China, is richly abundant in bamboo species, intricate floral elements and various other species of high economic value.

• The Americas Region

Covering the continents of South America, Central America and North America, this bamboo region extends from the southern part of Chile at 47ºS and north to 40ºN in the eastern part of the United States of America. It has approximately 270 species in 18 genera of woody bamboos plus over 110 species in 25 genera of herbaceous bamboos. Many of these species have short culms of low economic value. In the cultural development, production and living of the people of the Americas, bamboos play a far less important role than in Asia. The most important exception is the genus Guadua in NW South America where it has great cultural as well as economic value.

Fig. 3-2 The bamboo forest from Ecuador, *Dendrocalamus* asper from Nordoccidente (left) and Guadua angustifolia from Guayaquil (right). Photograph by Hui, Chaomao, 2002

• The African Region

Bamboos are distributed only in a very limited range of this region, south to the southern part of Mozambique at 22º S and north to the eastern part of Sudan at 6º N. Though native bamboo species are few and far between on the continent proper, bamboos form large areas of forest or accompany trees to form the middle or lower layer in mixed forests. There are 40 species in 11 genera on the island of Madagascar in East Africa, with floral diversity far richer than on the continent. World bamboos are also divided among major floral regions according to Dils's **Regionalization Principles for World Plants**; namely, the Pan-Arctic Region, the Palaeotropical Region, the Neotropical Region, and the Australian Region.

3.1.2 Origins and Evolutional Characteristics of World Bamboos

Of more than 1,000 species in 70~80 genera, world bamboos are considered together rather than isolated, though their relationships may be close or distant. They generally fall into two types; namely, the primitive community and the evolved community. Asia and South America have for a long time been regarded as the two centers of origin. Different opinions have been expressed on origins of world bamboos by various researchers working from aspects of evolutional features, initial forms, and distribution centers.

It is accepted that the model of the primitive community is the sympodial clumper in most cases, through evolutional analyses of vascular bundle forms, types of rhizomes, structures of inflorescences, and the stability of form quality. Of the type, chromosome numbers may be as many as 2n=72 and the vascular bundles may be broken or double-broken. Leaf blades, sheath blades, and bracts are wide. Pseudo-inflorescences and pseudo-spikelets grow laterally on the vegetative mass, recurring over time. Stamens more than 6, culms large and shooting period lasts for 3 months beginning in June or July. It takes more than 3 months for young culms to grow from shooting to foliating, while quite a few remain unfoliated till the next spring. The need of over wintering in the form of a young, immature culm makes it impossible for tropical bamboos to grow in cold places due to the lack of resistance to frost; bamboo macrophyl requires a humid habitat for heavy transpiration; and the giant size of young culms calls for an ample rainfall or a sufficient water supply. To sum up, the primitive types, with limited adaptability and resistance to adversity, are confined to a narrow range of distribution. They are easy to introduce and propagate artificially, however, and are productive where conditions suit. As for the more evolved type, it's just the other way round.

Research has shown that bamboos observe the evolutionary order from the primitive to the evolved in morphology and anatomy, and the general courses are as follows:

Rhizome: tight sympodial clump→open sympodial clump→compound or amphipodial mixture→monopodial runner
Vascular bundle: double broken→broken→binding→semi-open→open
Inflorescence: pseudo-inflorescence (indeterminate)→genuine inflorescence (determinate)
Stamen: numerous→few
Form quality: unstable→stable
Chromosome: 2n=24→2n=48, 72

Through worldwide examination of the geographical distribution of bamboo, it has been found that the middle and southern parts of Yunnan Provinces in China are the home of the most abundant, naturally occurring bamboo species in the world. On this vast landmass, about 700km long and 500km wide, some 30 woody genera are distributed, 14 of which belong to the older or more primitive type mentioned above. Its richness of species and high concentration of primitive bamboo communities has no parallel in the world. Every species has its center of origin (C. R. Darwin, 1859), while concentrations of centers of origin of many genera reveal the center of origin of the group. The shooting period of a primitive species is, without exception, tied to rain or the rainy seasons of its distribution area. That of many primitive species falls in June, an exact coincidence with the rainy season of the tropical monsoon zone. Although belonging to the tropical monsoon zone in South Asia, the middle and southern parts of Yunnan experience very distinct dry and wet seasons due to its special geographical conditions. In the meantime, this district possesses some geographical advantages, such as a low latitude, adequate summer heat, blockage of Siberian cold air currents by the Qinghai-Tibetan Plateau, big valleys formed by the Hengduan mountains and the beneficial influences of warm and humid currents from the Indian and Pacific oceans, as well as mild temperatures and adequate humidity in the winter. All these climatic features are in perfect accord with the biorhythms of the primitive types.

Based on the above discussion, the conclusion can be safely drawn that Yunnan is not only the original center of Asia's bamboos but also of world bamboos. (Wen, Tai-Hui 1983; Xue, Jiru; Yang, Yuming; Hui, Chaomao 1996; Hui, Chaomao 1999)

3.2 China's Bamboos and Their Distribution

3.2.1 Division of China's Bamboo Distribution

With over 500 species in about 40 genera, China ranks among the countries that are richest in native bamboos. 37 genera and about 500 species (including varieties and forms) are recorded in **Flora of China** (Keng, Bai-Jie, 1997), 43 genera and about 857 species (including varieties and forms) are recorded in **Illustration to Bamboos of China** (Yi, Tongpei, 2008). Despite this, accurate clear zonality and locality of bamboo distribution reveals five major zones (Zhou, Fang-Chun 1989; Hui, Chao-Mao; Yang, Yu-Ming 2002) (Fig. 3-3).

I Scattered or Running Bamboo Zone in the North

This zone includes the southeastern part of Gansu, the northern part of Sichuan, the southern parts of Shanxi and Shandong, the southwestern part of Heibei, as well as Henan, Hubei, Anhui, and Jiangsu. There are spread across this zone about 29 species in 10 genera, together with 10 varieties and forms. The dominate type is monopodial, as in *Bashania* and *Phyllostachys*. It is further subdivided into three natural distribution zones: a. the north subtropical warm and humid zone in then upper reaches of the Huaihe and Hanshui rivers; b. the warm humid and semi-humid zone in the middle and lower reaches of the Huanghe River and c. the warm temperate semi-arid zone in the border area of Shanxi, Gansu and Ningxia.

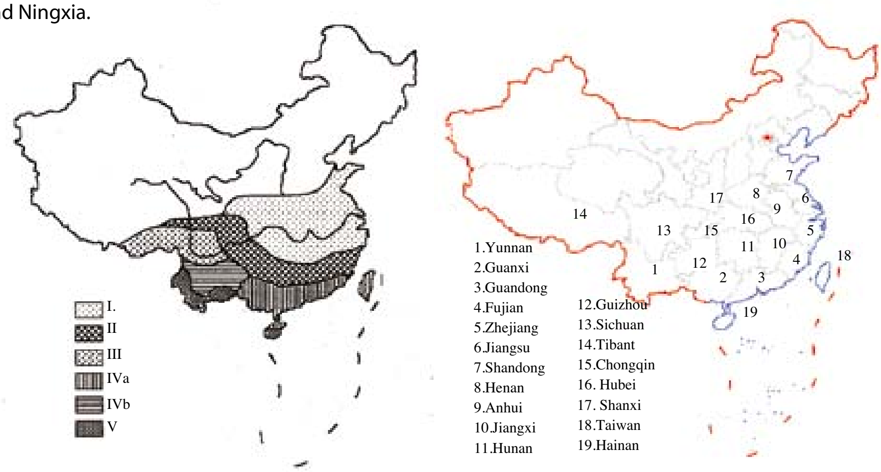

Fig. 3-3 A Sketch Map of China's Bamboo Distribution (left); China's Bamboo Growing Province Map (right)
I. Running Bamboo Zone in the North; II. Mingled Bamboo Zone South of the Changjiang River;
III. Alpine Bamboo Zone in Southwest China; IV. Clumping Bamboo Zone in the Southern part of China
IVa. Subzone of South China; IVb. Subzone of Southwest China;
V. Climbing Bamboo Zone in Yunnan and Hainan

II Mingled Bamboo Zone South of the Changjiang River

This zone contains the southeastern part of Sichuan, Hunan, Jiangxi, Zhejiang and northwestern part of Fujian, approximately 25~30ºN. Showing mingled features, this zone produces both types of bamboos -- the running types as in *Phyllostachys*, *Indocalamus*, and Pleioblastus and the clumping or clustered types such as Sinocalamus and *Bambusa*. Well developed in bamboo production, this zone stands out in China as the distribution center of *Phyllostachys edulis* with the widest man-made forests known as The Bamboo Sea and has the highest yield of bamboo timber, particularly of *P. edulis*.

III Alpine Bamboo Zone in Southwest China

Located in the mountainous area of the Hengduan Mountains, this zone includes the southeastern part of Tibet, the northwestern and northeastern parts of Yunnan, together with the southwestern and southern parts of Sichuan. Mainly dominated by alpine sympodial short and long necked clumpers such as *Fargesia* and Yushania, this zone includes areas 1,500~3,800m above sea level or even higher. Occasionally found in this zone are other genera such as *Indocalamus*, Chimonocalamus, and Chimonobambusa.

IV Clumping Bamboo Zone in the Southern Part of China

This zone consisting of two subzones is divided by different species constituents and habitat conditions. They are South China and Southwest China.

IV-a. Subzone of South China: Situated between the belts of the tropical monsoon evergreen broad-leaved forests and the tropical seasonal rain forests in South Asia, this zone includes Taiwan, coastal areas of Fujian, and the part of Guangdong south to the Nanling Mountains. Dominated by clumping bamboos in genera such as *Bambusa* and *Schizostachyum*, this zone serves as the center of distribution for *Bambusa* with many species. Some genera showing a mixture of rhizome types, such as Sinobambusa, can also be found in this zone.

IV-b. Subzone of Southwest China: Consisting of the western part of Guangxi, the southern part of Guizhou, and the major part of Yunnan, this zone mainly yields *Dendrocalamus*, *Gigantochloa*, Cephalostachyum, as well as Thyrsostachys, all clumping bamboos. It is especially rich in species of *Dendrocalamus*. This zone is regarded as the geographic center of distribution of this genus.

V. Climbing Bamboo Zone in Yunnan and Hainan

This zone covers the middle and southern parts of Hainan Island, the southern part and west border areas of Yunnan as well as the southern border areas of Tibet. This zone is characterized by genera of clumping and climbing bamboos, such as Melocalamus, Dinochloa, and *Schizostachyum* along with some species of *Bambusa*.

The sweep to the north of the Huanghe River and the Shandong Peninsula in East China belongs in the district of warm temperate deciduous broad-leaved forests. Though not a main distribution district, some locally cultivated or wild bamboo species of the running type can also be found on the mountain slopes. But few species, still fewer native species, and no endemic genera have ever been identified there. Pleioblastus chino, occurring wild on the eastern mountain slopes of Liaoning, is the best known species that spreads northeast in China.

Some scholars, having studied bamboo division from the perspective of management, present new methods for bamboo classification based on primary ecological factors such as precipitation, temperature, and monsoon influences. They divide China's bamboos into the following types (Liang, Tai-Ran 1990).

I. Sub-alpine Bamboo Zone
II. Running Bamboo Zone
  a. Natural Precipitation Running Bamboo Zone;
  b. Irrigation Running Bamboo Zone
III. Mixed Bamboo Zone
IV. Clumping Bamboo Zone
  a. Southeastern Monsoon Clumping Bamboo Zone;
  b. Southwestern Monsoon Clumping Bamboo Zone

Distribution of China's bamboos reveals both striking horizontal and vertical differences between the South and the North. Generally speaking, clumping bamboos dominate in places of low elevation, i.e. *Bambusa*, *Dendrocalamus*, *Schizostachyum*, and some species of climbing or lianoid bamboos. In places of high elevation, the dominant genera are *Borinda*, *Fargesia*, *Yushania*, and *Thamnocalamus*. *Chimonobambusa* and its sub-genus *Qiongzhuea* occur mostly in places of medium elevation. Vertical distribution of bamboos is illustrated to the fullest on the Gaoligongshan (mountains) in West Yunnan (Hui, Chaomao 1994) (Fig. 3-4).

3.2.2 Taxonomic System of China's Bamboo

Since bamboos seldom flower, their fruits are not readily available; consequently study of the bamboo taxonomic system is made more difficult than with other angiosperms.

Keng P.C. (1948) was first to make a list of all domestic bamboos known at that time and arrange them in taxonomic order. Based on analysis of different inflorescences, China's bamboos were divided into Series *Arundinariatae* and Series *Bambusatae* in **Illustrations of Major Plants in China–Family Gramineae (Juss)**, a book chiefly-edited by Keng (1959). Being of the pseudo-inflorescence type, Series *Arundinaria*tae contains only one tribe divided further into 2 subtribes according to the growing position of the inflorescences. Being of the genuine inflorescence type, Series *Bambusa*tae contains 4 tribes classified in terms of type of rhizome, characteristics of fruit, number of flowers embedded in spikelet, as well as breakability of rachilla. In this book 70 species in 40 genera are recorded.

A dozen new genera and hundreds of new species have been discovered in the past two decades through extensive investigations and research. Up until now more than 400 species in over 40 genera have been identified and the taxonomic system of domestic bamboos has been organized to include: 2 supertribes, 6 tribes, and 3 subtribes. Following is the new Taxonomic List of Subfamily ***Bambusoideae*** (Nees) in China. For the convenience of comparison, relevant groups in bordering areas are also listed, but are not numbered.

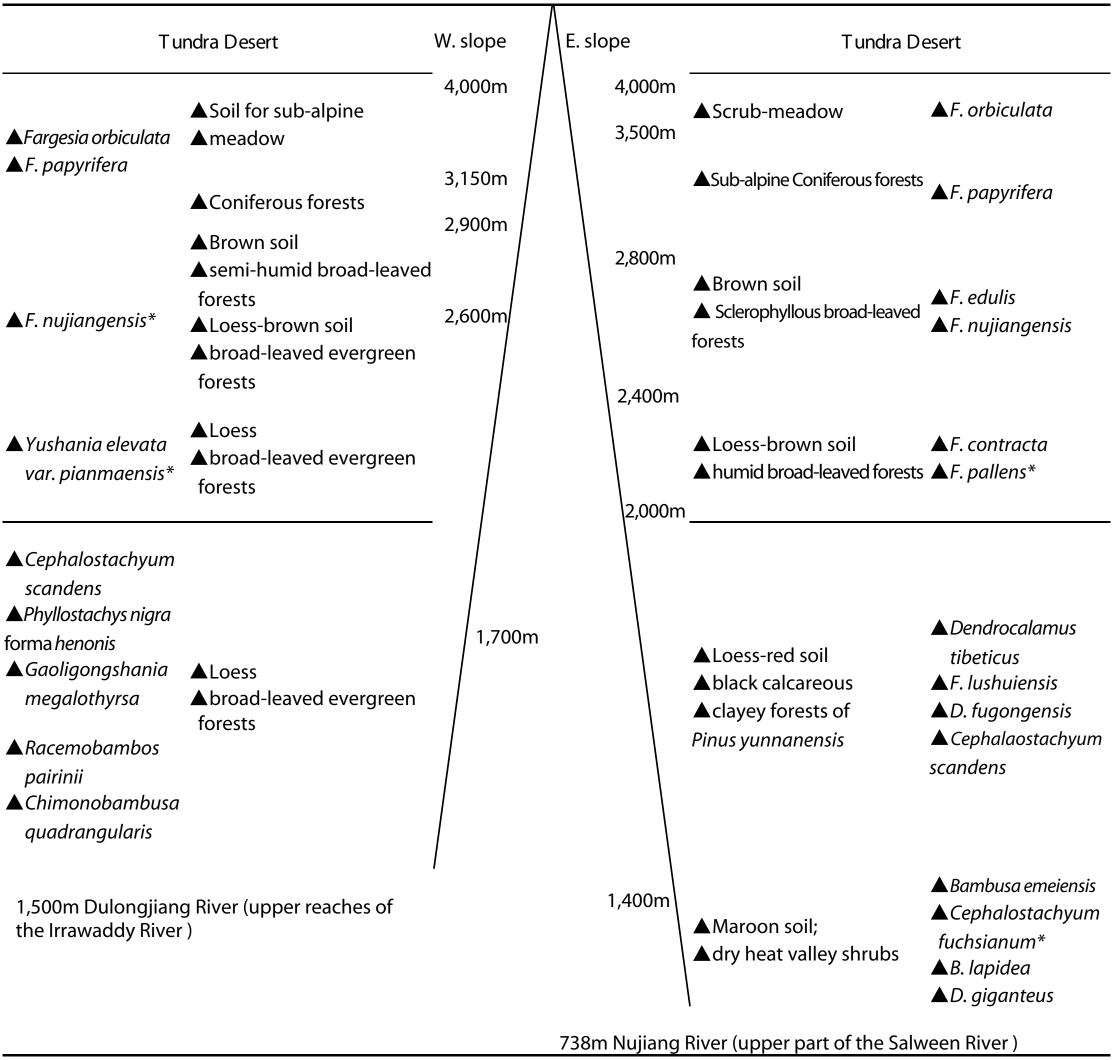

Fig. 3-4 Vertical Distribution of Soil, Vegetation,
and Bamboos in the Southern Part of Gaoligongshan (mountain), Yunnan, China
*Newly described species not yet in most reference books.

Taxonomic List of Bambusoideae Nees in China

Fam. *Gramineae* (Juss) (*Poaceae* Benth.)

Subfam. ***Bambusoideae*** Nees.

Supertrib. I *Bambusatae*

Trib. (I) *Melocanneae*

Genera

1. *Melocanna* (Trin.)
2. *Leptocanna* (Chia et H. L. Fung) (considered by some taxonomists to be included in *Schizostachyum*)
3. *Schizostachyum* (Nees)
4. *Pseudostachyum* (Munro)
5. *Cephalostachyum* (Munro)

Trib. (II) *Bambuseae* (Kunth.)

6. *Thyrsostachys* (Gamble)
7. *Melocalamus* (Benth.)
8. *Dinochloa* (Buse)
9. *Teinostachyum* (Munro)
10. *Bambusa* (Retz. corr. Schreber)
11. *Dendrocalamopsis* (Chia et H. L. Fung) Keng f.

Trib. (III) *Dendrocalameae* (Benth.)

12. *Neosinocalamus* (Keng f.)
13. *Dendrocalamus* (Nees)
14. *Gigantochloa* (Kurz ex Munro)

* Oxytenanthera (Munro) (* the genus is not native to China)

Trib. (IV) *Shibataeae*

Subtrib. A *Shibataeinae* (Nakai) Soderstrom & Ellis

15. *Shibataea* (Makino ex Nakai)
16. *Semiarundinaria* (Makino ex Nakai)
17. *Chimonobambusa* (Makino)
18. *Qiongzhuea* (Hseuh et Yi) (a sub-genus or section of 17)

Subtrib. B Phyllostachydinae Keng f.

19. *Indosasa* (McClure)
20. *Sinobambusa* (Makino ex Nakai)
21. *Brachystachyum* (Keng)
22. *Phyllostachys* (Sieb. et Zucc.)

Supertrib. II *Arundinaria*tae

Trib. (V) *Chusqueae* (Munro) E. G. Camus

23. *Chimonocalamus* (Hsueh et Yi)
24. *Drepanostachyum* (Keng f.)

* *Chusquea* (Kunth) (* the genus is not native to China)

Trib. (VI) *Arundinarieae* (Nees.)

Subtrib. A *Thamnocalaminae* (Keng f.)

25. *Fargesia* (Franch.)
26. *Yushania* (Keng f.)
27. *Thamnocalamus* (Munro)

28. *Gaoligongshania* (D. Z. Li, Hsueh et N. H. Xia)
29. *Ampelocalamus* (Chen, S. L., Wen et G.Y. Sheng)
30. *Racemobambos* (Holttum)

Subtrib. B *Arundinariinae* (auto-name)

31. *Acidosasa* (Chu et Chao et Keng)
32. *Oligostachyum* (Wang et Yi)
33. *Pleioblastus* (Nakai)
34. *Bashania* (Keng f. et Yi)
35. *Gelidocalamus* (Wen)
36. *Pseudosasa* Makino et Nakai)

* *Arundinaria* (Michaux) (* the genus is not native to China)

Subtrib. C *Sasinae* (Keng f.)

37. *Sasa* (Makino et Shibata)
38. *Metasasa* (W. T. Lin)
39. *Indocalamus*(Nakai)
40. *Ferrocalamus* (Hsueh et Keng f.)

3.2.3 Key to Genera of Bambusoideae in China

Since Bamboos seldom bloom, it becomes necessary for vegetative organs to be used as provisional taxonomic criteria. Vegetative organs are classified by type of rhizome, pattern of budding and branching, culm sheath characteristics and anatomic morphology of the vascular bundles. As vegetative mass and reproductive mass are unified in Bamboo, the description of growth habit, external morphology, anatomic structure and reproductive organs must be comprehensively applied to the identification of some complex groups. The following key to genera is based mainly on the vegetative descriptions for reference.

Key to Genera of Major Bambusoideae in China

1a. Rhizome sympodial.

- 2a. R.... hizome with pseudo-rhizomes formed by extension of rhizome neck, so aerial culms are in open clusters, appear scattered or somewhat scattered.
  - 3a.Occurring in mountain regions at high elevation; typical vascular bundles on traverse section of culm wall of semi-open type.
    - 4a. Pseudo-rhizome thick and short, its diameter thicker than mother culm; middle part thinner than both parts; internode mostly solid; short not extending far in the earth; culms in sparse clusters .... 25. *Fargesia*
    - 4b. Pseudo-rhizome thin and long, its diameter smaller than mother culm; both parts not thicker than middle portion; internode usually hollow and with ventilating tubes inside; with long extension in earth; culms in widely scattered form............26. *Yushania*
  - 3b. Occurring in places of low elevation; vascular bundle on traverse section of culm wall of binding type.
    - 5a. Culm wall extremely thin, only 1~2mm thick; culm top lax or weeping; sheath blade triangular; leaf blade elliptic........................4. *Pseudostachyum*
    - 5b. Culm wall thick; culm top erect and arching but not overhanging; sheath blade narrow lanceolate, leaf blade broad lanceolate........................ 1. *Melocanna*

2b. No pseudo-rhizome is produced on rhizome, for no extension of rhizome-neck ever takes place; aerial culms usually form detached clusters.

6a. Culm short or slender.

7a. Only 1 branch occurs at each node on the culm; large rudimentary vascular bundles grow densely at outer ridge and middle part of traverse section of the culm wall; but small vascular bundles grow near the inner wall ....28. *Gaoligongshania*

7b. Branching at each node variable few to many; vascular bundles uniform in size and distributed evenly on traverse section of the culm wall.

8a. Culm scandent; multiple branching sub-whorled at each node and spread in radiant pattern...30. *Racemobambos*

8b. Culm erect; branches fasciculate, held tight to culm,, not radially spread.

9a. Sheath top abruptly tapering like the neck of a bottle; sheath blade bent and facing outward; sheath ligule generally tall, buds 3 to numerous or, in a 3-bud succession...24. *Drepanostachyum*

9b. Sheath top obtuse; not pitcher like narrow; sheath blade coniform and erect; sheath ligule short. Only 1 bud at each node.....27. *Thamnocalamus*

6b. Culm medium-sized to large.

10a.Culm scandent or semi-scandent with pendent top; (rarely erect with top slightly bending).

11a.With silica on culm surface; rather scabrous (at least for new culm).

12a.Sheath not bulging; sheath blade facing outward...........3. *Schizostachyum*

12b.Upper part of sheath bulging; sheath blade facing outward2. Leptocanna

11b.With no silica on culm surface.

13a.Branches from 3 to numerous or, in a 3-bud succession; tapering to an extremely narrow tip; sheath ligule commonly perched high .... 24. *Drepanostachyum*

13b.Only 1 bud at each node of the culm.

14a.Sheath persistent with sclerotic texture; sheath ligule well developed. Principle branch thick enough even to replace culm; culm scandent. 7. Melocalamus

14b.Sheath tardily deciduous; thick papery or sub-leathery; principle branch not very conspicuous; culm semi-scandent.

15a.Sheath blade ovate or triangular; short setae on auricle not radial ....5. *Cephalostachyum*

15b.Sheath blade lanceolate; setae on auricle (sometimes) ....29. Ampelocalamus

10b.Culm erect with top slightly bent outward, or possibly hanging down like fishing line but never climbing.

16a.Culm surface scabrous with silica ....3. *Schizostachyum*

16b.No silica on culm surface.

17a.With 3 buds at each node; spiny aerial roots at lower nodes of the culm;

17b.At each node only 1 bud with no aerial roots.

18a.Hard or soft spines on culm or branches formed from contracted internodes..10. *Bambusa* (Subgen. *Bambusa*)

18b.Without spines.

19a.Sheath thin and persistent; no sheath ligule; leaf blade narrow lanceolate; generally no traverse veins........................6 . *Thyrsostachys*

19b.Sheath leathery or cartilaginous, deciduous.

20a.Base and top of sheath blade nearly the same in width, so sheath blade erect (with very few exceptions).

21a.Sheath auricle generally developed or microphyllous; base of leaf blade somewhat hastate, usually no traverse veins............ *Bambusa* (Subgen. *Leleba*)

21b. Sheath auricle weak; base of leaf blade obtuse; traverse veins vaguely present....... 11. *Bambusa* (Subgen. *Dendrocalamopsis*)

20b.Base of sheath blade narrower than top of sheath vagina, so sheath blade turning outward; base of leaf blade mostly cuneate, traverse veins vaguely present.

22a.Culm wall thin; sheath auricle unclear.

23a.Top of sheath broad hastate, retuse, 2~3 times as wide as base of sheath blade; sheath blade lanceolate and inverted; culm internode long........... *Bambusa* (Subgen. *Lingnania*)

23b.Top of sheath undulate like letter W, approximately twice as wide as base of sheath blade; culm internode medium-sized .... 12. *Bambusa* (Subgen *Neosinocalamus*)

22b.Culm wall mostly thick; sheath auricle microphyllous.

24a.Spikelet containing 4 mature flowers, apically growing 1~4 short reduced flowers; filaments dissected...13. *Dendrocalamus*

24b.Spikelet containing 1~4 mature flowers; no reduced apical flower existent; filaments tubularly coalescent .... 14. *Gigantochloa*

1b. Rhizome monopodial or amphipodial; rhizomes extending indeterminately horizontally in the earth.

25a.Rhizome monopodial; culms may be clustered.

26a.Each node of culm dichotomous.

27a.Internode with sulcus above unilateral branching; two branches (1 thick and 1 thin) slanting at a variable angle with the culm .... 22. *Phyllostachys*

27b.Internode cylindric, deplanate slightly only at the unilateral branching; two branches almost equally thick, but one erect while the other slanting ....38. *Metasasa*

26b.No dichotomous branching.

28a. 1 branch at each node, almost erect in parallel with culm; vascular bundle of semi-open type.. 40. *Ferrocalamus*

28b.Commonly 3 branches at each node, slanting.

29a.Sheath tardily deciduous; node somewhat prominent; branches short.................21 . *Brachystachyum*

29b.Sheath tardily deciduous; node swollen into a spine; branches almost equally thick and leveled out .... 19. *Indosasa*

25b.Rhizome amphipodial; culms scattered or sparsely clustered.

30a.1 branch at each node, in rare cases more than 1 branch occurs at upper nodes of the culm.

31a. Leaf blade large and broad lanceolate; culm thick and strong, 5~10m tall; 1 bud at each node; branches slender, the base somewhat adnate with culm .... 36. Pseudosasa

31b. Leaf macrophyllous and elliptic; culm short and slender, not much taller than 2m.

32a. At each node 2 buds can grow into 5~7 short branches with 1~2 leaves. But no further branching will occur afterwards. When 2 leaves come out on each branch, the lower leaf sheath usually grows taller and makes the lower leaf blade perch high. Traverse veinlets evident.. 15. *Shibataea*

32b. At each node only 1 branch bud.

33a. Node usually swollen but without rusty hair scar beneath; on traverse section of culm wall typical vascular bundles of semi-open type ....37. *Sasa*

33b. Culm node unswollen but with rusty hair scar beneath; on the traverse section vascular bundles of open type ....39. *Indocalamus*

30b. Branches at each node from 3 to numerous.

34a. Branches slender, short, and multiramose, but no further branching added when mature. On the terminal twig grow 1~2 leaves, shooting occurs in winter ....35. *Gelidocalamus*

34b. At the outset 3 branches are produced with more sometimes added or not. Shooting may occur in spring and summer, or in fall and winter.

35a. 3 buds grow at each node.

36a. Spiny aerial roots produced at middle and lower nodes of the culm; culm nodal ridges and branch nodal ridges are not swollen and sheath blade is small. Shooting comes in fall and winter, and shoot pulp may turn black under impact of enzymatic action... 17. *Chimonobambusa*

36b. No spiny aerial roots produced at nodes; culm nodal ridges and branch nodal ridges conspicuously swollen; sheath blade distinct; shooting in spring and summer, and shoot pulp not turning black from enzymatic action ....18. *Qiongzhuea*

35b. Only 1 bud occurs at each node.

37a. Typical vascular bundles on traverse section of culm of open type. ....20. *Sinobambusa*

37b. Typical vascular bundles on traverse section of culm of semi-open type.

38a. Internode flat only on the branching side of the base.

39a. Sheath scar often lignified and thicker with remnants on sheathing base; culm cavity membrane expressed as scattered powder; vascular bundles evenly distributed on the culm wall .... 33. *Pleioblastus*

39b. Sheath scar not thickened, remnants none; culm medulla parchment-like; vascular bundles close together at outside culm wall, but sparse near inside wall ....34. *Bashania*

38b. Internode flat on the branching side or mostly so.

40a. Sheath blade small, narrow, triangular or lanceolate, erect, sheath auricle non-existent; stamens 6 ....31. Acidosasa

40b. Sheath blade large, ovulate, capable of springing outward; sheath auricle small; stamens 3, to occasionally as many as 5 ....32. *Oligostachyum*

3.3 Major Economic Bamboo Genera in China

3.3.1 Ampelocalamus (S.L. Chen et. al.)

Rhizome sympodial, culm erect, and the top pendent like rattan. Though only 1 bud at each node, 3 are enclosed in protophyll that may form 2~3 or more branches. Culm sheath late deciduous, green, much shorter than internode, thick papery or leathery, but thin and submembranous in margins, glabrous or glabrate at the base. Sheath auricle apparent, deciduous, with radial setae. Sheath ligule rather short, with long fimbriate setae in margins. Sheath blade filiform and lanceolate; leaf auricle with setae evident. Leaf ligule truncate and sclerotic with long setae. Traverse veinlet obscure on leaf blade, panicle loose, 2~7 small flowers loosely arranged on spikelet. Apical flower often sterile; caryopsis ovate, oblong, smooth, and glabrous.

Eleven species of this genus have so far been discovered growing in the district between Yunnan, Guizhou and Sichuan with only one occurring on the Hainan Island. The most common species is *A. saxatilis*, a species distributed chiefly in limestone areas and most ideal for afforestation in stony places (Fig. 3-5).

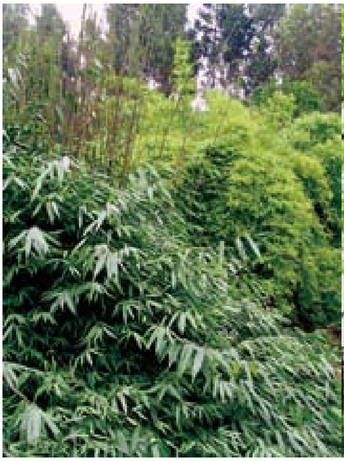

Fig. 3-5 Ampelocalamus scandens
From SWFC, Kunming, Yunnan
Photograph by Hui, Chaomao, 2005

Fig. 3-6 *Bambusa* lapidea
From Longchuan, Yunnan
Photograph by Hui, Chaomao, 2006

3.3.2 *Bambusa* ***(Schreber)***

Rhizome sympodial; branching multiramose. In some species undeveloped branches are often sclerified into branch thorns while in others secondary branchlets are modified into spiny form. Culm sheath late deciduous; culm blade erect or triangular; sheath vagina leathery or hard papery. Sheath auricle developed but bilaterally unbalanced. Leaf blade microphyllous to mesophyllous; traverse veinlet usually not conspicuous; leaf auricle present. At each branching node stands a pseudo-inflorescence composed by clustered round or multi-cephalous spikelets, which further made up of florets. Glumes 1~4, lemmas almost equally long. Scales 2~3, top obtuse, margins ciliate. Stamens 6, filaments separate, ovary commonly has a stem with apical setae, styluses divided into 2~3.

This genus, of high economic value, contains more than 100 species throughout the world. Of the 60 species that occur in China, the majority are distributed in South China while the rest are cultivated in Southwest China. Timber producing species of this genus include B. lapidea (Fig. 3-6), *B. sinospinosa*, *B. rigida*, and *B. intermedia*. Important ornamental species of this genus are *B. vulgaris* 'Vittata', *B. tuldoides* 'Ventricosa' and *B. multiplex* which has many forms or cultivars.

3.3.3 Cephalostachyum (Munro)

Fruticose or arborescent clumping species. Culm wall thin, internode long and smooth. Branching multiramose, sub-equally long, and semi-verticillate. Leaf blade can either be macrophyllous or microphyllous. Sheath vagina auriculate and shorter than internode. The inflorescence is an apical cephlous inflorescence or a panicle composed of several cephlous inflorescences Many spikelets assemble into a cephalanthium. Some spikelets may choose to pack up on one side or one point of the node and this is known as a spike. Every spike has its bract. Fruit oblong or ovulate, glabrous, and rostrate; pericarp thick and detachable.

Altogether there are 21 known species in this genus, most of which are distributed in Southeastern Asian countries and Madagascar. In China the 5 species are without exception confined to the western and southern parts of Yunnan. *C. pergracile* (Fig. 3-7), produced in Xishuangbanna, is locally called "fragrant bamboo" or "Maihao Lan" in the Dai language. The Dai people and the Burmese use new culm sections of this bamboo to cook tasty glutinous rice. This is a special type of bamboo utilization. Its internode is long; culm sheath far shorter than internode and sheath back colored burnt sienna and shiny. With sheath auricle prominent and of elegant contour, it serves well as an ornamental.

Fig. 3-7 *Cephalostachyum pergracile*
The natural bamboo cluster of *Cephalostachyum pergracile* from Simo, Yunnan.
The minorities in the south of Yunnan like to eat sticky rice and often use
this bamboo instead of a pot to cook rice.
Photographs by Sun, Maosheng. 2007

3.3.4 Chimonobambusa (Makino)

Rhizome amphipodial, culms scattered, internodes short and sometimes oblong. Internodes below the culm middle or at the base have spiny aerial roots. Branching trichotomous; culm sheath thin papery to thick papery, persistent, late deciduous or caducous. Sheath auricle lacking; sheath ligule not apparent; and sheath blade commonly reduced. Branchlet has 2~5 leaves, leaf auricle is undeveloped, and leaf blade is low. Setae usually developed at aperture of leaf sheath; traverse veinlet on leaf blade clear. Pseudo-inflorescence racemiferous or panicle; the base of branchlet with flower generally covered with a set of bracts. Spikelet contains flowers from few to many; caryopsis large; stigmas mostly residual.

Currently 38 species and a number of varieties of this genus have been identified growing in China, Japan, and South Asia. The species and varieties occurring in China are for the most part concentrated in the Southwest. Some are superior ornamental species such as C. quadrangularis and C. szechuanensis var. flexuosa. Others, for example C. utilis and C. yunnanensis, are good for making paper and also used for dried or canned shoots..

Fig. 3-8 Chimonobambusa yunnanensis
From mountain area of Yunnan , China.
Photograph by Sun Maosheng , 2001

Fig. 3-9 Chimonocalamus fimbriatus
From Jinping, Yunnan, China.
Photograph by Hui, Chaomao, 1992

3.3.5 Chimonocalamus (Hsueh et Yi)

Rhizome sympodial and clustered. A ring of spiny aerial roots grow in each of the middle and lower nodes and a yellow essential oil is found in the hollow internodes. Culm sheath deciduous, papery or thin papery. Sheath aperture narrow; sheath auricle often not apparent; sheath ligule apparent with fimbrate setae. Sheath blade filiform or lanceolate, erect or sprung outward. Branches 3, and aerial roots may sometimes grow at lower nodes on the top branch. Leaf blade small and narrow, traverse veinlet distinct. Pseudo-inflorescence paniculate, short, and on the ramilose apex. Spikelet contains 4~12 flowers arranged loosely. Fruit caryopsideous, long, and fusiform.

Of the 16 species and 1 variety in this genus, 2 species occur abroad. There is 1 in Tibet, and the rest are in sub-tropical mountainous areas in South Yunnan. As a renowned shoot-producing genus, its welcome shoots come out in summer and fall. It is also good for timber production, as its timber is hard and free from worm damage. Major species of this genus are C. delicatus, C. fimbriatus (Fig. 3-9), C. pallens and C. makunensis.

3.3.6 *Dendrocalamus* ***(Nees)***

An arborescent species with sympodial rhizomes; culms clustered, erect or slanting. Branching multiramose, top branch well developed. Culm sheath deciduous and leathery; sheath auricle not apparent or lacking; sheath ligule visible; sheath blade sprung outward. Auricle commonly undeveloped, leaf blade varies much in size. In pseudo-inflorescence several or many comate spikelets may be arranged in an open or spherical pattern. Each spikelet has several flowers, and the seeds are small.

With approximately 52 species known, this genus is distributed in tropical and subtropical zones in Asia. In China, 29 species and 2 varieties are spread in the four provinces and regions in the Southwest centered around Yunnan. Mostly large in size, they are of high economic value. D. sinicus and *D. giganteus* (Fig. 3-10) are two species of this genus that rank among the largest in size of all bamboos. They can reach a maximum height of over 30m and diameter of 35cm. Extensively cultivated in South Yunnan, these two species provide very fine timber for house building and material especially suitable for making dried shoots. *D. latiflorus* (Fig.3-11) and D. hamiltonii are two large-sized species of this genus that produce shoots of the highest quality. Forming the largest natural forest of this genus in China, *D. membranaceus* is exclusively confined to South Yunnan. It is economically promising to produce timber, make paper, and provide the people with shoots for food.

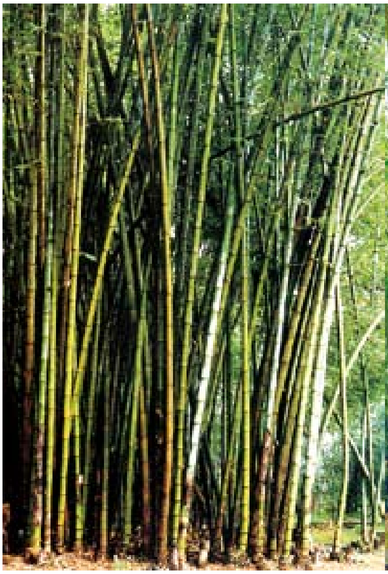

Fig. 3-10 *Dendrocalamus* giganteus
From Luxi, Yunnan, China.
Photograph by Yang, Yuming, 1999

Fig. 3-11 *Dendrocalamus latiflorus*
From Jinping, Yunnan, China.
Photograph by Sun,Maosheng, 2002

3.3.7 *Fargesia* ***(Franchet)***

Rhizome sympodial, culms scattered or clustered, medium or small in size. Culm wall thick or on some occasions nearly solid. Supranodal ridge less prominent than sheath scar; branching multiramose. Culm sheath persistent or late deciduous, few caducous, leathery or thick leathery. Sheath auricle absent or distinct; sheath ligule arching or truncate; sheath blade triangular or lanceolate. Veinlet on the leaf blade clear; genuine inflorescence panicled or racemiform on the ramilose apex. A series of spathes at the base make the inflorescence naked at the beginning of flowering on the opening side. Spikelet bears flowers from several to many; caryopsis narrow and long.

As a montane genus with culms of medium or small size, this genus currently contains 83 species mainly distributed on the mountain slopes in Southwest China, especially abundant in the Hengduan Mountains. Its modern distribution center lies in the joint area between Northwest Yunnan, West Sichuan, and Southeast Tibet. Several species of this genus are staple food bamboos for giant pandas (the most famous rare animals endemic to China), such as *F. denudata*, *F. robusta*, and *F. nitida*. Another species, *F. yunnanensis* (Fig.3-12), is a fine shoot- producing species. In mountainous areas of Northwest Yunnan where *F. yunnanensis* is abundant, the Lisu people often build houses with bamboos of this species and weave with the split skin. An issue worth further study is how to accomplish reasonable development and utilization of the rich bamboo resources in that area.

Fig. 3-12 *Fargesia* yunnanensis
From Kunming, Yunnan, China.
Photograph by Hui, Chaomao, 2005

Fig. 3-13 Indosasa sinica
From Pingbing , Yunnan, China.
Photograph by Yang, Yuming, 1990

3.3.8 Indosasa (McClure)

Bamboos of this genus are monopodial and scattered. More or less scurfy and spongy on inner wall of the culm; supranodal ridge markedly bumped and geniculate. Branching trichotomous; internode grooved on the branching side. Culm sheath deciduous, leathery or thin leathery. Veinlet on leaf blade traverse; pseudo-inflorescence occurring repetitively to form cluster of spikelets. Caryopsis ovate elliptic; stylus persistent.

Twenty-seven (27) species are recognized in this genus, which is concentrated in subtropical regions in China, including Guangxi, Guangdong, southern part of Guizhou, southern and eastern parts of Yunnan. Guangxi is the distribution center of *Indosasa*. As a large to middle-sized species, *I. sinica* (Fig. 3-13) is particularly abundant in Hekou county of Yunnan province, though widely distributed in Guangxi, Guizhou, and Yunnan. Locally called "Large Bitter Bamboo", it is a superior timber-producing species with high economic value that forms very large areas of natural forests.

3.3.9 Melocalamus (Bentham)

Rhizome sympodial; culms scandent and slightly flexuous; nodes swollen; branching multiramose and small at the middle and upper nodes. At each node 1 top branch extremely developed may be of the same size as the stem. Spiny aerial roots produced. Culm sheath persistent; sheath vagina firm. Sheath auricle developed; sheath blade erect or overhanging; leaf blade mesophyllous. Pseudo-inflorescence small and packed at each node om rachis. Spikelet contains 2 complete florets, and a reduced floret which occupies the apex of the rachilla where it extends to complete flowers. Fruit large and nearly spherical; pericarp rough, with a fat seed inside.

Fig. 3-14 Neosinocalamus affinis, (now *Bambusa emeiensis*) From Kunming, Yunnan, China. Photograph by Sun, Maosheng, 2001

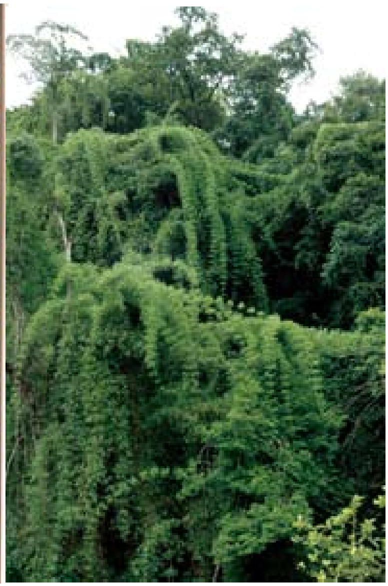

Fig. 3-15 Melocalamus arrectus From Cangyuan, Yunnan, China. Photograph by Sun, Maosheng, 2005

At present nine species are known in this genus which represents a special and interesting population in ***Bambusoideae*** (Nees). Besides being scandent, the features of large fruit and fat seed are uncommon in bamboos. In addition to the original species, M. compactiflorus which originated from India, Bangladesh and Burma, new species have been discovered in recent years. Among them are: M. elevatissimus, M. arrectus (Fig. 3-15), *M. scandens*, and *M. fimbriatus*, all of whose culms are all good for skin weaving.

3.3.10 Neosinocalamus (P.C. Keng)*

Rhizome sympodial; culm clustered, top arching and pendent; branching multiramose without top branch. Culm sheath thin leathery; sheath top crisp; sheath aperture projected in form of the letter W. Sheath auricle absent; margins of sheath ligule fimbriate; sheath blade generally overhanging. Pseudo-inflorescence pendent on culm; spikelets 2~4; fruit fusiform. *Now considered a subgenus under *Bambusa*.

There were only 2 species in this now submerged subgenus found in China. The first *N. affinis* (now considered an old synonym for *Bambusa emeiensis*) (Fig.3-14), is a species very widely cultivated in South-west China, particularly in Sichuan. It is most suitable for weaving. The other N. rectocuneatus is now assigned as Sinocalamus rectocuneatus and is found in Guangdong.

3.3.11 *Phyllostachys* ***(Siebold & Zuccarini)***

Monopodial and scattered; branching dichotomous; internode grooved from node to node on the branching side, branches usually 2 per node. These features distinguish it from other genera of subfam ily ***Bambusoideae*** (Nees).

Fig. 3-16 *Phyllostachys edulis*
From Changning ,Sichuan, China.
Photograph by Sun, Maosheng, 2003

Fig. 3-17 *Pleioblastus amarus*
From Yuxi, Yunnan, China.
Photograph by Sun, Maosheng, 2000

Dominating in East Asia, this genus includes some 76 known species. More than 40 species occur in China, and the distribution center falls in the region south to the Qinling Mountain and Huaihe (Yellow) River and north to the Nanling Mountain. With culm hard and wall tough, this genus is suitable for both timber and skin use. *P. edulis* (Fig. 3-16), with its high economic value, is the major species for afforestation and is cultivated on a large scale in the Changjiang (Yangtze) Valley, southern provinces of China and elsewhere. Remarkable achievements have been made in its construction and utilization. Second to *P. edulis*, *P. nigra* f. *henonis* also enjoys a wide distribution in Southwest China. *P. nigra* and *P. aurea* are noted ornamental species in this genus.

3.3.12 Pleioblastus (Nakai)

Shrub like to slightly arborescent (7 m.) bamboos; rhizomes monopodial or amphipodial; culms mixed. Internode slightly concave on the branching side; supranodal ridge convex or slightly bulged; corky ring at sheath scar well developed and often projecting with persistent sheath base. Branching 1~3 when young but 3~7 when old. Sheath vagina persistent or late deciduous, thick leathery, setae fimbriate at sheath aperture. Sheath blade coniform and lanceolate; racemes growing at nodes on lower part of the foliage branch. Spikelet contains several flowers; glumes 2 or 5; scales 3; caryopsis oblong. Suitable for uses of both timber and weaving.

P. amarus (Fig. 3-17), the most widely distributed species of this genus, occurs in the provinces in the Changjiang River valleys and has very extensive uses.

3.3.13 Qiongzhuea (Hsueh et Yi)*

Arbuscular bamboos with rhizomes amphipodial; culm flat on the branching side. Culm wall thick; supranodal ridge often raised and strongly projected. Sheath deciduous, thick leathery; branches 3. Leaf blade lanceolate or narrow lanceolate; traverse veinlet conspicuous. A large bract sticks to each node on rachis of the pseudo-inflorescence. Spikelet includes 3~8 flowers; nut pericarpic. *Now considered a section or subgenus under *Chimonobambusa*.

At present 8 species and 1 variety of this subgenus have been discovered in the adjacent belt between Sichuan, Guizhou, and Yunnan, solely restricted to Southwest China. C. tumidissinoda (Fig. 3-18) is distributed most commonly in Leibo, Emei, Mabian, Changning, Xuyong, and Junlian of Sichuan province and in Daguan, Suijiang, Weixing, and Yiliang of Yunnan province. With supranodal ridge extremely prominent as if artificially sculpted, it is of great ornamental value and famous for making walking sticks. These special sticks have been sold in India, Middle Asia and throughout Europe as far back as the Han and Tang dynasties. It is still highly sought after. The shoots are fleshy and crisp when fresh and lustrously drab and clear when dried. Well known for shoot producing, each year this species yields a large amount of shoots that are exported to other places from the growing areas.

3.3.14 *Schizostachyum* ***(Nees)***

Rhizome sympodial; culm erect; culm top sometimes pendent or sub-climbing. Remnants of sheath vagina are often left on sheath scars. Base of the internode is lubricous while the upper part is usually scabrous with silica. Sheath vagina hard and crisp with silica, setae conspicuous at sheath aperture. Sheath auricle usually absent; sheath ligule truncate; branching numerous and fascicular. Leaf blade is broad; pseudo-inflorescence apical or lateral; spikelet sessile, containing 1~2 flowers.

About 45 species of this genus are known to be distributed in Southeast Asia. Of the dozen species that occur in Southeast and Southwest of China, *S. funghomii* (Fig. 3-19) is a large species with internodes up to 50~80cm or longer. Commonly called Dabaozhu (big bamboo with thin culm wall) in Yunnan, it makes up a large area of natural forests from Hekou to Daweishan. With the advantage of a tall culm, a thin wall and tasty shoots, it brings very high economic profits.

Fig. 3-18 Qiongzhuea tumidissinoda
From Yiliang, Yunnan, China.
Photograph by Sun Maosheng, 2003

Fig. 3-19 *Schizostachyum funghomii*
From Mengla, Yunnan, China.
Photograph by Sun,Maosheng, 2001

3.3.15 Thyrsostachys (Gamble)

Rhizome sympodial; culm medium-sized, erect and clustered. Branching high and numerous, top branch unclear. Sheath vagina extended, thin, and persistent. Sheath blade narrow; sheath auricle non-existent; leaf microphyllous. Pseudo-inflorescence compound panicle; spikelet loose with 3~4 flowers, and the apical one infertile. Caryopsis cylindrical and with a sulcus on one side.

Only 2 species of this genus are currently known in Southeast Asia, distribution is mainly restricted to the southern part of Yunnan. Only a small quantity is cultivated in the South China Botanical Garden and Xiamen city of Fujian province, where they are called “foreign bamboos” since they were introduced from other countries. *T. siamensis* (Fig. 3-20), which finds extensive cultivation in Xishuangbanna, is one of the locally important commercial species. Bunched into small clumps, this species has very straight and upright culms. They are called “maihuo” in the Dai language meaning “clustered culms dense as hair”. They have a high economic value.

3.3.16 Yushania (P.C. Keng)

Arbuscular bamboos; rhizome sympodial; long rhizome-neck extended into pseudo-rhizome. Aerial culms scattered; mostly 1 branch at each node though numerous branches may eventually develop on upper part of the culm. Because rhizomes are buried deep in the earth, branches may emerge to form a rosette around the main culm. This is a type of sympodial variation peculiar to subfamily ***Bambusoideae*** (Nees). Raceme grows on apex of the foliage branch; spikelets commonly 2~3. Spikelet stipitate, containing several flowers (Fig. 3-21).

Fig. 3-20 Thyrsostachys siamensis
From Xishuangbanna, Yunnan, China.
Photograph by Sun,Maosheng, 2006

Fig. 3-21 Yushania levigata
From Gaoligongshan, Yunnan.
Photograph by Sun,Maosheng, 2001

About 84 species in this genus are distributed mostly in places of high elevation from South China to Southwest China. Due to difficulty of access, there are problems with development for utilization even though large quantities are available.

3.4 Bamboos by Types of Utilization

From the perspective of economic utilization bamboos roughly fall into the following categories: timber producing bamboos, shoot producing bamboos, skin-use bamboos, ornamental bamboos, and arts and crafts use bamboos.

3.4.1 Timber Producing Bamboos

Bamboos of this type are used for their timber in construction and paper-making, or are processed into various structural boards. Chief species of this type are elaborated in the following (see the colour pages).

Phyllostachys edulis Generally known as Maozhu (in the West called Moso), it is the chief species for afforestation in all districts south to the Changjiang River. At present it is worldwide the most thoroughly studied and successfully developed temperate zone species with a high economic value. As a large scattered or running species existing mainly in form of human cultivation, it covers a total area of 240×10^4ha throughout China. Of high quality and in extensive use, it produces both high quality timber and excellent shoots.

Dendrocalamus ***giganteus*** Large and clumping, this species ranks among the tallest in the world with a maximum height of 30m and a maximum diameter of over 30cm. Though occurring chiefly in Southeast China, it is most widely cultivated in tropical regions of Yunnan, and provides people with very good timber for their production, living, and construction. Its fibres, comparatively thick and strong, can best display the natural consistency of bamboos if processed into floor boards of superior quality. Its shoots, though unsuitable to eat fresh because of the bitter taste, can be made into perfect dried shoots and slivers that are no longer bitter when rinsed and cooked.

Dendrocalamus sinicus Called "big bamboo" by the locals. Dai people call it Maibo, and in the south of Xishuangbanna, "waijiao longzhu" (meaning "askew footed dragon bamboo"). It can grow to more than 30m tall and 35cm in diameter, and it is the biggest bamboo found in the literature. It is one of the bamboo species with excellent characteristics and great potential for extensive development. It is a rare species in other parts of the world and a very precious natural heritage.

Indosasa sinica Chiefly distributed in Southwest China, this species forms a large area of natural forests in Hekou of Yunnan. Middle to large in size, this species grows to a diameter of 8~14cm and a culm height of 16~22m. It offers people timber of high quality for construction and also shoots for food.

Schizostachyum funghomii Usually called Dabaozhu (big bamboo with thin culm wall) in its growing area, this species is distributed in a belt from South China to Southwest China, forming a large patch of natural forest in Hekou of South Yunnan. Diameter 8~10cm, clumping, culm wall thin and tenacious, internodes 60~120cm long. It provides people with fine timber, shoots, and skin for weaving, as well as a gracious form for ornament. The hand-made rocket firecrackers called "Gaosheng"which are set off during the Water-Sprinkling Festival of the Dai ethnic group in Xishuangbanna are made by filling its long internode with gunpowder.

Fargesia **spp**. This is a sympodial genus with some species demonstrating long necks or pseudo-rhizome and some with short. *Fargesia*s are dominant bamboos in high-altitude places of Southwest China. The large reserves can be reasonably developed into material for paper making or chipboard. They are also a major food species for the Giant Panda.

3.4.2 Shoot Producing Bamboos

Of all the abundant bamboo species in our country many produce tender and tasty shoots that are eaten fresh or processed into various shoot products. Some shoot producing species are renowned in both China and other countries (see the colour pages).

Chimonocalamus delicatus There are altogether 16 species and 1 variety in genus Chimonocalamus, all restricted to Yunnan except for 1 in Tibet. This species is called Xiangzhu or aromatic bamboo and is so named because of the aromatic oil contained in the internode cavities of the culm. Its shoots taste extremely delicious. It is advisable to have it nursery grown for greater development as a special species to provide more very high quality shoots.

Dendrocalamus ***brandisii*** Chiefly distributed in South Yunnan, it shares similar growth habit with many related species such as *D. hamiltonii*, *D. asper*, and *D. semiscandens*. As a high yielding shoot producing species of superior quality, it should be developed on a large scale for its shoots which are sweet, fragrant, crisp, and tender.

Dendrocalamus latiflorus As a shoot producing bamboo that occurs mainly in the southern provinces such as Taiwan and Fujian, it offers shoots in summer and fall as fine vegetables with high output over a long sprouting period. Its shoots sell well at home and abroad in the form of dried shoots or canned in tins.

Phyllostachys ***praecox*** This and many excellent shoot producing species of *Phyllostachys* are relatively small in size (5~12cm diameter), for instance: *P. dulcis*, *P. elegans*, *P. glabrata*, *P. propinqua* and *P. vivax*. They dominate in Zhejiang where the local people have gained much experience with high-yield shoot cultivation.

Schizostachyum ***pinbianensis*** Growing in South Yunnan, this is one of the finest shoot producing species in China. It produces shoots all year round.

Cephalostachyum pergracile This species is found only in South Yunnan, Myanmar and Laos. Its shoots are of high quality. As a special use of bamboos, a very flavorful rice is cooked in tubes of its young culms. It is planted around the houses and villages. Dai people like to eat sticky rice and often use this bamboo instead of a pot to cook rice. The rice cooked is fragrant so they called the bamboo Xiangnuo bamboo (fragrant and sticky bamboo). Its sheath is chestnut-red and shinning, and it has high ornamental value.

Chimonobambusa tumidissinoda This delicious species is found naturally growing only in northeastern Yunnan and southwest Sichuan provinces. Found primarily as an understory at medium altitude in sub-tropical broadleaf evergreen forests. It is one of the most popular shoot producing bamboos for export.

3.4.3 Skin Use Bamboos

These bamboos must be very tough and easily splittable. The culms are easily split into slivers or strips for weaving. The fibres are particularly long and tough. Some species are naturally superior weaving material. They are used mainly to weave various appliances and crafts.

Neosinocalamus affinis (now *Bambusa emeiensis*) This is one of the most productive and widely cultivated species abounding especially in Sichuan and Yunnan. This species finds extensive uses for weaving (It can be split so finely that mosquito nets were woven from it.), paper making, and furniture. It was formerly also used for construction.

Phyllostachys nigra ***f***. *henonis* Also called Huijinzhu, Baijiazhu, and Danzhu in Chinese, this species is spread over a wide range. Similar species include *P. bambusoides*, *P. heteroclada* and others, all good for weaving. Those with a small nodal ridge and especially long internodes include *P. rubromarginata* and *P. viridiglaucescens*.

Bambusa ***textilis*** Dominating in South China, this species ranks among the best for skin use with all good qualities such as a straight culm, little tapering, a nominal node ridge as well as a pliable texture. It is best suited for weaving exquisite bamboo-ware and crafts.

Bambusa ***chungii*** Growing mainly in Guangdong, Guangxi, Hainan and East Yunnan, this species provides fine bamboos for skin use owing to its long internodes and strength. With its blue canes it is also a beautiful ornamental.

Pseudostachyum polymorphum Sympodial, and semi-climbing with scattered culms, this is a special species whose rhizome necks commonly extend into pseudo rhizomes. These pseudo rhizomes are so tenacious and strong that they are frequently used by the natives to weave household appliances, to bind things with, and as straps to carry things. It is mainly distributed in tropical and subtropical areas from South China to Southwest China.

Cephalostachyum scandens This is a typical lianoid species restricted to the region from West Yunnan to Northwest Yunnan. Its culms may grow to dozens of meters long with diameters of only 2~3cm, and internodes up to 120cm long. The fibres are extremely long; it is known to be a very good material for traditional weaving in the locality. It, therefore, has a considerable value for additional development. Its mauve cephalanthium is rarely seen in other ***Bambusoideae***.

The species is naturally distributed in the uplands of west Yunnan. It is a typical rattan-like bamboo. It is also very good for making paper. So it is a rare and precious bamboo species. We suggest that it be included in the list of especially protected plants of China.

3.4.4 Ornamental Bamboos

With a strong sense of integrity and a very elegant contour, most bamboos remain green year round and have been praised by people since ancient times. They are not only indispensable components to gardens of classic style but also common ornament for modern houses or courtyards. Famous ornamental species in China include the following. (see the colour pages)

Pleioblastus argenteostriatus f. albostriatus: This is a small-sized bamboo species whose culm is usually only 10~50cm tall. Leaves sandy or white with green stripes, it is suitable for planting in flower beds, and can be used in areas with winter temperatures as low as -18ºC.

Phyllostachys ***aurea***: Internodes deformed in the middle or basal part of the culm, like tortoise shell. This is a noted ornamental species commonly seen in cultivation. It is also used in craft work and is cold tolerant down to -18ºC.

Thyrsostachys siamensis: Occurring in South and West Yunnan, this tropical species is cultivated in South China where local people call it "Nanyangzhu" which means "South China Sea bamboo". It has high ornamental value with small leaves on straight culms arranged in dense clumps.

Bambusa ***tuldoides*** **cv. Ventricosa**: When grown droughty or in a pot, the internodes in the middle or basal part of the culm are bulged like a Buddha belly, hence its common name is "Buddha Belly Bamboo". As a traditional ornamental species with fine contour, it is frequently used in the creation of Penjing, the renowned Chinese miniature potted landscape. This is one of the obligatory plants at Buddhist temples in semi-tropical areas.

Bambusa ***vulgaris*** **'Striata'**: Sometimes called "Painted Bamboo" because of its green stripes on bright yellow canes, it is a clumping species of large to middle size. *B. vulgaris* 'Striata' was originally distributed in tropical areas from Southwest China to South China. It is now found almost everywhere where climate is suitable (tropical) and as a popular atrium plant where climates are too cold. Other species with similar ornamental features include *Phyllostachys aureosulcata* 'Spectabilis' and *P. edulis* 'Bicolor', both of which are much more cold tolerant but not generally as large.

Bambusa ***multiplex*** Being a small to medium-sized clumping species, it and its many cultivars are well known for ornamental use. Some of the forms with unusual features of ornamental value include *B. multiplex* f. *nana* and *B. multiplex* 'Alphonse Karr', and the diminutive *B. multiplex* 'Tiny Fern'. They are planted extensively in gardens where winter air temperatures do not fall below -12ºC. It is also popular in potted landscapes known in the West as Penjing.

3.4.5 Bamboos for Arts and Crafts

Pseudosasa amabilis In China this species is eulogized as the "King of Bamboos" for its straight culms, flat nodes and tenacity. It is a celebrated species for craft use and large quantities are exported to more than 40 countries and regions.

Chimonobambusa tumidissinoda Small-sized with remarkably large nodes showing strongly raised supranodal ridges, this species is distinguished for both art and craft use as well as edible shoot production. It was sold to other countries in South Asia as far back as the Han and Tang dynasties and has been listed in the first group of specially protected plants in China.

Chimonobambusa quadrangularis Having amphipodial rhizomes and squarish internodes, the lower ones with spiny aerial root primordia. It is used both for arts and crafts work and cultivated as a very desirable ornamental. Culms of other species are sometimes artificially made square by the use of forms into which the young shoot is trained. These artificially-squared bamboo canes are highly desired for craft work and as interior architectural accents.

Phyllostachys ***bambusoides*** **'Tanakae'** With internode surface irregularly streaked, this species is most appropriate for the production of handicrafts. It is also ideal for bamboo swords having flat nodes and outstandingly straight internodes.

Phyllostachys nigra This is a mid-sized species, the older culms becoming black. It is known world wide as an extensively planted ornamental. It is very desirable for craft work and high quality furniture. It was the first bamboo imported to Europe in the 1800's.

Yushania **spp.** There are some small-sized species that occur mainly in high elevation mountainous areas of Southwest China. They belong mainly to the genera *Fargesia* and *Yushania*. These small bamboos are often made into bamboo beads, trinkets, and curtains as their internodes are solid or almost so.

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CHAPTER 4

STRUCTURE AND TYPES OF BAMBOO COMMUNITIES

4.1 Structural Features of the Bamboo Community

4.1.1 Macroscopic Features

For its peculiarities in macroscopic features, ecological characteristics, specific composition and geographic distribution, the bamboo community forms a special type of arborescent perennial evergreen plant. In general it reveals the following striking features (Hui, Chao-Mao; Du, Fan; Yang, Yu-Ming 1997).

A. Evergreenness: For most bamboo species, their leaves remain green the year round. (A few are drought deciduous and a few others winter deciduous.)

B. Groupness: In running or clumping bamboos the colony forms a united whole.

C. Ecological adaptability: Bamboo adapts itself to almost any climate, (within species temperature tolerance parameters).

D. Fast growth: A mature bamboo forest becomes possible within only 3~5 years in tropical and sub-tropical regions, for temperate bamboos 5~10 years are needed. So in the Classification of China's Vegetation, it is treated as a special type of plant group.

Apart from natural forests, man-made bamboo communities may be developed through human cultivation and management thus giving advantages such as extensive use and high economic value. A case in point is *Phyllostachys edulis*, which comprises the largest man-made forest in China. Bamboo forests are pure stands in general under human management, but they are usually mixed with some broad-leaf forests in natural conditions. In various forest communities of tropical and subtropical zones particularly, bamboos form dominant layers and play a vital or decisive role in the dynamic succession of the community, i.e. to constitute mixed forests. This is true of the vast majority of natural communities found in South Yunnan, including those of *Dendrocalamus membranaceus*, *Schizostachyum funghomii*, and *Indosasa triangulata*

4.1.2 Ecological characteristics

Formation of bamboo forests is in response to the ecological characteristics of the plant since generally speaking bamboo multiplies primarily through vegetative propagation. That is to say, bamboo stands are formed by rhizomes extending horizontally in the earth and the coming up of canes from node buds to form scattered or monopodial groves. Or, in the case of sympodial clumps that are unable to grow long horizontal rhizomes underground, bamboo stands are formed by the tillering of new shoots from the mother bamboos. In the latter case, new culms usually stand close to the old because the subterranean stems are determinate and incapable of long travel underground. In some special cases, however, scattered sympodial stands can be formed by rhizome necks extending into pseudo rhizomes. Still other species may produce mixed forests with amphipodial rhizomes which combine both sympodial and monopodial characteristics. Whichever type it may be, the bamboo is closely linked underground into a single colony even though the culms above the ground may appear as separate individuals. Botanically it is viewed as a single bamboo colony, with rhizomes interlinked by a horizontal "trunk" and the culms above ground as "branches". Ecologically they are indispensable to one another, as culms connect with rhizomes, rhizomes produce shoots, shoots come up as new culms, and the culms in turn produce food for more rhizomes. They exert mutual influences on one another and together they increase clump or grove size.

4.1.3 Specific Composition

Bamboo forests are comprised of woody bamboos which belong to the grass family and as such are monocots. There are approximately 80~90 genera and over 1,500 species known in the world. Of these some are quite large sized and arborescent. Some species like *Dendrocalamus giganteus* and *D. sinicus* for example, are exceptionally upright and may grow to 30 metres tall. Some middle-sized species are 5~15m tall, while species of *Indocalamus* and *Sasa* are usually shrub-like, with an average height of no more than 1 metre. There is another type whose culm is scandent, for instance certain species of *Melocalamus, Schizostachyum* and *Ampelocalamus*. These have a small diameter of only 2~3cm but they can grow to well over dozens of metres by climbing or hanging over other trees or plants. There are also some herbaceous bamboos in the subfamily Bambusoideae, which mostly occur in South America, with only 1 species with 1 genus found in Taiwan.

4.1.4 Geographic Distribution

According to incomplete statistics, bamboo forests cover a total area worldwide of approximately 1,500 x 10^4 ha. Asia has the most abundance, with a total area of over 1, 000×10^4 ha in Southeastern Asia alone. Then sequentially: Africa, America (North, Central, and South inclusive), and Oceania, but no natural distribution has been found in Europe since the last ice age (Table 4-1). It is worth mentioning that Africa, though rather poor in bamboo florae with only a few native species, has large areas of natural bamboo forests. There exists 13×10^4 ha of *Arundinaria alpina* in the Kenyan mountains and 10×10^2 ha of *Oxytenanthera abyssinica* in Ethiopia. Madagascar, an island off of East Africa, however, is extremely rich in bamboo florae with some 40 species representing 11 genera (Xiong, Wen-Yu 1983).

Bamboo forests occur over a wide geographic distribution in China, reaching south to Hainan Island, north to the Huanghe River valleys, east to Taiwan Island, and west to Nyalam in Tibet. This vast natural distribution covers a large area from about 18º to 35ºN and 85º to 120°E, and has been enlarged more southward and northward by cultivation. For instance, *Bambusa sauvis* is grown on Xisha Island in the South China Sea and certain species are planted in Beijing. But the main part of bamboo distribution in China lies chiefly in the tropical and subtropical areas. It is especially extensive and abundant in hilly or mountainous areas from 100~1,000m above sea level, and in valleys and flatlands south of the Changjiang River. This belt is located in southwestern and southeastern monsoon areas with a climate both warm and humid, with mean yearly temperatures of 14~26ºC., the lowest mean monthly temperature is 3~23ºC., annual rainfall is 1,000~2,000 mm, and wet and dry seasons are distinctive. Alpine bamboo species distributed in Southwest China are mostly found in places of 2,000~3,800m above sea level and make up the lower layer of vegetation in the broad-leaved or evergreen forests, i.e. alpine *Fargesia* spp. shrubs. The bamboo growing area of major producers in China (1985-1995) is shown in Table 4-2 (Zhou, Fang-Chun 1989).

Table 4-1 Geographical distribution of bamboos

Geographical area		Subtribes	Genera	Species	Bamboo Forest ($\times 10^4$ha)
Regions	Asia	6	45	600	1289
	Africa	2	14	50	150
	Pacific and Australia region	2	6	10	20
	Americas (N, C, S)	4	21	430	150
	Total	9	90	1200	
Countries	China		40	500	
	Yunnan, China		30	250	
	India		19	150	400
	Myanmar		17	90	217
	Thailand		12	50	100
	Bangladesh		13	30	510
	Japan		13	230	12.3
	South Korea		10	13	0.8
	Indonesia		9	30	6.0
	Vietnam		16	92	3.0
	Philippines		12	55	0.8
	Malaysia		7	44	2.0
	Sri Lanka		7	14	0.2
	Madagascar	2	6	20	

Table 4-2 A Statistical table of major bamboo producers in China

Province	*Phyllostachys edulis* (only)			Total all species	
	(10^4ha^2)	(10^4 culms)	(10^4tonnes)	(10^4ha^2)	(10^4tonnes)
Hunan	63.53	129,381	1940.7	68.35	2011.2
Fujian	63.26	94,380	1415.7	64.08	1508.1
Jiangxi	62.53	103,000	1545.0	70.93	1644.1
Zhejiang	52.81	91,162	1367.4	62.45	1490.1
Anhui	15.29	41,100	616.5	20.34	74.4
Guangdong	10.81	31,000	465.0	31.80	965.0
Guangxi	9.51	24,000	360.0	16.32	535.2
Hubei	6.22	14,743	221.1	8.75	268.2
Guizhou	2.00	4,317	64.8	4.43	134.0
Jiangsu	2.00	4,316	64.7	4.00	116.2
Sichuan	1.90	4,754	71.3	74.00	1671.1
Chongqing	0.33	785	11.8	5.41	219.3
Taiwan	0.33	1,096	16.4	17.56	459.8
Henan	0.20	360	5.4	1.67	43.2
Shangxi	0.03	55	0.8	13.45	266.0
Yunnan	-	-	-	33.10	-

4.2 Classification of Bamboo Community Types

In the classification of China's vegetation, bamboo forests are treated as a special vegetation type subordinate to the Broadleaf Vegetation Group. According to different habitats and hydrothermal conditions they are subdivided into three subvegetation types: temperate bamboo forests, warm temperate bamboo forests and hot bamboo forests, and further by types of association, (see below). In the study of evolution of plant communities, with bamboo as the primary taxon, plant communities sharing the same succession of species or concurrent assemblage of species combine into a "formation". In the same type of formation, all communities have similar constructions, floral integrants, bioproductive forces and dynamic features.

Of all integrants in the bamboo forests, many species in the same genus share similar ecological requirements and distribution, so one or several are often selected as representatives of the genus or the genus itself may serve as the type for classification (Table 4-3).

Table 4-3 Major Types of Bamboo Communities in China

Vegetation	Sub-vegetation	Formation	Major distribution zone
Bamboo Forests	Cool Temperate bamboo forests	1. *Fargesia* spp.	Mountains 2,000~3,800m above sea level.
		2. *Yushania* spp.	Mountains 2,000~3,800m above sea level
	Warm Temperate Bamboo Forests	3. *Phyllostachys edulis*	The Changjang River reaches & South China
		4. *P. nigra* f. *henonis*	Sichuan & Yunnan
		5. *P. heteroclada*	The Changjang River reaches
		6. *Chimonobambusa tumidissinoda*	Sichuan, Guizhou, & Yunnan
		7. *Chimonobambusa* spp.	Southwest China
		8. *Chimonocalamus* spp.	Yunnan & Tibet
		9. *Bambusa emeiensis*	Extensive cultivation
		10. *B. rigida*	Sichuan
		11. *B. sinospinosa*	South China & Southwest China
		12. *Pseudosasa amabilis*	South China
		13. *Pleioblastus amarus*	Extensive cultivation
		14. *B. textilis*	South China
	Thermophilic (hot) Bamboo Forests	15. *Dendrocalamus membranaceus*	South Yunnan
		16. *D. giganteus*	South Yunnan
		17. *D. latiflorus*	South China
		18. *Schizostachyum funghomii*	South Yunnan
		19. *Indosasa sinica*	South Yunnan
		20. *Cephalostachyum pergracile*	South Yunnan
		21. *B. lapidea*	South China & Southwest China
		22. *B. chungii*	South China
		23. *Melocalamus arrectus*	South Yunnan
		24. *Gigantochloa nigrociliata*	South Yunnan

Good examples are the formations of *Dendrocalamus membranaceus* and *Chimonobambusa* subgenus *Qiongzhuea* spp. In a formation based on floral integrants of each community and relative cover-abundance analysis of the mixed plants, ie. sub-dominants in the dominant layer or dominant species in the sub-dominant layer (bushes or herbs) can be classified as different associations. For example, formations of *Dendrocalamus membranaceus* can be divided into communities such as "*Ficus altissima / D. membranaceus*" and "*Microstegium ciliatum-Stereospermum terragonum- Spondias pinnata / D. membranaceus*". On the basis of these principles common bamboo communities of higher economic value in China are identified and differentiated into types.

4.3 Main Types of Bamboo forests in China

Types of bamboo formations in China are various since the country has a vast territory, with widely varied natural conditions, and a rich pool of bamboo species. What is introduced in this section are only the most common and typical types which are of high economic value in production. With steadily deeper studies of bamboo communities in recent years, tables measuring some types with higher economic value have been researched for production purposes. They include such formations as *Phyllostachys edulis, Dendrocalamus membranaceus, P. heteroclada, Schizostachyum funghomii, Cephalostachyum pergracile and others.*

4.3.1 Formations of Fargesia *spp.*

Genus *Fargesia*, a common yet complex genus in Southwest China, has various species of which more than 80 have been published. These known species are mainly distributed in alpine and sub-alpine coniferous forests 2,000~3,800m above sea level, in Northwest Yunnan, West Sichuan, and Southeastern Tibet. These places display certain sub-alpine climatic features, such as short summer, long snowy winter, foggy and damp the year round. But they are also found growing in broad-leaved forest areas 1,500m above sea level, such as on Ailao Mountain, Wuliang Mountain, Gaoligong Mountain, and other mountainous areas and plateaus in Middle Yunnan (Fig. 4-1).

Fig. 4-1 Formation of *Fargesia* melanostachys.
from North Gaoligongshan in Yunnan.
Photographs by Yang, Yuming and Xue, Jiarong 1992

Most species of *Fargesia* are small-sized and shrub like with sympodial rhizomes. They form open clumps or clusters as their rhizome necks usually extend into pseudo rhizomes, which are locally called "smooth bamboo" for their particularly smooth surface. With simple constituents of pure species or in dense patches mixed of 2~3 species, their stands hide under fir and spruce to make up the second layer in the forests or to form an alpine *Fargesia* "bush" at higher elevations. Usually they have an average height of 2~3m and a diameter of 1~2cm, but larger species may reach a height of 4~8m and a diameter of 2~4cm. Under the fir forests at 3,400m above sea level in Zhongdian County of Yunnan, *Fargesia* spp. stands grow to a height of 6m with a diameter of 2.5cm. In each hectare there are approximately 32,170 living culms, 12,400 dry culms and 6,200 new shoots which add up to a total of 50,000/ha. Within Sichuan borders *Fargesia* spp. forests are chiefly distributed in Dabashan area north of the basin and in mountainous areas in West and South Sichuan. In these places at 1,600~3,800m above sea level we can expect some mixed patches of evergreen and deciduous broad-leaved trees, and secondary vegetation after clear cutting or under thinly-stocked forests where sub-alpine conifers were damaged. A few surviving conifer species such as fir, and hemlock as well as some broad-leaved trees are found dotted in secondary vegetation.

With rich stocking and wide distribution, species of *Fargesia* offer the people important material to produce paper. But due to continual felling of alpine coniferous forests, much is destroyed before being put to use. These bamboos should be preserved and developed since these species are a staple food for the rare and much loved Giant Pandas in their natural range.

4.3.2 Formations of *Phyllostachys edulis*

As a major economic species grown in the subtropical area, it is widely spread and used in the Changjiang River valleys and other southern provinces., Its range is westward from Taiwan to Yunnan, and northward from Guangdong and Guangxi to the northern parts of Jiangsu, Anhui and even to the south of Henan. It is the largest artificial bamboo formation and is thoroughly exploited and studied. This is a varied topography comprised of mountain sides, rolling hills and plains. Large areas of forests are found from the plains to the mountain sides, from about 800m above sea level, to about 1200m in vertical distribution in some southward places. In the 1970s China launched a project called "Transferring Bamboo from South to North" and now shoots of bamboo are consequently introduced to Shandong, Hebei, North Henan, and to the north side of Mount Qinling (Fig. 4-2).

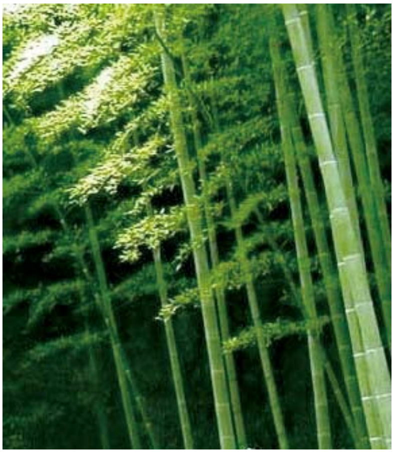

Fig. 4-2 Formation of *Phyllostachys edulis*
From Anji, Zhejiang
Photograph by Yang,yuming. 1998

Forests of *P. edulis* are usually found in subtropical areas with a humid climate where the average annual temperature is 16~20℃, the annual precipitation 100~200cm, and a relative humidity of over 80%. Requiring good drainage, its suitable soils include such types as acid, neutral purple, yellow soil, and reddish yellow soil.

Commonly, pure stands of *P. edulis* show densities from 1,500~4,200 culms/ha, with an average of approximately 3000 culms per hectare. The average diameter at breast height (DBH) is 11.6cm, maximum diameter 20cm, average height 18m, with a maximum height 22.5m. Total above ground biomass can range from 50,850~233,460kg/ha, weight of the culms alone is usually about 70-75% of the total biomass. The average single culm weight is approximately 35kg; leaf surface area can range from 2.23~7.4 m_2 per square meter of ground surface and average canopy density 50~90%. In a stand with an increase in mean diameter, the number of culms with a diameter close to the mean also increases. Obviously the group structure is more ideal and the stand is in a better growing state when the difference between minimum and maximum diameters tends to be least. *P. edulis* studies reveal that a close relationship exists between diameter, individual plant weight, culm weight, and culm height.

Relations between ecological and cultural factors that affect the output of *P. edulis* are rather complex. Each of these factors exerts a direct influence, and they also produce cumulative overall influences. Research indicates that the number of canes, diameter at breast height (DBH), index of leaf area, and regularity will all directly or indirectly produce some impact, notably the first two leading factors.

Associated species in natural stands of *P. edulis* frequently include *Camellia oleifera*, *Enrya japonica, Neolitsea sp., Schefflera octophylle, Symplocos sp.* (sweet leaf)*, Rubus sp., Ardisia japonica, Hydrangeavillo sp., Schima wallichii and Castinopsis chinensis*. The herbaceous layer consists of **Gramineae, Cyperaceae,** and some species of **Ferns** such as *Hicriopteris glauca* and Diranopteris dichotoma. On occasion various types of mixed formations are produced when *Phyllostachys* is found with Masson pine, Oriental beech, and Dendrobenthamia capitata. In these types of formations *Phyllostachys* often makes up the secondary layer with taller species such as Masson pine as the tallest layer. According to different types of management, three types of *Phyllostachys* formations can be classified. The first type, resulting from cultivating and fertilizing, are forests intensively managed with a stocking rate of over 3000 culms/ha. The second type, ordinarily managed by brush removal, refers to forests with a stocking rate of 1,500 ~ 3,000 culms/ha. The third type, which includes all forests under minimal management, may have a stocking rate of less than 1,500 culms/ha due to lack of proper management and/or over harvesting. Bamboo production management should be based on the various requirements with the intention to raise productivity to the higher density level of the first type.

It will be of practical benefit to promote the development of more species of *Phyllostachys* notably for its wide potential distribution in large areas, high economic value and great production potentials.

4.3.3 Formations of *Phyllostachys nigra* ***f.*** *henonis*

Also called Huijinzhu, Baijiazhu (in Sichuan), Fenjinzhu, *P. nigra* f. *henonis* is distributed in provinces in the Changjiang River valleys and widely cultivated in Southwest China. Since it favors a cool climate, it occurs in Middle Yunnan on flatlands and quasi-montane regions 1,600~2,100m above sea level.

Forests of *P. nigra* f. *henonis* are without exception single-layered and pure, for they are all artificially managed. Stocking density and growing state of the forests may vary from site to site and with different managerial conditions. In a neglected stand density is impractically high and dead standing culms are numerous resulting in poor growth due to lack of harvest. An abused stand, likewise, is in a less than ideal condition because the standing canes are few and far between wasting potential production area which is occupied by weeds and brush. But under intensive management, a stand may grow to an average height of 15m or higher and to a diameter of 10cm. Though a stand of *P. nigra* f. *henonis* may have an average DBH of about 6.0cm and a maximum height of 12m, its density may be so low that the stocking count is no more than 1,000/ha. In the same stand, height variation between individual plants is smaller than that of diameter, difference between the tallest and the shortest culms is no more than twice, and stocking percentage is higher inside than on the stand's edge. In the same age class, however, difference between the shortest and the tallest culms is less than that between different age classes. It becomes clear, then, that in a stand the bigger the average height, the smaller the height variation and greater the clear bole (unbranched trunk or culm) height tends to be. Moreover, thickness and quality of the culms increases in proportion to height.

Therefore, we can tell whether the management is good or bad simply by comparing average heights between different age classes. For example, if average height of the current new culms is bigger than those of the former age classes, the management is good and the stand is experiencing a productive period. Otherwise the management should be checked. Since output of *P. nigra* f. *henonis* (Fig. 4-3) depends heavily on quantity and quality of the new culms, age structure of the stand presents itself as a major concern in management.

Fig. 4-3 Formation of *Phyllostachys nigra* f. *henonis* from Longling, Yunnan. Photograph by Hui, Chaomao, 2003

Without human care some tree species may emerge inside the stand of *P. nigra* f. *henonis*, towering over the bamboo canopy, creating an "island" distribution. Different places may have very different species, however. For example, around Kunming Hot Springs, species associated with this bamboo include *Cyclobalanopsis glaucoides, Lithocarpus dealbatus, Prunus sp., Trachycarpus fortunei, Ophiopogon bodinieri, Polygonum multiflorum, Pueraria sp.,* and many species of ferns.

4.3.4 Formations of Bambusa emeiensis *(old name: Neomicrocalamus affinis)*

As a widely cultivated species in subtropical areas of Southwest China, its northern distribution extends to the south side of Mount Qinling in Shaanxi. It is distributed throughout Hubei, Hunan, Guangxi, Sichuan and Guizhou, where it is locally planted around villages at altitudes lower than 1,000m. It is applied to a wide range of uses. In Yunnan, (at a lower latitude), it is planted on flatlands at 1,600~2,000m above sea level. It is sometimes seen at similar elevations on mountain slopes in the Northwest. Starting from Kunming southward, cultivation of *B. emeiensis* is gradually reduced and replaced by *B. intermedia*. Further south at 1,200m above sea level, it becomes a rarity on flatlands.

B. emeiensis (Fig.4-4) is a species of marvelous adaptability. Though it displays a natural inclination for cool and humid climates, it also has a fairly strong cold tolerance and drought resistance. It grows best in properly shaded places, but it also enjoys normal growth in arid soil.

B. emeiensis is very productive of new shoots and is easy to plant. According to surveys around Kunming, *B. emeiensis* has an average height of 9m, a DBH of 3.8cm and a clump diameter of 2m. In each hectare there are about 1,200 clumps, this totals to $6^{10/}$ha culms with some 50 in each clump. For want of proper management, its diameter class is somewhat low.

In accordance with an investigation carried out on the Chengdu Plain, average diameter of *B. emeiensis* was 4.06cm while the maximum is 6.5cm; the average individual weight was 2.71kg but the maximum is 5.69kg.

4.3.5 Formations of *Bambusa* chungii

This is a superior species extensively planted in Guangdong, Guangxi, Hunan and some parts of Fujian. It has the characteristics of fast growth, quick establishment, short harvest cycle, strong adaptability, and easy propagation. Though its vertical distribution is over 500m above sea level, it best suits in places like slopes, flatlands, mountain feet and river banks. It can grow normally in either acid soil or limey soil, in a distribution range where yearly average temperatures are between 18~20℃ and annual precipitation is 999.1~2136mm.

Fig. 4-4 Formation of *Bambusa emeiensis* from Lufeng, Yunnan
Photograph by Hui, Chaomao, 2005

Forests of *B. chungii* (Fig.4-5) are mostly pure and artificial. They have very straight culms that curve only at the top, with a height of 8~12m and a diameter of 4~7cm. Their stands are regular, structure simple, and undergrowth sparse, with *Melastomataceae*, and *Symplocos chinensis* as the most common accompanying species.

Fig. 4-5 Formation of *Bambusa* chungii from Guangzhou. Photo by Hui, Chaomao, 2002

B. chungii is a very productive species with an annual timber yield of 10~12t/ha up to 30~75t/ha from more wisely managed forests. The culm wall is thin, node flat and sparse, internode as long as 1m; it is good for skin use and provides excellent material for paper making.

4.3.6 Formations of Chimonobambusa spp.

In this genus 19 species are known to be widely planted in Southwest China, its natural distribution center. Very often it appears in mixed patches as a second layer in evergreen broad-leaved forests on mountain sides, though in some cases, it may also be pure. A case in point is Jinfoshan Natural Protection Area in Nanchuan County of Sichuan where it brings a high economic return under careful management. In Yunnan *Chimonobambusa* spp. are spread widely in the Laojun mountains of Wenshan prefecture at more than 1,800m above sea level. There, second to Rhododendron simsii in quantity, it helps to form the second layer in forests with a coverage of 30%~70%, an average height of 4.5m, a DBH of 1.6cm, and a culm density of about 50/m^2. (Fig.4-6)

Fig. 4-6 Formation of *Chimonobambusa utilis*
From Tongzi, Guizhou. Photo by Hui, Chaomao, 2002

***4.3.7 Formations of** Dendrocalamus membranaceus*

Large sized, clumping and tropical, this species of bamboo occurs on the northern edge of the tropical zone at low latitudes. In China it is mainly distributed in the lower reaches of Lancang River, concentrated especially in river valleys of moderate heat in Xishuangbanna, Simao, Lincang and Honghe at 550~800 (1,000) m above sea level. Geographically this area belongs to the tropical monsoon forest region in South Yunnan. *D. membranaceus* here forms vast groves of natural, pure or mixed forests (Fig. 4-7). Its normal climate for growing has an average yearly temperature of 19.8~21.5℃, with 1862~2153 hours of annual sunshine. Annual precipitation ranges from 1207~1533mm. The distinctive climatic features can be summed up as a long cool summer, a short warm winter, with ample rain, foggy and humid but with a clear delineation between the wet and dry seasons.

Fig. 4-7 Formation of *Dendrocalamus membranaceus*
from Xishuangbanna. Photo by Hui, Chaomao, 2006

D. membranaceus usually starts to sprout in the first 10 days of July and reaches the peak of its shooting in the second 10 days of August. The peak of its height growth does not come until September or early October, and ceases gradually toward the end of October. Average elongation is 0.18m per day, with a maximum of over 0.31m/d. Shoot output and rate of height growth are, of course, dependent on environmental conditions.

Though originating in tropical forests, *D. membranaceus* has acclimated in certain areas due to advantages of strong adaptability, easy propagation, and fast growth. Specific composition of the plants, therefore, is rather complex. The chief accompanying plants include 58 families, 132 genera, 165 species of spermatophyte; 6 families, 6 genera, 8 species of ferns; as well as many species of moss. 90% of the accompanying floral elements are tropical. The most common are **Euphorbiaceae** (10 species in 10 genera), **Gramineae** (10 species in 10 genera), **Fabaceae** (16 species in 11 genera), **Orchidaceae** (5 species in 5 genera), and various giant trees representative of tropical and monsoon rain forest.

The *D. membranaceus* assembly displays a clear stratification as all layers help to create a well-proportioned array. In general this stratification is divided into arbor layer I, arbor layer II, shrub layer and grass layer, with a certain amount of interlayer plants dotted in between. Constituents of the uppermost layer are mostly representatives of tropical forests, such as *Daubanga grantiflora* (**Sonneratiaceae**), *Spondias pinnata* (**Anacardiaceae**), *Protium serratum* (**Oleaceae**), *Stereospermum terragonum* (**Bignoiaceae**), *Knema furfuracea* (**Myristicaceae**), *Rhamnoneurea balanse* (**Thymelaeaceae**), and *Dalbergia assamica* (**Fabaceae**). Dense and regular in the middle-upper layer, *D. membranaceus* has an average height of 11~18m and an average diameter of 13.8cm. The next layer is composed of bushes, shrubs, and young trees. The most common plants of the grass layer are grasses and ferns, and sometimes *Microstegium ciliatum* dominates with coverage of over 80%. Constituents of the grass layer are complicated in general, but species in a community are not many. This is caused by shading from the bamboo canopy (Fig. 4-8).

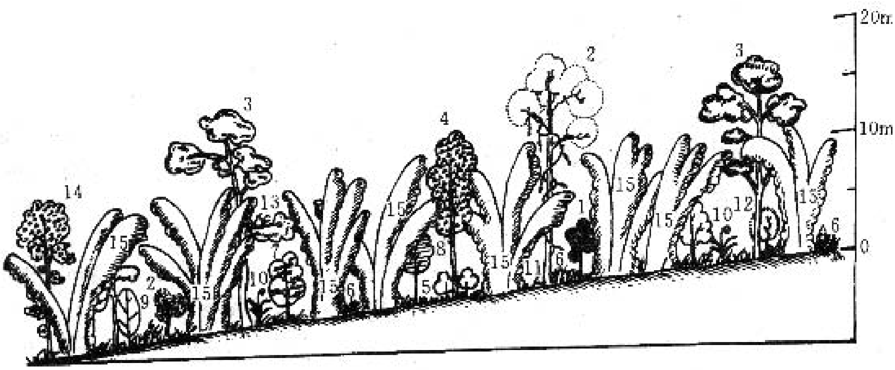

Fig. 4-8 Composition of a natural *D. membranaceus* community
1. Bauhinia variegata; 2. Dalbergia assamica; 3. Stereospermum terragonum; 4. Spondias pinnate; 5. Ardisia solanacea 6. *Microstegium ciliatum*; 7.Deospermum gracilentum; 8. Aporusa villosa; 9. *Mallotus philipinensis*; 10. Cyclosorus molliusalus; 11. Milletlia spp.; 12. Dendrobium spp; 13. Toone sureni; 14. Toona ciliata; 15. *Dendrocalamus membranaceus*

In normal cases, there are 300~500 clumps of *D. membranaceus* per hectare, and 8~15 culms in each clump with a maximum of more than 200 culms. The average clump diameter is 2.2m, and crown diameter 3.5~10m. In a stand the first, second, and third year culms are in a ratio of 12.7% to 17.3% to 69.8%. Research shows that the most stable communities at present are bamboo/tree mixtures with bamboo dominant.

4.3.8 *Formations of* Schizostachyum funghomii

As one of the most tropical, treelike and large-sized species, *S. funghomii* is mainly distributed in South China and North Vietnam. Its center of distribution is in Southeast Yunnan and some parts of Guangdong and Guangxi. Particularly in South and Southeast Yunnan in the tropical and subtropical regions, it makes up large areas of natural forests. The bamboo forest around Mount Dawei in Hekou alone covers an area of 4,280ha and houses a total stocking of 154.3×10^4 tonnes which yields an annual output of 24t/ha. With a tropical monsoon climate, this distribution area enjoys abundant heat and rain. In Hekou County the average yearly temperature is 22.6 ºC, annual precipitation almost 1,800mm, with a relative humidity of around 85%. *S. funghomii* is often found on both sides of ravines. (Fig. 4-9)

Although successive shoot occurrence is seen in the stand from March to September each year, the peak of shooting falls in the period between July and August when rain is abundant and accounts for more than 70% of the yearly total. Growth in height of young culms lasts 3~4 months in general, with the average being 103 days. Daily increase of height is approximately 12 cm/day with a maximum observed of almost 25cm during the peak (Yang, Yu-Ming 1990).

Fig. 4-9 Formation of *Schizostachyum funghomii* from Hekou, Yunnan. Photo by Hui, Chaomao, 2002

Located in the transitional zone of tropical rain forests and subtropical monsoon evergreen broad-leaved forests, *S. funghomii* grows in various habitats where lush growth of different types of vegetation occurs. The accompanying floral elements are particularly complex and exceedingly plentiful. Research indicates that there are 26 species of ferns and accompanying spermatophytes with the total amounting to over 300 species representing 232 genera in 100 families. Of these elements over 90% are tropical and seen mostly in tropical rain forests. Some species of trees are indicative of Yunnan's tropical rain forests. *These include Dipterocarpus retusus, Hopea mollissima, H. jianshu, Pometia tomentosa, Crypternia paniculata, Knema gtobuloria, Xanthophyllum siamensis, Gironniera subaepualis,* and *Canarium albuim*.

Based on the specific composition, i.e. spermatophytes/community structure/ecological appearance: *S. funghomii* forests are divided into different communities: *Aglaonema pierreanum–Pandanus furcatus/ S. funghomii; Phrynium capitatum–Gironniera/S. funghomii, and Microstegium ciliatum/S. funghomii*. (see Fig.4-12)

S. funghomii has a normal culm height of 15~20m, a DBH of 7~10cm, and a canopy density of 80~90%. With a clear demarcation line and a uniform size, each stand has 40~50 culms. There are over 200 clumps in each hectare, which amounts to a stocking rate of 8,000~12,000 culms/ha. Density of a stand has much to do with culm diameter and height.

4.3.9 Formations of Indosasa sinica

With geographic distribution similar to, yet higher than *S. funghomii*, *I. sinica* occurs generally between 400~1,000m above sea level. In large natural forests, this formation covers an area of over 8,580 hectares around Mount Dawei in Hekou alone. Sprouting in spring, young culms of this species usually experience a growing period of 80~100d, with the average being 93d. Young shoots enter their growth peak 20d after they emerge, with a maximum daily increase of 20~30cm. Again tropical, this formation has an accompanying 338 species of flowering plants belonging to 252 genera in 112 families, in addition to 14 species of ferns (Fig. 4-10).

Fig. 4-10 Formation of Indosasa sinica
from Pingbian, Yunnan. Photo by Yang, Yuming, 1987

With rhizomes of the running type, *I. sinica* has the characteristics of even distribution, straight culms, erect tops, typical stand, and clear stratification. Above the dense bamboo crown spreads a 20m tall open canopy of giant trees, which is mostly made up of the usual species found in the local mountain rainforests. *I. sinica* is the major layer with culm heights of 8~10m, The stocking rate is 5,000~7,000culms/ha. The average total culm weight can be from 120~140t/ha. Undergrowth layers are typically composed of shrubs, bushes, and herbs. *I. sinica* has a very high utilization value.

4.3.10 Formations of *Cephalostachyum pergracile*

This formation is distributed in India, Burma, Thailand, Laos and Southwest China. In China it is mainly distributed over Xishuangbanna, Simao, and Dehong of Yunnan province, in either natural or cultivated forms. Because its young internodes are used by the natives to cook rice to which it gives fragrant smells, this bamboo is also called "rice fragrant bamboo" (Yang, Yu-Ming 1989) (Fig. 4-11).

Extensive natural forests of *C. pergracile* grow luxuriantly along the banks of the Lancang River in South Yunnan, and in Mengyang and Little Olive Flatland of Simao County. And it is distributed in low altitude mountainous areas at about 550~950m above sea level. It is found mixed with *D. membranaceus* in mountain rain forests. It grows fairly well in mountain valleys or on ridges. The distribution range has an average yearly temperature of 21.7℃, and an annual rainfall of over 1200mm distributed among the nearly 200 rainy days experienced each year. Normally there are a little over 2000 hours of sunlight each year, and the relative humidity is just over 80%. The wet season is from May to October, and the dry season begins in November through the following April. Radiation fog is formed in winter and spring and helps to relieve any stress on the bamboo from lack of soil moisture. Suitable soils for *C. pergracile* are usually red and thick.

According to a survey from the sample site in Mengyang Protection Area, *C. pergracile* has an average diameter of almost 3cm (and a maximum of just over 7.5cm), an average basal diameter of 5cm, and an average height just under 12m. In each hectare there are 3400 standing culms in some 500 clumps, with an average clump diameter of about 1m and a crown diameter of about 3m, and a leaf area index of 1.52.

Fig. 4-11 Formation of *Cephalostachyum pergracile* from Xishuangbanna, Yunnan. Photo by Hui, Chaomao, 2006

This bamboo forest is made up of clumps, and the tree species that accompany it may include *Lithocarpus* sp., *Mallotus philipinensis*, and Dendrobium sp. Its undergrowth consists of *Lygodium salicifolium* and other herbaceous plants of the grass family such as *Microstegium ciliatum* and so on. It may also occasionally be found with *Dendrocalamus membranaceus*. Sometimes it may become broken, lodged or fall completely, resulting from gnawing and destruction done by wild elephants and bamboo rats. The years 1985~1986 witnessed *C. pergracile* in sporadic flowering.

In Xishuangbanna harvest of this bamboo is second only to *D. membranaceus*. It is widely used in paper making, in people's daily lives, also as an ornament. It should be protected and managed in a scientific manner so as to continue to be able to meet these demands.

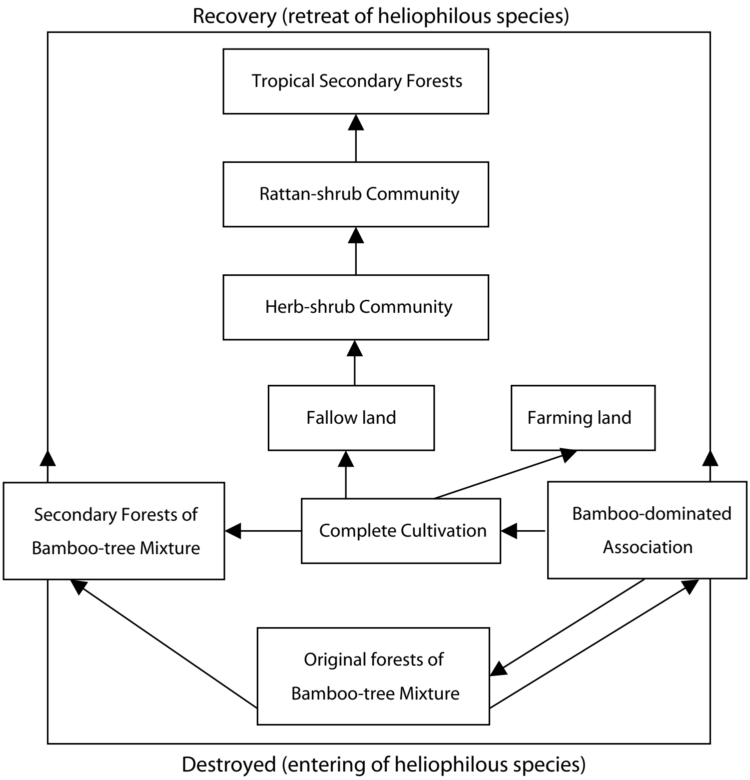

Fig. 4-12 Evolution of community structure of *Schizostachyum funghomii* (Yang, Yu-Ming 1990)

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CHAPTER 5

TECHNIQUES FOR BAMBOO CULTIVATION

5.1 Biological Characteristics

5.1.1 Bamboo Habitats

Bamboos, being strongly adaptive are found distributed in valleys, plains, hills, and mountainous areas. In fact they are able to grow in almost any soil except for deserts, heavy saline-alkali soil and water logged or swampy soil. Most species prefer a warm humid climate and deep fertile soil.

But different species require different living environments. We can use *Phyllostachys edulis* as an example. Although it is cold-resistant to some degree, its most appropriate environment is in a warm humid climate. Its distribution area is characterized by warm rain and high humidity, especially in spring. Average yearly temperature 17~18℃, frost period from the middle of December to the beginning of March, annual precipitation of about 1,555mm evenly distributed, relative humidity 75%~83%, vague distinction between wet and dry seasons. Predominantly purple and developed on the sand-shale rock of the Middle Jurassic Epoch, its preferred soil is thick, and moist with good crumb structure. It contains considerable organic matter and has a pH of 5.0~6.0. *P. edulis* is chiefly distributed in the provinces in the middle and lower reaches of the Changjiang River, in South China, and in Southwest China alike.

As a tropical species, *Dendrocalamus membranaceus* needs a suitable climate with an average yearly temperature of 19~22℃, annual sunshine of 1,800~2,200 hours, and an annual precipitation of 1,200~2,000mm. Its distinctive climatic requirements can be summed up as; a long and cool summer, short and warm winter, mutual alternation of fall and spring, ample rain, muggy and foggy with a clear distinction between wet and dry seasons. Suitable soils include brick red and crimson soil that is active in biological concentration. On the soil cross section leaching of silica and concentration of aluminum and iron are conspicuous, clay silica-aluminum ratio is 1.5~1.9, free iron oxide accounts for 80~85% of total iron. Heat and light loving and not shade-tolerant, *D. membranaceus* may be distributed on each side of a mountain with strong adaptability to harsh conditions. For these reasons, it is mainly distributed in the tropical zone at low altitudes in South China, i.e. about 500~1,000m above sea level in South Yunnan.

Species of *Fargesia* are found mostly in cool temperate zones, growing generally in mountainous areas at 2,000~3,800m above sea level. Here summer is short and winter is foggy and damp with accumulated snow. Concentrated distribution of this bamboo species is consistent with the similiar needs of coniferous forests in climate and soil, i.e. characteristic of sub-alpine climates.

There are other species that are very adaptable, such as *Bambusa emeiensis*. Being cold and drought resistant and fond of cool humid climates, this species grows best in slightly shady and damp places although it is capable of normal growth in some apparently dry places or arid soil. In general, any place is suitable to *B. emeiensis* so long as the average temperature is between 12~18℃, and absolute low temperatures never go below -7℃, annual precipitation no less than 750mm, and average humidity between 76%~80%. It is not particular about soil although it grows best in places where the soil is thick, porous, fertile, well drained, and wind-sheltered. That is why *B. emeiensis* is appropriate for planting around villages, on river banks, or on gentle slopes at the foot of mountains. Due to these habitat preferences, *B. emeiensis* has become the most widely cultivated species in subtropical areas of Southwest China. With northern distribution bordering the south side of Mount Qinling in Shaanxi. It also grows in Hunan, West Hubei, and North Guangxi. In Sichuan and Guizhou it is mainly scattered around villages lower than 1,000m above sea level while in Yunnan where its distribution is apparently higher where it is concentrated on flatlands at 1,600~2,000m above sea level.

Bamboos may be characterized by growth requirements into several types; i.e. the cold temperate, the warm temperate, and the thermophilic, or heat loving, according to differences in habitat characteristics. In distribution they are divided into five zones; namely, Scattered Bamboo Zone in the North, Mingled Bamboo Zone to the South Bank of the Changjiang River, Alpine Bamboo Zone in Southwest China, Clumping Bamboo Zone in South China and Climbing Bamboo Zone in Yunnan and Hainan. Used together, these two methods for classification are useful referents for the introduction of bamboo species.

5.1.2 Growth Habit

A. Growth Habit of Scattered or Running Bamboos

Although numerous in species, scattered bamboos share one cardinal feature, i.e. they enlarge their growing area by extending their rhizomes horizontally underground. And in growing they stick to the same pattern of development in rhizome and culm, with the latter further divided into such stages as shoot growth, culm growth, timber growth, and stand growth (Zhou, Fang-Chun 1998).

• Growth of Rhizome

Buried in the upper layer of soil, rhizomes of running bamboos exhibit wavy or serpentine horizontal growth. Those of *Phyllostachys edulis* are generally found at 15~40cm deep although they may occasionally come above the surface or dive to 1m deep. For medium and small sized species of running bamboos, the rhizomes are comparatively shallow, only 10~25cm deep. In fertile soil they tend to go deeper while in meager soil they are distributed nearer the surface.

The rhizome parts of running bamboos are neck, body, and tip. Together they are called rhizome segments and are formed through the extension of the rhizome tip. Growth activity of the rhizome tip occurs over much of the year, alternating with sprouting. Some species, e.g. *P. edulis*, present a sharp difference between on and off years. In an on year it produces a large amount of shoots yet adds very little increment to growth of the rhizome tip while in an off year, it is the other way round. When new culms start to develop branches and leaves, the rhizome tip starts its growing activity. This activity is most vigorous in late summer tapering off in early winter. Frequently, the tip rots in the winter soil, but new buds from the side become the new tip in the following year. In spring the stand changes leaves and enters the on year when new rhizomes grow out of the lateral buds and resume their growth activity. The peak of rhizome growth comes in May and June, and ceases again in August or September when the stand initiates shoots in large quantities for the following spring. Species that do not have clear on and off years produce shoots and new culms in spring and grow rhizomes and roots in fall.

Regardless of different bamboo types, the very end of the rhizome tip is enclosed with a hard sheath and is called the rhizome shoot. Being tapering and piercing, its branching growth makes possible the crisscross extension of rhizomes underground. After activation of lateral buds on the rhizome, their apical meristems, through differentiation, produce full lateral buds, rhizome sheaths, protoplasts of rhizome roots, and intercalary meristems. At the initial stage of rhizome formation, due to little activity of cells in the meristems, small and contracted rhizome necks are formed without buds or roots that function as connectors of mother and daughter rhizomes. In most cases, the intercalary meristems in each internode undergo division at the same pace to advance the rhizome tip by elongating internodes and adding suitable increments to the diameter.

In the course of growing rhizomes in running bamboos, apical dominance of the tip is usually strong enough to check the growth of lateral buds. The nearby lateral buds, however, will automatically activate and differentiate into new branching rhizomes known as crotches or lateral rhizomes if the tip breaks when butted against firm things, or rots when growing into water-logged areas, or gets injured after coming out, or when withered back in winter. These crotches fall into three types, i.e., unilateral single crotch, bilateral single crotch, and bilateral multiple crotch. The rhizome tip produces horizontal growth underground, but sometimes it comes out above ground and goes back immediately into the earth because of sunshine, so that an arch called a jumping rhizome or toe loop is formed. But if the rhizome keeps growing to form a culm after it comes out, a mal-developed rhizome culm known as a "whip" is formed. As the underground system of running bamboos, these rhizomes, rhizome roots, root balls, and new roots cross in the upper layer of soil forming the underground rhizome mass of a bamboo stand.

• Growth of Culm

Growth of Shoot

Initiation of shoots usually occurs in the middle part of the rhizome segment. The longer the segment is, the sturdier the buds are and more of them will become strong shoots. Also, a long segment tends to be thick, well rooted, and rich in stored nutrients. Thick rhizomes produce large shoots which in turn grow into huge culms so that the adult culms are of a high quality. Shoot growth underground slows in cool weather but can continue through the winter from late summer to early the next spring. In late summer or early fall lateral buds on the rhizomes of *Phyllostachys edulis* begin to activate and differentiate into shoot buds. Then apical meristems on the shoot buds further differentiate, through reproductive division of cells, into internodes, septums, shoot sheaths, and intercalary meristems, etc. They consequently expand and elongate at an angle of 20~50º with the rhizome, while the shoot tip turns upward. Early in winter when shoots swell and sheaths turn yellowish and tomentose, they are called winter shoots. In winter as temperatures drop, shoots become dormant, they resume growing as spring shoots when temperatures rise (Fig. 5-1).

The sprouting time of running bamboos varies from species to species and also somewhat due to site conditions though it generally falls in the period from March to June. Sprouting duration commonly lasts for 20~30d, or even shorter for certain species of medium and small-sized bamboos. At the initial stage only a small number of shoots emerge, very few of these are undersized due to the abundance of nutrients. Most shoots are robust and fat and emerge at the prime time to form adult culms of superior quality. Shoots emerging at the final stage, however, are weak and thin with a high rate of smaller ones since nutrients are now in short supply. As a result, they can only grow to be culms of lesser quality. In management, therefore, we should preserve as many of the shoots as possible which sprout at the initial and prime stages and dig up any small shoots from the final stage.

Sprouting of shoots has much to do with both air and soil temperatures as well as, moisture and depth of rhizome in soil. The general rule is that it is earlier in the South than in the North, and earlier on a south facing slope than on a north facing slope (These observations refer to the northern hemisphere and should be reversed for the southern hemisphere.). Also shooting begins earlier at the edge of a stand than in the interior due to soil temperature differences. In a stand with ample moisture shoots emerge early and in large quantities, but in a stand on arid soil that is continually dry, shoots emerge slowly and sparsely. Moreover, rhizome shoots in shallow soil emerge and grow quickly while deep shoots need to grow for a long time underground before they reach the surface.

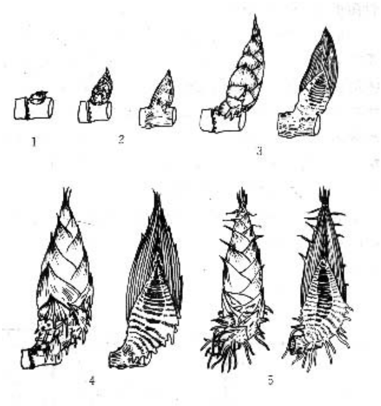

Fig. 5-1 Growth of *Phyllostachys edulis*
1. Latent lateral bud on rhizome;
2. Activated bud & its profile;
3. Newly formed shoot & its profile;
4. Unearthed winter shoot & profile;
5. Newly buried spring shoot & its profile.
(from Zhou, Fangchun, 1998)

Growth of Culm

Before the shoot comes out of the ground, the number of nodes is established and will not increase subsequently. It is the division activity of intercalary meristems that elongates the internodes to form a young culm. Growth of a culm goes through four stages; namely, the initiating stage, the rising stage, the prime stage, and the final stage. As a continuation of underground shoot extension, culm growth at the initial stage is very slow with a daily increment of only 1~2cm per day. When the shoot tip first appears, the transverse dilation is evident and length increment of internodes obscure. When the rising stage comes, internodes underground have already ceased their elongation and become the basal part of the culm. At this time roots are increased, the root system gradually takes form, and shoot growth has been shifted from the underground part to the aerial part and growth pace is quickened with a daily increase of 10~20cm. When the prime stage arrives, growth in height becomes fast and steady, and the shoot may increase by over 1m each day and night (with most growth occurring at night). In the meantime, basal sheaths start to fall off sequentially, branches begin to stretch out, also sequentially, height growth slows as the shoot gradually transforms into a young culm. At the final stage the tip of the young culm bends over, branches extend rapidly, growth in height dramatically ceases. Finally when all the culm sheaths have fallen off, branches are done, and leaves have uncoiled, a new culm has come into being.

Different species and habitats will have different timing for shoots to emerge and grow into new culms. Early shoots of *P. edulis*, for example, need approximately two months while final shoots one and a half months. Other species of middle and small sized bamboos may require a period of as little as 25 days or so. All nutrients used in the course from shoot to culm are supplied by the rhizomes, mother culms and root system. When the nutrient supply is sufficient, large shoots flourish and the number of undersized culms is low. But in a stand with poor site conditions and poor management, most shoots may wither and die for want of nutrients. It is a common phenomenon that some of the shoots wither and die, regardless of the state of nutrition, especially those of the second flush. Natural factors, such as insufficient nutrient supply, weather change, and insect damage can aggravate the phenomenon of shoot abortion. In bamboo cultivation, therefore, measures must be taken to provide abundant nutritive materials for producing and nursing new shoots, to prevent shoots from aborting, and to assure that shoots grow into healthy young culms. This means we have to preserve enough strong mother culms, intensify the work of nursing, improve soil conditions, and enhance the ability of the stand for photosynthesis and the accumulation of nutrients.

Growth of Timber

For bamboo, the diameter of the future culm is fully established when activation and partial elongation of the new shoot are underway. No changes take place in culm height, diameter, or volume after the initial growth period. But much is still to be accomplished later since tissues of the culm are still tender with a high water content and little dry matter. According to research, the dry matter of a young *P. edulis* culm amounts to only 40% of that of an aged, mature culm. If nothing is done in management, quality of timber and further development of the stand will be negatively affected.

Based on changes of a mature culm in physiological activities and physiochemical properties, timber growing of a culm can be divided into three stages. The first is young-mature stage when quality of timber is being improved. Deriving from mature rhizomes, young culms at this time are full of vitality. With increase in age, development of the root system and renewal of leaves, the culm body is rich in chlorophyll, sugars, and nutritive elements; the stand is at the peak of its metabolism and shoot sprouting. Gradually cell walls of the culm thicken, inner content is replenished, water content is reduced, dry matter increases, and both the strength and the density of timber is accordingly augmented. In the second stage or middle age, bamboo timber is in stabilization. The plant has entered a period nutritionally abundant and physiologically active, and the growth of timber has reached its maturity. The third stage is bamboo's old age when the quality of timber is declining. After middle age, the vitality of a bamboo culm is reduced. Due to consumption of respiration and transfer of substance, the culm is decreasing in weight, mechanical properties, and nutritive substances. Older culms cease to make significant contributions to the colony and their timber quality is greatly reduced so they should be removed, usually in their fifth year standing for temperate bamboos, third year for tropicals. With aging of the culm, content of water and other substances such as N, P_2O_3, K_2O_3, and total sugars are all on the decline.

• Growth of a Bamboo Stand

The bamboo stand is a special ecosystem that is united underground by rhizomes, though aboveground individual culms stand apart. They are all interconnected: the culm with a rhizome, the rhizome with a shoot, the shoot with a new culm, and the new culm with still another new rhizome. Mutually affected, they annually increase and form a self-regulating system for the stand with support from physiological activities such as photosynthesis, accumulation, allocation and consumption of organic and mineral nutrients. For running bamboos, these are characteristics of individual shoot or culm propagation as well as laws of formation, development and renewal of the stand.

Based on growth characteristics, bamboo stands are divided into even year stands that shoot every year and on-off year stands that shoot every other year. For a typical on-off year stand, substantial shoots and culms are produced in the on-year. Leaves are deep green, photosynthesis is vigorous, and both the underground system and the aerial parts have adequate nutrients in storage for the consumption of growing shoots and young culms. In its off-year the stand mainly changes leaves and grows rhizomes, its photosynthesis and metabolism tend to go down, and the new leaves become deep green again after a period of restoration. Growth of the rhizome tip is slow at the outset, quickening in the later period, and pushed to its peak in fall. This covers a large span of time that lasts till the end of December when leaves grow old and yellow. On the rhizome only a few of the lateral buds activate into crotches while the vast majority are dormant with very few new shoots produced. This continues till the next spring when old leaves are replaced by new uncoiling ones, and then the stand comes into another on-year. Leaf color changes now from pale to deep green, photosynthesis and assimilation are considerably reinforced, and the rhizome tip activates early thanks to the accumulation of nutrients in the off-year. At first the rhizome tip extends quickly, but it becomes slower and ceases in late summer or early fall because of enormous shoot formation. One-year old culms of *P. edulis* have to go through a leaf color transition of "twice-yellow and once-green" before their leaves give way to new ones in the following spring. Culms older than one year, however, have to experience a color transition of "thrice-yellow and twice-green" before they change leaves every other year.

Stands of medium and small-sized bamboos are mostly of the even-year type. Every year they produce shoots, culms, leaves, and rhizomes. Many undergo a color transition of "twice-yellow and once-green", and their yearly differences in volume of shooting, stocking rate, and rhizome producing are not so pronounced.

B. Growth Habit of Clumping Bamboos

As far as clumping bamboos are concerned, their subterranean stems are sympodial and their culms are composed of rhizome neck, culm base, and culm pole. No traverse rhizomes are found underground, the new culm is connected with the mother culm via a thin, contracted, and rootless rhizome neck that is usually made up of some 10 nodes. The culm base is short and thin with both buds and roots on it. Numerous large-sized buds, which can activate into new shoots, grow on the bilateral cross sections. Culm base, culm neck, and roots of a culm are collectively known as its rootball. Different rootballs that relate to each other through bonds of material energies form the underground system of clumping bamboos. Numerous hair or feeder roots are distributed in the upper layer of soil 40~60cm deep, but none in soil deeper than 120cm.

A large-sized bud grows alternately at each node on the basal part of the mother culm. The lowest one is called "first-eye", and the others upward are sequentially called "second-eye", "third-eye", and so on. The number of bud eyes differs from species to species. For instance, *Dendrocalamus latiflorus*, *Bambusa emeiensis*, and *B. sinospinosa* generally have 5~10 eyes while small clumping bamboos such as *B. multiplex* commonly have 2~6. Shoots arising from these bud eyes are correspondingly called "first-eye" shoot, "second-eye" shoot, and so forth.

Size and growing power of the bud eyes have a lot to do with their growing position. Being full and vigorous, those in the middle and lower parts of the culm base activate early and in a large quantity, their shoots are fat, and their subsequent adult culms are of good quality. Buds on the upper part, especially those exposed aboveground, are few, small, and weak, and begin growth late, if at all. Each year only 3~5 of the bud eyes on the culm neck of the mother culm are able to grow into new bamboo culms. The rest are called false eyes because they either do not grow at all or die for want of nutrients. On a culm base three or four-years old, the eyes have totally lost the power to grow. There are occasions when early young culms shoot in fall of the year. These are known as "second-rate shoots" or "secondary shoots", but they mostly die for want of nutrients.

Large sized buds on the culm base start their elongation in late summer or early fall depending on species and growing conditions. They first grow down, then a short distance horizontally followed by growing upward to become new bamboo culms. As an example, the culm neck of *Bambusa emeiensis* slants at an angle of 10~20°toward the earth center so that an angle of 60~80°is formed between base shaft of the new culm and that of the old culm. The shoot tip then turns toward the surface and grow into a bamboo culm. Usually the culm neck produces so short an extension that culms come up rather close to the parent culms. In some other species, i.e. those with long pseudo-rhizome necks, this is not the case.

Clumping bamboos in general shoot in the period from July to August. *B. emeiensis* and *Dendrocalamus membranaceus*, for example, grow shoots in July and August, while B. intermedia does so from July to September. *Schizostachyum funghomii*, nevertheless, shoots twice; from March to April and again from August to September with the second shooting being the major one. Looking at *D. membranaceus* again as an example, it begins with a few shoots in early July, initiated first in a shady and damp environment. But these seldom grow into adult culms due to poor growth. Most of them die on emergence or at a height of 2~5cm while some are encircled by ant mounds. The time between early and middle August is the shooting peak when shoots produced tend to have normal growth. Toward the end of August few shoots are produced as the shooting period is nearly finished. As for growth in height (GH) of the shoot, the peak falls from September to early October, gradually ceasing by the end of the month. Rate of GH displays certain rhythms in the whole process. When the shoot is shorter than 50~100cm, GH increases very slowly at a rate of 0.04m/d accounting for only 0.3% of the total assumed height of 15m. After this the growth speeds up until it slows again near full height. Average daily increment at this time is 0.31m/d, about 2.0% of the total height and the maximum reached is 0.50m/d. When approaching full height, growth slows with an average increment of only 0. 02m/day, or only 0.2% of the total height. The basal diameter of the shoot may reach its maximum 20~ 30d after emerging, and DBH is also definite 3~5d after breast height is gained. When the shoot is 1~2m tall, culm sheaths at the base start to fall off and as the culm sheaths fall off, branches subsequently begin to elongate, and the leafing period soon follows.

The growth process of *B. emeiensis*, in terms of time, parts, and features, can be divided into the following stages (Xiang, Xing-Ming 1983). Bud eyes on the subterranean stem of *B. emeiensis* (rootball) differentiate in March or April, activate in May, begin to elongate from the end of June to the middle of July, and emerge during the second 10 days of July. In the initial stage the shoot is only 19cm tall by August 10, with a daily increment of no more than 1cm. By August 25 it enters the rising stage with a height of 87cm and a daily GH of 5~12cm. The peak comes by October 10 when it is 790cm tall with a daily average GH of over 10cm. The rate of GH slows down afterwards. With an average daily increment of only 2cm GH continues till October 31 when in the final stage it ceases. Growing through a whole process in 108d, the shoot has now grown to a height of 833cm. The current new culm remains basically branchless and leafless until the over wintering period from November to the end of February. Then its culm buds germinate into branches and leaves. Leaves start differentiating in the first 10 days of March, and by early April needle like young leaves are visible. Branches grow on the young culm from top to bottom before leaves uncoil, and this growth of branches and leaves keeps on until the middle of June. Now the culm undergoes no more apparent changes in its height, diameter or volume, but as yet the tissues are still tender. Shooting capacity is powerful, culm tissues substantial, culm weight increased, chemical constituents of timber similar, one-year or two-year culms are now in their young-aged phase. In their middle-aged phase, three-year culms make few shoots, four-year culms hardly any or none. Culms over four years become dry and yellow, their branches and leaves decrease in number, their root system becomes thin, and their physical activities decline. When dry culms appear, growth of *B. emeiensis* is waning into its old-age phase.

Shoot sprouting of *B. emeiensis* also presents certain regularities, and regular investigations reveal the following results (Xiang, Xing-Ming 1983) (Tab. 5-1).

Tab. 5-1 Relations Between Shooting, Standing, Reducing and New Culm Yield

Item \ Unit \ Emerging Time		July 20	July 31	Aug. 10	Aug. 20	Aug. 31	Sep. 10	After Sep. 20	Total	Note
Shooting number	Ps	4	7	38	65	56	16	10	196	Ps-pieces
Shooting percentage	%	6		81		13			100	
Standing number	Ps	3	1	24	47	27	12	0	114	Total No. 389ps
Standing percentage	%	48		62		37				
Reducing number	Ps	1	6	14	18	29	4	10	82	Ps-pieces
Reducing percentage	%	52		38		54				
New culm yield	Kg	5.44	1.53	51.02	91.74	54.10	17.12	0	220.95	new culm × its weight various diameter classes
% of total weight	%	4		89		7			100	
Start-stop		Initial		Prime		Final				
Days in each stage	d	16		30		20			66	

Affected by various natural factors, shooting volumes of clumping bamboos on shaded, lower slopes, or in valleys are commonly greater than those on sunny or upper slopes. The case is true with GH of the shoot. In shoot growth, obstruction or even death can be caused by surrounding rocks, old rootballs, or damage from insects and disease. Temperature, humidity and precipitation are also important factors that influence growth of all bamboos. During the shooting season, it is hot and dry in the day when it is sunny. This intensifies transpiration of bamboos and site evaporation and decreases water facilitated expansion of the shoot. It influences merisis of the intercalary meristems, and in the end affects the GH of the shoot. When the temperature drops and humidity rises at night, growth volume of the shoot culm is often 20%~40% higher than in the day.

For clumping bamboos that have shortened rhizome necks, crowded culm bases, and dense culms, these factors impose some restriction on absorption, synthesis, and storage of nutrients. In the growth process from activation of the rhizome bud to formation of the new culm, all nutrients consumed are supplied by the connected mother culm. The more shoots that are produced, the more difficult to supply all needed nutrients. A mother culm may initiate numerous shoots, but only 1 or 2 of them can be expected to grow into high-quality culms while the rest die or are stunted due to shortage of nutrients.

In an ordinary stand, new culms of one-year old are still in their young-aged phase. They will not change in diameter, thickness or volume, but their internal tissues are still tender with a high water content, and little dry matter, branches, leaves, and roots are not yet fully developed. With increase in bamboo age, assimilation organs and absorption system are completed, physical metabolism becomes active, and organic substances are gradually accumulated. Two-year old culms possess the greatest shooting power, the three-year olds are second, and the four-year olds hardly shoot at all. As tissues of the culm become more mature, water content is reduced, dry weight is increased, and the bamboo's physical properties are improved. When the stand enters its old age, withered or dead culms are present. The leaf volume diminishes, the root system grows thin, physiological activities decline, and timber quality is progressively diminished. So in a given stand, the more young and strong culms there are, the greater its shooting capacity tends to be and the higher the quality of its adult culms.

C. Growth Habit of Mixed or Amphipodial Bamboos

Morphology and growth of amphipodial bamboos share features of both running or monopodial and clumping or sympodial bamboos. On one hand it has an indeterminate or leptomorph rhizome underground and on the other hand determinant or pachymorph clumps grow from it. Morphological features and growth habit of the rhizome are basically the same with those of running bamboos, but its internodes are thinner and longer, its rhizome roots fewer, traverse sections are round, and the budding side is grooveless. Lateral buds on the rhizome can either grow into new rhizomes or shoot into culms. The rhizome tip grows fast in summer, and its yearly increase can be up to 3~4m in porous fertile soil. The tip becomes withered and broken off in winter when growth ceases but new rhizomes sprout from lateral buds nearby the next spring.

Internodes on the culm base of amphimorph bamboo are longer with fewer roots and a smaller flexuosity. 2~6 lateral bud eyes can either activate into rhizomes that expand horizontally in soil or differentiate into shoots that grow close to the mother culm in clusters. Using *Pseudosasa amabilis* in Guangdong for an example, the results obtained are as follows.

• Growth of Rhizome and Root

With both monopodial and sympodial, subterranean stems *P. amabilis* has buds on both the traverse rhizome and the culm base that may grow into either new culms or new rhizomes. The growth of subterranean stems demonstrates a sharp difference between on and off years. They produce shoots in on years but rhizomes in off years (commonly known as "moving dragon"). Buds near breaking off of the old rhizome tip start to initiate new rhizomes in the first 10 days of January, and rapid growth of new rhizomes is accomplished during a growth period of 90~110d. After this time, growth in length of the rhizome tip increases little or comes to a virtual standstill until after summer when fast growth occurs again in September and October. The growth gradually slows down in winter until the tip gets withered and broken off. Showing a strong dominance in traverse growth, these rhizomes are numerous and strong while rhizomes extending straight ahead are few and poor. Culms younger than three-years old have the strongest bud vitality, and those over four-years old have lost the power to initiate shoots.

Rhizome growth differs considerably under different site conditions and management. Commonly distributed in surface soil at about 20cm deep, distribution depth of the rhizomes is not increased with that of soil layers. Nevertheless, in valleys and lower parts of slopes where soil is thick, loose and fertile, rhizomes are shallow with thick stems, large nodes, and small fluctuation. On upper parts of slopes and mountain ridges where soil is thin, they are distributed deeper with thin stems, small nodes, and great fluctuation.

Root systems of *P. amabilis* are primarily of two types. The first type refers to the stratified radial root system born from root eyes on the culm base. Generally there are 7~11 whorls and only 2~3 nodes grow shoot buds or rhizome buds instead of root whorls. Composed of 30~40 roots 60cm long and 3~15cm deep, the whorl develops no secondary roots (fibrous roots) until GH of the shoot and young culm is completed. The second type is the radial root system produced on the true rhizome, with roots to 40cm long and 5~25cm deep. Secondary roots of this type occur in the middle and late stages of shoot and young culm growth.

• Growth of Shoot and Young Culm

a. Formation and Emergence of Shoot: In Huaiji District of Guangdong Province, it generally takes 90~110d from late December to early April for shoot buds on the rhizome of *P. amabilis* to activate, swell, and emerge out of the earth. Shooting occurs 7~10 days earlier on the edge than the inside of a stand and lasts a period of 20~25 days usually from late March to middle April.

b. Growth of Bamboo Shoot and Young Culm: Daily observation of emerged shoots was conducted both on the edge and inside of a *P. amabilis* stand. From the data obtained we came to the following two observations. First, in the young stand there is still some increase in the diameter at ground level (DG) at the early stage of GH. On the edge it takes the shoot 15~27days (average 20 days), to accomplish its growth process from emergence to full height. During this period an average increase of 1cm in DG with a minimum of 0.3cm and a maximum of 1.7cm is observed. Inside the stand cessation of DG increase takes place in a shorter time than that on the edge, covering a span of only about 10d. Nor is much increment added to DG inside the stand with an average of only 0.45cm, a minimum of 0.1cm, and a maximum of 0. 8cm. Secondly, on the edge it takes the shoot 28~47 days (over 40 days in most cases) to go through the process from emergence to termination of GH. Inside the stand, however, it takes only about 35 days.

After emergence, the shoot starts to elongate and push its basal internodes up one by one, in a rhythmic pattern of slow-fast-slow from the bottom upward. In terms of difference in growth rates, GH of the young culm can be divided into four stages: initial, rising, prime, and final.

During the initial stage of about 12~15 days, the shoot grows slowly with a daily increase of about 14cm. Shoot growth is quickened in the rising stage of about 5~7 days with a daily increment of

5~20cm. Growth peak comes in the prime stage of about 10~12 days with a daily increment of 11~15cm but it slows down in the final stage of 10d when the daily increment is reduced to less than 10~20cm. By most or all shoot sheaths have fallen off and new branches are starting to grow.

Leaf unfurling on the new culm takes place 40~50 days after emergence of the shoot while the mother culm changes leaves only once every other year. As a rule new leaves are produced on the mother culm but never around early April when shoots are sprouting, and it takes about 7~8 years for all old leaves on the branches to become dry and fall off.

c. Climate Conditions for Growth of Bamboo Shoots and Young Culms: Observations of *Pseudosasa amabilis* stands indicate that soil temperatures suitable for underground shoot growth is 16~18℃ (Table 5-2). In April when air and soil temperatures rise to over 20℃ and rainfall becomes plentiful, conditions are most suitable for shooting and the initial growth of young culms. When air and soil temperature reach 25℃ with abundant rainfall in May, young culm growth is at its peak. Later when the temperature is further increased, it is time for the growth of branches, leaves, and culm timber.

d. Influences from Mother Culm on Growth of Shoot and New Culm: Within a unit area, shoot sprouting and young culm growth are dependent on the status of the mother stands. On the one hand, the denser the mother stands are, the fewer shoots are sprouted; on the other hand, the shoots are of superior quality if the mother stands are growing well with a strong vitality and an ample storage of nutrients.

Tab. 5-2 Climate conditions for Shoot & Young Culm Growth of *P. amabilis*

Month		1	2	3	4	5	6
Air Temp. (℃, @ 1.5m in height)		13.5	16.8	18.8	22.2	26.2	27.5
Ground Level Temp. (℃,)		17.9	20.8	21.3	23.4	27.0	28.7
Soil Temp. (℃)	5cm in depth	16.2	18.7	18.9	21.7	25.9	27.4
	10cm in depth	16.8	17.2	18.4	20.8	25.1	26.3
	15cm in depth	16.4	17.9	18.0	21.1	24.7	25.5
Precipitation in mm		33.8	77.7	142.7	599.7	410.0	220.8

• Growth of Adult Culm and Timber

When pole growth of the young culm is completed, there are no further increases in its height, thickness, or volume. Growth of the culm has now entered the stage of lignification or becoming woody. Culms of one or two-years old are called young bamboos or son bamboos; their stems are dark green and covered with brown waxy stripes. Culms of three or four-years old are known as middle-aged bamboos or father bamboos. Those over five are old bamboos in gray brown, with stems densely covered with waxy stripes as well as forking and overhanging branches.

Bamboos of the stand are united as a whole underground and aboveground. But with increase in age, competition between plant individuals for nutrients and space brings the stand a clear differentiation. So in a stand of average site conditions and normal management, Bamboo grows in a pattern of normal distribution. Generally bamboos of moderate diameter (2~5cm) make up the majority and account for 75%~90%, small diameter (<1.9cm) for 6%~15% and large diameter (>5cm) for 4%~8%.

For *P. amabilis* under intelligent management, differences in site conditions cause certain influences on stand density, growth of height and thickness, and GH of the same diameter class as well (Table 5-3). It is seen from the table that culm height varies between different parts of the stand even though they are of the same diameter class. Meanwhile, cultural measures such as fertilizing can bring about an increase in height for different diameter classes.

Table 5-3 Impacts of Site Conditions on Mature culms of *P. amabilis*

No. of stands/ site	Direction of slope	Section of slope	Incline	Degree of Management	Stand Density (CL/ha)	Mean Height (m)	Mean Diameter (cm)	Mean Height of various diameter grades (m)							
								1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
15	SW	M.Top	39°	Rational Felling	28620	6.1	2.1	3.3	4.6	5.9	7.0	7.8	8.5		
16	SW	M.Side	31°	Rational Felling	23730	8.2	3.1	-	-	6.1	7.1	8.0	8.9	9.7	10.3
17	W	M.Foot	35°	Rational Felling	15930	10.5	4.0	-	-	6.1	7.2	8.4	9.5	10.5	11.4
27	E	M.Foot	39°	Unfertilized	15570	5.2	1.9	2.8	4.3	5.5	6.2	6.7	-	-	-
29	E	M.Foot	29°	Fertilized	9495	7.5	3.1	-	4.6	5.7	6.5	7.4	8.2	-	-

5.2 Reproductive Propagation

Reproductive propagation here refers to developing new individuals through seeds. The disadvantage of this approach is the fact that most bamboos are monocarpic and seldom flower and even when they do flower, most of their seeds fail to fully develop and only a few are fertile, frequently with weak viability. Most of the seeds lose their vitality after one or two months and most of the bamboos will also die upon flowering (this is especially true of the tropical clumping bamboos), as the vegetative growth of the adult bamboo is considerably weakened during the flowering period. Only a few bamboo species bear viable seeds. Of course, when such viable seeds are available, they can be collected and used for bamboo reproduction.

5.2.1 Flowering Phenomenon

Like most other plants, bamboos go through a series of stages i.e. budding, leafing, flowering, seed bearing etc., to complete their life cycle. Since bamboos have a fairly long intermast cycle between flowerings, ignorant people are usually puzzled and see flowering as a bad omen, though it is quite a normal phenomenon.

Abnormal phenomena often occur in the stand or clump before it flowers, such as little or no shooting, leaves drying and falling, increase of saccharides and a decrease of nitrogen in the culm body. Although flowering may occur in any of the seasons, older bamboos commonly do this in spring when they change leaves. To begin a rachilla grows instead of a normal new leaf at the tip of the branchlet, which gradually changes to a raceme or spike or panicle with flowers following in succession. Some bamboos may flower all at one time, have leaves all come off, and then die. Other plants may flower only at upper parts or on one side at the outset while lower parts or the other side still produces green leaves. Flowers and leaves may simultaneously flourish and new flower buds are successively nursed, so that the plants remain alive for two or three years. Without regard for age, new culms in the flowering stand or cluster may also flower and sometimes can't be stopped even by external impediments. In Vietnam for instance, wild elephants frequently wreck the clumps of flowering *Bambusa arundinacea* and browse their inflorescence, but soon after a rain subterranean stems of the clump send up leafless tender twigs with flowers. When *Cephalostachyum pergracile* was burned by bush fire in Myanmar, small culms 2~30cm tall were regerminated by the subterranean stems and they flowered simultaneously along with the undamaged large culms 10~13m tall.

Beginning sporadically, bamboo flowering takes place first in specific clusters or plants before becoming general and spreading throughout the whole bamboo forest causing a total death after the period of flowering and seed bearing. This is mainly because of the nature of bamboo community structure. In India for example, *Dendrocalamus* strictus has been observed to have gregarious flowering and death in large areas. *D. membranaceus* in South Yunnan has also flowered and borne seed communally. Sporadic flowering has been found in recent years. Accounts of bamboo flowering are also recorded in Chinese historical books. It is written in Five Businesses of the Song Chronicles, that "In August Zhenghe 4th year under Emperor Huizong's reign (1114 CE), bamboos in Jianzhou (Jian'ou in today's Fujian Province) bore seed equaling several thousand dan (1 dan = 2.75 UK bushels)."

In Southwest China, bamboo species such as *Bambusa emeiensis*, *D. giganteus*, and *D. membranaceus* are frequently seen in sporadic flowering. The period 1984~1986 saw overall or gregarious flowering of *Melocanna arrectus* in Nangun River Natural Preservation Area in Cangyuan County, South Yunnan. The fruit as big as walnuts with a diameter of 2~3cm hung heavily on the plants and brought the bamboo forest a good natural regeneration. *Chimonobambusa utilis* in Jinfo Natural Preservation Area in Nanchuan County, Sichuan had a complete flowering in the 30s and early 40s of the 20th century. The seeds were called "bamboo rice" by the folk. These bamboos could still be regenerated though a great quantity died. In the 1980s flowering and fruiting occurred again but in a more limited range.

5.2.2 Causes of Flowering

Research on bamboo flowering has been approached from different angles and various opinions have been expressed about causes of the phenomenon (Chen, Rong 1984).

Fig. 5-2 Flowering of *Dendrocalamus membranaceus* from Jinghong, Yunnan. Photograph by Hui, Chaomao, 1986

• Theory of Cycle

The cycle theory holds that the flowering of each bamboo species possesses its own periodicity not dependent on environmental influences. In 1907, for example, *Phyllostachys nigra* f. *henonis* flowered about the same time in West Zhejiang in China, in Japan, and in the Royal Botanical Gardens in London. Some scholars believe that since bamboos are primarily propagated by rhizomes, they are more or less consistent in flowering age no matter how far away they may have been taken. Japan introduced them from China, the original source country, while England acquired them from

Japan. That is why they were consistent in flowering age though they were separated by vast oceans. *Pleioblastus simonii* also simultaneously flowered in 1903 in Algeria, France, and the Isle of Wight where they had been introduced from China.

Bamboo species can vary greatly in the length of their flowering cycles; some may even flower every year but not die. Listed in Table 5-4 are some occasions of flowering recorded that have been documented.

Table 5-4 Flowering Intervals of Different Bamboo Species

Unit: year

Cycle (y)	Scientific Name of Bamboo Species	Chinese Name	Distribution
1	*Bambusa atra*	Lini Zhu	India
1	*Ochlandra stridula*	Aokelan Zhu	Sri Lanka
3	*Nastus elegantissimus*	Yiligan Zhu	Sri Lanka
7	*O. travancorica*	Zhuawang Zhu	Sri Lanka
15~17	*Thamnocalamus spathiflorus*	Xiao Zhu	Sri Lanka
30	*Dendrocalamus strictus*	Mu zhu	India
30	*D. hamiltonii*	Banna Tian zhu	Burma
32	*B. bambos*	Yindu ci zhu	Brazil
30	*Guadua trinii*	Guaduo zhu	Argentina
48	*Thyrsostachys oliveri*	Datiao zhu	SE Asia
40	*D. giganteus*	Nong zhu	SE Asia
40	*Melocanna baccifera*	Li zhu	India
40~50	*Phyllostachys nigra*	Zi zhu	China
50~60	*P. bambusoides*	Gui zhu	China
55~60	*B. polymorpha*	Huigan zhu	Myanmar
70~75	*Bashania fargesii*	Bashan zhu	Fuping, China
Sporadic	*Bambusa emeiensis*	Ci zhu	China
Sporadic	*Cephalostachyum pergracile*	Xiangnuo zhu	SE Asia

• Theory of Environment

As many cases of bamboo flowering have taken place during or following harsh environmental stress events, such as extreme heat and/or drought or even fire, many scholars believe that an arid environment may be the remote cause. In February 1912 when Orissa in India was hit by a serious drought, the local *Bambusa* bambos flowered gregariously and bore fruit as large as wheat grains. The famine-stricken folks picked them up for food and thus many lived through the drought. The year 1935 also witnessed a drought in Sichuan when Chimonocalamus spp. flowered gregariously on Mount Jinfo.

Based on flowering specimens, assorted records and documents, American scholars came to the following conclusions after they used timing comparisons to verify coincident cycles of flowering, drought, and maximum values of sunspots. Firstly, communal flowering in China has been occurring frequently since 1580 in drought periods or within two years after the drought. The years from 1942 to 1962 were humid and communal flowering was rarely seen. Secondly, since 1870 the 33-year drought cycle west of the Himalayas has coincided with the flowering cycle of the local bamboo. Overall flowering of 14 species took place 1~5 years after a drought, while bamboos east of the mountains flowered extensively 1~2 years after an extreme drought. Thirdly, flowering of many species east of the Himalayas clustered around the average cycles of 11 and 22 years when sunspots were in cyclic yang strength and weakness respectively. Fourthly, a 22-year cycle was clearly identified in observing the 6 major earthquakes occurring in Sichuan and Yunnan which constitute the main part of the West China Earthquake Zone. Earthquakes have some relationship with the minimum value of sunspots prior to the maximum at the Arctic regions, and with the drought years as well as flowering cycle of bamboos in the Changjiang Valley. Events of mass bamboo flowering are 33.9 times more likely when we compare the 5 years during each of which more than three earthquakes occurred with the other non multi-quake-producing years.

Fig. 5-4 Flowering of *Dendrocalamus latiflorus* from Kunming, Yunnan. Photograph by Xue, Jiarong, 2000

Fig. 5-5 Flowering of *Pleioblastus amarus* from Kunming, Yunnan. Photograph by Hui, Chaomao, 1998

• Theory of Nutrition

Many scholars maintain that bamboo flowering is related to the internal state of the bamboo's nutrition. Greatly subjected to environmental influences, development of a plant can be modified and quickened when environmental conditions are improved. But environmental conditions exert their influences only via internal changes in the plant instead of in a direct way, especially via changes of ratios between different nutritive substances in the body. When the content of internal saccharides is higher than those of nitrides and minerals (other than Phosphorus), the plant is subject to flowering because this particular chemical balance typifies that found when the plant is in reproductive growth mode. When in normal vegetative growth mode, however, possibilities of flowering are greatly decreased.

Bamboo flowering is closely involved with the processes of aging and death, and flowering may be followed by immediate death. The life process of the plant is a conflicted yet united alternating process of aging and rejuvenating cycles. The aging cycle of bamboos varies from species to species, and the rejuvenating cycle differs due to varied environmental factors. So the aging cycle may be deferred if rejuvenating conditions are improved and the rejuvenating cycle is accelerated or enhanced by good management.

5.2.3 Control of Flowering

Based on bamboo's growing rhythms and flowering features, relevant measures can be taken to suppress or defer bamboo flowering.

• Ancient Measures

It is recorded in **Tree Planting** by Yu, Zongben in the Ming dynasty that "Bamboos wither and die when they flower. The fruit is like barnyard millet and is called bamboo rice. Once a culm does this, the whole forest will do so eventually. The cure is: Choose one bigger culm and cut it off about three meters above the root. Open up the nodes and fill in with feces and then it works." The same method is also found in **Notes by Three Farmers** by Zhang, Zongfa in the Qing dynasty. "When they reach 60 (years) bamboos flower, they wither and die after. The fruit is like barnyard millet. Once a culm flowers, the connected garden will be all in bloom. Choose one bigger culm and cut it off about two or three meters above the root. Pour in human excrement and then it will be stopped."

• Modern Measures

In an unflowered bamboo forest, its cycle of aging and flowering can be deferred or suppressed if measures are taken to intensify nursing management, improve water and fertilizer conditions, prevent and control diseases and pests and promote vegetative growth so the bamboos continue to produce new rhizomes and shoots.

When individual plants start to flower in the forest, we should fell them immediately, dig out the old rhizomes and rootballs, rip the soil thoroughly, spread human urine or ammonium sulfate (20kg/mu) or urea (5~10kg/mu). This will improve things to some extent.

(Note: "Mu" is the most used unit of land area in Chinese agriculture. 1ha=15Mu.)

In a forest of running bamboo that flowers in stretches, we first have to do away with all flowering culms as well as their old rhizomes and rootballs. Then rip the areas, apply more high nitrogen fertilizer, spread the extirpated weeds on the ground and cover with earth so that regenerated rhizomes may extend into the areas of loose soil. Do the same with the unripped stretches in a couple of years, then rejuvenation and regeneration of the whole forest will be only a matter of 5 or 6 years. Small culms should be reserved in the flowering period so long as they don't flower, for they may serve as the basis for a new generation. Experiments prove that in a communally flowering forest of *Pleioblastus amarus*, the combined approach of brush stripping, soil ripping, and urea applying is most effective rejuvenation.

Bamboos of different species, ages and origins can be used to build a collaborated and mixed forest in afforestation. In this case the growth of the entire forest will not be seriously affected even if some individual flowering still occurs.

5.2.4 Generative Propagation

• Fruit and Seed Bearing

Due to imperfect development of generative organs (resulting in pollen abortion), bamboos may flower often but seldom bear viable fruit. Furthermore, being wind pollinated, bamboo flowers achieve a very low rate of fertilization because most species have long filaments, short styluses, exerted anthers, and embedded stigmas. The fertilization rate is usually lower than 10% even at the flowering peak, and 9 out of 10 remain sterile. Even after apparent fertilization, many will abort or be sterile for various reasons. For example, only a few viable seeds are borne on each plant of *Dendrocalamus sinicus* after flowering. Bamboos experience a long period of flowering. Generally the seed mature in succession and subsequently drop about a month after fertilization.

Generally speaking bamboo fruits are caryopses. They vary greatly in shape, size, and weight between different species (Tab. 5-5). Bamboo seeds are edible with a rich starch content. In West Zhejiang, when *Indocalamus* tessellatus flowered gregariously during 1958~1962, the maximum number of seed from an individual plant reached over 3,800, and seed yield of each mu came to about 200kg.

Tab. 5-5 Seed Weight of Some Bamboo Species

Chinese Name	Scientific Name	Weight per Thousand seeds(kg)
Mao zhu	*Phyllostachys edulis*	8~15 kg (cleaned), 15~25 kg (with chaff)
Gui zhu	*P. bambusoides*	35~40 kg
Nuo zhu	*Indocalamus sp.*	28~30 kg
Mu zhu	*Dendrocalamus strictus*	31~35 kg
Ma zhu	*D. latiflorus*	48~50 kg
Li zhu	*Melocanna baccifera*	19~78 kg

• Germination and Growth

Bamboo seeds are apt to germinate at a high rate when they first become mature and fall off. There may be 4~6 seedlings on each square meter under a *D. membranaceus* forest that has died of flowering. The indoor germination rate of *P. edulis* can be 50~70%, but only 20~40% when sown immediately outdoors in the nursery, and nearly none after 1-year in storage. Dehulling can improve the germination of bamboo seed. In a typological study of graminaceous seedlings, bamboo seedlings are classified by some scholars into the eubamboo subtype of the bamboo type seedling population. The bamboo seedling has a short mesocotyle (about 0.5mm) and a seed root which will develop into an advanced root system. The mesocotyle sheath has no adventitious roots at the nodes and the coleoptile becomes venose. The first few seedling leaves are incomplete: with only leaf sheath but no leaf blade, or with leaf blade degenerated so that a scaled acerose mark is left. Vegetative leaves, i.e. green true leaves that grow afterwards are stipitate and separated from the sheath by a joint where the leaf blade is apt to fall off from the stalk. This difference between the two types of seedling leaves is very peculiar indeed. And though similar to that between common leaves and sheaths on culms arising from subterranean stems, it is in fact the result of long adaptation to the warm humid monsoon climate and to the habitat of organic matter in the surface layer of soil. Plants of eubamboo subtype seedling have lasting nucleoli in their root tip cells. They have embryos of the bamboo type, brachiate cells on cross section of the leaf, and 2~3 layers of tunica at the branch tip. All these demonstrate their peculiarities.

Though generally over 20℃, different species have different temperature requirements for seed germination. During germination elongation of the hypocotyl is 1~2 times quicker than that of the germ. Root hairs grow earlier than lateral roots on the radicle, the embryonic stem steadily elongates, leaves emerge and GH is accomplished within 30~60d. Then embryonal bamboos, i.e. seedlings of the first generation, are produced. The first year seedlings of *P. edulis* are usually less than 20cm tall with 10~18 leaves.

Fig. 5-6 Seedlings of *Chimonocalamus delicatus* from Kunming, Yunnan. Photograph by Hui, Chaomao, 2002

All bamboos, whether they are to become sympodial, monopodial or amphipodial, have lateral buds at basal nodes of their seedlings. When seedlings achieve their full height, lateral buds start to activate to produce tiller culms which finish elongation in about one month. Bamboo seedlings are able to tiller 4~6 times within one year and form clusters of small bamboos and tillers which get thicker after awhile. For 1-year old seedlings of *Dendrocalamus latiflorus*, each clump is able to produce at least 3~4 new tillers, 15~16 in general, and 80 at most. Of 1-year old monopodial and amphipodial bamboo seedlings, generally none has any running rhizomes yet. In their second year lateral buds at the base of tillers germinate, some into new bamboo culms and some into true rhizomes that take their final form even though still small.

From the perspective of biological evolution, clumping bamboos are more primitive than running bamboos. For monopodial and amphipodial bamboo seedlings, the early form and habit are typical of clumpers. This in fact is a repetition of phylogeny in the early stage of individual development that mirrors properties of their ancestors and repeats their evolutionary path.

• Heredity and Breeding

After years of study in bamboo heredity and breeding, Guangdong Institute of Forest Science has developed and selected the following hybrids through hand pollination. They are; namely, "*Bambusa pervariabilis*×*Dendrocalamus latiflorus* (B. textilis) #1", "*B. pervariabilis*×*D. latiflorus* #25", "B. *textilis*×*D. latiflorus* #4", and "*D. minor*×*D. latiflorus* #5". Form and anatomical features of these hybrids vary generally between those of their parents with one or two properties super apparent. Take fibre length for example, in "*B. pervariabilis*×*D. latiflorus* #25" it is 2,332mm while its pollen and seed parents are 1,778mm and 1,530mm respectively. "*D. minor*×*D. latiflorus* #5" has yellow and green stripes at the culm neck but neither of its parents does. Some hybrids are very powerful in vegetative propagation and their seedlings have a high rate of survival. Furthermore, hybrids may be superior to their parents in terms of straightness, vitality, and edibility of shoots (Zhang, Guang-Chu 1986).

Bamboos are easy to multiply through vegetative propagation. Thus a promising new hybrid can be reproduced or cloned limitlessly without feature loss; its superior qualities remain with all divisions. Therefore, it will be worthwhile to increase new cultivated types by making full use of any synchronimous sporadic flowering to carry out crossbreeding experiments. The more recent development of induced in-vitro flowering techniques makes possible the hybridization of species without regard to their natural cycles. This could lead to the creation of desirable new hybrids with elite characteristics.

Fig. 5-7 The hybrid of *Bambusa* textilis ×*Dendrocalamus latiflorus* 11. from Guangzhou, Guangdong. Photograph by Hui, Chaomao, 2001

5.3 Vegetative Propagation

5.3.1 Propagation Nursery

The following should be taken into account when selecting the site for a propagation nursery. First, it would be best to have fertile loam or sandy loam rather than heavy clay soil. Second, it should be near water resources for the convenience of irrigation and drainage. Third, it should be facilitated with good transportation not far from the planting site. Fourth, it should be on even terrain or a gentle slope of no more than 5%. But if it has to be a mountain side with steep grade, soil and water should still be properly maintained.

Preparation of the land should be intensive, thorough, and 20cm deep in general. Break, with a hoe or harrow, large soil clods into small lumps no bigger than 5mm and clear away all weeds and roots. New plants of clumping bamboos may be propagated by burying whole culms or culm sections or even just nodes. Planting holes may be unnecessary on gentle slopes of good drainage. When propagules are bedded in a double-lined belt 70cm wide, each ditch in the line can be prepared 15cm deep and 20cm wide. The length of the ditch is decided by the potential size of the bamboo species, though the usual practice is 5m to 10m. Lines of nursing ditches can be set 50cm apart. Approximately 160~180 culms are needed to propagate the starts for each mu (2400 – 2500 per hectare). When propagules are bedded on level flat land, nursing beds should be designed for the convenience of drainage. Each bed is dug 1m wide, 20~30cm high and 5m to 10m long. Two nursing ditches are then made alongside the bed, 20cm deep and wide. In each ditch about 50kg of marl is blended with soil as base manure for future availability.

When propagations of running bamboos are nursed by way of rhizome burying or mound layering, bed making depends on terrain and drainage of the site. But for propagation by sowing of seeds, it is best to make a bed 1m wide, 20~30cm high and 10m long along the contour of the land.

5.3.2 Multiplying Bamboo

Though methods of bamboo afforestation are numerous, they can be roughly summed up as follows; namely, divisions, transferred rhizomes and induced rhizomes, cuttings and culm cuttings, induced aerial roots (layering), branch cuttings, and tissue culture. Afforestation with transplanted bamboos or with seedlings is suitable for either clumping bamboos or running bamboos. Afforestation with transplanted rhizomes or with induced rhizomes is good for both running and amphipodial bamboos. And afforestation with buried nodes and with cuttings is applicable only to tropical or subtropical species of clumping bamboos that have notable major branches.

Studies on bamboo propagation are mainly focused on those species with considerable known economic value. Sympodial bamboos can be propagated through both reproductive and vegetative approaches. In any case, if successful transplanting is to be expected, the propagules must be encouraged to develop fibrous roots so that shoots can grow from the rhizomes.

• Propagation through divisions

In this method, a part of the rhizome and the attached culm is separated from the major rhizome and used as the propagule. It is often used to propagate both monopodial species and amphipodial species whose culms do not cluster, it can also be applied to long-necked sympodial species with open or scattered aboveground clumps, such as *Schizostachyum* spp. Bamboo species (such as species from *Phyllostachys*, *Melocanna*, *Schizostachyum*) which cannot be successfully reproduced through culm cuttings or branch cuttings can be propagated by this method. But for tropical sympodial species, which usually have short rhizomes and densely clustered above-ground stems, this method is not very practical because the propagules can be readily injured. There is also the higher cost incurred by transportation of larger starts.

• Propagation through culm cuttings

This method can be divided into two types: direct method and nursery method.

a. Direct method: In this method, one or two year old culms with live buds and leaves are cut into one or two node segments and planted in situ as propagules. Mature methods and technologies concerning nursing and transplanting have been developed and applied for the propagation of most of the sympodial bamboos such as species of the *Dendrocalamus*, *Bambusa*, *Gigantochloa* and *Schizostachyum* genera. If the distance between the propagule suppliers and the planting site is not great, the propagules can be transported directly to the site after being cut into sections. In practice, this method has been used successfully with satisfactory survival rate. But it is limited by the local availability of bamboo clumps and the number of culms which can be used as propagules. What is more, the distance between the propagule collection site and the planting site must be relatively short. Because of the short time delay allowed, the cut propagules must be planted in the soonest manner. Adequate site preparation must be conducted in advance to ensure timely planting of the propagules. Thus, for large area planting activities a sufficient number of propagules must be developed in nurseries. (See Fig. 5-8)

b. Nursery method: In this method, the propagules (here culm cuttings) are first cultivated in nurseries for some time before being transplanted to the field for planting. Compared with direct planting, the propagules are more vigorous and can grow better because they already have established roots and have already been graded for vigor. During the transplanting period, the managers can select the right propagules according to the site conditions. For large area plantations, the nursery method can reduce the work in preparation and transportation. The plantations created by this method have a greater survival rate and a higher stand quality and the age of the stands will also be more uniform. The cost per unit area will also be lower.

Depending on the type of parent stocks, availability and the nursing conditions, propagules with one node, two nodes or more can be used.

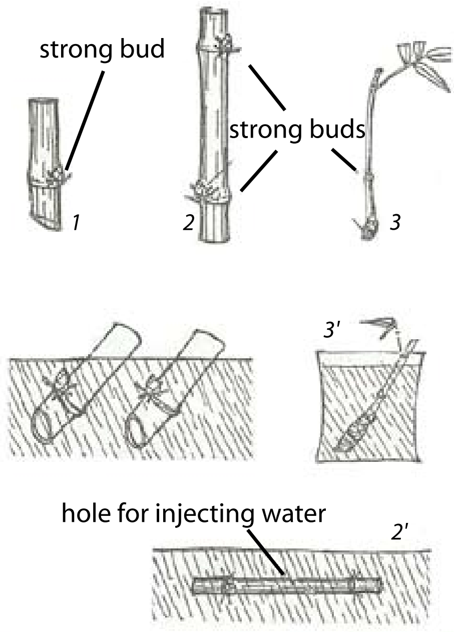

Fig. 5-8 Asexual method of tropical bamboo propagation
1, 1′ culm cuttings with one node
2, 2′ culm cuttings with two nodes
3, 3′ branch cutting with main branch in container

• Aerial root inducement

Aerial root inducement or air layering is similar to the previous method; the difference is that before preparing the cuttings, branch roots are induced through aerial layering. This method adapts well to situations when the bamboos are too small to be propagated through whole culm cuttings. It involves more labor and consumes more material, but has a greater chance to succeed. Fifteen days will be needed for root inducement and once the roots are developed, the survival rate will be assured and growth will be accelerated.

Aerial root inducement includes the following steps: (1) Find a common plastic bag and cut the sides of the open end so that it takes the shape of an inverted "T"; (2) Fill the T-shaped bag with water-holding material such as peat moss, leaf mould, coir or other medium; (3) Select a 1 or 2-year-old healthy culm, trim it at a node so that only the dominant branch is left; (4) Moisten medium thoroughly and wrap the T-shaped bag around the basal part of the branch, with the water-holding material in direct contact with the branch; (5) After 15 days of aerial layering, roots will come out from the basal part of the branch and grow into the peat moss in the bag. At this stage, the culm can be cut down to be used for making pre-rooted cuttings, which can then be planted in containers or in ground nurseries or used for direct planting in the field (Fig.5-9).

• Propagation through branch cuttings

For many of the clumping bamboo species, a dominant main branch is found at every node and clustered around the base of the main branches are the secondary or lateral branches. Both the main branches and the secondary branches have adventitious buds which can develop into roots. Due to this characteristic, the branches can also be cut as propagules for cultivated plantations. Researchers in the Philippines have performed many experiments using this technique with considerable success in production. This method has several advantages over other methods. It does not require whole culms with commercial value and the branches used can easily be obtained from 2 to 3-year-old bamboos.

The techniques involved are easy for people to master, and it can achieve the same survival rate and stand growth as previous methods while requiring less investment.

Branch cuttings should be made during the rainy season. Dominant branches with root primordia and well-developed adventitious buds should be selected and cut from 2 to 3-year-old bamboos. The branch should be cut in such a way that each cutting has 2 or 3 internodes. Thus, each segment is cut at a point 2 or 3cm above the third internode; and the leaves of the top node should be retained for photosynthesis. Prune all the lateral branches at the base of the leading branch but leave one lateral branch with good growth on the second node. The branch sheath, if any, should be removed so as to expose the buds. The branch cuttings, once prepared, should be placed in containers (bags or pots) or a well prepared seedbed immediately.

Fig.5-9 Aerial root inducement of *Dendrocalamus* brandisii, From Xingpin,Yunnan, Photo by Yang,Yuming, 1999

Nursery stock: Trenches of 15cm×15cm are prepared in the seedbed and the cut branches are buried in the trenches slanting at 30 to 40 degrees (Fig. 5-8). The bottom nodes should be buried 3 to 6cm under the soil and the middle node should be at the same level with the ground surface, with the third internode (top internode) exposed above the ground. After that, the seedbed must be mulched and shaded and deeply watered. Generally, after three months, these branches will have grown into new plants. Aerial inducement has a high survival rate and the plantlets cultivated this way have better growth. Branch cuttings which cannot be wrapped or placed in the seedbed immediately should be kept in running water or shaded where direct sunshine can be avoided. During transportation, they should be wrapped in wet grasses or large leaves to maintain both ventilation and moisture.

Cultivating plantlets in a sandy seedbed is somewhat similar to rearing stocks in nurseries. The only difference is that the base material used in a sandy seedbed is moist fine sand and the bed is often covered with transparent films so as to maintain necessary temperature and moisture. After 20 to 30 days, roots will have come out from the basal part of the leading branches and at this stage, they should be put one little plant in each container for further tending.

Lateral branches can also be used for this purpose when the availability of leading branches is limited if the following factors are considered: (1) The lateral branches chosen should be sturdy enough with short internodes. (2) The buds of the first 3 nodes should be large and ready to sprout. (3) Root primorda should be visible. (4) The sheaths are loose or off and the top leaves have begun to emerge. (5) The branches have become woody with yellow-green or yellowish color. (6) Slim branches, which are either too young or too old, should be avoided (see Fig. 5-8).

• Tissue Culture

Laboratory studies and field practice performed in recent years indicated that tissue culture techniques have a very promising future in bamboo propagation. Several of the successful methods reported include: (1) Tissue culture from seeds and embryo cells. (2) Tissue culture from buds, inflorescence, leaves and internodes. (3) Tissue culture from nodes. (4) Tissue culture from sterile, bacteria-free plantlets.

Among those techniques, researchers have already found ways (developed protocols) of cultivating large quantities of plantlets through tissue culture by using seeds and embryo cells. In 1988, technicians in India successfully produced more than 14,000 plantlets of *Dendrocalamus* strictus through this method. *D. strictus* is highly drought resistant and is especially suitable for afforestation purposes in hot and arid areas. In many cases, seed supply is a factor limiting afforestation activities. While in tissue culture, also known as micropropagation, large quantities of propagules can be developed from very few seeds, resulting in a sharp reduction of plantlet prices. Researchers in the Philippines also developed advanced methods in tissue culture from embryo cells. Tissue culture of vegetative organs such as shoot tips, branch buds, and tender internodes has also been researched with success.

Though bamboo propagation through tissue culture techniques is still somewhat at the experimental or small-scale production stage, it is developing at great speed and with remarkable success. Compared to other methods, tissue culture is bound to gain wider application and has the greatest potential for large scale bamboo propagation.

Fig. 5-10 Tissue cultivation using seeds of *Dendrocalamus sinicus* in SWFC directed by Prof. Zhang, Guangchu. from Guangdong Forest Academy

5.4 Planting a Bamboo Stand

5.4.1 Selection of Planting Season

In China an old saying about the best planting times goes: "Bamboo in the first moon but tree in the second moon". As far as running bamboos are concerned, they sprout shoots from March to May and have luxuriant growth from June to July. From August to October they extend rhizomes and activate buds, but from November to December they grow very slowly, they are in a semi-dormancy. That is why winter and spring (from November to February) are considered good seasons for planting. But for clumping bamboos which foliate from March to April and sprout from July to August, the most appropriate time for afforestation is from January to March because in dormancy mother culms can be conveniently dug, transported, and planted with a high survival rate. Afforestation with seedlings or small cultivated plantlets, however, can be done all year round. There is a proverb that says "bamboo planting has no specific season, so long as it is done after a rain".

5.4.2 Selection of Planting Site

Site Selection: Most bamboos have a relatively wide tolerance of site conditions. Despite the fact that bamboos grow best in well drained sandy to clay loams, especially on alluvial soil; most bamboo species, especially those with high economic as well as ecological value, grow well in various site conditions as long as the sites are neither too acid nor too alkaline (tolerance can vary with species) nor too wet. Most bamboo species prefer moist but well-drained soil conditions although some species also grow well on relatively dry sites. Most bamboos prefer soil with pH value between 5 and 6.5 and grow poorly on saline-sordic soil and coastal solonchak soil conditions. Site selection is of vital importance to achieve a high yielding bamboo forest. In addition to a proper season length for each species, attention should be given to such factors as climate, soil, and landform.

Soil Conditions: With massive underground systems, bamboos generally require soil that is fertile, moist, thick, well-drained, and over 50cm deep. The most suitable type for bamboo growing is sandy soil or sandy loam. Growing poorly on alkaline soil, most bamboos ask for acid, sub acid or neutral soil with a suitable pH of 4.5~7.0. Due to their strong adaptability, some species of bamboos can grow in almost any soil; however productivity and performance may be affected.

Landform Conditions: "Plant palm on ridge, bamboo near water and walnut in forest; cultivate mulberry in fat land, tea around bushes and chestnut on slope". This folk saying makes clear the general requirement of landform conditions for bamboo planting. Specifically in selection, the site should be chosen in valleys, mountain feet or sides that have adequate humidity (instead of alpine areas, dry windy ridges and slopes, or places liable to ponding). Clumping species are predominantly distributed on plains and hilly districts, particularly on alluvial belts of rivers where the soil is deep and loose. They are most suitably located around dams, near canals and ditches and on river banks so as to help preserve soil and water.

5.4.3 Site Preparation

With its own peculiarities, bamboo afforestation depends on the mother culm for growing of rhizomes, culms, and forest. So a loose and deep soil is critically important. When planting on level ground or gentle slopes, total preparation of land should be done to improve the soil if laborers are available. If conditions do not allow, preparation should be done at least in strips or belts. Planting holes on contour or parallel with the slope should be dug when land is ready. Holes should be approximately 1.5m long, 0.7m wide, and 0.5m deep. Planting density is decided by species growth habit as well as different purposes of the would-be stands.

Degree of site preparation is dictated by the original vegetation and the goal of plantation. If the purpose is to develop commercial bamboo stands, then the original shrubs and herbaceous plants should be removed, leaving only the trees. While if the stands are developed for ecological purposes, the clearing of 0.5m to 1.0m wide along the contour line or a circular clearing of 1.0m diameter will be enough. If the plantation is made along river banks, roads, dikes of rice fields or forest margin, spot preparation is usually more suitable to minimize environmental disturbance.

In case of hole planting, the size of the holes must be large enough for the seedlings or plantlets. Depending on the size of the propagules, the width of the holes can range from 30cm to 50cm and the depth of the holes which is also determined by the propagating material used should be such as to allow for 2cm of soil coverage above the original soil depth. Shoot sprouting will be affected if the propagules are planted too deep. Before digging the hole, efforts should be made to loosen the surface soil, clear the remaining roots or rhizomes of the original vegetation and remove stones so as to guarantee a high survival rate of the newly set out plantlets. In the process of hole digging, the original top soil and the newly dug subsoil should not be mixed together. Planting should be made at the following steps: (1) Place the top soil in the bottom of the pits; (2) place the propagules or seedlings in the pit; (3) Refill the pit with the newly dug subsoil; (4) Tamp the soil firmly but not hard to compact it.

In developing bamboo stands for ecological purposes along river banks or mountain edges, the density and layout of the stands should be designed according to the specific micro-topography. Bamboo plantations should be carefully planned with the densities designed according to the growth habits of the species selected. The preferable spacing for medium sized clumpers is 4m x 5m or 5m x 5m. But for bamboo species with tall culms and dense clumps, the planting holes can be spaced at 7m x 7m and even 10m x 10m. For medium and large sized running bamboos such as those in the genus *Phyllostachys*, a spacing of 3m x 3m is generally recommended with fill in expected in 3~4 years.

5.4.4 Transport and Field Planting

Depending on the distance and site access, plantlets and seedlings can be transported by manpower, beast of burden, or other appropriate means. However, in every case, the small plants must be handled carefully to avoid desiccation or injuries. Cut propagules such as culms, rhizomes and root balls should be wrapped in wet bags or grass mats before being transported so as to hold moisture. Avoid direct sunshine. Once lifted from the nurseries, the seedlings or propagules should be planted in the fields as soon as possible. The root tips of the naked plantlets should be cut immediately upon lifting and wrapped in moisture-holding materials such as grass mats before being transported to the site for planting. The containerized seedlings or plantlets should be transported in boxes or baskets which can facilitate loading and unloading and protect them from injury. It is better that these boxes be transported by manpower so as to reduce damage from the shaking and jolting common with vehicle transportation. The seedlings and plantlets should also be protected from direct sunshine and water loss.

The culm cuttings used for planting should be buried in ditches along the contour line whereas the seedlings and plantlets should be planted in pits. The seedlings should be positioned as they were in the nurseries and care should be taken to ensure that the root system is not crowded and is free to extend.

For containerized seedlings, watering should stop two days before field planting. When removing the containers or bags, people should take care not to loosen the soil ball that goes with the plant. Some time after field planting, organic fertilizers can be applied within 15cm around the holes, which will promote the growth of the little plants. To reduce water loss from evaporation and to prevent top soil compaction, the planted seedlings should be mulched with grass or other litter; if possible, bamboo leaves are preferable because of their high silica content which favors bamboo growth.

5.5 Management of Bamboo Stands

After planting, the healthy growth and high yield of a bamboo stand are determined by management. There is a popular saying that "management plays a vital role in cultivation". For improving the functions of bamboo's ecological system and raising the yield of a bamboo stand, the following three aspects represent major approaches at present.

Environmental Control: Environmental conditions in a bamboo ecological system can be improved by cultivation measures such as irrigation, brush removal, soil scarification, manure application, and intercropping. But these measures may be heavily constrained by social and economic conditions. Though certain measures are biologically effective, they may not be directly worthwhile in an economic sense.

Biological Control: We may improve the genetic quality of bamboo stands, regulate their populations, speed up the flow of materials and energy in the system, as well as control their flow directions for higher productivity in the target population. Biological measures such as selective breeding of elite species, afforestation of mingled forests, and control of insects and diseases are of significant importance to the potential yield of a bamboo stand. Although they are both costly and demanding, these and measures such as hereditary variation are not liable to result in immediate effects.

Fig. 5-11 A afforestation demonstration base of *Dendrocalamus* brandisii, with help from SWFC, from Xinping, Yunnan
Photo by Hui, Chaomao., 1999

Structural Control: We should convert unplanned time and space structures to well thought out optimal structures in order to make best use of natural forces to enhance productivity of the ecological system. In the comprehensive field of biological and environmental controls, we aim to reinforce the bamboo's natural ability so as to more fully take advantage of environmental conditions by adjusting structures of the stands. The gist of structural control is to try to discern optimal structures for the present bamboo stand and regulate it for a better microenvironment, to more effectively use fertility and light to achieve the intended yield. This agrees very well with the ancient Chinese scholar Jia, Sixie's thought that "Easy success can be made with little effort if weather and fertility are acknowledged and conformed to; but a man harvests little though hard he may labor if natural laws are neglected for his stubborn will". This is the crux of a high yield.

Similar to that of other economically important forests, management of a bamboo forest is divided into two stages, i.e. the young forest and the mature production forest.

5.5.1 Management of Young Stands

When bamboos have survived but not yet matured, they are known as a young forest. The main purpose of management for a young forest is to increase its survival rate and speed mature forest formation. Management measures for a young forest include watering, weeding, cultivating, fertilizing, intercropping with green manures (i.e. bean, rape, etc.), as well as preventing damage by domestic animals, wild beasts, insects, and diseases. As the foundation for any adult forest, a healthy young forest is a prerequisite to high yields. This is especially true for a bamboo forest.

a. Tending: In the early stages, measures such as weeding and soil loosening are only performed if and as required by the specific situation. The major concern is to control and if possible, eliminate climbing vines.

b. Fertilizing: Fertilizing efforts should be made some time soon after planting if the situation allows. Inorganic fertilizers will be more immediately favorable to the vegetative growth of bamboo plantlets. The following fertilization application rate is recommended for each hectare of bamboo: Nitrogen: 20 –30kg; Phosphate: 10-15kg; Potassium: 10-15kg; Silica: 20-30kg.

The best timing for the first synthetic fertilizer application is 1 month after field planting when the transplanted plantlets have resumed growth. The second fertilization may be performed 4 months later, and then 6 months later organic fertilizers can be added. Of course, the timing for fertilizing should be advanced or delayed according to the actual growth state of the young bamboo.

In view of the high and rising cost of synthetic fertilizers, manures, mixed compost and the like can also be applied to effectively stimulate the development of the bamboos. Bamboos have a high demand for the element silica. Therefore, fertilizers with adequate silica content should be applied to bamboo stands for better growth. The most convenient way is to use the composted bamboo leaves collected from the old bamboo stands. The bamboo leaves have a rich silica content which can be easily absorbed and utilized when the leaves decompose due to fermentation and digestion by beneficial microbes.

c. Fire control: Bamboo forests usually have a greater tolerance to fires than other forests. When the organs (culms and leaves) above ground are removed by forest fires, the underground rhizome can easily sprout and in the next year, shoots will come out to form a new stand. In spite of this, efforts should still be made to prevent fires from happening. Fires are very destructive to bamboo forests and the burned stands can more easily be infected by pests and diseases. Besides, burning may also stimulate bamboo flowering, which could cause the death of large area of forest stands. Special attention should be paid to the newly established bamboo stands.

The down materials in bamboo stands, such as fallen leaves, dry twigs, dead shoots, and surface litter are all highly inflammable. This often makes the bamboo stand an area of high fire risk. Fire breaks and greenbelts are possible preventive measures in bamboo stands. Besides fire prevention, the greenbelt can also act as a wind break. Site specific fire breaks or green belts should be designed in at the planning stage.

d. Guarding: Animal grazing must be prohibited in bamboo stands. Cattle will destroy the bamboo shoots and new leaves by grazing and trampling. Rodents have the tendency to feed on the bamboo shoots, making holes at the basal part of the bamboo stem and eating the rootballs and rhizomes. Ineffective rodent control frequently leads to degradation and even destruction of bamboo stands. In forests with serious rodent damage, poison should be used for immediate control (one way of doing this is to put the poison into a bamboo section with only one node and place the bamboo containing poison in the forest). However, for the long run, biological control measures should be adopted. The natural enemies of the rodents such as eagles and hawks, weasels and other viverine animals should be protected and even introduced. Even trapping can be very effective in reducing pest populations.

e. Control of bamboo shoot collection: Shoots of many bamboo species have a delicious taste and thus are often collected by people to be used as vegetables. But in the first few years after planting, shoot collection should be strictly controlled to allow the stand to build energy reserves to maximize the normal growth potential of the stands. Collection should be limited to only the underdeveloped, disease infected or otherwise degraded bamboo shoots.

5.5.2 Management of Adult Stands

When the young forest begins to produce shoots in large numbers, it has reached its adult stage. Measures to achieve high yields as the forest becomes mature mainly consist of improving growing conditions for the forest and managing its population structure.

A. Management of Monopodial Bamboos

• Improving Conditions for Bamboo Growth

This mainly refers to soil cultivation, manure application, brush removal, digging out old balls, reasonable irrigation and assuring drainage.

Cultivating and Manuring: A total cultivation should be carried out every 5 years after the forest becomes mature. Get rid of old rhizomes, weeds, and rocks, and apply manure in a timely manner. With organic fertilizer as the dominant part, manure applications can be of tender grass or rape cake in summer and fall, supplemented with a fertilizer such as urea in spring and summer. Application can be done 1~3 times a year (usually just before new shoots emerge, then again when height growth stops, and again just before cold weather begins) and at 10~15kg/mu (150~225 kg. per hectare) each time. But it would also be best to have a shade-tolerant green manure intercropped in the forest. Soil cultivation and manure applying can improve the physiochemical properties and nutritive conditions of the bamboo forest soil to attain the objective of high yields.

Brush Removal: Brush removal can be done 1~2 times a year. Clear away all weeds and bushes and spread them inside the forest as manure. It is good timing to have brush stripped during June and July when high temperatures and plentiful rain cause the tender grass and bushes to decay quickly, contributing to available fertility and decreasing the possibility of damage by insects.

Digging out Old Balls: When running bamboos are felled, their root balls will generally remain underground for up to 10 years before thoroughly decomposing. These undecayed culm bases are as hard as rocks and can impede growth of the rhizomes so that the stand becomes thinner and sparser with each passing year. New culms may still keep shooting, but year after year the bamboos may become increasingly thinner and their yield may fall because their roots, pinched between dried root balls, are unable to stretch into soil for water and nutrition. So getting rid of old balls and rhizomes in a timely manner is regarded as a key to regeneration, rejuvenation, and improved harvest from the bamboo stand. When combined with cultivation, these procedures are beneficial to the growth of new rhizomes and shoots.

Irrigation and Drainage: Mostly bamboos are water loving but intolerant of being waterlogged. So adequate irrigation is a must in dry seasons while drainage may be a necessity in wet seasons, otherwise growth of the bamboo stand will be negatively affected.

• Adjusting Population Structures

Bamboo stand organization involves eight factors; namely, specific composition, age dynamics, individual numbers, individual sizes, individual regularity, distribution homogeneity, leaf area index, and yield ratios. Constructing a high yield stand is a certainty only if these eight (8) norms are given consideration. The basic attributes of a high yield stand are "dense, big, regular, high, young, and even". That is to say stocking should be dense, average DBH big, bamboo size uniform, leaf area index high, average age young, and bamboo distribution of different ages even (Table 5-6).

Table 5-6 Structural Features of High yielding *Phyllostachys* ***edulis*** **stands**

Site condition	I	II	III	IV	V
Composition	10	10	10	10	10
Stocking (culm/mu)	400~450	350~400	300~350	250~300	300~400
Average diameter DBH (cm)	>12	10~12	8~10	6~8	6
Regularity	>8	7~8	6~7	5~6	4~5
Culm retention Class	V~VI	V	IV	III	III
Average age (year)	5~6	4~5	3~4	3~4	3~4
Homogeneity	>5	4~5	3~4	3~4	3~4
Leaf Area Index	>10	8~10	6~8	5~6	4~5

Note: This table from Zhou, Fang-Chun; Yi, Shi-Ji; Mao, Gao-Xi 1987

Specific composition covers the dominant bamboo species and any accompanying species in the stand; individual number refers to the number of bamboo culms on an unit area, i.e. stocking percentage. On some occasions stocking percentage is interpreted as the ratio of chest height cross-sections of the current stocking to that of the high-yield model stand. Age structure is indicated by the ratio of plant numbers in different classes and classification is done in terms of bamboo distribution of different ages. For instance, 1st year culms of *P. edulis* are termed "class one", 2 to 3-year old culms as "class two", 4 to 5-year old culms as "class three", and accordingly 6 to 7-year old culms and 8 to 9-year old culms are respectively known as "class four" and "class five". A saying concerning felling is "preserve class three, fell class four, and dispose of all those of class five". Or more simply stated all culms 5 years and older should be removed. Reflecting size difference between stocking culms, individual size means average DBH of the stand and individual regularity, and is in fact the ratio of average DBH to standard DBH. Yield structure refers to distribution of bamboo yield according to different ages. Different combination manners of these factors result in different structures and hence, varied amounts of yield.

Reasonable bamboo stand organization can best be realized through intensive management which includes the following concrete measures: thinning shoots for propagation, protecting shoots to nurture bamboos, changing "on and off year bamboos" into "even year bamboos", controlled pollarding, appropriate cultivation, and rational felling.

Shoot Thinning and Shoot Protection: Shoot thinning means digging out of weak and small shoots. Research indicates that weak and small shoots are inevitable and doomed to die if not dug out in a timely manner. Every year in a stand only 10%~40% of the shoots grow into mature bamboo culms while 60%~90% abort or remain small. The higher the yield of a bamboo stand, the more dead and small shoots it will tend to have. It is impossible to wipe out all dead shoots, for it is natural for the stand to have big and small, strong and weak shoots every year. In production, therefore, we ought to preserve strong shoots for propagation but dig out or take the thin and small for food. This not only brings good economic results but is also in accord with natural laws.

Shoots of *Phyllostachys edulis* can be harvested every 2 to 3 days. Dig out small shoots at the early stage and the thin ones at the final stage. Thinning in general should remove 50%~70% of the total new shoots. To harvest or thin a shoot, rake the earth away at the base with a hoe, then, cut at the joint between the shoot and the rhizome taking care not to hurt the rhizome. Refill the hole with earth after the shoot is taken out. For the shoot intended to keep as a new culm, protect it from damage by man or animal and forbid digging. Shoot protection is one of the key steps to raise the useable culm count in a mature bamboo stand.

Changing "On-off Year Bamboos" into "Even Year Bamboos": Both theory and practice indicate that bamboo stands in even years can increase their stocking count and leaf area index so as to produce maximum organic matter or biomass with the help of solar energy. So in bamboo production it is advisable to change on-and-off year bamboo groves into even year bamboo groves. Specific measures include: 1) preserve more shoots to nurture bamboos in the off year; 2) thin shoots for propagation in the on year; 3) increase felling in the on year; 4) decrease felling in the off year and, 5) increase bamboo stocking.

Controlled Pollarding: Pollarding here means to cut off tops of the new culms with a sharp knife. The purpose of pollarding is to lessen snow damage in winter and early spring so as to make culms straight, produce maximum usable materials, and increase profits. But cutting too low would lead to a reduced leaf area and a thin canopy so that the stand would be unable to produce adequate nutrients from sunshine, and then weeds would become overgrown in the stand, land fertility would be depleted, productivity would be lowered and quality of bamboo timber would also be affected. So in places that are free from damage of snow and wind, pollarding is not advocated. Even in places at risk from snow and wind, pollarding should be regulated so that over 15 whorls or sets of branches should be retained for each standing culm.

Directive Cultivation: Bamboo growth naturally tends toward light and loose, rich soil. Based on this, measures can be taken to guide rhizome extension and stand expansion so as to gain a more ideal distribution of culms and a full use of site space. There are two ways to guide shooting, i.e. to prohibit bamboo from shooting in inappropriate directions by rhizome pruning, shoot harvesting or felling and to guide bamboo shooting in desirable directions by cultivating and manuring and mulching.

Rational Felling: Rational felling considers time, age, intensity and methods. Felling time is generally chosen during the time after autumn in the on year and before spring in the off year, i.e. in winter. The general principle observed in felling is to first fell the weak, the old, the crowded, and the inside while preserving the strong, the young, the well spaced, and the outside. Felling age is decided by different site classes, and quantitatively is kept to the rule that the annual felling should not be greater than the annual increment.

As the major means to regulate density of a bamboo stand, felling alone may be used to bring about an ideal stocking density, homogeneity, and age structure so as to enhance the average DBH and leaf area index. A rational stocking density varies depending on site conditions, management, and growth. A stand with favorable site conditions, generally speaking, possesses nutrient rich soil and hence can support a higher rate of stocking. A stand under intensive management with good growth can maintain a higher stocking density than a stand with rough management and poor growth.

B. Management of Sympodial Bamboos

Management of clumping bamboos is also concerned with measures to improve growing conditions and regulate bamboo population structures. Under specific conditions measures are to be taken with consideration given to the development features of clumping bamboos.

Developing a Young Stand:

If a spring drought occurs within 7~10d after *D. latiflorus* is planted, irrigation should be done once every 3~4d; a light manuring is welcome every two weeks until after fall when it becomes unnecessary. Weeding and cultivating should be done in ordinary times. In April and May of a given year about 50% of the mother culms produce new shoots while the other half wait until the next spring. But if they don't make new shoots in the next year, their shoot buds may possibly have been injured. They then should be dug out and replaced with new mother bamboos in the third spring.

Shoot Cutting and Regeneration with Retained Mother Bamboos: The shooting period of *D. latiflorus* commonly lasts from May to October with rare exceptions even to November. It occurs in three stages, namely the early, the peak, and the final. Shooting in the early stage from May through June produces about 26% of the total shooting volume, approximately 52% arise in the peak stage from July through August, and about 22% in the final stage from September through October or later. Mostly arising from the lowest several basal buds (first eye, second eye, or third eye), early shoots come from deep in the earth with a strong vitality. Shoots from shoot buds near the end of the final stage are shallow in the earth and have weak vitality. In production if early shoots are retained, those in the peak and late stages are unable or delayed to activate due to lack of adequate nutrition as growth of earlier, new bamboos has consumed the stored nutrients. This can cause a sharp decline in the current year's output of bamboo shoots. Therefore, in order to resolve the conflict between mother bamboos retained and shoots cut, the best solution is to select shoots in the peak stage which are strong and well-directed to be new mother bamboos.

Each mother culm of *D. latiflorus* may have a productive life of 4~6 years during which it demonstrates its most powerful shooting capacity. Shoot cutting can be done annually and new shoot buds keep sprouting at the cutting heads. After 4~6 years, however, mother bamboos become nutritionally exhausted when shoot heads and buds are constantly increased. The stand will gradually degrade if new mother bamboos are not retained. So at least every 4~6 years new mother bamboos will have to be selected and retained for regeneration.

A common practice is to retain shoots from the first three bud eyes and let them grow into new mother culms during April to June of the plant year when buds on the mother culms activate into shoots. In year 2 when 2~4 shoots sprout on every mother culm, choose 1~2 from the first two bud eyes and retain them as the second batch of new mother culms. Now each clump of *D. latiflorus* has 7~8 mother culms, in years 3, 4, and 5 cut all shoots and do not retain more mother bamboos. In year 6, 3~4 new mother culms should be retained in each clump while 3~4 old mother culms are cut in the winter. Cut shoots in years 7, 8, and 9, retaining no new mother culms. In year 10, 3~4 new mother culms should be retained in each clump, cutting all other shoots. In this winter harvest of 3~4 year-old mother culms, dig out old rootballs of the first felling (in the winter of year 6) as well as any old rhizome balls without living buds. From then on, we may keep 7~8 mother culms for each clump of *D. latiflorus*, replacing 3~4 mother culms every 4 years, digging out old rootballs and rhizome balls once every 8 years, and harvesting all shoots in the other years.

Fig. 5-12 A field experiment in afforestation of *Dendrocalamus sinicus*, Ninger, Yunnan

Earth Raking: This means in the middle and end of each February (around the beginning of rainfall) to rake open earth around the clump with a hoe from outside to inside and expose buds on the rootballs in the sun. The purpose of this is multiple: to raise soil temperature, to stimulate early activation, and make it more convenient for applying manure.

Manure Application: Because of high yields of shoots, *D. latiflorus* consumes much manure and has to be remanured 2 or 3 times every year. The first manuring can be done about 10 days after raking and is called spring manuring by bamboo farmers. The following are suitable to use: human urine, animal manure, garbage and dust, pond sludge, and cake manure. For each clump 25~50kg of urine, or 5~10kg of decomposed cake manure, or 150~200kg of pond sludge and garbage is suitable. When the small shoot bud grows to 6~7cm tall, its shoot sheath turns from yellow-brown to green-brown, restore raked earth to the original place upon emergence of a liver-colored inner sheath at the fissure. The second and third times of manuring are after manuring commonly done at the early and peak stages of shooting. Every time each clump may be spread with 10~15kg of human urine, or about 0.5kg of urea and ammonium sulfate, to be diluted and applied in the ditch around the cluster. But remember to keep strong or concentrated manure water away from tender shoots lest they should wither and die from fertilizer burn.

Earthing up and Pit Filling: Before emerging, shoots of *D. latiflorus* have a yellow-brown color and their pulp is tender and fresh. But once emerged, their shoot sheaths turns from yellow-brown to green-brown when exposed to the sun, their shoot pulp becomes fibrous and bitter flavored, and general quality is degraded. In order to preserve the fine flavor of *D. latiflorus* shoots, it is necessary to have the shoots blanched or earthed up before they emerge. Deep shoots can be earthed up to 12~16cm but shallow shoots have to be earthed up to 30cm or precovered with broken basins and pots before they are filled with wet earth.

Pits left after shoot cutting have to be refilled with earth. They can be filled with earth immediately after cutting in April, May, or after September, but during the span from June through August they have to wait 3~5d (or 5~7d when overcast) till the cut has slightly dried up. If recovering is not well timed, the cut may rot and normal development of other shoot buds can be affected.

C. Assessment of Productive Factors in a Bamboo Stand

Analysis of the productive factors is an essential means to measure and assess productivity potentials and the management effectiveness of a bamboo stand. Productive factors are multiple, they include economic index, stocking rate, leaf area index, habitat quality and others.

The economic index refers to the ratio of output to biomass in a stand. Under the same site conditions and management status, the higher the output of a stand, the higher its economic index tends to be. The economic index of clumping bamboos is usually one time higher than that of running bamboos while in an intensively managed stand it can be raised by 30%. As a means to assess and verify the feasibility of a given density, stocking percent is denoted by ratio of cross-sectional area at chest height of a stand to that of a high-yield pattern stand. Generally, when the mother culm count of a stand is more than 8 it is considered a high-yield stand; when between 3~8 it is a medium-yield stand; when lower than 3 it is a low-yield stand. Leaf area index is the ratio of total leaf area to site area. When leaf area index of a stand is between 1~4, the stand is low-yield; when between 5~7 it is a medium-yield stand; when between 8~10 it is a high-yield stand. Average DBH can be used as a comprehensive criterion to assess habitat conditions, management effectiveness, and cane quality of a bamboo species. This comprehensive quality may be stated as growth class.

D. Research and Popularization of High-yield Techniques

Since 1965 the Bamboo Research Institute at Nanjing University has been doing systematic research on high-yield structures of *Phyllostachys edulis* (Zhou, Fang-Chun; Yi, Shi-Ji; Mao, Gao-Xi 1987). They have established 13 individual research stations in 9 provinces of the *P. edulis* production area. They tested 25 thousand mu of bamboo forest, and set up 869 plots on regular standard land beginning in 1981. Through data analysis, a preliminary understanding of numerical relations between major structural and ecological factors and yields of *P. edulis* was obtained. A mathematical model of high-yield structures for *P. edulis* was also defined. With the help of this model high-yield techniques have been evolved and introduced to over 5.2×104 ha with an average increase of ￥4080. Yuan in value per ha, i.e. 975. Yuan /ha.

[Note: Yuan (￥) is the basic unit of Chinese money. 8.3Yuan (￥)≈1$US as of early 21^{st} century.]

This research holds that yield (Y) of a bamboo stand formation (BSF) is decided by site conditions (Si) and structures of the stand (St). That is to say the former is a function of the last two, which may be denoted as: Y=BSF(Si,St).

In order to find out exactly what is involved in this function, 420×10^4 experimental and investigatory data were gathered by combining individual experiments with typical investigations. Through computer data processing, a mathematical model of high-yield structures for *P. edulis* has been established.

The year 1990 witnessed a new tool in the 'Development of and Comprehensive Utilization of High-yield Bamboo' (1990~1994), i.e. one of the Spark Projects in forestry at state level. The document was issued jointly by the State Ministry of Forestry and the State Scientific and Technological Commission. With the help from Longyou County Bureau of Forestry in Zhejiang Province and Subtropical Forest Institute at the Chinese Academy of Forestry Science, this project was completed in 1993, one year ahead of schedule. This project resulted in 107 thousand mu of *P. edulis* forest that produced both shoots and timber. Their average yield in timber output was 1,475kg/mu and in shoot output the average was 154.4kg/mu. Included in the forest were 13,700 hundred mu of high-yield bamboo stands which yielded an average of 1747.6kg/mu for timber and an average of 252.5kg/mu for shoots with 70% suitable for in-grade canning. Increases in output value amounted to ￥1.45×10^8, in taxes ￥$1,345.\times10^4$, in profits ￥$5,363.\times10^4$, and in foreign exchange earning US$$636.\times10^4$. Bamboo has become the backbone of the country's industries and income to bamboo growers has greatly increased. There appeared a large number of "Million-Yuan Villages", "Ten Thousand Yuan Families", and bamboo mountains each with an economic output value of over one thousand Yuan per mu. Effect analysis of this project is seen Tables 5-7 and 5-8 (Xiao, Jiang-Hua 1994).

Tab. 5-7 Changes of Shoot Yield

Unit: kg/ha

Types of Bamboo forests	Area (ha)	Yield of shoots in 1988-89	1990~91		1992~93		
			Yield	Increase compared with 1988-1989(%)	Yield	Increase compared with 1988-1989(%)	Increase compared with 1990-1991(%)
I	910.1		1954.3		3787.5		93.8
II	9149.2	877.5	1491.0		2784.0		86.7
III	4293.9		1072.5		1791.0		67.0
X	7153.2	877.5	1299.0	48.0	2316.0	168.9	78.3

Note: In age calculation of *P. edulis*, 1 year is regarded as class 1, 2; 3 y as class 2; and 4-5 y Class 3. Each class may last 2 years.

Tab. 5-8 Effect of Bamboo Cultivation

Types of Bamboo forests	1990~1991 (￥/ha)				1992~1993 (￥/ha)			
	Yield	Input	Taxes	Net Income	Yield	Input	Taxes	Net Income
I	5541.0	1755.0	975.0	2811.0	14065.5	2205.0	2619.0	9241.5
II	4627.5	1455.0	837.0	2335.5	11767.5	1815.0	2299.5	7653.0
III	3600.0	1125.0	663.0	1812.0	9273.0	1425.0	1927.5	5920.5

Note: 1. The data results from statistical analysis of information obtained from regular standard sites.
2. Yield here includes the value of timber and shoots. Value of gross plant and bamboo sheaths is excluded, however.
3. Input includes expenses such as manual labor, for felling, and digging.
4. Net income includes no expenses such as breeding, felling, and digging.

5.5.3 Management of Special Bamboo Stands

A special bamboo stand refers to one cultivated for a certain production or utilization purpose, such as for timber, shoots, paper pulp, ornament, or multi-purpose. Since management of a timber stand is similar to what has been elaborated above, it will not be discussed further in this section.

A. Shoot Production Stand (Hu, Chao-Zong 1986)

• Density Control

Density is a central issue in shoot production. Relevant experiments and production experience show that the culm density of a shoot stand should be less than that of a timber stand, as different stand types with different end purposes naturally call for different management techniques. When viewed from the perspective of eco-physiology, the climatic factor that plays a leading role in shoot initiation is temperature while in timber stand growing it is humidity. Since the aim of a shoot stand is to yield as many quality shoots as possible, site conditions such as slope, aspect (or direction), and fertility should be taken into account, with priority given to an adequate leaf area for production of organic matter when optimal density for a stand is being decided. As far as ideal size of a standing culm, generally the less the density and the thicker the mother bamboo is, the bigger the shoots it tends to grow. A medium-sized culm with a DBH of 8~10cm is more productive than a large-sized culm of 11~14cm, and most consumers prefer middle and small-sized shoots. Other factors to be considered are underground space, adequate light in interior, and ground temperature of the stand. An ample underground space would be beneficial to increase and elongate the rhizomes, and this in turn would increase the growth rate of strong rhizomes and the number of rhizome buds. Only when light permeation, temperature, and humidity are appropriate and management is optimized in the stand can differentiation of shoot buds be increased. Therefore, the density of a shoot stand should be slightly less than that of a timber stand. Based on the above discussion, density for a stand of large-sized shoots of a species such as *Phyllostachys edulis* can be 1,800~3,300 culms/ha, for a stand of small-sized shoots 18,000 culms/ha, and for medium-sized shoots 10,500~12,000 culms/ha.

Fig. 5-13 *Dendrocalamus* brandisii, a species for high quality shoots from Luxi, Yunnan
Photograph by Hui, Chaomao, 2000

• Manure Application

In 1963, the Japanese scholar Wuedako, Yichilo systematically summed up his long-time study of manuring in his book **Useful Bamboo and Shoot–New Cultivation Techniques**. He pointed out that in fertilizer utilization a stand needs more of N than P and K, though the most ideal is a combination of the three which can bring about a yield 1.5 times more than that of a stand not fertilized at all. The ratio of N, P, K needed by a stand is 5:4:3, according to experiments. Research in optimal amounts of fertilizer application was done on this basis. The results show that the highest yield of a stand is attainable when a maximum of 250kg/ha of N is applied and no cost effective increase in production occurs when the rate is exceeded. To verify this conclusion, the same experiment was repeated in a *P. edulis* stand by Ueda and Suzuki, and the results reveal that timber is increased by 10 times more in an N standard area, but only 11 times more in an N double area, and none further in an N triple area. As far as silica is concerned, experiments tell us that in an area where silicic acid is used along with the three major elements new shoots occur 2.5 times more than the number from an area not treated at all and .5 times more than an area where only the three fundamental elements are used. In order to find out which is better, a sequence of tests was done on different types of N fertilizers. The results show that in an area where human waste and compost are applied, shoots are 7 times the amount of an area not treated. The other kinds ranged from 11 to 16 times and their fertility was in reverse order as follows: solid manure→urea→ammonium chloride→nitrolime→ammonium nitrate→human waste→composted animal manure. Where fertility is concerned, good application times are in March, August, and October with *P. viridis* as a case in point. The location most favorable for manuring is 1m around the mother culm.

In his **Bamboo Shoot Production and Stand Management**, the Japanese scholar Nonaka Jioji claims that bamboo shoots are limited in yield, retarded in sprouting, and poor in quality when importance is attached only to stand management. To bamboo, another vital element–silicic acid has to be added besides the essential three with an appropriate ratio of 10:5:6:8 (N, P, K, S). Fertilizer amounts should be kept consistent with the objective of shoot production. That is to say, 20kg of N, 10kg of P, 16kg of K, and 16kg of SiO_2 are needed to produce 1,000 kg of shoots; to produce 2,000kg of shoots, 47kg of N, 12kg of P, 30kg of K and 37kg of SiO_2 are required. So far as fertilizing time is concerned, the first should be done in early spring for output increase and early shooting; the second should be chosen when the mother bamboos are recovering and the rhizomes are elongating; the third should be timed and carried out to establish nutrients for rhizomes and to boost shoot buds.

Chinese scholars have also done some research in fertilizer ingredients and their results reveal a sequence of N P K in order of importance. They find that for each hectare the optimal amounts are 103.5kg of N (225kg of urea), 63kg of K (450 kg of phosphate), and 40.5kg of K (75kg of potassium sulfate). So the most appropriate formula seems to be N:P:K=5:3:2 .

In fertilization experiments on the shoot producing stands, N stands out as the major element absorbed. Application of N, P, and K in the ratio of 5:4:1 brings the highest yield of new shoots. Output of shoots is in linear correlation when fertilization amounts of N for each hectare varies between 799.5kg and 3, 100.5kg over 5 dispersals. With increase in fertilizer amounts, shoots remain the same in aspects of length, thickness, and individual weight with the above variations. No significant test of dispersals has ever shown a significant level of deviation. The three-time division of fertilizer application (30% in February, 40% in May, and 30% in September) is generally considered better than a one-time application in February or September. Site conditions and soil type can influence the ideal ratios, while species, growth habit, and weather affect optimum timing of applications.

It is universally agreed that a bamboo stand requires Nitrogen and that a more or less balanced combination of N, P, and K produces the most significant effect. But since different experiments yielded different results, the ratio of N, P, K has to be specifically decided with regard to available nutrient conditions in the local soils at different places. Different soil conditions require modified variations of the ratio of ingredients. And fertilizing for years running also calls for variations in the ratio. P and K, for example, can be reduced because they have a low rate of utilization in the current year. Also, different species have needs for different amounts of fertilizer. This can only be resolved in the light of knowledge of local conditions and species requirements. Time of fertilizing is not always consistent either. For instance, fall fertilizing in China used to be strikingly different from fertilizing at early spring in Japan, but this can be understood as the result of difference in types of fertilizer resources. As what was used in China was mostly fresh animal manure, it was effective to shift application to early fall for slow decomposition. But what Japan applied was for the most part predigested human manure, and its application in spring produced instant effect owing to quick absorption. Now a unanimous agreement has been reached that, given the growth rhythm and possible absorption of a stand, it would be more scientific to apply different fertilizers at various appropriate times.

• Management of Rhizomes

As the foundation for shoot growth, the health of underground rhizomes has a very close relationship to the yields of a bamboo stand. So the study of growth and distribution habits of rhizomes serves as a prerequisite to increase in shoot production. Among all reports at home and abroad, research in *P. edulis* is most exhaustive. Some results follow.

In clumping bamboos, due to shoot digging, the average length of rhizome sections and internodes are shortened in a grove managed for shoots. But the number of rhizome sections is clearly increased and total length and volume of net rhizomes is also increased accordingly. In the meantime forked crotches are increased 13% more than those of a timber stand, multiple crotches appear even unilaterally, and most of them grow at the first four nodes near the breakpoint. Soil of the shoot stand is made loose and fertile by intensive management; elongation directions and vertical distribution of rhizomes are also somewhat different from those of a timber stand. Most rhizomes, about 90% of the total system, are concentrated in the layer at 10~40cm, approximately 10cm deeper than in a timber stand. As age increases, strong buds on rhizomes gradually become fewer and the weak ones increase, especially true of rhizomes of 3~4 years old. Later they become rotten and fall off one after another. Rhizomes of a timber stand are in their prime of shooting when they are 3~4 years old while those of a shoot stand are at their best when they are 1~3 years old. But to the running bamboo, *P. edulis*, rhizomes of a timber stand have their strongest shooting capacity when they are 3~6 years old while those of a shoot producing stand are at their best when they are 2~5 years old. It can be safely said that rhizomes of a shoot stand come into the prime-stage one year earlier than those of a timber stand. Strong buds are mostly distributed in the middle part of the rhizome where shoots originate. Most lateral buds near the breakpoint germinate into rhizomes. Winter shoots are spread on the section where strong buds are numerous, occurring mostly on rhizomes 3~4 years old. About 8.47% of the lateral buds are able to germinate into rhizomes or shoots.

A grove of *P. edulis* is composed of several independent yet interactive bamboo rhizome systems each of which is further composed of standing culms and subterranean stems of various ages and sizes and thus a metabolic flow system of energy and substances is formed. Capacity of a bamboo rhizome system to regenerate and grow is first of all decided by its components which include the number and age distribution of standing culms, the age structure of subterranean stems, the number, length, and thickness of subterranean stems of different ages as well as the extent of root systems. Research indicates that a stand is likely to have a low productivity if it has few bamboo rhizome systems or a single bamboo rhizome system which is too massive. If a single rhizome section is too long (over 3m) or too short (below 50cm), it shows a low rate of producing new rhizomes and shoots. Rhizomes over 8 years old, having no viable buds, are no longer able to grow new rhizomes or shoots. Therefore, it is necessary to adjust the stand to an optimal state through human management. The specific requirements are: 1) To build a multiple system. For a stand with a culm stocking rate of 3,750/ha, it is desirable to have 20 bamboo rhizome systems each with a stocking of 20 plants and a proper age structure; 2) Age structure of subterranean stems also should be young with 80% of the rhizomes young to middle-aged; 3) The single rhizome section should be moderate. Rhizome sections 1~2m long should account for over 80%, rhizome body should be strong and untwisted, and the root system well developed; 4) The interweaving net of subterranean stems should be thick yet loose. Although adjustment in subterranean structures of the stand is not so easy as the part aboveground, the stated requirements can still be satisfied if adequate measures are taken.

• Shoot Digging and Reservation

As important steps in the management of shoot producing stands, shoot digging and reservation may seem to be contradictory at first glance while in fact they are not. In an experiment a 2m rhizome was deprived of the surrounding earth, all 12 of the winter shoots (three germinated buds included) were cut off, both ends were tied with lead thread, clear marks were left on the ground, then it was recovered with earth. This rhizome grew two new culms the next spring of normal size. This experiment was repeated three times and each rhizome was able to develop shoots into culms. Another case was in Miaoshan, a suburb township of Ningbo, Zhejiang Province. There they dug out all winter shoots in the plot at one time averaging 2407.5kg/ha, then the plot was fertilized, and still harvested 24,000kg of spring shoots for each hectare. It can be seen that when winter shoots are dug up, spring shoots of a stand can still be adequately vernalized if proper management measures are taken to increase fertility and accelerate differentiation of shoot buds. So the seeming contradiction can be resolved in practice. When mother bamboos are reserved around early April, only an average of 6,495 (culms/ha) can come up weighing 9,522kg. Though this provides a guarantee to quality of mother bamboos, it will surely affect shoot output. But if mother bamboos are reserved between early April and late April, an average of 8,685 (culms/ha) is attainable weighing 13,362kg. In this case shoot output is increased, of course, but quality of mother bamboo is moderately affected. It is inferred, therefore, that only when digging and reserving are carried out during the prime shooting period can shoot output and mother quality both be assured.

Except for shoots reserved to become culm mother bamboos, all other shoots should be dug up. New shoot reservation can best be done in the prime shooting period of the stand. If reservation is done too early, shoot output will decrease though output target of the stand can still be reached. This is because the over consumption of nutrients by the growth of new bamboo will place a check on the germination and growth of more shoots. If reservation is done too late, however, shoot output may be increased but number and size of the mother culms will be difficult to ensure. So, all shoots at different stages can be dug up except those reserved for future mother bamboo culms. Digging should be done in a timely manner to ensure quality, quantity, and weight of harvested shoots.

When shoots of *Phyllostachys edulis* come up naturally, more than half of them will fail for lack of adequate nutrition. Even in a shoot stand that is intensively managed, a certain number will abort for this reason. So it can be understood that digging out a certain part for food is well reasoned rather than contradictory. The main purpose of rational digging, then, is to regulate nutrient distribution in the stand. Early reservation of mother shoots (culms) will surely absorb too much nutrition and check shoot germination in the prime and final stages, thus affecting total shoot output. Late reservation, on the other hand, commonly causes a trend of new mother bamboos becoming smaller, since most cumulative nutrition of the bamboo rhizome system will have already been consumed by new shoots for harvest.

• Basic Construction for Shoot Stands

The purpose of basic construction for shoot production stands is to raise land availability and economic profits of the stand. In nature a shoot base is also an economic unit engaged in agricultural production. To construct a shoot base is to open up a special and sometimes considerably large area for shoot production. It not only marks transition of production from rough management to highly intensive management, but also turns this specialized production area into a research site for bamboo management. Constant improvement should be carried out to raise unit output and quality; detailed plans of transport and sales have to be made to minimize expenses of sales. To guarantee ample raw material for processing, shoot production and sales or marketing need to be integrated. All these demand that cultivation, processing, and sales be highly specialized. So the following factors should be taken into account when constructing a base for shoot stands: 1) The base should be set up where transport is convenient and as close as possible to a city with fair industrial foundation; 2) Soil conditions should be good, i.e. loose but not scattered, fertile but not rotten, with a strong capacity to hold water and let air in; 3) Water resources have to be easily accessible, with irrigation equipment; 4) The base should be large enough for profitable investment and full use of various mechanical apparatus; 5) Reasonably arrange road systems to improve transport capacity, build 1~2 temporary warehouses and one preliminary processing factory for normal handling; 6) Choose suitable species for a reasonable match to use, land, and climate. To evaluate a shoot producing species the following factors are to be considered: **a**. Morphological features of the shoot (identification of shoot as raw material); **b**. Biological features (precondition for base construction); **c**. Nutrients; **d**. Output (including normal output and maximal potential); **e**. Processing conditions (including length and thickness of shoot body, thickness of internode and wall thickness).

B. Paper Production Stands

Possessing long fibres, bamboo timber serves as excellent material for paper making. Though both India and China rank among the top countries in the world with rich bamboo resources, about 66% of paper making material in India is from bamboo while in China only 2% is currently from bamboo. So how best to adjust material structures of paper making and bring forth a modern industrial system with Chinese features for the paper industry. This has become a major concern for the Chinese. Experts believe that replacing wood with bamboo is an essential approach to developing a more ecological paper industry and that the crux lies in base construction for paper production stands(Li, Qi-Ji 1986).

The management of bamboos for paper is similar to that of bamboos for timber; however, in base construction the following points should be born in mind.

• Choosing High Quality Species

Criteria for species assessment change according to different purposes of utilization. So far as paper making species are concerned, first and foremost it has to be adaptable to the ecological environment of the site, so best if an indigenous species with a strong adaptation. Second, it should produce straight and large culms with moderate wall thickness. And third, it should have a high content of long fibres but a low content of lignin and silica. In the hills and basins in Sichuan, for example, *Bambusa emeiensis*, *B. pervariabilis*, and *B. rigida* are preferable; in West and South Yunnan, *Schizostachyum funghomii*, *Dendrocalamus membranaceus*, and *Cephalostachyum pergracile* are perfect; but in the middle and lower reaches of the Changjiang *Phyllostachys edulis* is most suitable. Other species such as P. rubromarginata are also worth evaluating as candidates for pulp production, especially for use in colder areas.

• Identifying Mature Ages of Bamboos

The optimal harvest age of a species is determined by its intended application or end use. Once its end use requirements are known, the canes considered to be mature can be harvested for the purpose intended. Research shows that chemical elements in bamboo undergo changes with advances in age. During the stage of 1~4 years not much change can be expected in content of cellulose, lignin, and silica of *Phyllostachys edulis*. But when over 5, the culms are past prime and the cellulose content drops from 48.36% to 44.28%. So 4-year old culms should be protected considering quality of both the stand and paper and all culms of 5 years harvested. But on the other hand for tropical clump forming bamboos, the bud producing capacity of the mother bamboos should be regarded as a key factor in deciding felling age, since the development of new canes of clumping bamboos depends on activation of basal buds on their mother culms.. For example, 4-year mother culms of *Bambusa emeiensis* have totally lost their budding capacity and the stand grows best when 4 generations are simultaneously preserved. In the meantime no distinct changes of chemical elements take place between culms of 3~4 years old and those of 1~2 years old. So felling age of this species would be better identified as all years over 4. It is a good practice to determine optimal felling ages of different species for paper making through scientific research.

• Setting Reasonable standards for Unit Output

At present plans for base construction are on the whole made on the broad assumption that each year 1 ha of bamboo forest provides 15,000 kg of material for paper making. Bamboo output is closely related to and dependent on species, habitat, and management. With proper management in Sichuan for instance, each year 1 ha output of *B. emeiensis* may reach 12,000kg while *P. nigra* var. *henonis* reaches only 9,000kg. In a specific case of base construction a suitable standard of output should be established by thorough investigation of local conditions.

• Keeping Fertility Over Time

This can only be guaranteed by means of repeated manure application and green manure intercropping.

• Reducing Insect Boring and Fungal Moulding

Staining mould and borers are two problems currently encountered in the process of bamboo paper making. When mouldy, bamboo timber is decreased in pulpability and bleachability by 10% and 9% respectively. Its quality is also either decreased or in some serious cases it can't be pulped at all. These problems call for immediate study and solutions for protection from time of felling to transport and storage.

C. Ornamental Stands

Fig. 5-14 The bamboo garden at the International Horticultural Exposition in Kunming, China(1999), from Kunming, Yunnan. Photograph by Hui, Chaomao, 2000

Developing ornamental stands is an important aspect of promoting the ecological and social benefits of bamboo. The Chinese people have long nurtured a tradition of treasuring bamboo, since its noble character not only provides people with keen enjoyment but also influences their temperament. In fact it has been regarded as indispensable to gardens of the classical Chinese style. It enormously beautifies people's lives and enhances their spiritual civilization. Wangjiang Park in Chengdu, with many celebrated bamboo species, offers a great attraction to tourists from everywhere. A bamboo arboretum functions as a base with dual purpose; to specialists it is a herbarium but to the public it is a fresh, clean resort for rest and recreation.

Then how best to develop the ornamental aspects of bamboos and further popularize their uses in landscaping? How best to give full play to the advantages of various bamboo species in our country and the world? How best to combine plant appearance with ecological and environmental aspects to combine with local flavor in city greening and garden design? The major issues to be dealt with are introduction, expansion, proper management, and construction of Bamboo Gardens.

• Suitable species and provenance

Manifesting special rhythms, the growth habit of bamboos differs sharply from that of familiar tree species. In the period of shoot development, sprouting, and growth in height, bamboos rely on cooperation from certain ecological factors including soil, temperature, moisture, and so on. Though the leading factors are rhythms of temperature and precipitation, the crux still lies in division frequency of these indexes between seasons. If seasonal rhythm distribution of temperature and precipitation in the intended district accords harmoniously with growth rhythms, i.e. seasonal growth rhythms of the to be introduced species, that is to say they mutually agree and synchronize, introduction should be a success. If ecological factors are adjusted by human measures such as irrigation and warming to fit growth rhythms of the introduced species and synchronization is achieved, introduction is also likely to turn out a success. On the contrary, if synchronization can't be achieved and we are unable to satisfy growth requirements of the introduced species by human means, then introduction will most likely fail.

It is true that species for the horticultural landscape do not necessarily require a high productivity. Their introduction value should be assessed by ornamental standards rather than by economic ones, i.e. those for timber or shoot production stands. That is to say, if an introduced species is able to grow and propagate well with fine ornamental effects in the garden instead of withering, dying, or suffering from insects and diseases, it should be reckoned as a success though it may not be as productive nor grow to the height and thickness found in its home provenance.

Based on the rhythm synchronization theory of ecological factors, value norms of horticultural ornamental species, and features of local ecological factors, chief candidate species to introduce and corresponding management measures to take can be preliminarily decided. The first type is those from similar conditions which require no specific measures of cultivation and management after introduction. The second type refers to those which need only simple measures of cultivation and management, such as planting in shady places or with proper irrigation. The third type includes those which have a high introduction value but also a demand for indoor growing or other special measures because of strong differences in conditions between the introducing district and the original provenance.

• Introduction Techniques and Development

Deciding Introduction Time and Methods: In order to make introduction a success, proper timing and seasons must be considered for various places since bamboo species may differ greatly in their peak periods of shooting and growing. Bamboos are more apt to survive when introduced during dormancy a short time before shooting, when their physiological activities and metabolism are weakest and their reserves of stored nutrients are highest. For example, species of *Phyllostachys* can be introduced in winter as they generally shoot in spring; species of *Gigantochloa* are suitable for introduction in spring as they shoot in summer; and introduction of some other species such as *Bambusa emeiensis* should be done in summer since they shoot in fall. Planting with bamboo transplants is a method frequently used in introduction, but propagation with buried nodes and cuttings for clumpers (only) is preferable when sources are limited but demand is heavy.

Setting up Archives of Introduction and Management: Complete original records of the introduced species should be kept, preserved, and replenished for future summary and spreading. Main items of the archives include time, provenance, habitat at provenance, growing state, introduction method, measures of cultivation and management taken at the introducing district and others. Introduction archives should be timely set up and steadily maintained.

Expanding Introduction Field and Means: Build up "Bamboo Streets" In urban landscape reform and street tree regeneration, clumping bamboos can be considered as a special plantation or tree species. Development and utilization of ornamental bamboos should be popularized and promoted wherever climatically suited. Some streets may be designated as "Bamboo Streets". To achieve an ideal effect, we may match certain elegantly- figured species of clumping bamboos with varied flowers and trees, open up some stores for bamboo ware and crafts, hold some bamboo exhibitions or run some wall newspapers on bamboo culture to further educate the people.

Create "Spring Yards of Bamboo" Widely spaced bamboo forests can be created through species configuration, such as *Phyllostachys nigra* f. *henonis*, *P. edulis*, P. decora, *P. nigra*, and *P. bambusoides* with meadows interspersed. With culms slender and full of spring vigor, they function as a desirable cover for rough terrains marginal belts in public places such as factories, government agencies, educational institutions, and parks. They offer people a distinctive spring view, especially attractive in fall and winter when other trees have lost all their leaves. **Design "Living Bamboo Museums"** This in fact means to design and construct special Bamboo Gardens of different sizes and styles, which will be elaborated below.

• Construction and Management of Bamboo Gardens

Bamboo Gardens have been established in quite a few places in China and are becoming ever more popular worldwide. In China, for example, the bamboo arboretum at the Nanjing Forestry University, Anji Bamboo Arboretum at the Subtropical Forest Institute of Chinese Academy of Forest Science, the bamboo arboretum at the South China Botany Institute of the Chinese Academy of Science which were built mainly for scientific research. There are also purely ornamental Bamboo Gardens, such as Wangjiang Park in Chengdu, built mainly for the purpose of tourism.

1) Purposes and Significance of Bamboo Gardens

a. Preserving Bamboo Genes: Being generally abundant in resources and complex in floral elements, China also enjoys a wide diversity of bamboo species which constitute a rich reservoir of important bamboo genes. The primary task of a bamboo arboretum is to conduct a broad introduction of all site compatible species so as to have them preserved and developed under human care for future research and special uses, and to protect them from both natural and social catastrophes which they sometimes suffer in natural conditions.

b. Establishing a Base for Research: Difficulties are frequently encountered in bamboo research. In taxonomic classification, for example, discrimination errors are caused by a short shooting period, long flowering interval, and many incomplete specimens, especially by lack of culm sheaths which are taxonomically significant yet seldom available because of decay. In the study of ecological features, it is necessary to observe and record regular patterns of development and phenological changes in different bamboo species. But for species growing in remote mountainous districts, this is either nearly impossible or can't be accomplished to the desired degree, even though much time, money, and man power may be spent. In physio-chemical studies, in order to obtain accurate data and determine relevant indexes, it is a preferred practice to have fresh samples for experiment and analysis. This, however, is not easy for species occurring in places far away from the research site. In cross-breeding research, pollen collection is all the more necessary for seed cultivation through hand-pollination and artificial segregation, to selection and appraisal of filial generation through artificial propagation for fine strains. Problems like these can be more easily solved once Bamboo Gardens are built. A bamboo arboretum, therefore, is an ideal base and a living herbarium for scientific research of bamboo.

c. Offering a Tourist Destination: People need a tranquil place to rest themselves after intensive work; people who are getting materially richer have an urge for fine recreation. With a unique cultural connotation and outstanding ornamental landscapes, a bamboo arboretum satisfies people's special needs by offering them an ideal place to nourish their nature and soothe their temperament. If each species is sign boarded with a brief introduction including names (local and scientific), distribution, biological features and economic value, the arboretum is then functionally turned into a living "bamboo museum". Visitors will subconsciously acquire some knowledge about the vast territory and rich resources of our motherland while being properly impressed by colorful figures of bamboo culms. Their passions may be aroused to love the country better and help protect our natural resources.

d. Providing Bamboo Species for Greening: After construction of an arboretum, appropriate bamboo species can be chosen to propagate in large quantity to satisfy needs of planting in and around the host city.

2) Measures for Construction and Management of an Arboretum

To make an arboretum a success, the following four points are important: a fair investment, specialized personnel, selection and preparation of the site, and the introduction itself.

a. Making an Appropriate Plan: To construct an arboretum, the first step is to plan for the ditches, roads, tubes, pavilions, landscape, and other aspects of infrastructure for the convenience of planting, managing, and visiting. The general layout can be divided into a clumping bamboo section, a running bamboo section, and a mixed bamboo section. Different species can be configured into a reasonable match with similar types that are tall, low, thick, and thin. Small-sized species can be rendered into bamboo hedges and flower beds; large-sized species can be planted into bamboo walls and forests; and species with graceful figures can be designed into some ornamental pieces of art. Since rhizomes of running bamboos are liable to extend far underground, cement barriers are commonly used as blockage to prevent them from getting mixed up, even so some management is needed. To kill two birds with one stone, bamboo may also be planted at suitable but detached places on the basis of landscape needs. The general layout can also be arranged into a specimen section, a rare section, and an ornamental section. To sum up, the final decisions depend on the vision and chief purposes of the arboretum.

b. Tightening Management: A balanced plan of introduction, cultivation, development, and management becomes the premise and basis for the successful construction of an arboretum.

c. Scientific Research: To ordinary visitors a bamboo arboretum is a fine place for rest and recreation; but to the professional staff and visiting bamboo scholars, it means a valuable living herbarium. To put it to full use, as much research should be done as possible, such as observing and recording regularities of bamboo growth and development, contrasting tests of different cultural measures, and physio-chemical studies.

d. Expanding Business of the Arboretum: The arboretum has a multiple function once it is set up. When developed to a considerable scale, the arboretum can have its business expansion realized through different ways such as opening up to tourism and exchanges, harvesting shoots and timber for direct economic profits, contributing more to social gardening and beautifying people's lives with more desirable bamboo species. In a word, a bamboo arboretum should become an integrated synthesized entity combining tourism, ornament, research and production.

D. Multi-purpose Stands

The purpose of building a multi-purpose bamboo stand is to make full use of bamboo's ecological environment. In this section we are going to discuss the theory of constructing such a stand by analyzing the utilization by bamboo of the ecological environment (Li, Chang-Rong; Tu, Liu-Ban 1987).

Utilization of bamboo has long been confined to the production of shoots and timber. Even from ancient times, bamboo timber has been used to build houses and to create devices for man's production and life; and, of course, bamboo shoots have been collected for food. Bamboo utilization, however, has been expanded in recent decades. To give fuller scope to their ecological impacts, bamboo stands are used to conserve soil and water, and to protect slopes and banks. To bring their social effects into full play, their beautiful impact in the landscape is made use of in tourism and recreation. But as to material things, bamboo gives only timber (including tops and branches) and shoots. In recent years culm sheaths have been used as raw material for carpeting and sofa stuffing, but it is too small in quantity to form a separate type of bamboo product. When bamboo is applied in paper making or made into kinds of bamboo wares and panels, when shoots are processed into dried shoots and tinned shoots, utilization and commodity types of after harvest timber and shoots are increased but with no increase yet in their primary production. So in the final analysis, if viewed in terms of industrial bamboo production and primary output from bamboo ecological systems, there have historically been only two basic types from very ancient times to now–timber and shoots.

This is not consistent with the boom of industry and agriculture in China. We need to go beyond the old conventions of bamboo utilization and produce various new biological products.

The phrase "utilization of bamboo's ecological environment" refers to people's biologically based industries (for higher economic profits) which make use of its ecological environment (beneficial to raising or improving the ecological quality of a bamboo stand). With this in mind, we may draw an essential demarcation line between "burning bamboo for farmland" and "utilization of bamboo's ecological environment". The practice of burning down a vast stretch of bamboo forest for mere farmland belongs to the most primitive use of a bamboo stand. Once the stand is destroyed and the ecological environment completely vanished, how can that be called utilization of the bamboo ecological environment?

The bamboo ecological environment is a three dimensional system that includes not only the ground area and the 40cm soil layer below, but also the canopy and the space under it to the ground. Any kind of biological production within this stated scope is an instance of utilization of bamboo's ecological environment. For example, by spreading spawn culture media on the stand ground or by putting up racks and bags, the ecological space of the stand can be more fully used to grow edible fungus, bamboo fungi, black fungi, *Lentinus edodes*, and other valuable plants such as medical and ornamental plants. Or by combining functions with biological control of pests and diseases, space and canopy of the stand can also be used to raise various economic birds.

Conditions of the bamboo ecological environment differ tremendously between different species and structures. Comparatively speaking, the stand of *Phyllostachys edulis* holds superiority in ecological environment. If managed well, it offers an ideal site for all types of biological industries with the advantages of fertile soil, rich in organic matter, fair ventilation, as well as spacious and weed free ground.

5.6 Management Measures Taken in the Past Dynasties

5.6.1 Bamboo Documents

China has of a long history of bamboo production recorded in many historical documents that date back to the Shang (16th–11th B.C.E.) and Zhou (11th century B.C.E.–221 B.C.E.) dynasties. Legend has it that bamboo musical instruments appeared even earlier during the period of the Yellow Emperor (Earliest legendary ancestor of the Chinese some 4,000 years ago) and bamboo cultivation became popular from the Zhou dynasty. It is recorded in **Book of Zhou** by Jizhong that "…during the reign of Emperor Cheng (circa 1,000 B.C.E.), a traveler presented the Majesty with a gigantic bamboo". Bamboo production experienced a great development during the Han and Tang dynasties (206 B.C.E. -- 907 C.E.). It is written for example, in **Records of the Great Historian** that "There are planted a thousand mu of bamboo in the Wei Valley." **Book of the Han Dynasty** maintains that "There are in Qin a vast tract of Edu bamboo and a huge forest of bamboo on the South Mountain, which they call a 'land sea'." (Chen, Rong 1984).

Following is a list of main historical works from the Jin to Qing dynasties (317–1911 C.E.) with accounts of bamboos.

5.6.2 Management Measures

Rich experience of bamboo planting in China has been accumulated over its 3,000-year history. The following extracts are selected from documents above (Chen, Rong 1984).

• Site Selection

Fundamental Techniques of the Qi People: "Bamboo growing occurs suitably on a leveled flat land, particularly near mountains or hills with soft yellow-white soil. When their rhizomes extend into water-logged fields, however, bamboos are bound to wither and die." "Bamboos grow well on leveled hill sides with soft sandy soil."

Shoot Illustration: "Bamboos grow exuberant on a leveled land with yellow and ventilated soil. They grow well near mountains or hills, but wither and die when their rhizomes touch water in the field."

Book of Tree Planting: "Bamboo beds should be built up with earth until they are 0.66~1.0m higher so that they won't be damaged when showered in the rain. These are called 'bamboo feet' by the Qiantang people."

Guide to Flora: "With a strong resistance to heat and cold, bamboos live through the four seasons with evergreen culms and leaves. Their nature of integrity ranks them with such noble trees as pine and cypress. Preferably wet than dry, their roots should be watered." "Bamboo planting is best done towards the sun."

• Transplanting of Mother Bamboos

Bamboo Chart: "Any bamboo initially planted is said to be a 'mother bamboo'."

Fundamental Techniques of the Qi People: "In the first and second months of the lunar year, transplant bamboos from the southwestern to northeastern corner of the garden. Preserve roots and stems but cut off leaves. Make the hole 66cm deep and recover with earth to 20cm after the planting is done. As bamboo shows a natural tendency of extending southwesterly, it is planted northeasterly in the common practice. The garden will surely grow full after years go by. The proverb says that 'When one family plants running bamboos, its close neighbor may get the land prepared.' This refers mainly to the probable extension of rhizomes. Fertilize it separately with loose manure of rice and wheat straws. Irrigate not with water, otherwise may die. Domestic animals are denied entrance."

Shoot Illustration: "Bamboos in the middle of autumn are also regarded as Xiaochun (crops or plants harvested in late autumn), for at this alternating time of heat, cold, and chilly wind trees are in flower, grasses produce fruit, and bamboos also have their roots extended. In common language the extended roots are called rhizomes and their elongating heads pseudo- shoots."

Book of Arviculture: "It is advisable, in the process of planting, to have bamboo tops and branches cut off. Cushion the hole with blended mud, put the bamboo in, and then cover with earth. Stamp it solid with a chisel instead of foot till the cover is 20cm thick."

Book of Tree Planting: "When planted in a fenced yard, bamboos will inevitably flourish in one or two years. To put it in the gardener's words, he practices no real skills but merely chooses thin planting, dense planting, shallow planting, or deep planting. Thin planting means to plant every 1~1.3m apart with space big enough for rhizome extension. Dense planting involves growth of 3 or 4 culms in the same hole for interwoven roots though the plantings are far apart. Shallow planting means to insert the bamboo shallow in earth when it is planted. Deep planting refers to covering the bamboo with channel mud though it is shallow at planting." The above applies to clumping bamboos only.

Guide to Flora: "To start with, cut off the surrounding lateral roots 30~70cm apart from the culm, recover with earth, and frequently spray with water. The bamboo survives immediately if transplanted after rain, and the leaves remain unexchanged. Dig out their southwestern roots and have them transplanted intact. It would be even better to support with a frame." "Transplant bamboos with host earth stuck on, and not stamp with human foot. Do not pick away all leaves if they are in exchange." "Another method for bamboo transplanting: to abide by weather winter is the choice; to consider moisture rain is good; to have more shoots the roots are to be combined." "Bamboo planting should conform to natural mandate. The 5th and 6th months of the lunar year serve as a good season for transplanting when old shoots have grown up and the new ones haven't started yet. Do not tramp with foot. It would be better to have it done in cloudy or rainy days." This also is for clumping bamboos.

Encyclopedia of Farming Affairs: "Soil block should be thick in bamboo transplanting, which means to preserve host earth as much as possible. Dig a hole of 40cm deep in flat land, transplant the bamboo with host earth, cover with loose soil, and do not tramp with foot. Spray with water everyday and stop when it is assumed to take stand. A support is necessary to prevent wind shaking. Another method: Cut off from 4 or 5 nodes upward in transplanting the mother bamboo. Since it does not break the wind, it would be simple to do without any support." "The proverb goes that it takes one person ten years to plant flourished bamboos while ten persons one year to do this. This means to do transplanting in bundles for the sake of not hurting roots." For clumpers.

Phenology in Leisure Time: "Bamboo transplanting is best timed in the early summer when old shoots have grown up and new ones have not yet started. First cut off the roots with a knife 60~100cm apart from the culm 2~3 months old or even, half a year old. Restore earth, spray with water four times till transplanting and survival takes place right away. Shaking should be prohibited all the time. It would be desirable to cut off the top, prop up with a support, and plant with a mixture of horse waste and soil instead of mud and water. Stamping or tramping with foot should be avoided." "Cut away the culm with 70cm preserved, stuff brimstone inside the internode, turn it upside down with roots over, and cover with earth. Shooting occurs in the same year. Culms should be transplanted in a large quantity so as to have several in a cluster, as a single culm by itself is unlikely to survive." For clumpers.

Notes by Three Farmers: "In bamboo transplanting, first cut off the lateral roots 0.6~1.0m apart from the tap root, recover with earth, and spray frequently with water. Immediate survival comes when transplanting is done after a rain." "Choose a large bamboo culm and cut off its upper section with 10~15cm reserved near the root. Open up the nodes, stuff inside with brimstone, plant it in a reversed position, and small shoots are produced in the first or second year." For clumpers.

• Nursing (of clumping bamboos)

Shoot Illustration: "Bamboo roots are called rhizomes, and rhizome heads are called shoots or rather, pseudo-shoots in common language. In mid-autumn countrymen at Wukuai habitually dig out shoots for sale on the market. This, however, harms not only spring shoots but also mother bamboos."

Flower Culture: "Fertilizing a bamboo garden should be done in mid-autumn with thick manure of barley or rice straw."

Notes by Three Farmers: "Hoeing of orchards can be done in summer while that of bamboo gardens in mid-autumn."

Annals of Profitable Plants: "Bamboo planting is really profitable. Shoots may serve as food and culms as tools that have very extensive uses. People need not bother themselves with anything like irrigation, except for hoeing once a year. They just grow well in the open field."

• Felling and Regeneration (of clumping bamboos)

Bamboo Chart: "Some bamboos have a longevity of 60 years and a regeneration of 6 years. That is to say, they change roots every 60 years when they bear fruit and die. After their fruit fall to the ground, they repeat growing and form a new generation in 6 years."

Fundamental Techniques of the Qi People: "Bamboos meant to produce bamboo wares should be felled at least one year old. If younger they are still soft because of immaturity."

Guide to Flora: "Amongst bamboos the three-year old should be protected while the four year old should be done away with. As the proverb says: "Grannies and granddaughters never meet but mothers and daughters never separate." This is to say bamboos are to be felled every other year. They are not strong enough for wares if younger than one year. They cannot flourish unless the old are dispersed of. But felling should be regularly timed." "When felled in early spring bamboos will not be bored through. Bamboo fluid is consumed in sprouting in spring, stored in culm in summer, and transported back to the roots in winter. When felled in the 11th lunar month, they are to crack from end to end within one day. When felled before the 5th month, their roots and rhizomes become decayed. They won't get bored through if felled in summer, but it does harm to the stand. Felling occurs best in autumn and winter, whereas later than this bamboo becomes useless."

Notes by Three Farmers: "Felling of trees and bamboos is best done in late summer. Wares made from bamboos felled in winter are free from insect damage."

• Shoot Collecting

Fundamental Techniques of the Qi People: "Shoots of Glaucous bamboo are in season in the 2nd month while shoots of bitter bamboo come in the late spring or early summer."

Shoot Illustration: "Dehydrating methods: for large shoots, prune off the sharp heads before they are cut in halves. Have them salinized for long in salt and then dry them in the scorching sun. Small shoots are usually steamed and salinized before they are dried over a gentle fire. To keep their wonderful flavor, shoots are without exception steamed before they are served for food."

Book of Arviculture: "One method for shoot collection is to cut off the dense, slanting ones in the cluster. It is undesirable to dig up those in the rhizome extension, or the stand cannot flourish."

Phenology in Leisure Time: "To make dried shoots, 50kg of shoots are to be soaked for a fairly long time in the solution of 5 litre salt in a small bucket of water before they are taken out of leaching. Cook them thoroughly in the clarified original brine, take out to squeeze and dry in the sun. To have them prepared for food, soak them until soft first in clear water and then cook in the original water."

5.6.3 Bamboo Proverbs

"Millions of culms planted, the descendants blessed" (illustrating the high economical value of bamboo).

"A patch of bamboos constitute virtually a single tree" (Rhizomes combined into a whole).

"Bamboos are interconnected by roots: mothers give birth to daughters and daughters to granddaughters" (ditto).

"Sprouting in early April and growing up by late April" (*Phyllostachys edulis* in Zhejiang).

"Bamboos fear drought in autumn and winter, since their shoots may decrease by half" (Zhejiang).

"Around Beginning of Summer the whole garden turns red" (shooting season of *P. glauca*)

"Two-year green, four-year white, and ten-year red" (age density of *P. edulis*).

"Prepare land when your neighbor is planting bamboos, for shoots usually grow outside of the fence." (runners)

"Bamboos extend across a wall while fish slip into a neighbor pond, for bamboos never extend across water." (runners)

"Monthly planting of bamboos no better than on 26th of the 1st month; bamboo planting at the Winter Solstice while tree planting at the Beginning of Spring."

"Bump not in bamboo planting; loosen not in pine growing." (method for bamboo cultivation).

"Ten persons carrying makes a bamboo forest in one year; one person carrying makes a bamboo forest in ten years."

"Grannies and granddaughters never meet but mothers and daughters never separate" (Hunan).

"When three generations are together kept, grannies and granddaughters meet" (Jiangsu).

"Felling in May makes kids and mums cry" (felling unfavorable in May).

"Fell in autumn of the on-year but before spring in the off-year" (felling season).

"Felling after the Double Ninth Festival brings no boring; bamboo boring occurs in spring while tree boring takes place in winter."

"Fell the dense, bent, small, and weak; preserve the sparse, erect, large, and strong."

"A thriving garden is unexposed; an exposed garden is unthriving."

"Dig not good shoots; preserve not reduced shoots" (preservation of mother shoots).

"Cut brush in summer, clip grass in autumn, and rip soil in winter" (bamboo stand nursing).

"Field unploughed yields no grain; mountain unstripped grow no bamboos" (Jiangxi).

"Shovel off one Cun in the on-year; dig to the root in the off-year."

"Bamboos consume no manure but a Cun each year" (bamboo fertilizing).

"One year green, two year purple; fell not at three, go hell at four" (*P. nigra*).

5.6.4 Management Techniques

• Management of bamboo plantations

Thinning of culms: For well-managed stands of clumping bamboos, rampant shoots will occur within 3 to 4 years time. The excessive development of bamboo shoots frequently leads to stand overstocking or overcrowded clumps, which often hinders shoot emergence, affects bamboo quality and brings difficulties to harvesting activities. Therefore, adequate thinning operations should be made upon the canopy closure of the clumps to remove a certain proportion of the old bamboos over 3 or 4 years old, especially those which are crowded with each other and those of bad growth. The intensity of thinning depends on the size of the culms and the density. Thinning operations should be designed so as to result in a more reasonable spatial structure of the stands so that the clumps can have free horizontal extension. Both the shoots and the bamboo canopy will have more space for development, which is beneficial to shoot development and bamboo growth. Thinning operation can also be used to make the age structure of the stands more desirable. Retention of the 1 or 2 year-old bamboos, partial removal of the 3-year-old culms and total cutting of the 4-year-old culms will surely help keep productivity high.

Thinning of shoots: Due to the biological features of bamboos, the effect of environmental factors and the infection of pests and diseases, not all shoots develop into culms. Some of the shoots will abort after a certain time, which is called shoot degradation. These degraded shoots, if detected at an earlier time, can be culled and utilized. The timely removal of degraded shoots will also prompt stand growth. Generally, shoot degradation is more likely at the beginning as well as the end of the shoot producing season. Bamboo shoots from 2-year-old culms, overstocked clumps, bad growers, or culms infected by pests have a high percentage of degradation.

If the shoots are too dense, efforts should be made to remove some of the normally developed shoots (at either the beginning or the end of the shoot producing season) so as to ensure the stand quality.

Harvesting of bamboo timber: Harvesting of bamboo timber from clumping species should be carefully managed in terms of stand age, intensity and timing. Fully developed, 3 to 5 years old, bamboo culms have a tight texture, maximum accumulation of both organic and inorganic materials, a high fiber content and stable physical and chemical properties. They are highly lignified with the greatest mechanical strength. Also, their durability, antiseptic capacity and pest resistance are at their peak. After this stage, the physiological processes of bamboo growth will slow down gradually till the death of the individual clumping bamboo culms. Therefore, 3 to 5 years after planting will be the optimal time for first bamboo timber harvesting. Generally, bamboos older than 3 to 5 years will stop yielding shoots and at this stage, their nutrient consumption begins to exceed their contribution to the stand. The development of shoots and the growth of the young bamboo culms will both be negatively affected by a high percentage of over-mature culms. This can easily lead to over-mature stands, lowered productivity and gradual degradation of stands. Thus, if the stands are developed mainly for producing bamboo shoots, the timely removal of all the culms older than 4 years and some of the 3-year-old culms will not have a detrimental effect on shoot production. Instead, it will promote stand regeneration which often results in a more rational age structure, a higher productivity and more vigorous stand growth. For commercial stands, the appropriate time for the first harvesting is 5 years after planting.

For newly created plantations, the intensity of the first felling operation should be kept at a relatively low level. The felling intensity of the other plantations depends on the species and stand density concerned. Studies on the large-sized clumping bamboo species indicate that for most bamboo plantations, the proper harvesting intensity is realized by retaining all the 1 to 2-year-old culms and most of the 3-year-old culms, culling some of the 3 to 4-year-old bamboo culms and removing all of the bamboo culms older than 4 years.

For clumping bamboo species, harvesting can be accomplished during the dry season when the clumps do not produce shoots and the physiological process is weak. Harvesting at this time will not result in serious damage to the remaining bamboos. Also at this time, bamboo's content of sugar and other soluble organic substances is relatively low and the harvested bamboo timber is less likely to be attacked by pests. What is more, because of the low water content, bamboos harvested during the dry season do not mould or shrink easily and thus have superior processing quality.

To minimize waste in the course of harvesting, the culms shall be cut at the point as close as possible to the basal part. For bamboo species with thorny bases, harvesting can be done in two phases. In the first phase, the culms can be cut at the point 2 to 3 meters above the base, the rest can be harvested half a year later. The basal section is usually stronger and can be used for furniture.

• Improvement of natural stands

Efforts should be made to transform natural stands or over-mature stands with poor management into productive plantations. As most natural stands or over-mature stands are mainly composed of older culms and in some cases it is hard to tell the stand age. Then artificial measures must be adopted to improve the stand quality. Currently, the preferred technique is selective thinning.

Principles and approaches concerning selective thinning: Thinning should not be completed in one operation but must be implemented through different stages. It will usually take 3 to 5 years with one or two thinning operations each year to improve the quality of neglected natural bamboo stands through selective thinning. For each operation, the harvested volume should be controlled and kept at a low level. The resultant stands should have a more reasonable stand structure.

Timing of selective thinning: The optimal time for thinning of clumping bamboos is the dry season. In tropical regions of south China, this season usually falls from December to March, during which the physiological activities of the bamboo are weak and the bamboo culms have a higher content of sugar and other organic substances which favor bamboo utilization. Also during this season, the physical effect of the thinning operation on the remaining stands will be minimized. Thinning should not be planned for rainy seasons when the stands are producing shoots. The objective of natural stand improvement is to cull the overstocked old culms, stimulate shoot sprouting and promote the growth of young culms so as to result in a well reasoned age distribution and spatial structure of the stands and to realize a sound energy flow and substance circulation within the bamboo forests.

At the beginning, it is not easy to tell the age of the culms and people can only find the oldest bamboos (usually more than 6 years of age) through rule of thumb. The first operation should start from those oldest culms and goes to the younger individuals. After 3 years of continuous thinning, the oldest remaining bamboo culms will be 3 or 4 years old and at this time it is possible to have a precise designation of the age distribution of the concerned stand. With the help of this description, the managers can take appropriate measures to maintain the stands ideal age structure.

Intensity and approaches of thinning: Though the timely removal of old culms will promote stand regeneration, excessive harvesting will negatively impact the bamboo clumps. Therefore, intensity of the first thinning operation is strictly controlled. If we take the number of culms older than 4 years as the basis, the intensity of the first thinning should be limited within 25-50%. In case of small and loose clumps, culling 25% of the culms older than 4 years will be appropriate and for large and dense clumps, 50% will be the upper limit.

Thinning procedures: Generally, in natural stands, the old culms and young culms are not distributed evenly in the clumps. Culms younger than 3 years old often cluster at part of the clump such as at the center or to one side.

If the newly developed culms are primarily found at the center of the clump, then the thinning should start from the side with the oldest culms. If the newly formed culms mainly concentrate on one side of the clump, thinning operation should start from the opposite side so as to draw the new culms towards the opening left from thinning. During the thinning activities, culms older than 5 years, bad growers and culms infected by pests or diseases shall be culled first. Then through successive activities, culms older than 4 years, and any additional dead culms or culms with pests and diseases will be eliminated. From the first thinning operation on, the newly sprouted shoots should be marked year by year and the age distribution of each clump should be carefully recorded. From the fourth year of thinning, all the unmarked bamboos should be removed and marking of new shoots continued. Beginning from the fifth year, the age distribution of the clumps will be clearly understood and can be used to guide the future thinning operations which should concentrate only on the culms older than 3 years. Depending on the specific situation, stands should be thinned at different frequencies.

• Establishment of bamboo bases

Establishing artificial bamboo bases or plantations undoubtedly involves enormous investment. This is especially true if the propagules have to be purchased from commercial nurseries. When the nurseries are too far from the planting site, the cost of plant transport, loading and unloading will also add to the cost.

But compared with tree plantations, the investment of establishing bamboo bases is lower for the following reasons:

a. Clumping bamboo is usually spaced at 7m x 7m or 10m x 10m while spacing for tree seedlings is 2m x 2m or 3m x 3m on average. Due to this difference, the propagule number per unit area of clumping bamboo plantations is less than for tree plantations.

b. Bamboos have strong vegetative propagation ability. Once planted, they can keep regenerating and so can maintain the harvest for a long time.

c. Economically, bamboo stands can generate profits at an earlier age and in a shorter time than tree plantations. Plantations designed for shoot production will begin to generate income from the third year after stand creation and plantations for timber will begin to be profitable after 4 or 5 years.

d. Bamboo plantations do not need complicated tending measures and management efforts, thus the cost for management of the mature stands is also relatively low.

e. Bamboos are more adaptable than many tree species. Besides, clumping bamboos do not necessarily need a large and continuous site and can be planted wherever the spatial condition allows.

Thus it can be said that bamboo plantations involve relatively low initial investment and management cost but can yield high economic returns beginning early and continuing over a long time. The ratio of input to output is more favorable than that of tree plantations. It is because of this that bamboos are praised as "the timber of the poor people" in many Southeast Asian countries.