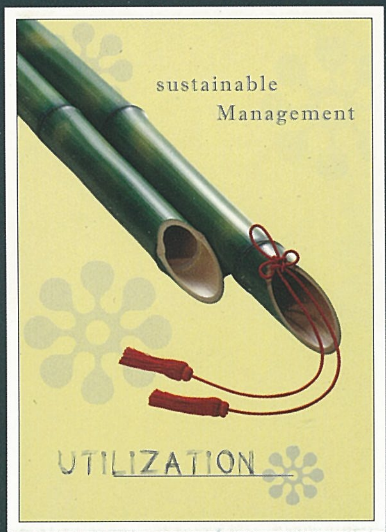
Sustainable Management and Utilization

Sustainable Management and Utilization of Sympodial Bamboos



Fu Maoyi

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PREFACE

Bamboo has already been used in China for about 6,000 years. Since Han dynasty (206 B. C. - 220 A. C.), its cultivation and utilization has been recorded formally in some historic and technical books. During that time, the center government even laid out a special official position in charge of all relative business. But in the ancient China, its northern part, where there are mainly monopodial bamboos distributed, were much developed. So these kinds of bamboos have been paid much attention. Indeed the Chinese bamboo resources include not only the monopodials but also the sympodials, which is as the same as what has occurred in all tropical/south subtropical countries and has occupied around fifty percent of the genetic resources (19 genera), and its areas of plantation/forest have reached one third of the total area of bamboo stands in China.

Comparing the situation of research on the sympodials with that of the monopdials in China, it is found that there is an unbalance i. e. it is much weaker than what happened for the monopodials. It is necessary to be changed. In other side, the rain forest in the tropical area of the world should be protected urgently. What can the good alternatives be instead of tropical tree species to produce woody material? The sympodial bamboo is one of the best choices. So with help/support from both of the relative Departments of the Chinese government and the International Tropical Timber Organization (ITTO), also with the cooperation of the local governments of Guangdong, Guangxi and Fujian Province, the Research Institute of Subtropical Forestry (RISF) under the Chinese Academy of Forestry (CAF) has conducted an international cooperative research project, Sustainable Management and Utilization of Sympodial Bamboos in South-China, since 2000. It has contained 5 aspects as following: (1) Conservation of the genetic diversity of sympodial bamboo, hybridization and cultivation of superior clones. (2) The knowledge of the ecological functions of various sympodial bamboo stands and sustainable management of sympodial bamboo stands, establishing two experimental sustainable management models of sympodial bamboo. (3) The processing and utilization of bamboo culms, including improvement of bamboo flooring-processing technology, establishment of bamboo charcoal-processing mill and preservation of bamboo culms. (4) Research and development of bamboo shoot products and doing some experiments for comprehensive chemical utilization of bamboos. (5) A training and promotion program on the sustainable management and utilization of sympodial bamboos.

This book as a technical report for the project is the results of whole team members' 5-year hard working. As the authors, Mr. Yang Xiaosheng (RISF), Mr. Jiang Shenxue and Mr. Xiu Bin (Nanjing Forestry University) have been involved in bamboo shoots/socio-economy and bamboo charcoal, bamboo preservation respectively while Mr. Ma Naixun, Mr. Xie Jingzhong, Mr. Zhou benzhi, Mr. Li Zhengcai, Mrs. Xing Xingting, and Mrs. Yuan Jinling (RISF) have been involved in biodiversity, stand management techniques, environment, carbon sequestration and bamboo breeding/biological techniques respectively.

Besides, I would like to give my special thanks to Dr. Wuan Ok Ma (an ITTO Project Manager), Prof. Walter Liese (International Consultant on Processing), Dr. Manuel Ruiz Perez (International Consultant on Cultivation), and Ms. Zheng Linping (Project assistant). Without their contribution, the Project could not be conducted smoothly and no book could be published.

Fu Maoyi
January, 2007

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Management Analysis and Development Strategies for Sympodial Bamboos in China

1 Management Status and Its Problems for Sympodial Bamboos

1.1 Less Species Used in Limited Areas

There are 208 sympodial bamboos species including variations and forms (see Table 1) occurred in China, among which more than 40 to 50 species have economical value for utilization, but only around 10 of them have been exploited in larger scale and most of them a limited distribution in the region. For example, *Dendrocalamus giganteus* grows in southern part of Yunnan Province; *Schizostachyum funghomii* in Xishuangbanna and its vicinities in Yunnan Province. Most of sympodial bamboos species are planted in a small scale, which is not beneficial for further industrial utilization. Some species occupy more than 30×10^3 ha, such as *Neosinocalamus affinis*, *Dendrocalamus latiflorus*, *Bambus textilis*, *Dendrocalamus membranaceus*, *Bambus chungii*, *Dendrocalamus giganteus*, *Cephalostachyum fuchsianum*, *Bambus pervariabilis* (see Table 2).

Table 1 Sympodial Bamboos Resources in China

No.	Genus	Chinese bamboos species cyclopedia (1994)		New species from 1994		Total	
		Number of species	Number of variations or forms	Number of species	Number of variations or forms	Number of species	Number of variations or forms
1	*Ampelocalamus*	2				2	
2	*Bambusa*	63	21	6	3	69	24
3	*Cephalostachyum*	4		2		6	
4	*Chimonocalamus*	9				9	
5	*Dendrocalamopsis*	9				9	
6	*Dendrocalamus*	30	9	2		32	9

(Continued)

No.	Genus	Chinese bamboos species cyclopedia (1994)		New species from 1994		Total	
		Number of species	Number of variations or forms	Number of species	Number of variations or forms	Number of species	Number of variations or forms
7	*Drepanostachyum*	5		1		6	
8	*Gaoligongshania*			1		1	
9	*Gigantochloa*	8		1		9	
10	*Melocalamus*	5				5	
11	*Monocladus*	3	1		1	3	2
12	*Neohouzeaua*	1				1	
13	*Neomicrocalamus*	2				2	
14	*Neosinocalamus*	2	4	(1)		2	4
15	*Schizostachyum*	9		2		11	
16	*Thyrsostachys*	2				2	
Total		154	35	15	4	169	39

Table 2 Main Provinces of Sympodial Bamboos and Their Dominant Types

Province	Total bamboo area (1×10^3 ha)	Sympodial bamboos area (1×10^3 ha)	Dominant types of sympodial bamboos stands and their area
Sichuan	438	280	Total area of 200×10^3 ha for *Neosinocalamus affinis*, 30×10^3 ha for *Dendrocalamus latiflorus*, 10×10^3 ha for *Bambusa rigida*, 7×10^3 ha for *Bambusa pervariabilis* × *Dendrocalamopsis daii*
Yunnan	331	190	Total area of 70×10^3 ha for *Dendrocalamus membranaceus*, 80×10^3 ha for *Dendrocalamus giganteus* and *Cephalostachyum fuchsianum*, 20×10^3 ha for *Schizostachyum funghomii*, 10×10^3 ha for *Neosinocalamus affinis*
Guangdong	320	150	Total area of 66×10^3 ha of *Bambusa textilis*, 25×10^3 ha for *Dendrocalamus latiflorus*, 25×10^3 ha for *Bambusa chungii*, 20×10^3 ha for *Bambusa pervariabilis*
Taiwan	184.5	120	Total area of 90×10^3 ha for *Dendrocalamus latiflorus*, 15×10^3 ha for *Bambusa blumeana*
Guangxi	240	60	Total area of 20×10^3 ha for *Dendrocalamus latiflorus*, 20×10^3 ha for *Bambusa chungii*, 10×10^3 ha for *Bambusa pervariabilis*, 10×10^3 ha for *Bambusa pervariabilis* × *Dendrocalamopsis daii*
Fujian	680	50	Total area of 20×10^3 ha for *Dendrocalamus latiflorus*, 10.3×10^3 ha for *Dendrocalamus oldhami*, 5×10^3 ha for *Bambusa albo-lineata*
Hainan	51.8	40	Total area of 25×10^3 ha for *Bambusa chungii*
Guizhou	60.9	4.4	Total area of 2×10^3 ha for *Bambusa distegia*

1.2 Extensive Management of Sympodial Bamboos Stands and Their Lower Economical Benefits

The total area of sympodial bamboos of China is about 1 million ha, of which more than 90% are only extensively managed. Some bamboo species, such as *Dendrocalamus latiflorus*, *Bambusa textilis*, *Dendrocalamopsis oldhami*, *Neosinocalsmus affinis*, *Bambusa chungii*, *Bambusa pervariabilis*, occupy larger areas, but most stands are nearly desolate. Only for few stands, management is applied. But for more than 20×10^3 ha area of the natural stands of *Schizostachyum funghomii*, in Xishuangbanna and Dehong, Yunnan Province, almost no management measures have been adopted.

Due to the lower yield of shoots and culms in extensively managed stands, the economical benefits are very low (see Table 3). For example, although *Dendrocalamus latiflorus* is a high-yield species, only 6 – 7.5t/(ha · a) shoots are harvested in the extensive bamboos stands, while it produces 30 – 37.5 t/(ha · a) shoots in intensive managed stands. The stands of *Dendrocalamus oldhami*, *Bambusa textilis* and *Neosinocalamus affinis*, yield just 3 – 6t/(ha · a) shoots, 3 – 4.5t/(ha · a) and 3 – 4.5t/(ha · a) respectively in extensive stands, but their yield are lower than in those extensive stands. Consequently, sympodial bamboos stands have a great potential to be exploited further.

Table 3 Yield of Shoots and Culms of Sympodial Bamboos Stands at Different Management Levels

Management levels	Yield of shoots (t/ha · a)		Yield of culms (t/ha · a)	
	Dendrocalamus latiflorus	*Dendrocalamus oldhami*	*Bambusa textilis*	*Neosinocalamus affinis*
Extensive	6.0 – 7.5	3.0 – 6.0	3 – 4.5	3 – 4.5
Intensive	30.0 – 37.5	10.0 – 11.7	15.0 – 22.5	15.0 – 18.0

1.3 Management Techniques

In sympodial bamboos production areas, farmers have a little technology on cultivation and the techniques used for management are the traditional, which just includes harvest season and intensity. They have never adopted the intensive management measures such as weeding, soil preparing, fertilizing, disease and pest control, and watering etc.

1.4 Bamboo Diseases, Insect Pests and Pesticide Pollution

The bamboo shoot pests, such as *Cyrtotrachelus buqueti* Guer, *Cyrtotrachelus longimamus* Fabricius etc. , occurred frequently and sometimes seriously. At some certain places, the shoot pests have occurred almost year-by-year, and the loss of shoots and culms are considerable. For example, about 20×10^3 ha of *Bambusa textilis* in Guangning county, Guangdong Province, have been harmed in various levels by *Cyrtotrachelus longimamus* in 2001, so that the number of new culms was reduced to only one third to a half. The economical loss is considerable.

People prevent diseases and pests only in the intensive managed stands, because the bamboo area harmed is very large while the manpower and funds for prevention are limited.

A pollution due to pesticide utilization happened in many bamboo areas when diseases and insect pests should be controlled, but the farmers ignored the residual toxicity in bamboo shoots. For example, Longshan township, Nanjing county, Fujian Province, is a main growing and processing area for *Dendrocalamus latiflorus* in China, with more than 20 bamboo shoots processing factories. In order to control insect pests in bamboo shoots e. g. by *Cyrtotrachelus longimamus*, etc. , local farmers used some toxic pesticides such as Furan. It has resulted in a higher residual toxicity in fresh shoots over the State Standard of Food Security. Consequently, shoot products of local processing factories there could not be sold and exported, whereby the local processing factories lost millions of dollars.

1.5 Negligence of Ecological Benefits

Sympodial bamboos stands have a good ecological preventative function. These stands possess the ability to conserve soil and water. Their canopy can intercept precipitation and the abundant litter and can also absorb a large amount of rainfall to delay and reduce the serious water runoff. The litter layer has the potential of absorbing 2.7 – 2.9 times rainfall of its dry weight, and the 0 – 60cm soil layer can store 315.3 – 326.3mm water. In the stand of *Dendrocalamus latiflorus* with a density of 825 culm/ha, the runoff coefficient and soil loss are only 2.83% and 0.073t/(ha · a) respectively (Xie, 2003). In addition, sympodial bamboo stands possess a strong self-fertilization capacity because of its leaf litter. In some processing developed areas of sympodial bamboos, farmers are investing in the bamboo stands and usually unilaterally pursue the maximum economical benefit. However, not enough attention is paid to the ecological environment. During the management of bamboo stands, they ignore to preserve the underforest vegetation, especially in the steep hills they cut all underforest vegetation, so that the soil will be lost seriously.

2 Development Trends and Strategies for the Management

Environment and development today are key issues in the world. Therefore, people cast for new ways to improve economical benefits of sympodial bamboos, and also actively to conserve the environment by applying sustainable management practices in the future. Along with the natural forest conservation project, new products of bamboo shoots and culms have been developed, and their market demands will be further enlarged. This will provide a good opportunity to manage bamboo stands as shoot-use, culm-use, mixed-use and pulp-use stand for different end use pupurses in large-scale.

In order to follow the strategies of sustainable sympodial bamboos management, the following work should be carried out:

2.1 Breeding and Popularizing Superior Species and Improving Their Management at Large-scale

Using both of traditional genetic breeding methods and modern molecular biological techniques, to access the breeding procedures of the superior sympodial bamboos species, varities and colones. The main local species, such as *Dendrocalamus brandisii*, *D. latiflorus*, *Dendrocalamopsis oldhami*, *Dendrocalamopsis beecheyana* var. *pubescens*, *Bambusa textilis*, *Bambusa chungii*, *Bambusa pervariabilis*, *Bambusa tulda*, *Neosinocalamus affinis*, should be exploited continuousely. In the meantime, optimal species with high economical value and ecological benefit should be introduced from abroad, such as *Dendrocalamus asper*. Those superior bamboos can be used for regeneration and afforestation in the national project called "forest converting from arable land at hills" to increase their planting area and to enlarge their commercial scale so that development of shoot and culms processing will be accelerated.

2.2 Oriented Cultivation of Sympodial Bamboos for the Market of Shoots and Culms

For the growing market needs of shoots and culms, an oriented cultivation of bamboo stands should be carried out. In developed areas of bamboo-timber processing, the size of bamboo timber stands should be enlarged. For example, there are more than 100 millions US Dollars in 2002 for exported bamboo waving products made from the culms of *Bambusa chungii* in Xinyi City, Guangdong Province. Because culm demand is enlarging, the 20×10^3 ha area of *Bambusa chungii* should be oriented towards for culm-use each year. In developed areas of bamboo pulp-making, the area of bamboo pulp-use stands should be enlarged. For example, there is 180×10^3

t/a of bamboo pulp made from *Neosinocalamus affinis* in several regions in Sichuan Province, such as Ya-an, Leshan and Yibin city, etc. With several big bamboo pulp mills being setup in those areas, the production of bamboo pulp will reach 262×10^3 t/a in the future. So, high-yield bamboo pulp-use stands should be developed in those areas to meet the demand of raw material for the bamboo pulp mills. In developed areas of bamboo shoot processing, this area should also be enlarged. For example, because sympodial bamboos shoot processing of *Dendrocalamus latiflorus* has been developed in Nanjing county, Fujian Province and in Qingxin county, Guangdong Province, the market demand for fresh shoots became very large. Therefore, high-yield bamboo shoot-use stands should be developed in these areas to meet the demand of raw material for bamboo shoot processing.

Since farmer's life quality has improved, they now pay much attention to food safety. So if the so-called oriented cultivation of bamboo organic shoot-use stands were managed, applications of organic, biological fertilizer and biological pesticides etc. are most important. Sympodial bamboos shoot-use stands with those measures will help to conserve the environment and provide additionally high-yield and also high-beneficial effects.

2.3 Generalization and Improvement of Sustainable Management Techniques

Controlling of bamboo density and clump structure reasonably are fundamental techniques for obtaining high yield. When bamboo density increases properly, the yield of shoot and culm will be enhanced, and the ecological function of bamboo stands will also be improve, especially regarding bamboo self-fertilization and water and soil conservation capacity. Proper bamboo clump and age structure are the base of a stable stands and high yield. Proper management measures such as plowing, soil adding and fertilization in spring, weeding, proper maintaining the amount of new mother culms and digging shoots in summer and autumn, as well as proper cutting methods and intensity of old bamboo culm in winter will all guarantee a high and stable yield of sympodial bamboos. In order to improve the management level, sustainable management techniques should be further studied, based on the different ecological and biological features of different bamboo species. At the same time, the training of sustainable management techniques will be conducted and demonstration models of sympodial bamboos stands will be established.

2.4 Techniques for Sustainable Productivity and Ecological Management of Soil

For achieving and maintaining the sustainable stability of soil fertility in a sympodial bamboos stand and then obtaining high and stable productivity, the traditional methods for bamboo cultivation should be changed. It means that the pure stands should be reduced, and the agroforestry methods should be adopted, especially the shrubs and herbs with stronger nitrogen fixation capacity and ecological function should be used. Application of chemical fertilization should be reduced and organic fertilization increased. In order to lower the water and soil loss, the amount of whole plowing in bamboo stands should be diminished. So, it is necessary to select the suitable intercropping trees and under-forest vegetation, to study their planting models for improving the ecological management level and then promoting the soil sustainable productivity.

2.5 Controlling Bamboo Diseases and Insect Pests

It is so important for obtaining high and stable yield by sustainable management of bamboo stands to prevent and control large-scale outbreaks of bamboo diseases and insect pests. So, it is necessary to control its occurrence and also any pollution caused by pesticides. The new integrated methods by using biological pesticides have to be studied.

Study on Sustainable Management Techniques of Sympodial Bamboos

1 General Information of Research Areas

1.1 Guangning, Guangdong Province

Guangning county is located in the northwest of Guangdong Province, the middle reaches of Suijiang river, the branch of Beijiang river(112°04′ - 112°44′E,23°22′ - 23° 59′N). The climate is southern sub - tropical monsoon type with an annual average temperature of 20. 7℃, extreme minimum temperature of - 2. 0℃, extreme maximum temperature of 39.4℃, 313 frost-free days and an annual rainfall of 1,732mm. Latosolic red soils and red soils are dominant in the area, accounting for 92.5 percent of total area. The percentage of Mountainous yellow earth and Mountain meadow soil is 7.5 percent.

1.2 Cangwu, Guangxi Autonomous Region

Cangwu county is located in the east of Guangxi Province, located at 110°51′ - 111°40′12″E and 22°58′12″ - 24°10′14″N. The tropic of cancer gets across the midland bias south of the county . Because alp dominates the north and hills dominate the south, the topography is like a saddle which is high in north and low in south, all of which are the southern extendable cordillera of Dayao Mountain and Dazhu Mountain. Climatically, it is in the southern sub-tropical zone characterized by monsoon. There are strong radiant intensity, moderate climate and plentiful rainfall in this region. The summer is long and the winter short with many more frost-free days, the light and temperature coordinate with rain in the season. The annual average radiation is 462. 6414kJ/km^2, the annual average temperature is 21. 2℃, the maximum temperature is 39. 5℃, the minimum temperature is - 3℃, the annual rainfall is 1,500. 7mm, the annual average evaporation is 1,581. 1mm, the annual average relative humidity is 80% , the number of frost-free days is 331 and the annual average hours of sunlight is 1,825. 2. The forest is dominated by zonal red soil derived from various soil parent materials which is fecund.

Mushuang is situated at the east of Cangwu County , low hills which is 100 -

500m in altitude dominate there, with latosolic red soils and arenaceous shale. The soil is good at texture and humid ,with moderate fertility.

1.3 Nanjing, Fujian Province

Jingdu bamboo center is located in Jinshan town, Nanjing county, which is in the transition zone of southern sub-tropical zone (117°20'E, 24°27'N), near by Taiwan Strait characterized by monsoon, which is the main producing area of sympodial bamboos in China, ranging from 40 – 300m in altitude, with an annual temperature of 20.9℃, an extreme minimum temperature of – 2.0℃, an extreme maximum temperature of 40.5℃, an annual active accumulative temperature (≥10℃) of 7,512.7℃, an annual rainfall of 1,587.5mm (the rainfall from April to September is 77.7% of the total) and a relative humidity of 79% – 87%. The research site is situated at cutting blank of secondary forest, with southeast slope and gradient of 20° – 35°. The soil type can be categorized as brick red soil derived from metamorphic rock, whereas suitable conditions include over 120cm of deep fertile loams with a pH ranging from 4.7 to 5.3 and moderate fertility. The study forest is established in spring 1996, the total area of which is 100ha and the species is *Dendrocalamus latiflorus* Munro (planted with spacing 4m × 5m).

2 Research Methods

2.1 Study on the Sustainable High-yield and High-efficient Management Models of Bamboo Shoot Stands

2.1.1 The Sustainable High-yield and High-efficient Management Models of *Dendrocalamus brandisii* Stands

2.1.1.1 Experimental Design

The study is arranged according to the orthogonal design (four factors with three levels) $L_9(3^4)$. Each level value of the factors and nine treatment collocation of each block and one check are shown in Table 1 and 2. This test locates 2 repetitions and 20 compartments (each 200m^2). The stand density is adjusted to the spacing 4m × 4m and the age structure of 1-year-old: 2-year-old is 2:1, fertilizing is done by digging soil around clump, the fertilizer compounding ratio of N,P and K is 4:3:1.

Table 1 Level Value of Every Factor

Level	A Clump density (culms · clump^{-1})	B Adding soil in depth (cm)	C Fertilization time; frequency and quantity
1	3	0	June; 0.5kg/clump/time
2	6	15	June, July; 0.5kg/ clump/time
3	9	30	March, June, July; 0.5 clump/time

Other management technical measures include: harvesting bamboo shoots from beginning of May to end of November. Adjusting the stand structure in February every year and removing all old bamboo stumps in March and April, raking out soil around clumps from ten days to 2 weeks for shoot buds differentiation, and then adding soil in 15cm depth around each clump base, and weeding once in September.

2.1.1.2 Data Processing

The number and yield of shoot from each plot in the study field have been investigated and summarized for four years, initiating from summer of 2001. Statistical analysis has been done by using of orthogonal design intuitive analysis and ANOVA.

Table 2 Treatment Collocation

No.	A Clump density (culms · clump^{-1})	B Adding soil in depth (cm)	C Fertilization time; frequency and quantity	Plot number	
				Block I	Block II
1	3	0	June; 0.5 kg/ clump/time	5	13
2	3	15	June, July; 0.5kg/ clump/time	8	9
3	3	30	March, June, July; 0.5kg/ clump/time	2	16
4	6	0	June, July; 0.5kg/ clump/time	1	14
5	6	15	March, June, July; 0.5kg/ clump/time	7	10
6	6	30	June; 0.5kg/clump/time	6	18
7	9	0	March,June, July; 0.5kg/ clump/time	4	12
8	9	15	June; 0.5kg/ clump/time	17	15
9	9	30	June, July; 0.5kg/ clump/time	3	11

2.1.2 The Sustainable High-yield and High-efficient Management Models of *Dendrocalamus latiflorus*

2.1.2.1 Experimental Design

The study is arranged according to the orthogonal design (four factors with two levels) $L_8(2^4)$. Each level value of a factor and eight treatment collocation of each block and two checks are shown in Table 3 and Table 4. This test has 3 repetitions and 30 compartments (each 200m^2). The stand density is adjusted to the spacing 4m × 4m and 0.5 kg N, P, K composed fertilizer has been applied in ferrow by digging soil around clump in May and July respectively, the compounding ratio of N, P and K is 4:3:1.

Table 3 Level Value of Every Factor

Level	A New culms (culms · clump^{-1})	B Age structure	D Adding soil in depth (cm)
1	2	1:1	15
2	3	1:1:1	30

Other management technical measures include: digging bamboo shoots from the beginning of May to the end of November. Adjusting the stand structure in February every year and removing all old bamboo stumps in March and April, raking out soil around clumps from ten days to 2 weeks for shoot buds differentiation, and then adding soil in 15cm depth around each clump base, and weeding once in September.

2.1.2.2 Data Processing

The number and yield of shoot every plot in the study field have been investigated and summarized for two years, beginning from summer in 2003. Statistical analysis has been done in use of orthogonal design intuitive analysis and ANOVA.

Table 4 Ten Kinds of Treatment Collocation

No.	A New culms (culms · clump^{-1})	B Age structure	A × B Clump density (culms · clump^{-1})	D Adding soil in depth (cm)	Plot number		
					Block 1	Block 2	Block 3
1	2	1-year old: 2-year-old = 1:1	4	15	2	15	20
2	2	1-year old: 2-year-old = 1:1	4	30	13	8	25
3	2	1-year old: 2-year: 3-year-old = 1:1:1	6	15	6	10	18
4	2	1-year old: 2-year: 3-year-old = 1:1:1	6	30	3	16	22
5	3	1-year old: 2-year-old = 1:1	6	15	11	7	24
6	3	1-year old: 2-year-old = 1:1	6	30	4	17	19

(Continued)

No.	A New culms (culms · clump⁻¹)	B Age structure	A × B Clump density (culms · clump⁻¹)	D Adding soil in depth(cm)	Plot number		
					Block 1	Block 2	Block 3
7	3	1-year old: 2-year: 3-year-old = 1:1:1	9	15	12	14	21
8	3	1-year old: 2-year: 3-year-old = 1:1:1	9	30	5	9	26
9	(check 1)2	1-year old: 2-year-old = 1:1	6	0	1	30	23
10	(check 2)3	1-year old: 2-year: 3-year-old = 1:1:1	9	0	27	29	28

2.2 Study on the Sustainable High-yield and High-efficient Management Models of Bamboo Timber Stands

2.2.1 The Sustainable High-yield and High-efficient Management Models of *Bambusa textilis* (River Bank)

2.2.1.1 Experimental Design

The same as for *Dendrocalamus brandisii*, the orthogonal design $L_9(3^4)$ with one check and 3 repetitions has been adopted. Totally, it has 30 plots (each 400m^2). The clump stand age structure of 1-year-old: 2-year-old is adjusted to 2:1 and NPK (4:3:1) compound fertilizer has been applied. See Table 5 and 6.

Table 5 Level Value of Every Factor

Level	A Stand density (culms · mu⁻¹①)	B Clump density (culms · clump⁻¹)	C Fertilization time; frequency and quantity	D Harvesting time; frequency and quantity
1	39	12	June; 0.5kg/clump/time	January; 100%
2	51	15	June, July; 0.5kg/ clump/time	January, March; 50% per time
3	63	18	March, June, July; 0.5kg/ clump/time	March; 100%

Other management technical measures include: Adjusting the stand structure in January and February every year and removing all old bamboo stumps in March and April, raking out soil around clumps from ten days to 2 weeks for shoot buds differentiation, then adding soil in 15cm depth around each clump base, and weeding once in September.

① 1mu = 1/15ha

Table 6 Treatment Collocation

No.	A Stand density (culms · mu⁻¹)	B Clump density (culms · clump⁻¹)	C Fertilization time; frequency and quantity	D Harvesting time; frequency and quantity	Plot number		
					I	II	III
1	39	12	June; 0.5kg/clump/time	January; 100%	8	15	34
2	39	15	June, July; 0.5kg/clump/time	January, March; 50% per time	10	12	32
3	39	18	March, June, July; 0.5kg/ clump/time	March; 100%	4	13	36
4	51	12	June, July; 0.5kg/clump/time	March; 100%	5	18	33
5	51	15	March, June, July; 0.5kg/ clump/time	January; 100%	1	14	42
6	51	18	June; 0.5kg/clump/time	January, March; 50% per time	6	9	41
7	63	12	March, June, July; 0.5kg/ clump/time	January, March; 50% per time	7	16	38
8	63	15	June; 0.5kg/ clump/time	March; 100%	2	17	40
9	63	18	June, July; 0.5kg/ clump/time	January; 100%	3	11	37
10	51	15	0	January; 100%	31	35	39

2.2.1.2 Data Processing

The number of new culms and its yield from esch plot have been investigated and summarized for four years, starting from summer in 2001. Statistical analysis has been done in use of orthogonal design intuitive analysis and ANOVA.

2.2.2 The Sustainable High-yield and High-efficient Management Models of *Bambusa textilis* (on Hill Slop)

2.2.2.1 Experimental Design

It is the same as for that on river bank. Table 7 and 8 have given the details.

Table 7 Level Value of Every Factor

Factor level	A Stand density	B Clump density (culms · clump⁻¹)	C Fertilization time; frequency and quantity	D Harvesting time; frequency and quantity
1	2.2m × 2.5m	9	June; 0.5kg/clump/time	January; 100%
2	2.0m × 2.3m	12	June, July; 0.5kg/ clump/time	January, March; 50% per time
3	2.0m × 2.0m	15	March, June, July; 0.5kg/ clump/time	March; 100%

Other management technical measures are also the same as for that on river bank.

Table 8 Treatment Collocation

No.	A Stand density/ (culms · mu^{-1})	B Clump density (culms · $clump^{-1}$)	C Fertilization time; frequency and quantity	D Felling time; frequency and quantity	Plot number		
					a	b	c
1	123	9	June; 0.5kg/clump/time	January; 100%	a3	b5	c8
2	123	12	June, July; 0.5kg/ clump/time	January, March; 50% per time	a2	b6	c2
3	123	15	March, June, July; 0.5kg/clump/time	March; 100%	a5	b1	c9
4	145	9	June, July; 0.5kg/clump/time	March; 100%	a6	b4	c1
5	145	12	March, June, July; 0.5kg/clump/time	January; 100%	a8	b2	c7
6	145	15	June; 0.5kg/clump/time	January, March; 50% per time	a4	b3	c5
7	167	9	March, June, July; 0.5kg/clump/time	January, March; 50% per time	a9	b8	c3
8	167	12	June; 0.5kg/ clump/time	March; 100%	a1	b9	c6
9	167	15	June, July; 0.5kg/clump/time	January; 100%	a7	b7	c4
10	145	12	0	January; 100%	a10	b10	c10

2.2.2.2 Data Processing

The number of new culms and timber yield every plot in the study field have been investigated and summarized for three years, beginning from summer in 2001. Statistical analysis has been done in use of orthogonal design intuitive analysis and ANOVA.

2.2.3 The Sustainable High-yield and High-efficient Management Models of *Bambusa pervariabilis*

2.2.3.1 Experimental Design

The study is arranged according to the orthogonal design (four factors with three levels) $L_9(3^4)$ [each level value of every factor (Table 9) and nine treatment collocation of each block and one check (Table 10)]. This test locates 3 repetitions and 30 plots (each $300m^2$). The clump stand age structure of 1-year-old: 2-year-old is adjusted to 2:1 and fertilized composed fertilizer of N, P and K for each · clump by digging soil around clump, the compounding ratio of N, P and K is 4:3:1.

Table 9 Level Value of Every Factor

Level	A Stand density (culms · mu^{-1})	B Clump density (culms · $clump^{-1}$)	C Fertilization time; frequency and quantity	D Harvesting time; frequency and quantity
1	39	12	June; 0.5kg/clump/time	January; 100%
2	51	15	June, July; 0.5kg/ clump/time	January, March; 50% per time
3	63	18	March, June, July; 0.5kg/ clump/time	March; 100%

Other management technical measures include: Adjusting the stand structure in January and February every year and removing all old bamboo stumps in March and April, raking out soil around clumps for ten days to 1-2 weeks for shoot buds differentiation, and then adding soil in 15cm depth around each clump base, and weeding once in September.

Table 10 Treatment Collocation

No.	A Stand density (culms · mu^{-1})	B Clump density (culms · $clump^{-1}$)	C Fertilization time; frequency and quantity	D Felling time; frequency and quantity	Plot number		
					I	II	III
1	39	12	June; 0.5kg/clump/time	January; 100%	8	15	22
2	39	15	June, July; 0.5kg/ clump/time	January, March; 50% per time	10	12	25
3	39	18	March, June, July; 0.5kg/ clump/time	March; 100%	4	13	23
4	51	12	June, July; 0.5kg/ clump/time	March; 100%	5	18	21
5	51	15	March, June, July; 0.5kg/ clump/time	January; 100%	1	14	19
6	51	18	June; 0.5kg/clump/time	January, March; 50% per time	6	9	20
7	63	12	March, June, July; 0.5kg/ clump/time	January, March; 50% per time	7	16	24
8	63	15	June; 0.5kg/ clump/time	March; 100%	2	17	27
9	63	18	June, July; 0.5kg/ clump/time	January; 100%	3	11	26
10	51	15	0	January; 100%	28	29	30

2.2.3.2 Data Processing

The number of new culms and timber yield every plot in the study field have been investigated and summarized for three years, beginning from summer in 2001. Statistical analysis has been done in use of orthogonal design intuitive analysis and ANOVA.

2.2.4 The Sustainable High-yield and High-efficient Management Models of *Bambusa chungii*

2.2.4.1 Experimental Design

The study is arranged according to the orthogonal design (four factors with three levels) $L_9(3^4)$ [each level value of every factor (Table 11) and nine treatment collocation of each block and one check (Table 12)]. This test locates 3 repetitions and 30 plots (each $300m^2$). The clump stand age structure of 1-year-old:2-year-old is adjusted to 2:1 and fertilized composed fertilizer of N, P and K for each · clump by digging soil around clump, the compounding ratio of N, P and K is 4:3:1.

Table 11 Level Value of Every Factor

Level	A Stand density (culms · mu^{-1})	B Clump density (culms · $clump^{-1}$)	C Fertilization time; frequency and quantity	D Harvesting time; frequency and quantity
1	60	12	June; 0.5kg/clump/time	June; 100%
2	80	15	June, July; 0.5kg/ clump/time	June, March; 50% per time
3	100	18	March, June, July; 0.5 clump/time	June, February, March; 33.3% per time

Other management technical measures include: adjusting the stand structure in January and February every year and removing all old bamboo stumps in March and April, raking out soil around clumps for ten days to 1 – 2 weeks for shoot buds differentiation, and then adding soil in 15cm depth around each clump base, and weeding once in September.

Table 12 Treatment Collocation

No.	A Stand density (culms · mu^{-1})	B Clump density (culms · $clump^{-1}$)	C Fertilization time; frequency and quantity	D Felling time; frequency and quantity	Plot number		
					I	II	III
1	60	12	June; 0.5kg/clump/time	January; 100%	5	17	23
2	60	15	June, July; 0.5kg/ clump/time	January, March; 50% per time	2	16	25
3	60	18	March, June, July; 0.5kg/ clump/time	January, February, March; 33.3% per time	1	14	22
4	80	12	June, July; 0.5kg/ clump/time	January, February, March; 33.3% per time	10	21	30
5	80	15	March, June, July; 0.5kg/ clump/time	January; 100%	3	20	24

(Continued)

No.	A Stand density (culms · mu^{-1})	B Clump density (culms · $clump^{-1}$)	C Fertilization time; frequency and quantity	D Felling time; frequency and quantity	Plot number		
					I	II	III
6	80	18	June; 0.5kg/clump/time	January, March; 50% per time	4	15	11
7	100	12	March, June, July; 0.5kg/ clump/time	January, March; 50% per time	9	19	29
8	100	15	June;0.5kg/ clump/times	January, February, March; 33.3% per time	7	13	26
9	100	18	June, July; 0.5kg/ clump/time	January; 100%	6	18	27
10	60	15	0	January, March; 50% per time	8	12	28

2.2.4.2 Data Processing

The number of new culms and timber yield every plot in the study field has been investigated and summarized for three years, beginning from summer in 2001. Statistical analysis has been done in use of orthogonal design intuitive analysis and ANOVA.

2.2.5 The Sustainable High-yield and High-efficient Management Models of *Pseudosasa amabilis*

2.2.5.1 Experimental Design

The study is arranged according to the orthogonal design (four factors with three levels) $L_9(3^4)$ [each level value of every factor (Table 13) and nine treatment collocation of each block and one check (Table 14)]. This test locates 3 repetitions and 30 compartments (each $300m^2$). The clump stand age structure of 1-year-old: 2-year-old is adjusted to 1:1 and fertilized composed fertilizer of N, P and K for each · clump by digging soil along contour line, the compounding ratio of N, P and K is 4:3:1.

Other management technical measures include : loosing, weeding and removing old scourge in July and August, reclaiming land in 20-30 cm depth biennially, weeding once in September every year combining with fertilization.

Table 13 Level Value and Factor Value of *Pseudosasa amabilis*

Level	A Stand density (culms/mu)	B Harvesting time and intensity	C Fertilization time; frequency and quantity
1	1,500	November(on-year); 100%	February – March; 25kg/mu/time
2	2,000	November(on-year), January (off-year); 50% per time	September; 25kg/mu/time
3	2,500	November(on-year), January, March(off-year); 33.3% per time	February – March, September; 25kg/mu/time

Table 14 Treatment Collocation

No.	A Stand density	B Clump density / harvesting time and intensity	C Fertilization time; frequency and quantity	D	Plot number	
					I	II
1	1	1	1	1	2	18
2	1	2	2	2	7	11
3	1	3	3	3	4	15
4	2	1	3	2	9	13
5	2	2	1	3	1	12
6	2	3	2	1	5	16
7	3	1	2	3	3	10
8	3	2	3	1	6	17
9	3	3	1	2	8	14
10	2	1	0	–	19	20

2.2.5.2 Data Processing

The number of new culms and timber yield every plot in the study field have been investigated and summarized for four years, beginning from summer in 2001. Statistical analysis for the timber yield during 2003 – 2004 has been done in use of orthogonal design intuitive analysis and ANOVA.

2.3 Establishments of the Sustainable High-yield and High-efficient Management Demonstration Models

There are 2,390 ha of sympodial bamboos model stands (include: bamboo shoot stand and bamboo timber stand) have been established in Guangdong, Guangxi and Fujian successively from 2001 to 2002 (see Table 15 and Figure 1).

Table 15 The Distribution of Areas of All Kinds of Sympodial Bamboos Model Stands

No.	Bamboo type	Site	Area/ha	Establishing time
1	*Dendrocalamus brandisii*	Guangning, Guangdong Province	120	2001.6
2	*Dendrocalamus latiflorus*	Nanjing, Fujian Province	200	2002.9
3	*Bambusa textilis* (river bank)	Guangning, Guangdong Province	600	2001.6
4	*Bambusa textilis* (mountain)	Guangning, Guangdong Province	210	2001.6
5	*Bambusa chungii*	Cangwu, Guangxi Province	410	2001.9
6	*Bambusa pervariabilis*	Cangwu, Guangxi Province	650	2001.9
7	*Pseudosasa amabilis*	Guangning, Guangdong Province	200	2001.6
	Total		2,390	

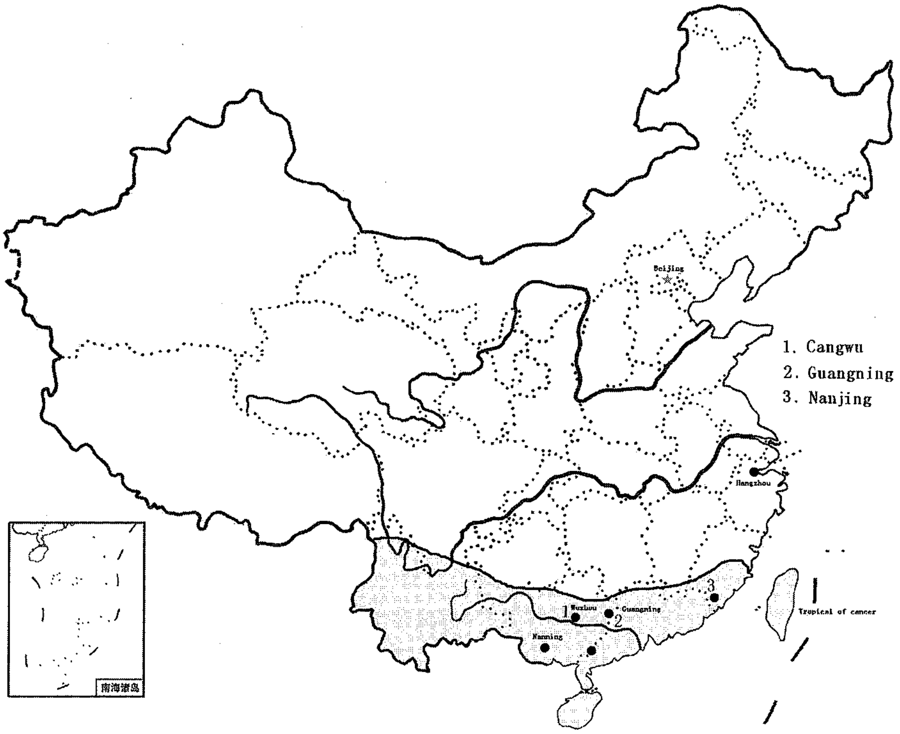


Figure 1 Scatter Diagram of Sympodial Bamboos Model Stands

2.3.1 Sustainable High-yield and High-efficient Management Model of *Dendrocalamus brandisii* stands (Guangning, Guangdong Province)

The established area is 120ha. Adjusting the bamboo stand density structure to 450 clumps · ha^{-1} and keep 6 culms · $clump^{-1}$, which age structure of 1-year-old: 2-year-old is 2 : 1; adding soil in 15-30cm depth in March every year; fertilizing 0.5 kg composed fertilizer of N, P and K for each · clump by digging soil around clump in June, the compounding ratio of N, P and K is 4:3:1.

2.3.2 Sustainable High-yield and High-efficient Management Model of *Dendrocalamus latiflorus* (Nanjing, Fujian Province)

The established area is 200 ha. Adjusting the bamboo stand density structure to 450 clumps · ha^{-1} and keep 4 – 6 culms · $clump^{-1}$, which age structure of 1-year-old: 2-year-old is 1:1; adding soil in 15-30cm depth in early March every year; fertilizing 0.5 kg composed fertilizer of N, P and K for each · clump by digging soil around clump in May and July, the compounding ratio of N, P and K is 4:3:1.

2.3.3 Sustainable High-yield and High-efficient Management Model of *Bambusa textilis* (Guangning, Guangdong Province)

Establishing two demonstration models, one is *Bambusa textiles* (river bank) with area 600 ha; the other is *Bambusa textiles* (at mountain), area is 210 ha.

For *Bambusa textiles* (at river bank), adjusting the bamboo stand density structure to 765 clumps · ha^{-1} and keep 18 culms · $clump^{-1}$, which age structure of 1-year-old : 2-year-old is 2:1; fertilizing 0.5 kg composed fertilizer of N, P and K for each. clump by digging soil around clump in early June every year, the compounding ratio of N,P and K is 4:3:1; harvesting old culms in January and March every year, in which the percentage of felling quantity is 50% per time.

For *Bambusa textiles* (mountain), adjusting the bamboo stand density structure to 2,505 clumps · ha^{-1} and keep 12 culms · $clump^{-1}$, which age structure of 1-year-old: 2-year-old is 2:1; Fertilizing 0.5 kg composed fertilizer of N, P and K for each. clump by digging soil around clump in early June every year, the compounding ratio of N, P and K is 4:3:1; harvesting all old culms in March every year.

2.3.4 The Establishment of Sustainable High-yield and High-efficient Management Model of *Bambusa pervariabilis* and *Bambusa chungii* (Cangwu, Guangxi Province)

Establish a demonstration model of *Bambusa pervariabilis* which areas is 650 ha and establish a demonstration model of *Bambusa chungii* which areas is 410 ha.

For *Bambusa pervariabilis*, adjusting the bamboo stand density structure to 945 clumps · ha^{-1} and keep 15 culms · $clump^{-1}$, which age structure of 1-year-old: 2-year-old is 2:1; fertilizing 0.5 kg composed fertilizer of N, P and K for each clump by digging soil around clump in early June every year, the compounding ratio of N, P and K is 4:3:1; harvesting all old culms in March every year.

For *Bambusa chungii*, adjusting the bamboo stand density structure to 1,500 clumps · ha^{-1} and keep 12 culms · $clump^{-1}$, which age structure of 1-year-old : 2-year-old is 2:1; applying 0.5 kg composed fertilizer of N, P and K for each clump by digging soil around clump in March, June and July every year, the compounding ratio of N, P and K is 4:3:1; harvesting old culms in January and March every year, in which the percentage of felling quantity is 50% per time.

2.3.5 The Establishment of Sustainable High-yield and High-efficient Management Model of *Pseudosasa amabilis* (Guangning, Guangdong Province)

The established area is 200 ha. Adjusting the bamboo stand density structure to 30,000 – 37,500 culms · ha^{-1}, which age structure of one du (2 years) old bamboo: two du (2 years) old bamboo is 1:1; fertilizing 375 kg composed fertilizer of N, P and K for each ha by digging soil along contour line in late February and early September, the compounding ratio of N, P and K is 4:3:1; harvesting old culms from November of on-year to next February.

3 Result Analysis

3.1 The Analysis of Sustainable High-yield and High-efficient Management Model

3.1.1 *Dendrocalamus brandisii*

From the analysis of the factors with levels (Table 16), the result shows that the factor of clump density is the most important one among three factors, and the factor of adding soil in depth is in the next place, stand density should be 450 clump · ha^{-1}, keep 6 culms · $clump^{-1}$ as mother culms, adding soil in 15cm depth around each clump base and 0.5 kg composed fertilizer of N, P and K (4:3:1) for each clump by digging soil around clump in early June are the better treatment levels for each factor levels respectively.

Because of a continuance of dry weather in summer in south of China in 2003, it has produced a negative effect for sympodial bamboo stands growth and shoot bourgeon. The shoot yield of in 2003 only has less than 1/3 of normal year shoot yield (see Table 16).

From the experimental results of 2002 and 2004, it shows that the best cultivation model is adjusting the bamboo stand density structure to 450 clumps · ha^{-1} and keep 3 culms · $clump^{-1}$ as mother culms in January and February, and removed all old bamboo stumps before April; raking out soil around clumps from ten days to 2 weeks for shoot buds differentiation, and then adding soil in 15cm depth around each clump base and fertilizing 0.5 kg composed fertilizer of N, P and K for each clump by digging soil around clump in early June, etc. If this model has been adopted, the shoot yield can reach 19.32 – 23.57t · ha^{-1} (see Figure 2), which is 1.46 – 1.94 times higher than the control's, and its net income and adding income can be obtained 14,989.01Yuan · ha^{-1} and 5,941.52Yuan · ha^{-1} respectively.

Table 16 Orthogonal Design Analysis for High - yield Techniques Study of *Dendrocalamus brandisii* Bamboo Shoot Stands

No.	A	B	C	2001 ($kg/200m^2$)		2002 ($kg/200m^2$)		2003 ($kg/200m^2$)		2004 ($kg/200m^2$)	
				1	2	1	2	1	2	1	2
1	3	0	June; 0.5kg/clump/time	186.8	190.6	354.8	345.4	111.6	141.8	293.2	285.5
2	3	15	June, July; 0.5kg/ clump/time	142.9	177.0	371.0	358.7	107.0	102.9	306.6	296.4
3	3	30	March, June, July; 0.5kg/clump/time	193.1	169.4	356.0	353.7	122.0	107.9	294.2	292.3
4	6	0	June, July; 0.5kg/ clump/time	212.0	202.7	412.2	391.0	119.0	102.9	340.7	323.2
5	6	15	March, June, July; 0.5kg/clump/time	195.4	230.0	418.9	395.6	115.5	104.1	346.2	326.9
6	6	30	June; 0.5kg/clump/time	191.3	198.1	424.5	418.6	114.4	110.2	350.9	345.9
7	9	0	March, June, July; 0.5kg/clump/time	163.9	164.8	371.3	360.0	112.5	124.3	306.8	297.5
8	9	15	June; 0.5kg/ clump/time	170.6	164.6	407.5	398.0	130.2	120.6	331.8	325.6
9	9	30	June, July; 0.5kg/clump/time	154.4	153.6	379.8	380.2	115.1	115.2	313.9	314.2
10	6	0	0	135.5	148.5	235.5	251.3	79.8	69.3	258.7	271.3
2001 M_1	176.6	186.8	183.6	316.2		181.2		383.2		115.4	
M_2	204.9	180.1	173.8								
M_3	162.0	176.6	186.1								
R	42.9	10.1	12.3								
2002 M_1	356.6	372.4	391.5								
M_2	410.1	391.6	382.2								
M_3	382.8	385.5	375.9								
R	53.5	19.2	15.6								
2003 M_1	115.5	118.7	121.4								
M_2	111.0	113.4	110.4								
M_3	119.6	114.1	114.4								
R	8.6	5.3	11.1								
2004 M_1	294.7	307.8	322.1								
M_2	339.0	322.3	315.8								
M_3	315.0	318.6	310.7								
R	44.2	14.5	11.5								

Note: 2001, the best collocation: A2B1C3; yield: 12.33t · ha^{-1}; 1.74 times higher than control one (7.10 t · ha^{-1})

2002, the best collocation: A2B2C1; yield: 23.57t · ha^{-1}; 1.94 times higher than control one (12.17 t · ha^{-1})

2003, the best collocation: A3B1C1; yield: 7.02t · ha^{-1}; 1.88 times higher than control one (3.73 t · ha^{-1})

2004, the best collocation: A2B2C1; yield: 19.32t · ha^{-1}; 1.46 times higher than control one (13.25 t · ha^{-1})

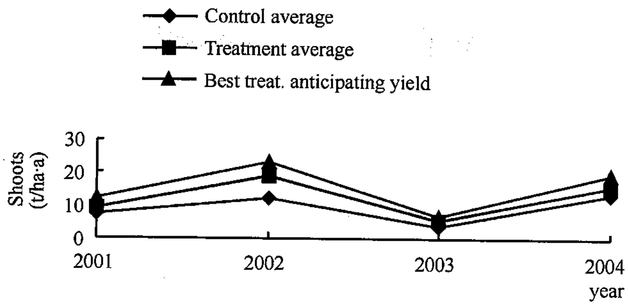


Figure 2 Comparison the Culm Yield of *Dendrocalamus brandisii* Stand between Best Treatment and Averages

3.1.2 *Dendrocalamus latiflorus*

From the analysis of the factors with levels (Table 17), the result shows that the two factors of keeping new culms amount as mother clums and adding soil in depth are more important than the factor of fertilizer. , the stand density should be 450 clump · ha^{-1}, keep 2 new culms · clump^{-1} · year^{-1} as mother culms, adding soil in 15cm depth around each clump base are the best treatment levels.

The continuance of dry weather in summer in Guangdong and Fujian Provinces in 2003 also has produced a negative effect for *Dendrocalamus latiflorus* stands growth.

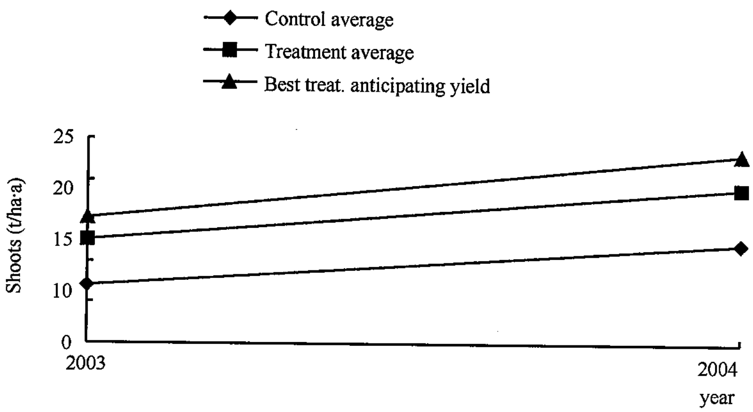


Figure 3 Comparison the Culm Yield of *Dendrocalamus latiflorus* Stand between Best Treatment and Averages

From the experimental results of 2004, it shows that the best cultivation model is adjusting the bamboo stand density structure to 600 clumps · ha^{-1} and each year keep 2 new culms · clump^{-1} as mother culms in January and February, and removed all old bamboo stumps before April; raking out soil around clumps from ten days to 2 weeks for shoot buds differentiation, and then adding soil in 15cm depth around each clump base in April and fertilizing 0.5 kg composed fertilizer of N, P

Table 17 Orthogonal Design Analysis for High – yield Techniques Study of *Dendrocalamus latiflorus* Bamboo Shoot Stands

No.		A	B	C	2003(kg/200m²)			2004(kg/200m²)		
					1	2	3	1	2	3
1		(1)2	(1) 1 – year old: 2 – year – old = 1:1	15	319.2	303.3	313.2	480.9	456.9	471.8
2		(1)2	(1) 1 – year old: 2 – year – old = 1:1	30	225.0	245.7	234.0	339.0	370.1	352.5
3		(1)2	(2) 1 – year old: 2 – year: 3 – year – old = 1:1:1	15	139.2	155.4	159.3	209.7	234.1	240.0
4		(1)2	(2) 1 – year old: 2 – year: 3 – year – old = 1:1:1	30	361.8	343.7	355.0	545.0	517.8	534.7
5		(2)3	(1) 1 – year old: 2 – year – old = 1:1	15	255.0	278.5	265.2	384.2	419.5	399.5
6		(2)3	(1) 1 – year old: 2 – year – old = 1:1	30	157.8	176.1	180.5	237.7	265.3	272.0
7		(2)3	(2) 1 – year old: 2 – year: 3 – year – old = 1:1:1	15	316.5	292.6	352.4	476.8	440.9	530.9
8		(2)3	(2) 1 – year old: 2 – year: 3 – year – old = 1:1:1	30	204.2	198.7	207.2	307.6	299.4	312.1
Check 1		2	(1) 1 – year old: 2 – year – old = 1:1	0	148.9	143.5	155.8	253.6	244.3	265.4
Check 2		3	(2) 1 – year old: 2 – year: 3 – year – old = 1:1:1	0	135.0	128.0	137.0	229.9	218.0	233.3
	M_1	262.9	246.1	262.5			251.6			379.1
2003	M_2	240.4	257.2	240.8						
	R	22.5	11.0	21.7						
	M_1	396.1	370.8	395.4						
2004	M_2	362.1	387.4	362.8						
	R	33.9	16.6	32.7						

Note:
2003, the best collocation: A1B2C1, shoot yield: 15.34t · ha^{-1}; 2.17 times higher than control one (7.07 t · ha^{-1})
2004, the best collocation: A1B2C1, shoot yield: 23.12t · ha^{-1}; 1.92 times higher than control one(12.04 t · ha^{-1})

and K (4:3:1) for each clump by digging soil around clump in early June, etc. If this model has been adopted, the shoot yield of *Dendrocalamus latiflorus* can reach 23.12t · ha^{-1} (see Figure 3), which is 1.92 times higher than control one, and the net income and adding income can be obtained 11,329.63Yuan · ha^{-1} and 6,145.46Yuan · ha^{-1} respectively.

3.2 The Analysis of Sustainable High-yield and High-efficient Management Model of Bamboo Timber Stands

3.2.1 *Bambusa textilis* (at River Bank)

From the analysis of the factors with levels (Table 18), the result shows that the factor of stand density is the most important one among four factors, and the factor of time and proportion of harvesting old culms is in the next place. The factor of fertilization time and quantity is the least important one. Adjusting the stand density to 765clump · ha^{-1}, keeping 18 new culms · $clump^{-1}$ as mother culms, harvesting old culms in January and March every year, in which the percentage of felling quantity is 50% per time or harvesting all old culms in March, and fertilizing 0.5 kg composed fertilizer of N, P and K for each clump by digging soil around clump in March, June and July every year (the compounding ratio of N, P, K is 4:3:1) are the best treatments.

It also can be seen that: the continuance of dry weather in summer in 2003 has produced a little negative effect stands growth. It may be related to the growth environment, for alluvial plain can provide enough water to the growth.

The best cultivation model is adjusting the bamboo stand density structure to 765 clumps · ha^{-1} and keep18 new culms · $clump^{-1}$ as mother culms, the age structure of 1-year-old : 2-year-old = 2 : 1, harvesting old culms in January and March every year with intensity of 50% per time or harvesting all old culms in March meanwhile removing all old bamboo stumps, raking out soil around clumps

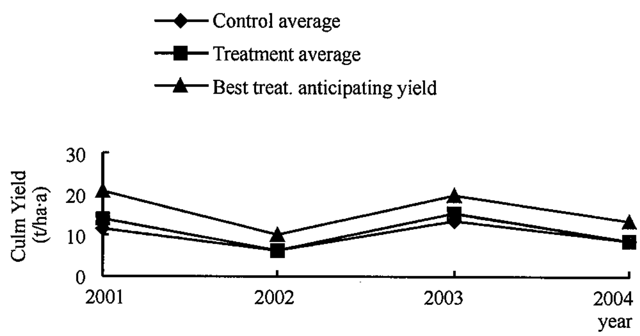


Figure 4 Comparison the Culm yield of *Bambusa textilis* Stand between Best Treatment and Averages

Table 18 Orthogonal Design Analysis for High - yield Techniques Study of *Bambusa textilis* (River Bank) Bamboo Timber Stands

No.	A	B	C	D	2001 (kg/200m^2)			2002 (kg/200m^2)			2003 (kg/200m^2)			2004 (kg/200m^2)		
					1	2	3	1	2	3	1	2	3	1	2	3
1	(1)39	(1)12	(1) June; 0.5 kg/clump/time	(1) January; 100%	400.9	529.0	545.4	198.8	167.9	191.8	508.1	572.2	491.0	280.4	303.4	294.6
2	(1)39	(2)15	(2) June, July; 0.5 kg/clump/time	(2) January, March; 50% per time	436.9	512.1	543.1	174.6	317.2	242.1	628.1	668.2	583.6	297.1	299.7	357.6
3	(1)39	(3)18	(3) March, June, July; 0.5 kg/clump/time	(3) March; 100%	514.5	721.5	641.5	216.0	223.3	307.8	580.2	747.6	556.5	349.9	346.3	357.2
4	(2)51	(1)12	(2) June, July; 0.5 kg/clump/time	(3) March; 100%	541.3	671.7	574.7	228.6	185.7	222.3	666.6	400.7	632.4	366.7	374.5	462.0
5	(2)51	(2)15	(3) March, June, July; 0.5 kg/clump/time	(1) January; 100%	401.8	589.3	581.1	213.7	191.4	271.3	656.4	583.4	644.1	342.5	385.4	515.2
6	(2)51	(3)18	(1) June; 0.5 kg/clump/time	(2) January, March; 50% per time	725.2	686.1	623.8	392.6	297.5	307.8	764.5	573.0	791.2	358.7	361.9	411.4
7	(3)63	(1)12	(3) March, June, July; 0.5 kg/clump/time	(2) January, March; 50% per time	717.8	512.1	432.8	385.4	173.1	300.7	546.6	537.4	671.5	300.5	320.0	330.2
8	(3)63	(2)15	(1) June; 0.5 kg/clump/time	(3) March; 100%	329.9	588.7	655.9	165.4	181.0	285.1	550.2	547.5	684.7	356.8	433.7	405.2
9	(3)63	(3)18	(2) June, July; 0.5 kg/clump/time	(1) January; 100%	550.6	549.0	370.8	310.6	268.0	252.1	708.0	498.5	702.7	235.6	281.8	388.8
Check	51	15	0	January; 100%	390.4	437.2	578.3	247.6	218.1	262.1	460.0	552.7	591.4	381.2	347.9	302.3

(Continued)

No.		A	B	C	D	2001 (kg/200m²)			2002 (kg/200m²)			2003 (kg/200m²)			2004 (kg/200m²)		
						1	2	3	1	2	3	1	2	3	1	2	3
2001	M_1	538.3	547.3	565.0	502.0			553.6			247.1			610.9			352.5
	M_2	599.5	515.4	527.8	576.7												
	M_3	523.1	598.1	568.1	582.2												
	R	76.4	82.7	40.3	80.2												
2002	M_1	226.6	228.3	243.1	229.5												
	M_2	256.7	226.9	244.6	287.9												
	M_3	257.9	286.2	253.6	223.9												
	R	31.3	59.3	10.5	64.0												
2003	M_1	592.8	558.5	609.2	596.0												
	M_2	634.7	616.2	609.9	640.5												
	M_3	605.2	658.0	613.8	596.3												
	R	41.9	99.5	4.6	44.4												
2004	M_1	320.7	336.9	356.2	336.4												
	M_2	397.6	377.0	340.4	337.5												
	M_3	339.2	343.5	360.8	383.6												
	R	76.9	40.1	20.4	47.2												

Note:

2001, the best collocation: A2B3C3D3; yield: 20.83t · ha^{-1}; 1.78 times higher than control one (11.72 t · ha^{-1})

2002, the best collocation: A2B3C3D2, yield: 10.31t · ha^{-1}; 1.70 times higher than control one (6.07 t · ha^{-1})

2003, the best collocation: A2B3C3D2, yield: 20.03t · ha^{-1}; 1.50 times higher than control one (13.37 t · ha^{-1})

2004, the best collocation: A2B2C3D3, yield: 13.43t · ha^{-1}; 1.56 times higher than control one (8.59 t · ha^{-1}).

from ten days to 2 weeks for shoot buds differentiation, and then adding soil in 15cm depth around each clump base and fertilizing 0.5 kg composed fertilizer of N, P, K (4:3:1) for each clump by digging soil around clump in March, June and July, etc. This model has high potential to enhance yield, the timber yield can reach 20.03 – 20.83t · ha^{-1} (see Figure 4), which is 1.50 times higher than control one, and the net income and adding income can be obtained 8,145.3Yuan · ha^{-1} and 2,720.59Yuan · ha^{-1} respectively.

3.2.2 *Bambusa textilis* (Mountain)

From the analysis of the factors with levels (Table 19), the result shows that the factor of fertilization time and quantity is the most important one among four factors, and the factor of stand density is in the next place. The factor of time and proportion of harvesting old culms is the least important one. Adjusting the stand density to 2,505 clump · ha^{-1}, keeping 12 new culms · $clump^{-1}$ as mother culms, harvesting old culms in January and March every year, in which the percentage of felling quantity is 50% per time or harvesting all old culms in March, and fertilizing 0.5 kg composed fertilizer of N, P and K for each clump by digging soil around clump in June and July every year (the compounding ratio of N, P and K is 4:3:1) are the best treatment levels for each factor levels respectively.

It also can be seen that: the continuance of dry weather in summer in 2003 has produced a little negative effect stands growth. It may be because of the bigger stand density.

The best cultivation model is adjusting the bamboo stand density structure to 2,505 clumps · ha^{-1} and keep12 new culms · $clump^{-1}$ as mother culms, age structure of 1 – year-old : 2-year-old = 2:1, harvesting old culms in January and March every year, the percentage of felling quantity of 50% per time or harvesting all old culms in March meanwile removing all old bamboo stumps, raking out soil around clumps from ten days to 2 weeks for shoot buds differentiation, and then adding soil in 15cm depth around each clump base and fertilizing 0.5 kg composed fertilizer of N, P, K (4:3:1) for each clump by digging soil around clump in June and July, etc. This model has high potential to enhance yield, the timber yield can reach 12.22 – 15.05t · ha^{-1} (see Figure 5), which is 1.60 times higher than control one, and the net income and adding income can be obtained 3,263.29Yuan · ha^{-1} and 1,003.68Yuan · ha^{-1} respectively.

Making a comparison between the two kinds of *Bambusa textilis* cultivation, it can be seen that the yield of *Bambusa textilis* (river bank) outclasses *Bambusa textilis* (mountain), and on the economic benefit, the former is much better than the latter.

Table 19 Orthogonal Design Analysis for High - yield Techniques Study of *Bambusa textilis* (Mountain) Bamboo Timber Stands

No.	A	B	C	D	2001 (kg/200m²)			2002 (kg/200m²)			2003 (kg/200m²)		
					1	2	3	1	2	3	1	2	3
1	(1)123	(1)9	(1) June; 0.5 kg/clump/time	(1) January; 100%	378.1	357.7	240.3	253.1	167.9	393.3	225.7	270.0	482.6
2	(1)123	(2)12	(2) June, July; 0.5 kg/clump/time	(2) January, March; 50% per time	339.5	365.0	411.3	202.5	281.7	440.3	372.4	383.5	491.9
3	(1)123	(3)15	(3) March, June, July; 0.5 kg/clump/time	(3) March; 100%	286.8	349.0	237.9	229.2	303.1	247.4	270.6	552.1	209.3
4	(2)145	(1)9	(2) June, July; 0.5 kg/clump/time	(3) March; 100%	346.7	370.2	321.7	237.5	226.7	437.5	395.7	362.5	604.3
5	(2)145	(2)12	(3) March, June, July; 0.5 kg/clump/time	(1) January; 100%	219.0	407.5	255.8	293.7	221.6	440.5	185.2	425.2	334.0
6	(2)145	(3)15	(1) June; 0.5 kg/clump/time	(2) January, March; 50% per time	308.8	424.4	263.5	173.3	220.2	460.3	228.8	428.9	383.8
7	(3)167	(1)9	(3) March, June, July; 0.5 kg/clump/time	(2) January, March; 50% per time	282.6	283.5	307.6	319.3	203.5	338.2	265.3	371.9	366.4
8	(3)167	(2)12	(1) June; 0.5 kg/clump/time	(3) March; 100%	330.5	483.9	409.2	283.5	238.6	534.5	345.7	452.3	564.3
9	(3)167	(3)15	(2) June, July; 0.5 kg/clump/time	(1) January; 100%	329.0	341.6	398.6	263.7	236.7	447.2	243.0	341.8	541.0
Check	145	12	0	January; 100%	287.7	298.5	333.6	249.3	254.2	287.2	343.7	351.5	383.9
2001 M_1	329.5	320.9	355.2	325.3			335.2			299.8			374.0
M_2	324.2	358.0	358.2	331.8									
M_3	351.8	326.6	292.2	348.4									
R	27.6	37.0	66.0	23.1									
2002 M_1	279.8	286.3	302.8	302.0									
M_2	301.3	326.3	308.2	293.3									
M_3	318.4	286.8	288.5	304.2									
R	38.5	39.5	19.7	11.0									
2003 M_1	362.0	371.6	375.8	338.7									
M_2	372.0	394.9	415.1	365.9									
M_3	388.0	355.5	331.1	417.4									
R	26.0	39.5	84.0	78.7									

Note:
2001, the best collocation: A3B2C1D3, yield: 12.22t · ha^{-1}; 1.60 times higher than control one (7.67 t · ha^{-1})
2002, the best collocation: A3B2C2D2, yield: 10.21t · ha^{-1}; 1.55 times higher than control one (6.59 t · ha^{-1})
2003, the best collocation: A3B2C2D3, yield: 15.05t · ha^{-1}; 1.67 times higher than control one (8.99 t · ha^{-1})

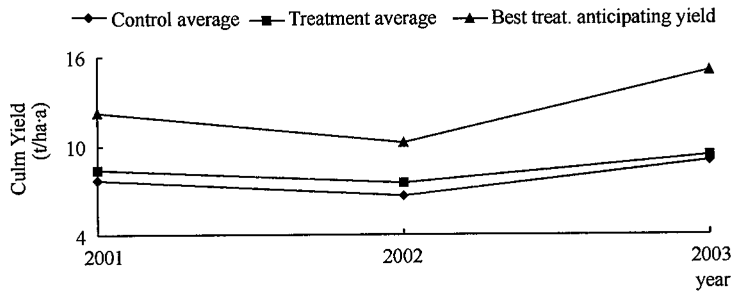


Figure 5 Comparison the Culm Yield of *Bambusa textilis* (Mountain) between Best Treatment and Averages

3.2.3 *Bambusa pervariabilis*

From the analysis of the factors with levels (Table 20), the result shows that the factor of stand density is the most important one among four factors, and the factor of time and proportion of harvesting old culms is in the next place. The factor of fertilization time and quantity is the least important one. Adjusting the stand density to 945 clump · ha^{-1}, keeping 15 – 18 new culms · $clump^{-1}$ as mother culms, harvesting all old culms in March, and fertilizing 0.5 kg composed fertilizer of N, P and K for each clump by digging soil around clump in June and July every year (the compounding ratio of N, P, K is 4:3:1) are the best treatments.

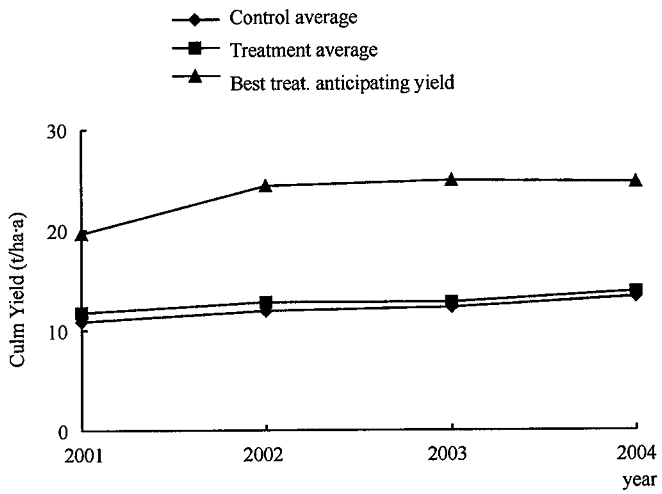


Figure 6 Comparison the Culm Yield of *Bambusa pervariabilis* Stand between Best Treatment and Averages

The best cultivation model is adjusting the bamboo stand density structure to 945 clumps · ha^{-1} and keep 15 – 18 new culms · $clump^{-1}$ as mother culms ,which

Table 20 Orthogonal Design Analysis for High - yield Techniques Study of *Bambusa pervariabilis* Bamboo Timber Stands

No.	A	B	C	D	2001 (kg/200m²)			2002 (kg/200m²)			2003 (kg/200m²)			2004 (kg/200m²)		
					1	2	3	1	2	3	1	2	3	1	2	3
1	(1)39	(1)12	(1) June; 0.5 kg/clump/time	(1) January; 100%	477.3	455.9	373.4	524.0	471.0	404.5	471.4	528.2	383.0	450.1	604.7	558.1
2	(1)39	(2)15	(2) June, July; 0.5 kg/clump/time	(2) January, March; 50% per time	458.5	507.6	469.4	410.2	446.4	423.1	420.5	543.1	448.7	482.2	618.9	590.1
3	(1)39	(3)18	(3) March, June, July; 0.5 kg/clump/time	(3) March; 100%	504.5	457.3	482.7	549.9	571.2	510.8	468.5	553.3	469.8	540.4	637.5	601.4
4	(2)51	(1)12	(2) June, July; 0.5 kg/clump/time	(3) March; 100%	516.4	480.6	404.8	649.1	492.8	422.3	539.3	647.7	438.5	575.1	704.1	409.5
5	(2)51	(2)15	(3) March, June, July; 0.5 kg/clump/time	(1) January; 100%	526.0	526.6	352.5	427.7	515.7	449.1	429.2	601.1	408.1	575.4	491.4	463.0
6	(2)51	(3)18	(1) June; 0.5 kg/clump/time	(2) January, March; 50% per time	510.3	469.0	484.5	527.2	419.7	468.9	510.8	511.4	491.0	576.2	565.2	409.5
7	(3)63	(1)12	(3) March, June, July; 0.5 kg/clump/time	(2) January, March; 50% per time	462.8	385.5	406.5	641.9	463.0	552.0	485.6	455.5	505.6	484.4	489.6	494.3
8	(3)63	(2)15	(1) June; 0.5 kg/clump/time	(3) March; 100%	588.7	478.5	428.2	625.7	585.7	642.7	687.9	573.1	553.6	683.8	632.9	602.7
9	(3)63	(3)18	(2) June, July; 0.5 kg/clump/time	(1) January; 100%	559.5	514.1	464.6	669.3	435.0	594.0	611.8	641.4	523.9	515.3	540.3	655.2
Check	51	15	0	January; 100%	425.7	439.0	448.8	479.7	455.3	501.0	468.5	500.7	512.2	542.7	613.3	546.9

(Continued)

No.		A	B	C	D	2001 (kg/200m²)			2002 (kg/200m²)			2003 (kg/200m²)			2004 (kg/200m²)		
						1	2	3	1	2	3	1	2	3	1	2	3
2001	M_1	465.2	440.4	474.0	472.2			472.1			514.6			514.9			553.7
	M_2	474.5	481.8	486.2	461.6												
	M_3	476.5	494.1	456.1	482.4												
	R	11.3	53.7	30.1	20.8												
2002	M_1	479.0	513.4	518.8	498.9												
	M_2	485.8	502.9	504.7	483.6												
	M_3	578.8	527.3	520.2	561.1												
	R	99.8	24.4	15.5	77.5												
2003	M_1	476.3	495.0	523.4	510.9												
	M_2	508.6	518.4	535.0	485.8												
	M_3	559.8	531.3	486.3	547.9												
	R	83.5	36.3	48.7	62.1												
2004	M_1	564.8	530.0	564.8	539.3												
	M_2	529.9	571.1	565.6	523.4												
	M_3	566.5	560.1	530.8	598.6												
	R	36.6	41.2	34.8	75.2												

Note:
2001, the best collocation: A3B3C2D3, yield: 19.6t · ha^{-1}; 1.79 times higher than control one (10.95t · ha^{-1})
2002, the best collocation: A3B3C3D3, yield: 24.39t · ha^{-1}; 2.04 times higher than control one (12.98 t · ha^{-1})
2003, the best collocation: A3B3C2D3, yield: 24.85t · ha^{-1}; 2.01times higher than control one (12.35 t · ha^{-1})
2004, the best collocation: A3B2C2D3, yield: 24.72t · ha^{-1}; 1.85times higher than control one (13.88 t · ha^{-1})

age structure of 1-year-old : 2-year-old is 2:1, harvesting all old culms in March, removing all old bamboo stumps , raking out soil around clumps for ten days to 2 weeks for shoot buds differentiation, and then adding soil in 15cm depth around each clump base and fertilizing 0.5 kg composed fertilizer of N, P, K (4:3:1) for each clump by digging soil around clump in June and July, etc. This model has high potential to enhance yield, the timber yield can reach 12.35 – 13.88 t · ha^{-1} (see Figure 6), which is 1.85 times higher than control one, and the net income and adding income can be obtained 8,695.74 Yuan · ha^{-1} and 2,315.08 Yuan · ha^{-1} respectively.

3.2.4 *Bambusa chungii*

From the analysis of the factors with levels (Table 21), the result shows that the influence of stand density, time and proportion of harvesting old culms and fertilization time and quantity is obvious equally. Adjusting the stand density to 9,451,500 clump · ha^{-1}, keeping 15 new culms · $clump^{-1}$ as mother culms, harvesting all old culms in March, and fertilizing 0.5 kg composed fertilizer of N, P and K for each clump by digging soil around clump in June and July every year (the compounding ratio of N, P, K is 4:3:1) are the best treatments.

The best cultivation model is adjusting the bamboo stand density structure to 1,500 clumps · ha^{-1} and keep 15 new culms · $clump^{-1}$ as mother culms, their age structure of 1 – year-old : 2-year-old = 2:1, harvesting old culms in January and March every year, in which the percentage of felling quantity is 50% per time , removing all old bamboo stumps , raking out soil around clumps for ten days to 2 weeks for shoot buds differentiation, and then adding soil in 15cm depth around each clump base and fertilizing 0.5 kg composed fertilizer of N, P, K (4:3:1) for each clump by digging soil around clump in March, June and July, etc. This model has high potential to enhance yield, the timber yield can reach 46.43 – 47.6 t · ha^{-1} (see Figure 7), which is 1.92 times higher than control one, and the net income and adding income can be obtained 19,565.87Yuan · ha^{-1} and 6,101.43 Yuan · ha^{-1} respectively.

3.2.5 *Pseudosasa amabilis*

This *Pseudosasa amabilis* stands have the character of biennial bearing, so the statistical analysis about timber yield should be done in use of the unit (du: two years).

From the analysis of the factors with levels (Table 22), the result shows that the factor of stand density is the most important one among three factors, and the factor of fertilization time and quantity is in the next place. The factor of time and proportion of harvesting old culms is the least important one. For the number of new culms, the factor of fertilization time and quantity is the most important one (see

Table 21 Orthogonal Design Analysis for High - yield Techniques Study of *Bambusa chungii* Bamboo Timber Stands

No.	A	B	C	D	2001(kg/200m²)			2002(kg/200m²)			2003(kg/200m²)			2004(kg/200m²)		
					1	2	3	1	2	3	1	2	3	1	2	3
1	(1)60	(1)12	(1) June; 0.5 kg/clump/time	(1) January; 100%	698.0	664.1	846.2	641.7	721.9	1012.1	966.2	811.9	879.2	1117.4	684.7	1002.9
2	(1)60	(2)15	(2) June, July; 0.5 kg/clump/time	(2) January, March; 50% per time	935.2	914.7	1054.5	778.0	1033.3	1294.7	1157.7	1133.2	1250.8	1149.4	1057.5	1180.7
3	(1)60	(3)18	(3) March, June, July; 0.5 kg/clump/time	(3) January, February, March; 33.3% per time	880.1	886.1	1026.4	766.3	873.0	951.1	961.5	1268.6	1081.5	1039.5	1130.5	1122.4
4	(2)80	(1)12	(2) June, July; 0.5 kg/clump/time	(3) January, February, March; 33.3% per time	640.6	870.5	710.2	531.7	822.8	877.1	830.9	1042.4	912.2	756.5	1044.4	897.8
5	(2)80	(2)15	(3) March, June, July; 0.5 kg/clump/time	(1) January; 100%	794.4	945.6	735.7	696.7	892.6	836.5	1109.9	1185.6	1083.6	1084.1	1225.9	1057.3
6	(2)80	(3)18	(1) June; 0.5 kg/clump/time	(2) January, March; 50% per time	1025.8	1063.7	949.6	861.3	817.8	530.9	1230.6	1130.9	927.8	1499.8	1075.0	837.7
7	(3)100	(1)12	(3) March, June, July; 0.5 kg/clump/time	(2) January, March; 50% per time	906.7	881.1	1271.2	842.9	802.1	1430.5	1210.3	757.7	1299.8	1169.6	957.9	1284.4
8	(3)100	(2)15	(1) June; 0.5 kg/clump/time	(3) January, February, March; 33.3% per time	713.1	747.9	767.3	691.8	877.8	1096.5	914.0	1038.3	1029.0	922.1	1241.9	1004.2
9	(3)100	(3)18	(2) June, July; 0.5 kg/clump/time	(1) January; 100%	806.7	946.7	890.7	651.8	778.1	924.4	949.3	1254.6	1103.3	897.4	1168.8	1105.0
Check	40	15	0	January; 100%	827.3	884.9	641.7	887.3	668.5	743.3	955.3	778.7	950.1	975.5	1019.3	902.1

(Continued)

No.		A	B	C	D	2001 (kg/200m²)			2002 (kg/200m²)			2003 (kg/200m²)			2004 (kg/200m²)		
						1	2	3	1	2	3	1	2	3	1	2	3
2001	M_1	878.4	832.1	830.6	814.2	873.1			853.2			1056.3			1063.5		
	M_2	859.6	845.4	863.3	1000.3												
	M_3	881.3	941.8	925.3	804.7												
	R	21.7	109.7	94.6	195.6												
2002	M_1	896.9	853.6	805.8	795.1												
	M_2	763.0	910.9	854.7	932.4												
	M_3	899.6	795.0	899.1	832.0												
	R	136.5	115.9	93.3	137.3												
2003	M_1	1056.7	967.9	992.0	1038.2												
	M_2	1050.4	1100.2	1070.5	1122.1												
	M_3	1061.8	1100.9	1106.5	1008.7												
	R	11.4	132.4	114.5	113.4												
2004	M_1	1053.9	990.6	1042.8	1038.2												
	M_2	1053.2	1102.6	1028.6	1134.7												
	M_3	1083.5	1097.3	1119.1	1017.7												
	R	30.3	112.0	90.5	96.5												

Note:
2001, the best collocation: A3B3C3D2; yield: 43.16t · ha^{-1}; 2.20 times higher than control one(19.62t · ha^{-1})
2002, the best collocation: A3B2C3D2; yield: 44.54t · ha^{-1}; 2.33times higher than control one 19.16 t · ha^{-1})
2003, the best collocation: A3B2C3D2; yield: 47.60t · ha^{-1}; 2.13times higher than control one(22.37 t · ha^{-1})
2004, the best collocation: A3B2C3D2; yield: 46.43t · ha^{-1}; 1.92times higher than control one(24.14t · ha^{-1})

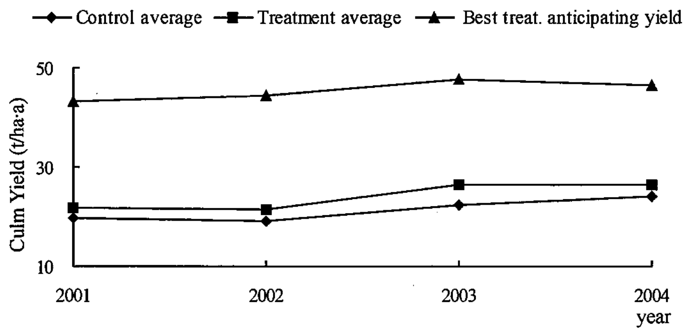


Figure 7 Comparison the Culm Yield of *Bambusa chungii* Stand between Best Treatment and Averages

Table 22 Orthogonal Design Analysis for High-yield Techniques Study of *Pseudosasa amabilis* Bamboo Timber Stands

No.	A Stand density (culms/mu)	B Harvesting time and intensity	C Fertilization time; frequency and quantity	2003 – 2004 (kg/300m²)	
				1	2
1	1500	November(on-year); 100%	February-March; 25kg/mu/time	450.6	453.1
2	1500	November(on-year), January (off-year); 50% per time	September; 25kg/mu/time	560.7	466.5
3	1500	November(on-year), January, March(off-year);33.3% per time	February-March, September; 25kg/mu/time	518.3	599.4
4	2000	November(on-year); 100%	February-March, September; 25kg/mu/time	807.3	716.2
5	2000	November(on-year), January (off-year); 50% per time	February-March; 25kg/mu/time	650.9	618.3
6	2000	November(on-year), January, March(off-year); 33.3% per time	September; 25kg/mu/time	700.0	656.0
7	2500	November(on-year); 100%	September; 25kg/mu/time	810.7	634.9
8	2500	November(on-year), January (off-year); 50% per time	February-March, September; 25kg/mu/time	674.0	605.9
9	2500	November(on-year), January, March(off-year);33.3% per time	February-March; 25kg/mu/time	654.8	549.0
10	2000	November(on-year); 100%	0	549.0	536.4
2003 – 2004 M_1	508.1	645.5	562.8		618.1
M_2	691.4	596.0	638.1		
M_3	654.9	612.9	653.5		
R	183.4	49.4	90.7		

Table 23). Adjusting the stand density to 30,000 culms · ha^{-1}, harvesting all old culms in November of on-year, and fertilizing 375 kg composed fertilizer of N, P and K for each-ha by digging soil along contour line in late February and early September every year (the compounding ratio of N, P and K is 4:3:1) are the best treatment levels for each factor levels respectively.

Table 23 Orthogonal Design Analysis for the Number of New Culms of *Pseudosasa amabilis*

No.	A Stand density (culms/mu)	B Harvesting time and intensity	C Fertilization time; frequency and quantity	2003 - 2004 (kg/300m²)	
				1	2
1	1500	November(on-year); 100%		525	694
2	1500	November(on-year), January (off-year); 50% per time	September; 25kg/mu/time	359	405
3	1500	November(on-year), January, March(off-year); 33.3% per time	February-March, September; 25kg/mu/time	616	500
4	2000	November(on-year); 100%	February-March, September; 25kg/mu/time	386	468
5	2000	November(on-year), January (off-year); 50% per time	February-March; 25kg/mu/time	524	539
6	2000	November(on-year), January, March(off-year); 33.3% per time	September; 25kg/mu/time	496	527
7	2500	November(on-year); 100%	September; 25kg/mu/time	345	368
8	2500	November(on-year), January (off-year); 50% per time	February-March, September; 25kg/mu/time	461	573
9	2500	November(on-year), January, March(off-year); 33.3% per time	February-March; 25kg/mu/time	417	518
10	2000	November(on-year); 100%	0	405	334
2003 - 2004 M_1	516.5	464.3	536.2		484.5
2003 - 2004 M_2	490.0	476.8	416.7		
2003 - 2004 M_3	447.0	512.3	500.7		
2003 - 2004 R	69.5	48.0	119.5		

For *Pseudosasa amabilis* stands, the best cultivation model is adjusting the bamboo stand density structure to 30,000 culms · ha^{-1} and fertilizing 375 kg composed fertilizer of N, P and K for each ha by digging soil along contour line in late February. and early September every year (the compounding ratio of N, P and K is 4:3:1) and harvesting all old culms in November of on-year, etc. This model has high potential to enhance yield. For two years, the timber yield can reach 31.39t · ha^{-1} (see Figure 8), which is more than 1.74 times higher than control one, and the net income and adding income can be obtained 7,349.30 Yuan · ha^{-1} and

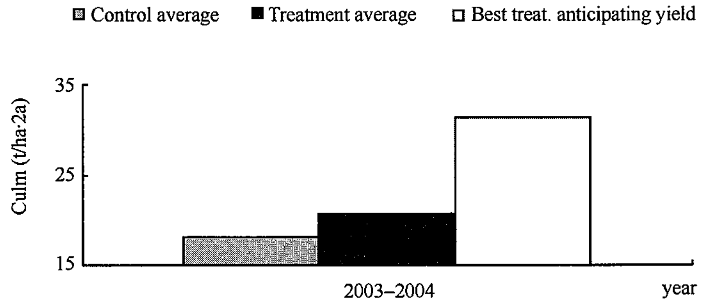


Figure 8 Comparison the Culm Yield of *Pseudosasa amabilis* between Best Treatment and Averages

2,943.50Yuan · ha^{-1} respectively.

3.3 Economical Benefits Evaluation of the Sustainable High-yield and High-efficient Management Demonstration Areas of Sympodial Bamboos Stands

It has been done that the economical benefits analysis on seven kinds of sustainable high-yield and high-efficient management demonstration areas, the result shows that (see Table 24 and Figure 9): the difference in economic benefit between different sustainable high-yield and high-efficient management demonstration areas is remarkable. Most demonstration areas have high potential to obtain more benefits, except of *Bambusa textilis* (mountain) and *Bambusa pervariabilis*. For bamboo timber stands demonstration areas, the unit area net highest income of *Bambusa chungii* stands reached 15,030.45Yuan · ha^{-1}, while adding income of *Bambusa textilis* stands reached 1,669.75Yuan · ha^{-1} and can be considered as the highest. For bamboo shoot stands demonstration areas, the unit area's highest net income of *Dendrocalamus brandisii* stands reached 11,598.85 Yuan · ha^{-1}, whereas adding income of *Dendrocalamus latiflorus* stands reached 3,715.66 Yuan · ha^{-1} and can be considered as the highest.

There are 2,390 ha of sympodial bamboo model stands have been established in Guangdong, Guangxi and Fujian. The net income and adding income can be obtained 19,445,784.72Yuan and 3,044,899.24Yuan respectively. If the recent research achievements obtained from this project can be applied in these demonstration areas in future, the benefits could be much higher than what have been obtained now (see Table 25).

Table 24 Economical Benefits Evaluation of the Sustainable High – yield and High – efficient Management Demonstration Areas of Sympodial Bamboos Stands

	Type	Plot area (m^2)	Income							Payout						Net income (Yuan · ha^{-1})	Add income (Yuan · ha^{-1})	Demonstration areas (ha)	Demonstration areas total net income (Yuan)	Demonstration areas total adding income (Yuan)
			Bamboo timber			Bamboo shoot			Total (Yuan · mu^{-1})	Fertilize cost (Yuan · mu^{-1})	Labor cost				Total (Yuan · mu^{-1})					
			Mean yield (kg/plot)	Sale (Yuan · kg^{-1})	Income (Yuan · mu^{-1})	Mean yield (kg/plot)	Sale (Yuan · kg^{-1})	Income (Yuan · mu^{-1})			Foster (Yuan · mu^{-1})	Fertilize (Yuan · mu^{-1})	Lop (Yuan · mu^{-1})	Shoot harvesting (Yuan · mu^{-1})						
Demonstration area	*Dendrocalamus brandisii*	200	150. 0	0. 20	100. 01	374. 5	0. 8	998. 83	1098. 8	55. 73	90. 00	30. 00	25. 00	124. 85	325. 58	11598. 85	2551. 36	120	1391862. 06	306163. 27
	Dendrocalamus latiflorus	200	180. 0	0. 22	132. 01	374. 0	0. 7	810. 27	942. 3	74. 30	90. 00	30. 00	30. 00	124. 66	348. 96	8899. 72	3715. 56	200	1779944. 81	743111. 34
	Bambusa textilis (river bank)	400	634. 1	0. 60	634. 10	0. 0	0. 0	0. 00	634. 1	48. 30	30. 00	30. 00	52. 84	0	161. 14	7094. 46	1669. 75	600	4256677. 42	1001851. 19
	Bambusa textilis (mountain)	400	379. 0	0. 48	303. 23	0. 0	0. 0	0. 00	303. 2	46. 44	30. 00	35. 00	31. 59	0	143. 02	2403. 08	143. 47	210	504647. 75	30129. 24
	Bambusa chungii	300	1048. 4	0. 60	1397. 89	0. 0	0. 0	0. 00	1397. 9	92. 88	30. 00	40. 00	232. 98	0	395. 86	15030. 45	1566. 01	410	6162485. 01	642063. 31
	Bambusa pervariabilis	300	559. 9	0. 54	671. 86	0. 0	0. 0	0. 00	671. 9	46. 44	30. 00	30. 00	124. 42	0	230. 86	6615. 12	234. 46	650	4299826. 59	152400. 55
	Pseudosasa amabilis	300	360. 4	0. 65	520. 63	0. 0	0. 0	0. 00	520. 6	46. 44	30. 00	30. 00	64. 08	0	170. 51	5251. 71	845. 90	200	1050341. 09	169180. 32
	Total																	2390	19445784. 72	3044899. 24
Check	*Dendrocalamus brandisii*	200	120. 0	0. 20	80. 00	254. 2	0. 8	677. 90	757. 9	0. 00	50. 00	0. 00	20. 00	84. 74	154. 74	9047. 5				
	Dendrocalamus latiflorus	200	80. 0	0. 22	58. 67	191. 0	0. 7	413. 96	472. 6	0. 00	50. 00	0. 00	13. 33	63. 69	127. 02	5184. 2				
	Bambusa textilis (river bank)	400	449. 0	0. 60	449. 07	0. 0	0. 0	0. 00	449. 1	0. 00	50. 00	0. 00	37. 42	0	87. 42	5424. 7				
	Bambusa textilis (mountain)	400	279. 9	0. 48	223. 97	0. 0	0. 0	0. 00	224. 0	0. 00	50. 00	0. 00	23. 33	0	73. 33	2259. 6				
	Bambusa chungii	300	852. 8	0. 60	1137. 16	0. 0	0. 0	0. 00	1137. 2	0. 00	50. 00	0. 00	189. 53	0	239. 53	13464. 4				
	Bambusa pervariabilis	300	486. 2	0. 54	583. 42	0. 0	0. 0	0. 00	583. 4	0. 00	50. 00	0. 00	108. 04	0	158. 04	6380. 7				
	Pseudosasa amabilis	300	271. 3	0. 65	391. 96	0. 0	0. 0	0. 00	392. 0	0. 00	50. 00	0. 00	48. 24	0	98. 24	4405. 8				
The best cultivation model	*Dendrocalamus brandisii*	200	150. 0	0. 20	100. 01	471. 4	0. 8	1257. 13	1357. 1	55. 73	90. 00	30. 00	25. 00	157. 14	357. 87	14989. 01	5941. 52	120	1798680. 74	712981. 96
	Dendrocalamus latiflorus	200	180. 0	0. 22	132. 01	462. 3	0. 7	1001. 71	1133. 7	74. 30	90. 00	30. 00	30. 00	154. 11	378. 41	11329. 63	6145. 46	200	2265926. 44	1229092. 97
	Bambusa textilis (river bank)	400	801. 2	0. 60	801. 24	0. 0	0. 0	0. 00	801. 2	111. 45	30. 00	50. 00	66. 77	0	258. 22	8145. 30	2720. 59	600	4887180. 50	1632354. 27
	Bambusa textilis (mountain)	400	499. 9	0. 48	399. 94	0. 0	0. 0	0. 00	399. 9	55. 73	35. 00	50. 00	41. 66	0	182. 39	3263. 29	1003. 68	210	685291. 10	210772. 59
	Bambusa chungii	300	1362. 9	0. 60	1817. 30	0. 0	0. 0	0. 00	1817. 3	130. 03	30. 00	50. 00	302. 88	0	512. 91	19565. 87	6101. 43	410	8022008. 30	2501586. 61
	Bambusa pervariabilis	300	701. 7	0. 54	842. 10	0. 0	0. 0	0. 00	842. 1	46. 44	30. 00	30. 00	155. 94	0	262. 38	8695. 74	2315. 08	650	5652231. 22	1504805. 18
	Pseudosasa amabilis	300	470. 8	0. 65	680. 09	0. 0	0. 0	0. 00	680. 1	46. 44	30. 00	30. 00	83. 70	0	190. 14	7349. 30	2943. 50	200	1469860. 44	588699. 68
	Total																	2390	24781178. 74	8380293. 26

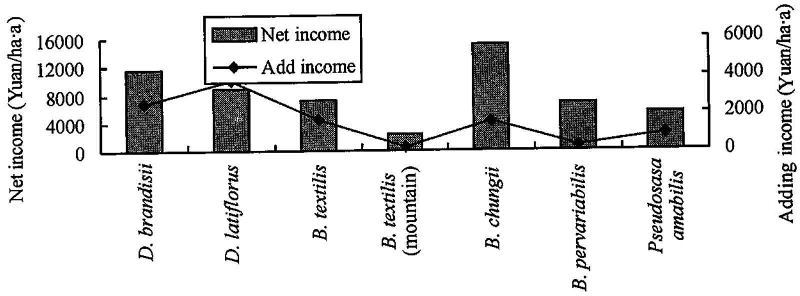


Figure 9 Comparison the Net Income and Add Income among Different Types of Demonstration Area

Table 25 Potential Adding Benefits Analysis for Each Demonstration Area (Yuan · ha^{-1})

No.	Type	Demonstration areas		The best cultivation model		Potential adding profit	
		Net income	Adding income	Net income	Adding income	Net income	Adding income
1	*Dendrocalamus brandisii*	11598.85	2551.36	14989.01	5941.52	3390.16	3390.16
2	*Dendrocalamus latiflorus*	8899.72	3715.56	11329.63	6145.46	2429.91	2429.9
3	*Bambusa textilis* (river bank)	7094.46	1669.75	8145.30	2720.59	1050.84	1050.84
4	*Bambusa textilis* (mountain)	2403.08	143.47	3263.29	1003.68	860.21	860.21
5	*Bambusa chungii*	15030.45	1566.01	19565.87	6101.43	4535.42	4535.42
6	*Bambusa pervariabilis*	6615.12	234.46	8695.74	2315.08	2080.62	2080.62
7	*Pseudosasa amabilis*	5251.71	845.90	7349.30	2943.50	2097.59	2097.6

4 Conclusions

The better management techniques for different species from the studies are as follows:

For *Dendrocalamus brandisii*: to adjust the density of plantation to 450 culms/ha, keep three new genets per clump every year, adjust stand structure during January and February, remove all old bamboo stumps during March and April, rake out soil around clumps and under the sun for 2 weeks and then add soil in 15cm depth around each clump base, apply 0.5 kg composed fertilizer of N, P, K (4:3:1) for each clump by digging soil around clump in June. If this model has been adopted, the shoot yield can reach 19.32 – 23.57t · ha^{-1}, which is 1.46 –

1.94 times higher than control one, and its net income and adding income can be obtained 14,989.01Yuan · ha^{-1} and 5,941.52 Yuan · ha^{-1} respectively.

For *Dendrocalamus latiflorus*: to adjust the density of plantation to 600 culm/ha, keep two new mother culms per clump every year, adjust stand structure during January and February , remove all old bamboo stumps in March and April, Rake out soil around clumps and under the sun for 2 weeks and then add soil in 15cm depth around each clump base, fertilize 0.5 kg composed fertilizer of N, P, K (4:3:1) for each clump by digging soil around clump in June. If this model has been adopted, the shoot yield of *Dendrocalamus latiflorus* stands can reach 23.12 t · ha^{-1}, which is 1.92 times higher than control one, and its net income and adding income can be obtained 11,329.63Yuan · ha^{-1} and 6,145.46Yuan · ha^{-1} respectively.

For *Bambusa textilis* (at river bank): to adjust the stand density structure to 765 clumps · ha^{-1} and keep 18 culms · $clump^{-1}$ as mother culms in January and February, which age structure of 1-year-old :2-year-old is 2:1; harvested 50% old culms in January and March respectively or harvested old culms before March, and removed all old bamboo stumps, raking out soil around clumps for ten days to 2 weeks for shoot buds differentiation, and then add soil in 15cm depth around each clump base in April and apply 0.5 kg composed fertilizer of N, P, K(4:3:1) for each · clump by digging soil around clump in March, June and July respectively, etc. If this model has been adopted, the shoot yield of Bambusa textilis stands (in river bank) can reach 20.03-20.83t · ha^{-1}, which is 1.5 times higher than control one, and its net income and adding income can be obtained 8,145.3Yuan · ha^{-1} and 2,720.59Yuan · ha^{-1} respectively.

For *Bambusa* (at mountain): to adjust the stand density structure to 2,505 clumps · ha^{-1}, keep 12 culms · $clump^{-1}$ as mother culms in January and February, which age structure of 1-year-old :2-year-old is 2:1; harvested 50% old culms in January and March respectively or harvested old culms before March, and removed all old bamboo stumps, raking out soil around clumps for ten days to 2 weeks for shoot buds differentiation, and then adding soil in 15cm depth around each clump base in April and fertilizing 0.5 kg composed fertilizer of N, P, K(4:3:1) for each clump by digging soil around clump in June and July respectively, etc. If this model has been adopted, the shoot yield of *Bambusa textilis* stands (in mountain) can reach 12.22 – 15.05t · ha^{-1} (see Figure 5), which is 1.6 times higher than control one, and its net income and adding income can be obtained 3,263.29Yuan · ha^{-1} and 1,003.68Yuan · ha^{-1} respectively.

For *Bambusa pervariabilis*: to adjust the stand density structure to 945 clumps · ha^{-1} and keep 15 – 18 culms · $clump^{-1}$ as mother culms in January and February, which age structure of 1-year-old : 2-year-old is 2:1; harvested old culms before

March, and removed all old bamboo stumps, raking out soil around clumps for ten days to 2 weeks for shoot buds differentiation, and then adding soil in 15cm depth around each clump base in April and fertilizing 0.5 kg composed fertilizer of N, P, K for each clump by digging soil around clump in June and July respectively, etc. If this model has been adopted, the shoot yield can reach 12.35 – 13.88 t · ha^{-1} (see Figure 6), which is 1.85 times higher than control one, and its net income and adding income can be obtained 8,695.74Yuan · ha^{-1} and 2,315.08Yuan · ha^{-1} respectively.

For *Bambusa chungii*: to adjust the bamboo stand density structure to 1500 clumps · ha^{-1} and keep 15 – 18 culms · $clump^{-1}$ as mother culms in January and February, which age structure of 1-year-old : 2-year-old is 2:1; harvest 50% old culms in January and March respectively, and remove all old bamboo stumps, rakie out soil around clumps for ten days to 2 weeks for shoot buds differentiation, and then add soil in 15cm depth around each clump base in April and apply 0.5 kg composed fertilizer of N, P, K(4:3:1) for each clump by digging soil around clump in March, June and July respectively, etc. If this model has been adopted, the shoot yield of *Bambusa chungii* can reach 46.43 – 47.6 t · ha^{-1}, which is 1.92 times higher than control one, and its net income and adding income can be obtained 19,565.87 Yuan · ha^{-1} and 6,101.43Yuan · ha^{-1} respectively.

For *Pseudosasa amabilis* stand: to adjust the stand density structure to 30,000 culms · ha^{-1} and keep the age structure of 1 du : 2 du to 1:1; apply 375kg · ha^{-1} · $time^{-1}$ composed fertilizer of N, P, K (4:3:1) by digging soil along contour line in February and September respectively; harvest old culms in November of on – year, etc. If this model has been adopted, for two years, the shoot yield of *Pseudosasa amabilis* can reach 31.39t · ha^{-1}, and its net income and adding income can be obtained 7,349.3Yuan · ha^{-1} and 2,943.5Yuan · ha^{-1} respectively.

The difference in economic benefit between different sustainable high-yield and high-efficient management demonstration areas is remarkable. For bamboo timber stands demonstration areas, the unit area highest net income of *Bambusa chungii* stands reached 15,030.45 Yuan · ha^{-1}, whereas adding highest income of *Bambusa textilis* stands reached 1,669.75Yuan · ha^{-1}. For bamboo shoot stands demonstration areas, the unit area net income of *Dendrocalamus brandisii* stands reached 11,598.85 Yuan · ha^{-1}, whereas adding income of *Dendrocalamus latiflorus* stands reached 3,715.66 Yuan · ha^{-1}.

The 2,390 ha of sympodial bamboo model stands have been established in this project, and its net income and adding income can be obtained 19,445,784.72 Yuan and 3,044,899.24 Yuan respectively. If recent research achievements obtained from this project can be applied in these demonstration areas in future, the large potential benefits from demonstration areas could be obtained further.

Techniques of Vegetative Propagation for Sympodial Bamboos

To plant offset is the traditional way for establishing sympodial bamboos plantation. The method includes some problems as damaging parent clump, lower surviving rate, inefficiency and high costs and thus restricts large scale planting. Studies have been undertaken since late 1950s on techniques for raising plantings in nursery by using main branch, sub-branch and culm cuttings and for field transplanting. Those applied techniques have been practiced in large scale from the early 1960s, resulting in a rapid enlargement of sympodial bamboos areas in China. Since 1990s, tissue culture has been applied widely in South-East Asian Countries, Indian, and China, etc.

1 Nursery Practice

1.1 Nursery Site Selection and Soil Preparation

The bamboo nursery should be established on the site, which is

a. fertile loam or sandy loam soils;
b. near waters and easy for irrigating and draining;
c. near planting sites with convenient transportation; and
d. less than 5 degrees in slope. Certain measures for water and soil conservation should be met when the nursery is located at more sloping sites.

For intensive soil preparation, it is recommended to plough the whole site up to 20cm in depth, harrow the soil into particles less than 5mm in diameter, and finally, if any, remove out grasses and roots of trees. It may be not necessary to make planting beds when plantings are raised by means of culm cutting on gentle slop sites. The common practice on such site is to hoe strips on well-prepared ground with an espacement of 70cm between strips and makes two parallel planting drills at an espacement of 50cm in each strip. Each drill is about 15cm in depth, 20cm in width and 5 or 10m in length, depending on the size of different bamboo species. 2,400 to 2,700 offset will be needed for one hectare of such nursery. Planting beds are usually necessary to meet the need of draining, when the nursery is on plain site. It can be made about 1 m in width, 20 to 30cm in height and 5 or 10 m in length. Two drills, 20cm in both depth and width, are then made along the two edges of each bed. As base fertilizer, about 50kg burned ground litter should be applied to each drill and mixed with the soil.

1.2 The Season of Planting Raising

Sympodial bamboos usually start to sprout new leaves from early February. Planting raising can be operated from mid February to late March, but perfectly in the early and mid March. It is not recommended to raise plantings later than early April. Experienced farmers determine the time of planting raising by monitoring the growing stage of bamboos and they usually start to operate when only a few culms commence sprouting new leaves. It is believed to be too late for training plantings when dominant culms are in this situation.

Generally, in the rainy, early spring season, temperature commence to rise and the soil is fairly moist, thus resulting in the most favourable time for planting raising and its growth.

1.3 The Method of Planting Raising

1.3.1 Raising with Branch or Sub-branch Cutting

Similar to the culm structure, the branch or sub-branch of sympodial bamboos comprises 3 parts, i.e. the branch body, the branch base and the branch handle. The shoot buds and root tips on the basal part of culm and branch respectively provide the possibility to propagate them.

Raising plantings through branch or sub-branch cutting propagation is most suitable for relative large-sized species with dominant branches and sub-branches, such as *Dendrocalamus* spp. , *Neosinocalamus* spp. and *Bambusa* spp. Main and sub branches are used in most cases and around 90 percent of them can produce new stocks.

The main or sub-branch at 1 to 2 years of age collected from a 2 or 3-year-old culm is usually used for propagating. The branch cutting, about 40 to 50cm long, is made by discarding the top part and leaving 2 or 3 basal internodes of the selected branch. It is placed obliquely in the plant drill on the bed, leaving the basal end in the soil up to 5 – 6cm in depth and keeping the node bud on the upper end just at the level of the soil surface. The procedure ends after covering with thatch above the drill and watering.

Propagation with branch cuttings has several advantages. There will be no or much less injury to the mother culm and its shooting ability. Planting-raising in this manner can be operated from February to September, but the operation in February and March can obtain higher survivals. Branch cuttings, much smaller than culm in size, are easy for storing, handling and transporting, thus lowering the costs. Finally, if well-managed, plantings raised have a well-developed root system and a strong culm, and a high survival at field planting could be expected.

1.3.2 Raising with Single-node Culm Cutting

Culm cuttings can be taken from one or two-year-old culms, which are felled either with the culm base and handle for the former or at the ground level for the latter. The top part and lateral branches of the selected culm should be discarded, leaving the top-off culm with the basal part of main branches which contains only 1-2 internodes. The offset about 4cm in diameter can offer 10 useful nodes and larger culms over 6cm in diameter may contain 15 to 20 nodes. After transporting to the nursery site, the single-node cutting should be made carefully, without any injury to the culm and node bud. The cutting should be placed horizontally in the prepared drill, kept at the position with the node bud towards the right or left side, at the depth of 6 to 10cm and watered after covering with dry grasses above the drill.

Propagation of thin-walled bamboos with culm cuttings is usually less successful and has problems of tedious handle and inefficiency, so it is difficult to be used in large scale. However, it is suitable for thick-walled and large-sized species, such as *Dendrocalamus latiflorus* and *Dendrocalamus brandisii*, etc. Although every node-bud can germinate, only around 30% finally survive. Differing with seed propagation, the cutting produces a root system about one month after shooting and, during this period, the exhaustion of the nutrition stored in the culm cutting and any unfavourable condition, such as drought and impeded drainage, will cause considerable death of the cuttings. The survived plantings are higher and stronger, with well-developed root systems, than those raised from the whole culm.

1.3.3 Raising with Two-node Culm Cutting

This kind of cutting can be taken and treated in the same procedure as for the single-node cutting, but it contains two culm nodes and is buried in the soil with the two buds towards the left and right respectively. Propagation with 2-node cutting can achieve a higher survival of plantings than that with single-node cutting but slightly lower than that with whole culm.

Planting raising using culm cutting of either single or two nodes may not be recommended for establishment of large scale plantations because of its tedious handling and lower labouring efficiency.

1.3.4 Raising with Opened Culm Attaching the Handle

The propagating material is collected from one-year-old culm. The offset should be taken with the handle part and then treated by removal of the top and all branches.

A cross opening, being two third or three fourth of the culm diameter in depth, is made at the center of each internode at the direction opposite to the handle. The treated culm is placed in a prepared drill with the openings upwards at the depth of 6 – 10cm, then covered with dry grasses and watered finally.

This method of propagation usually achieves good survival and has been the best approach of vegetative propagation using culm materials for at least two reasons: first, the openings made on the culm enhance sprouting of node buds, compared with the similar method using culm without openings whereby most of the culm buds fail to develop; second, water and nutrients absorbed by the handle can be transported through the linkage remained to each node and meet nutritional requirement for planting development before rooting, thus avoiding their failure due to exhaustion of nutrients, as in the case of culm cutting propagation. For instance, each offset can produce 6 – 7 new clumps in raising plantings of *Lingnania chungii* in this manner, but only 3 – 4 ones using culm cuttings or intact culm.

1.3.5 Raising with Opened Culm

A culm of 1 or 2 years is used. In comparison with the propagation using opened culm attaching the handle, the operation is the same, except the offset is simply taken at the ground level without the handle attached. Therefore, it is less in labour-consuming and costs, but produces plantings lesser in number and each culm can produce about 4 plantings in average in the case of propagating *Lingnania chungii*. This method is more suitable for raising plantings at the site near the stand from which the offset will be collected. When distant transportation is essential, certain measures like watering and covering with thatch or plastic sheet should be taken to prevent drying out of the offset.

1.3.6 Ground Layering

A young culm which has finished its height growth is selected and the top removed to stimulate the development of node buds. When the buds enlarge enough, the culm is layered in a drill already prepared in 10 – 15cm in both width and depth with fertilizers placed and mixed with the soil in it. The layering culm is covered with 2 – 3cm soil and then dry grass. To make sure of regular watering but avoiding any impeded drainage in the drill is much important for the success of the propagation. Layering is often done in February or March and shooting will take place in April or May, followed by rooting in July or August. The 1 – year-old plantings about 120cm in height are ready for transplanting.

The determination of propagating approaches mentioned above will depend on the involved bamboo species, the possessed techniques and other conditions. Generally, propagating using branch and culm cuttings needs well-practiced operation and is suitable for thick-walled species, while the culm-burying may be the reasonable choice for propagating mid-sized species at the site where it is less developed in technical and economic aspects.

1.4 Nursery Tending

The development of vegetative plantings for the propagation with opened culm, can be divided to 6 stages, referred as planting of offset; its root-recovering; plantings' culm growing; rooting; tillering and resting. Plantings turn to each next stage in certain regularity. Tending will have influence on earlier or delayed changing of the stages. So it should be based on the features of different stages.

1.4.1 Planting offset

The offset easily dries out after digging out of the soil, so it should be kept in shade, moist and cool condition. Adequate shading and regular watering are essential when the offset is in storing, on transportation and after planting in nursery so as to improve recovery of the root system.

1.4.2 Root-recovering

The recovery of the offset's root system usually takes place 1-2 weeks after planting. Sufficient watering at the base of offset after planting will significantly improve its recovery and survival.

1.4.3 Shooting

Shooting stage lasts from the recovery of the offset to the end of the first shooting about one month after nursery planting. The new shoots younger than one month have no own root system. It is much important to prevent them from damage by drought and sun-insolation, which can be achieved by regular irrigating and keeping the original cover for lowering the ground temperature. Fertilization during this stage, at the base part of the offset, can improve the quantity and quality of shoots. Complete weeding should be done in time, but carefully for avoiding any injury to the offset and young generation.

1.4.4 Rooting

Rooting takes place about 30 days after shooting when the new culm has completed its height growth, passing through sheath-shedding, branching and leave-producing. The young plantings without root system developed are easy to die from drought and exhaustion of nutrition reserved in the offset. They develop root system from late May to mid June. Weeding, soil-loosening and fertilizing at this time will stimulate tillering.

1.4.5 Tillering

The plantings which have already established their well-developed root system can produce 2 to 3 generations of culmlets from July to November, provided with sufficient water and nutrients. The first generation of culmlet appears from mid July to mid August, the second from early September to early October and the third from late October to late November. Large amounts of water and nutrients will be consumed by the plantings during this stage and fertilizers should be applied at an interval of 2 or 3 weeks. Weeds should be controlled in time to avoid their competition for water and nutrients. It is necessary to earth up on the culm handle in the depth of 5 – 6cm if it is exposed. Pest control may be needed, which will be discussed elsewhere in the text.

1.4.6 Resting

The plantings will be in a dormant condition from December to next February and, generally, no measures are adopted during this stage.

2 Field-planting Practice

2.1 Planting Site

Plantations should be established at sites suitable for bamboo' growth and survival, otherwise it will be hard to achieve the goal of planting. For example, sympodial species are susceptible to cold injury and such damage will occur on some species if the temperature falls below −4℃.

Bamboos likes the porous, deep and fertile soil with well-drainage and relative high moisture. While the sympodial bamboos species with their dense and concentrated root system demand particularly high level of soil moisture and nutrients. Therefore, plantations of these species are best established on sites such as valley, mid and lower slopes, stream and river-along area, reservoir or pool-around land and home-around land as well. Plantations established on dry and infertile soils can only produce small culms with limited economic profit.

2.2 Soil Preparation

If the planting site is covered by dense grasses and shrubs, burning will be necessary before soil preparation. Soil preparation can be done in 3 ways.

2.2.1 Overall Preparation

Completely breaking up soils to a depth of 20cm and then making planting holes at designed spacing between rows and plants respectively.

2.2.2 Strip(belt) Preparation

Hoeing or ploughing parallel strips of 1 to 2 m in width and 20cm in depth, leaving 1 to 2 m wide strips of unbroken ground in between.

2.2.3 Pit Preparation

Directly making interval-fixed planting holes being 50cm × 50cm × 40cm or 100cm × 50cm × 40cm in length, width, and depth respectively.

2.3 Planting Season

The local experience is to plant bamboos in February, this earlier than trees in usual. This is because bamboos recover from winter resting earlier than trees do and temperature begins to rise in February, favourable to planting bamboos. Sympodial bamboos are usually planted from February to April and survival of new plantings would be improved if they are planted after rains when the soil moisture is fairly high.

2.4 Planting Density

The initial density of planting depends on site conditions and size of the involved species. Generally, higher density is suitable for establishment of small-sized bamboos, or on fertility sites. Plantations established with unfavourable low density will suffer from much delayed canopy closure, low soil moisture and strong competition from weeds. Poor performance and productivity, and labour-consuming in tending will be result. Over planting at planting will also result in low productivity from smaller plants due to the sharp competition among bamboos for light, space, soil moisture and nutrients. It appears that the occurrence and incidence of the bamboo shoot weevil are somewhat related to over planting of stands.

The initial density of 1,666 clumps per hectare by the espacement of 2 by 3 m is usually adopted for the species with culm less than 6cm in diameter and can be reduced to 1,111 clumps per hectare at espacement of 3 by 3 m on fertile sites. Similarly, establishment of species with large-sized culm can employ the initial density of either 833 clumps per hectare at espacement of 3 by 3 m or 625 clumps per hectare at espacement of 4 by 4 m.

2.5 Field Planting

2.5.1 Transplanting

Plantings propagated with vegetative materials are ready for transplanting at one year of age. Prior to field planting, they are treated in nursery by discarding the top with only 2 or 3 basal nodes left. The treated ones are dug up in clumps and then divided into smaller clumps each containing 1 to 3 culms. After root-soaking in thick mud of soil, they are ready for transporting and planting. The planting practice involves placing them upright in the planting hole, covering and pressing soils and finally earthing up the base part with loosening soil of 3 to 4cm in depth.

2.5.2 Planting of Offset with the Handle

A one-year-old offset is selected and taken by removing the soil around the base and cutting at the handle part. After discarding its top part, the culm about 1m in height is placed horizontally in the prepared planting hole with the handle part downwards and covered with soil of 10cm in depth. Plantations established in this way can achieve high survival and fast growing rate of new plantings same as that in transplanting. However, it costs more in preparing and transporting of offset.

2.5.3 Planting of Branch Cutting

Establishment of bamboo stands directly using branch cutting is suitable for large-sized species, provided with good site conditions intensive soil preparation and sufficient supply of water and nutrients as done in nursery. The practice of field planting is the same of that in planting raising.

This method has been widely practiced as one of the major approaches in plantation establishment for sympodial bamboos in Guangxi Province. For example, stands of *Dendrocalamopsis beecheyanas*, covering 200 ha in area, have been established in this way in Zhuguang Farm of Hepu County, Guangxi Chuang Autonomy Region, with the initial density of 900 clumps/ha, each containing 2 cuttings, with a survival rate over 90%.

2.5.4 Planting of Culm and Culm Cutting

The culm cutting containing 2 or more nodes is collected from offset at 2 or 3 years of age and planted in the same way as planting propagation using 2-node culm cuttings. This method is suitable for planting of thick-walled bamboos on fine site, provided with high level of management.

3 Bamboo Tissue Culture and Its Utilization

3.1 Past Work

Many reviews of grass tissue culture have not included similar work undertaken on bamboo species. However, it appears that bamboos behave in similar ways to non-bambusoid grasses in vitro. The methods developed for non-bambusoid grasses can hardly be transferred to the bamboos because of the difficulty in obtaining immature explants such as inflorescences and anthers. Instead bamboo micropropagation has to depend on other plant material to initiate cultures, primarily, and ironically, seed. If such methods are to be of real use to bamboo propagators, ways of initiating cultures from more commonly available plant tissue have to be developed.

Of the methods available, that of multiple shoots is the most likely to produce a simple micropropagation procedure. However, most research work reported describes the use of callus. Callus has a high potential rate of multiplication, but this is rarely achieved in practice. Past reports of bamboo tissue culture are listed in Table 1. The only successful attempts at regenerating plants from callus have repeatedly been reported, when seed or immature inflorescences have been used as explants.

Table 1 Published Reports Describing the Tissue Culture of Bamboo Species

Author	Species	Results
Huang(1981), Huang and Murashige (1983)	*Dendrocalamopsis oldhami* *Bambusa multiplex* *Sasa pygmaea* *Phyllostachys aurea*	Callus formed from apical meristem explants failed to regenerate. Shoots obtained directly from explants using cytokinin
Mehta *et al.* (1982)	*Bambusa arundinacea*	Embryogenic callus directly from seed on N6 medium +2,4-D, BAP+PVP. Regeneration achieved
Nadgir *et al.* (1984)	*Dendrocalamus strictus* *Bambusa arundinacea* *Bambusa vulgari*	Multiple shoots obtained from seeds of *Dendrocalamus strictus* and branch nodes of all 3 species. Poor rooting
Rao *et al.* (1985)	*Dendrocalamus strictus*	Embryogenic callus obtained from seed using 85 medium + 2,4-D. Regeneration using IBA and NAA
Rao *et al.* (1986)	*Dendrocalamus strictus*	Histological study of callus production from seed
Yeh and Chang(1986)	*Bambusa beecheyana* var. *pubescens*	Regeneration from embryogenic callus using immature in florescences as explants. Also reports regeneration from root callus
Yeh and Chang(1986)	*Dendrocalamopsis oldhami*	Similar results to those on *Bambusa beecheyana*
Mansur(1986)	*Guadua angustifolia*	Germination of immature embryos on MS medius, and nodal cuttings
Banik(1987)	*B. glaucescens*	Shoot production from dormant culm buds. Rooting and transfer to soil
Dekkers *et al.* (1987)	*Schizostachyum brachycladum* *Thyrsostachys siamensis*	Callus obtained from immature culm sheaths, but no regeneration
Yeh and Chang (1987)	*Sinocalamus latiflora*	Regeneration of plants from mature embryo-derived callus. MS+5% sucrose, 2,4-D
Dekkers and Rao (1987)	*Dendrocalamus strictus* *Bambusa ventricosa* *Schizostachyum bracyicladum*	Repetition of the Indian work on callus of *Dendrocalamus strictus*. Mature nodal cuttings of *Bambusa ventricosa* proliferated using liquid medium

(Continued)

Author	Species	Results
EL Hassan and Debergh (1987)	*Phyllostachys viridis* *Phyllostachys nigra*	Regeneration of plants from immature leaf callus. Species misidentified, but apparently same technique works with *Phyllostachys nigra*
Huang *et al.* (1988)	*Bambusa multiplex*; *Dendrocalamopsis oldhami Phyllostachys aurea*; *Sasa pygmaea*	Suspensions cultures of 4 species grown
Huang *et al.* (1989)	*Bambusa multiplex*; *Dendrocalamopsis oldhami Phyllostachys aurea*; *Sasa pygmaea*	"Organogenic callus" grown from lateral shoot-tip cultures of 4 species; *Dendrocalamus latiflorus* also mentioned as used
Nadgauda *et al.* (1990)	*Bambusa arundinacea* *Dendrocalamus brandisii* *Dendrocalamus strictus*	In vitro flowering of 3 species using similar hormonal regime (BAP + C. Milk) as Nadgir *et al* (1984)
Rao and Rao (1990)	*Dendrocalamus strictus* *Bambusa arundinacea*	In vitro flowering of somatic embryos
Chambers *et al.* (1991)	*Dendrocalamus hamiltonii*	In vitro flowering from planting nodes
G. DAS; P. K. SINGH SAMANTA (2000)	*Bambusa vulgaris*	In vitro shoot multiplication of *Bambusa vulgaris*
Shinjiro Ogita (2005)	*Phyllostachys nigra*	A modified 1/2MS medium supplemented with 3 mu M 2,4-D for callus induction from bamboo shoots

A number of conference reports show that tissue culture work is ongoing on a wider range of bamboo species than listed below, in the Philippines, Singapore, Taiwan, Thailand, India, and China.

The real challenge for bamboo tissue culture remains the induction of cultures from mature, field grown plants. Once such cultures are established, it would be relatively easy to multiply material in vitro.

3.2 Propagation of Bamboos through Tissue Culture

In vitro methods offer an attractive alternative to conventional methods for the mass-propagation of bamboos. The two principal methods that can be utilized for this purpose are somatic embryogenesis and micropropagation.

3.2.1 Somatic Embryogenesis

Somatic embryogenesis is defined as embryo initiation and development from cells that are not products of genetic fusion. Thus hundreds of plants can be obtained from somatic embryos. The following explants can be utilized for somatic embryogenesis:

3.2.1.1 Juvenile Materials

1. Zygotic embryo
2. Immature embryo
3. Planting parts-node, leaf sheath, root, rhizome

3.2.1.2 Tissue-culture Raised Materials

1. Somatic embryo
2. Parts of plantlets regenerated from somatic embryos

3.2.1.3 Adult (Mature) Materials

1. Node
2. Shoot-tip
3. Leaf sheath base
4. Rhizome

With juvenile or tissue-culture raised materials of *Bambusa arundinacea* and *Dendrocalamus strictus*, callusing starts soon after inoculation on B5 + 2,4-D. The callus has both nodular (compact) and friable regions. On subculture, the compact callus gives rise to somatic embryos. These arise as protuberances on the surface of the callus. Several green embryos are observed in the compact callus. Germination of the embryoids takes place on the same medium. The scutellar region of the embryoids can be made to proliferate and give rise to a second generation of embryoids. Thus, the initial callus phase can be kept very short and reduced to the minimum. Once the initial crop of embryoids is obtained, these can be made to "bud" off several daughter embryoids and the process repeated ad infinitum. With each round of budding, there is a several-fold increase in the number of embryoids, each of which has the ability to give rise to a completely well-formed plant. It is important to remember that there is no callusing involved throughout and all daughter embryoids arise from pre-existing differentiated embryoids. Callusing is only in the very initial phase when the embryogenic compact callus is being formed.

Somatic embryogenesis has three major advantages:

The embryoids have pre-formed shoot and root poles, thus, eliminating the need for a rooting step as with shoots.

Multiplication of somatic embryos is very rapid. Whereas a nodal or a shoot culture may have a few shoots and embryonic culture will have over a hundred embryos.

Maintaining and manipulating embryogenic cultures is easier and quicker, and hence less labour-intensive and cost than a shoot culture.

Todate, somatic embryogenesis has been obtained in *Bambusa arundinacea*, *Dendrocalamus strictus*, *Dendrocalamopsis oldhami*, *Bambusa beecheyana*, and *Si-*

nocalamus latiflora.

There have been some initial successes with explants from mature bamboos. The work has shown that embryogenic compact callus can be obtained from cultured nodes. Zamora *et al.* (1989) have also obtained shoots from node and rhizome explants. The results are very promising and need to be investigated further.

3.2.2 Embryogenic Suspension Cultures

The raising of embryogenic suspension cultures is an area which deserves more attention than it is presently attracting. Once such suspension cultures are established and methods developed to differentiate embryoids in these, the way will open up for a truly mass-scale production of bamboo plantlets at minimum cost. It would also enable the production of artificial seeds. The attempts made so far have not resulted in embryogenic suspensions, but, continuous efforts are being made in this direction. In our laboratory also continuously growing suspension cultures have been established.

3.2.3 Micropropagation-nodal Explants

The technique of micropropagation or in vitro vegetative propagation can yield faithful duplicates of an original parent plant. In bamboos, the nodes bear axillary buds which remain dormant most of the year and generally sprout during the rainy season: these buds have the capacity to be transformed into complete plantlets. There is even the possibility of inducing rhizomes in these buds. In such cases, a separate root formation step is not required as the rhizomes are capable of producing both culms and roots, thus, giving rise to complete plants. If successfully established, the use of the dormant axillary buds or nodes would make available a large resource for propagation presently unusable. Thus, the technique of micropropagation offers the potential ability to raise thousands of plantlets from the nodal regions of the existing clumps.

The results so far have shown that it is relatively easy to get the axillary buds in the nodes of *Bambusa vulgaris* and *Dendrocalamus strictus* to sprout. Multiple shoots can also be obtained. However, it has been difficult to get a sufficiently high percentage of them to root. Presently, depending on the species, between 4 to 10 percent of the nodal shoots can be rooted. This needs to be improved.

3.2.4 Micropropagation-multiple Shoots from Seeds

Yet, another approach is the formation of multiple shoots from seeds. The multiple shoots can be rooted or subcultured to obtain another set of multiple shoots. It has been observed that multiple shoots are easily induced from zygotic embryos and these can be rooted. In *Bambusa arundinacea*, 58.4% of the seed cultures formed multiple shoots on B5 medium supplemented with BAP (5 – 10M)

3.2.5 Induction of Rhizome

Bamboo plantings go through a juvenile phase with flimsy and short shoots. The plantings attain maturity with the development of a rhizome which occurs towards the later part of the first year. The upward growing portions of the rhizomes develop into the tall mature bamboo shoots (culms). An evaluation of the published literature has shown that the physiology of rhizome formation and the factors leading to subsequent rapid growth often quoted as the prime asset of bamboo, are relatively unknown.

Methods have now been developed to precociously induce rhizomes in plantlets from somatic embryos and in plantings. The induction of rhizomes helps in the early establishment of the plants in the field as well as enables earlier culm production. When done in vitro this provides an additional tool for plantlet multiplication through excision of the rhizome. The germinating rhizome produces both a shoot and a root, giving rise to a complete plantlet.

3.2.6 In Vitro Flowering

In vitro flowering was first noticed by Rao at the University of Delhi in 1987. The methods used have been reported in a 1988 conference. Flowers were observed in cultures derived from "compact callus with embryos".

Using a different method to Rao's, both Nadgauda *et al.* (1990) and Chambers *et al.* (1991) have described the flowering from planting nodes of various bamboo species, notably *Bambusa arundinacea*, *Dendrocalamus strictus*, *Dendrocalamus brandisii* and *Dendrocalamus hamiltonii.*

In all three reports in vitro flowering is a phenomenon seen when using planting material. Although the methods using callus and planting nodes are fundamentally different, flowering was achieved in both cases with the addition of BA or BAP (6-benzyladenine or benzyl-amino-purine). Although other chemicals were used in the processes, this is the only one common to all three, and it seems reasonable to hypothesize that BAP is a stimulus for the appearance of flowers on bamboo. Nadgauda *et al.* (1990) also report the production of viable seeds, which were shown to be capable of germinating and producing plantings.

Having observed the phenomenon of flowering in vitro, what use is it?

Firstly, there have been suggestions that the technique could be used to produce hybrids between bamboo species. Whilst this may be possible, it must be remembered that all three succeses to date have depended on seed to initiate cultures. There is no tested method available to apply the method to species for which seed is not available. This is a significant restriction.

Even if further development of techniques allowed the induction of in vitro flowering of a wider range of species, further problems in transforming flowers into seed can be anticipated. This process is by means straight forward, although Nadgauda *et al.* (1990) appeared to have few problems producing seeds from their cultures.

Secondly, the technique should provide a workable hypothesis as how to bamboo flowering is controlled, and, possibly, the mechanisms for gregarious flowering. It may provide a scientific method for investigating the idea of a flowering clock.

Thirdly, the method may be transferrable to mature plants in the field. It may be possible to induce flowers on these plants, thus, allowing identification and taxonomic work to be conducted. It may even be possible to produce reasonable quantities of seed on field-grown plants. If such a method of control were possible, bamboo propagation would be revolutionised.

The initiation of flowering on cultures derived from seed is useful where physiological methods are being investigated, but is of little practical benefit. Due to the lack of suitable clean plant material, it is difficult to initiate cultures of many bamboo species. To broaden the applicability of these techniques, it will be necessary to start work on the field-initiation of flowering.

3.3 Application for Bamboo Tissue Culture

Generally, bamboo propagation for tissue culture include four steps: 1) explant materials selection; 2) explant multiplication; 3) explant rooting; and 4) in vitro plantings transplanting.

3.3.1 Explant Materials Selection and Disinfection

Based on the recent research reports, it is the most important step for bamboo tissue culture success that the explant materials have been selected suitably. Normally, seeds, young culm buds and branch buds have been used. For example, more than 90% branch buds from 2-year-old bamboo culm can be induced, but only 30% branch buds from 20-year-old bamboo culm can be induced.

Because all materials can be infected by microorganism, it is necessary to disinfect them. Usually, 0.1% Hg or 2.5% –5.0% hypochlorite sodium can be used for seeds disinfection.

3.3.2 Explant Multiplication

MS culture medium is the basic culture medium for bamboo tissue culture. Prof. Zhang Guangchu (2001,2003) have used MS, 3/4MS, 1/2MS with different concentration of BA and NAA, and got the best combination of 1/2MS + 4mgBA +

0.25mgNAA for inducing stem top of *Dendrocalamus latiflorus*. The inducing ratio is more than 90% for branches from 2-year-old bamboo culm. The pH of MS is 6 – 6.5.

3.3.3 Explant Rooting

It is the best combination of NAA: IBA = 1:1 and the gross concentration of 3mg/l for explant rooting. When each hormone separately has been used, its concentration must be less than 3mg/l. If its concentration is higher than 3mg/l, plantings will died.

3.3.4 In Vitro Plantings Transplanting

It includes four steps for in vitro plantings transplanting. The first step is to select suitable medium to create a good aerated condition for plantings roots. As a general medium, for example, vermiculite, perlite, rice chaff, sawdust, ash-residue, etc., has been selected and mixed. The second step is to use membrane of poly-chlorothene to cover plantings for keeping air moist. It is important for plantings to grow. The third step is to reduce the chances for plant diseases and insect pest invasion. The last one is to plant planting with cluster. The suitable temperature for plantings to transplant is 20℃.

Generally, the new leaves and shoot buds will be sprouting 20 – 30 days and 40 – 50 days respectively after transplanting when the natural management measures will be adopted.

3.4 Prospects for Bamboo Tissue Culture

Tissue culture provides a variety of techniques that may be of use in bamboo science, propagation and utilization. The results of a number of studies show their potential usefulness for bamboos. However, many of those are very inefficient.

If bamboo tissue culture is to realise this potential, and be useful, micropropagation should be centred on species that are both economic importance, or with some potential, and also have some difficulty in propagation. There is little need to develop tissue culture systems for species that produce seed regularly.

To achieve this, tissue culture laboratories need better access to field grown material. Tissue culture laboratories often centre their efforts on species and genotypes that have readily available and easily stored explants.

Developing tissue culture systems using field grown material as a source of explants is not an easy task, and various difficulties can be expected. Contamination can be expected to be significant. Explants will have to be chosen that minimize this. These are likely to be situated where there is little chance exposure to microbial spores. The immature leaf has high potential for initiating useful cultures. Alternatively, an intermediate step may be needed, for example, by bringing plants or cuttings into a protected area, and/or by increasing vigor. Alternatively, some form of cover or protection could be put over newly formed shoots as they emerge from the ground.

A recent interesting development has been the occurrence of flowering in vitro both from planting nodes and somatic embryos. If those techniques are repeatable, an insight into the control mechanisms of bamboo flowering may be gained. To be of practical use however, bamboo tissue culture systems will have to be developed first.

The Sowing Property of Controlled Pollinated Seeds and the Growth of Young Seedlings of *Dendrocalamus latiflorus*

Dendrocalamus latiflorus Munro, belonging to Bambusoideae of Gramineae and Subgen. Sinocalamus of *Dendrocalamus* Nees, is excellent both in bamboo shoot and in bamboo culm with delicious bamboo shoot, long shooting period and high economical value, which is widely distributed and preferred by farmers and consumers in south China. But due to the long time cultivation and fertilization, the bamboo stands are flowering and the quality of bamboo shoot is decreasing. Crossbreeding and selection of variation are effective ways to solve such problems. During the latter period of the last century, Yu Fugen and Hu Chenghua studied the seed morphological and anatomical characters of 39 bamboo species of 21genus in detail; Dong Wenyuan conducted some researches on seed features and growth of young seedling of *Qiongzhuea tumidinoda* Hsueh et Yi; Fu Sunhua studied the seed features and growth of young seedling of *Phyllostachys praecox* C. D. Chu et C. S. Chao; Anan Anantachote reported the seed-thousand weigh and seed geographical variation of some bamboo species in Thailand; Mukunthakumar reported the bourgeon ratio in culture medium of *Dendrocalamus strictus* (Roxb.) Nees species; Richa studied the factors which affected the seed's vigor of *Thyrsostachys siamensis* (Kurz ex Munro) Gamble and *Dendrocalamus strictus*(Roxb.) Nees. So far there is no any such reports about the *Dendrocalamus latiflorus* Munro. The sowing properties of controlled pollinated seeds and the growth of young seedlings *Dendrocalamus latiflorus* Munro were studied, which would surely lay some foundation on the variation's selection about this bamboo species.

1 General Information of Study Region and Study Method

1.1 General Information of Study Region

The flowering mother bamboo individuals were introduced from ten places in

Guangdong and Fujian Provinces and bamboo seeds are cross breeding from these flowering individuals which are regarded as parents and 7,542 bamboo seeds are acquired after two times pollination. The experimental site was selected in forest nursery of Nanjing county, which is located in the south-east part of the Fu Ping mountain, and belonging to the hill site condition of south-east part of Fujian Province. The soil belongs to latosolic red soil types. The average elevations are from 5.6 – 1,390.9m. The mean annual temperatures are 17 – 21.4℃ and the maximum and minimum temperatures are about 40.5℃ and 2℃ below zero, and the annul accumulate temperate are 5,323.1 – 7,512.7℃, which last from 273 days to 341 days. The county's non-frost days are about 322.4 days. The annual rainfall ranges from 1,587.5 – 1,879.6mm with relative humidity being from 79% – 87%. The county's climate belongs to monsoon climate of south subtropical, which is moderate with ample heat and superior in light and water. The original vegetation is subtropical rain forest, even-green broad leaf vegetation, or mixed with some conifer trees. But due to the human interference in, the succession took place, which the superstratum dominated plants are *Pinus massoniana* Lamb., *Schima confertiflor* Merr., *Liquidambar formosana* Hance.

1.2 The Study Method

1.2.1 The Study of the Seed Quality

Mature seeds of bamboo were collected and seed purity, water content, thousand-seed weight and burgeon ratio were measured. The surveying methods saw reference ten.

1.2.2 Seed Sowing and Nursing Experiments and Surveying of Seedling Growth

The total 3,461 bamboo seeds from the first pollination are sowing, using the receptacle nursing method with only one seed in one container. After one day and night seed pregermination, on March 26, 2002, the seeds were sowing and surveying of bourgeon and growth were written down.

2 Outcome and Analyse

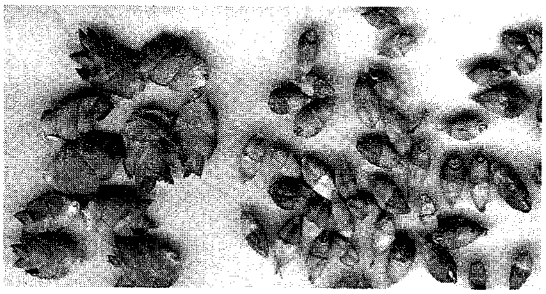
2.1 Sewing Quality of Bamboo Seeds with Manual Pollination

During the last ten days of October, 2001, the introduced mother bamboo individuals began to show the variance leaves and the small bamboo branches stopped growing which meant that it would be flowering. The flowering bamboo individuals were transplanting in nursing field. After one month slowing growth of bamboo, the top part of branch bulged to form the flower bud and in the last ten days of November, bamboo were flowering which would last four months.

2.1.1 Morphosis Features of Bamboo Seeds

There were variations in seed size and morphosis. The seeds were caryopsis with nut morphosis, ellipse and with outer and inner glume. 40 seeds from the first pollination and 180 seeds from the second pollination were randomly selected for the surveying of the seed length and diameter. The first pollination seeds vary from 6.84 – 10mm in length and 4.46 – 6.40mm in diameter, while the second are from 5.42 – 9.40mm and 2.90 – 5.60mm respectively. The seeds are smooth with no hair and have an apparent vertical groove. When seeds are mature, they show tan color (see Figure 1). The upper seeds had beak, developed from growth of the full or part of the flower style. From the seeds direct morphosis, we could see that when pollinated in the same year as the mother bamboo transplant, the seeds were plump with brilliant color; otherwise the seeds were small and crimpled with dim color. It showed that the quality of the seeds pollinated in the first times was superior to the seeds in the second times. The reason was that when bamboo was flowering, they consumed a large amount of nutrient, while the flower nutrient were mainly coming from the mother bamboo storage, so the pollinated seeds in the next times were crimpled.

The first times pollinated seeds



The second times pollinated seeds

Figure 1 The Shape of controlled Pollinated Seeds of *Dendrocalamus latiflorus*

2.1.2 Air-dried Thousand Seed-weigh

The air-dried thousand-seed weigh reflected the seeds satiated degree. The thousand-seed weigh from the first times pollinated seeds with and without coat were 121.29g and 91.29g. The thousand-seed weigh from the pollinated seeds in different times varied greatly. The thousand-seed weigh from the second times pollinated seeds with and without coat were 63.87g and 91.29g. The average thousand-seed weigh of these two times pollination with and without coat were 92.58 g and 66.59g. Due to the different growing situation and climate among flowering mother bamboo individuals, thousand-seed weigh with coat of the two times pollination was 49.41g differentiation. See Table 1.

Table 1 Variation in Thousand-seed Weigh of Controlled Pollinated Seeds of *Dendrocalamus latiflorus*

Pollinated time	Numbers of surveyed seeds	Thousand-seed weigh(g)	Average	Max.	Min.	Extreme deviation	Standard deviation	Coefficient of variation
The first time pollination	2548	Without coat	91.29	140.00	64.10	75.90	19.1089	20.93
2001,11 - 2002 - 01		With coat	121.29	170.00	86.67	83.33	20.9037	17.23
The second time pollination	1399	Without coat	41.89	55.56	29.73	25.83	6.0469	14.44
2002,02 - 2002,04		With coat	63.87	77.78	45.95	31.83	7.3635	11.53

2.1.3 Bamboo Seed Purity

When removing the seed coat, shrunken seeds and litters, 7,542 in all bamboo seeds were surveyed about the seed purity. The seed purity of the first and second pollination were 65.95% and 85.50%, and the average was 75.72%, which was belonging to better than average level.

2.1.4 Bamboo Seed Water Content

Six gram purity seeds with three samples were selected and were heated in 105℃ in oven. After the heated seed weigh was stable, then the seed weigh were measured. The average water content of the first and second pollinated seeds were 66.89% and 33.3%. This differentiation could be due to the climate drought. Because of the high water content, abundance in starch, seed germinate rate would decrease with seeds storage, and after one year, the seeds would lose life totally. So it was important that bamboo seeds should be sowing after harvesting.

2.1.5 Bamboo Seed Vigor

Bamboo seed vigor has a direct effect on the seed germination rate. Seed vigor of two times pollination were measured in the red ink dyeing method with two replicates. In each samples, 100 seeds are surveyed. The seed vigor were 95% and 84.85% with average vigor being 89.93%, which meant that the mature seed was of high vigor and should be sowing after seed harvesting.

2.1.6 Field Germination Rate

Germination rate of seed is the most important index in seed sewing quality and is also the important item in seed quality survey. It usually uses germination rate, germinability, average germination rate, field germination rate as the sign. But field germination rate is more important actually. In March 26, 2002, 3461 bamboo seeds were sowing and in May 10, there were about 2014 bamboo seeds germination, which the field germination was 58%. When young seedling were transplanted in May 16, the survival rate was 69%.

2.2 The Growth of Young Seedlings

When seed germinated, a white radicle sprouted from umbilici and went downwards into the soil; the embryo came out then; then Epicotyl came up out of the land. Sowing on March 26, 2002, on April 1, there were germinating seeds. When seedling came up out of the land about 3 cm in height, the first leaf was sprouted, and when grew up to 5 cm, the second leaf, 11 cm and the third leaf. When seedling stop growing, they had 7 - 9 leaves. Before seedling was transplanting, the average height was 19.5cm. see Table 2.

Table 2 The Growth and Development of Young Seedlings of *Dendrocalamus latiflorus*

Days after sowing(d)	10	15	21	26	33	38	43	48	53	58	63	68	80
Average height (cm)	3.12	5.00	8.00	12.0	13.0	14.7	15.3	17.0	18.1	18.5	19.1	19.2	20.5

Annotation: the surveying number of bamboo seedling were 50.

When the seedling stopped growing, they were transplanted in the first time and the young bamboo individuals generated shoot bud. They were mainly generated from culm base and what is more important was that shoot bud enlarged later by later, the internode increased quickly and leaf was larger than ever before. On June 6, 2002, the average height of bamboo shoot was 50 - 100 cm; while On July 7, the hightest shoot reached 2.0 m and the largest root diameter reached 2 cm.

2.3 Variation of Seed and Seedling

2.3.1 Variation of Seed

There were some variations in morphosis of the acquired controlled seeds. The length, width and their ratio of the two times pollinated bamboo seeds were 8.79 mm and 7.73mm, 5.39mm and 3.91mm, 1.64 and 2.00 with nearly double differentiation between the largest and the lowest figure. The length, width and their ratio of the two times pollinated bamboo seeds varied greatly and the second was more varied than the first. If the seed morphosis would have apparent relation with the yield and quality of bamboo shoot, these would be available for the early selection of the bamboo variations. Anyway it needed further study. see Table 3.

Table 3 Variation in Morphological Traits of Controlled Pollinated Seeds of *Dendrocalamus latiflorus*

Pollinated time	Seed numbers	Morphological traits (mm)	Average	Max.	Min.	Extreme deviation	Standard deviation	Coefficient of variation
The first time pollination	40	Length	8.79	10.00	6.84	3.16	0.7493	8.53
2001,11 – 2002 – 01		Diameter	5.39	6.40	4.46	1.94	0.5081	9.43
The second time pollination	180	Length	7.73	9.40	5.42	3.98	0.7214	9.33
2002,02 – 2002,04		Diameter	3.91	5.60	2.90	2.70	0.5805	14.84

2.3.2 Variation of Seedling

Due to the great difference among seedlings generated from bamboo seeds, there were some white seedlings (see Table 4). There were also some partly white seedlings, which would become green and be normal seedlings during the growth. In total 2,014 bamboo seedlings, the normal and white seedlings were 1,395 and 255, which occupy 69% and 12.7% of the total seedlings. The white seedling would die during their growth because they lacked chlorophyll and could not have photosynthesis to produce nutrient. Before transplanting, there were 287 seedlings, which died and many of them were white seedlings, and the other died from the insect snapping. There were difference in normal seedlings and On June 6, 2002, the height of some bamboo shoot reached one meter, while some were only 30 cm height. This showed that there was some variation from pollinated seeds and by means of further surveying, the superior bamboo individual would be selected.

Table 4 The Differentiation of Young Seedlings of *Dendrocalamus latiflorus*

Seedling types	Normal	White	Died
Numbers	1395	255	287
Proportion(%)	69%	12.7%	14.0%

Annotate: total seed numbers were 2014.

3 Discussion

There were some great differentiation in the two times pollinated seeds, and the differentiation in length were greater than in diameter. The coefficient of variation were 9.43% and 14.84% respectively in the two times pollinated seeds. From the seed morphological, the first times seeds were satiated with brilliant color, while the second were shrunken with dim color because of the mother bamboo nutrient. During the first times pollination, the mother bamboo were ample in nutrient and the climate were suitable for flowering also, plus watering and fertilization, so with ample nutrient, the ovary developed after pollination quickly. In the second pollination times, due to the consumption of the flowering, the mother bamboo could not provide ample nutrient, plus drought climate in spite of irrigation, the pollinated flowers fell off and caused the decrease of the seed number and quality. So in order to acquire high quality bamboo seed, it was suitable for pollination when bamboo were transplanting, plus irrigation and fertilization.

The thousand seed – weigh and morphological in different pollination times varied greatly. The thousand seed- weigh in two times with coat and without coat were 121.29g and 63. 87 g, 91. 29g and 41. 88g, which were higher than seed weigh which Mr. Zhou reported before. These showed that manual pollination could increase the thousand-seed weigh. But due to the sexual reproduction and genetic recombination, there were some white seedlings. During the normal growth, there were some differentiation in bamboo shoot yield and height, so it was important to write down the growth, death and number of white seedlings and to survey the growth of the normal seedlings, which would provide the basic information for the variance selection.

Study on the Optimization of RAPD Conditions of *Dendrocalamus latiflorus*

Dendrocalamus latiflorus Munro is one of the main bamboo species both for culm – and shoot-producing purposes in China, mainly distributed in Fujian, Taiwan, Guangdong, Guangxi, Hainan, Guizhou and Yunnan Provinces. *Dendrocalamus latiflorus* Munro has a long term of shoot-growing with high yields and good quality of shoots that is a kind of fine vegetable during the summer and autumn. *Dendrocalamus latiflorus* Munro for shoot-use purpose are widely cultivated in draining fertile soils around the roadsides, banks and near the villages of Fujian, Southern Guangdong and Taiwan. After a long term of cultivated, *Dendrocalamus latiflorus* Munro has many cultivating types. Therefore, it remains to be studied the relation between the genetic variations and their yields, as well as the classification of the cultivating types.

RAPD(random amplified polymorphic DNA) technology is most widely applied in genetic research of forest tree. According to the molecule biology of bamboo, the general molecule-marking methods with no peculiar difference of species, such as RAPD and AFLP, are available for bamboo genetic research. *Phyllostachys* family was analyzed by RAPD (Geilies, 1996). RAPD-PCR was applied in identification of clone and genetic analysis of the important bamboo species with high economic value in Taiwan Province (Lao, 1997). different cultivating types of *Phyllostachys praecox* C. D. Chu et C. S. Chao and the variations different cultivating types and of *Phyllostachys heterocycla* var. *pubescens* (Mazel) Ohwi were researched by means of RAPD (Fang Wei *et al.* ,2001;Shi Lihua *et al.* ,2002). The molecule systematics of bamboo was studied by using the SSR primer of *Oryza sativa* L. But *Dendrocalamus latiflorus* Munro, an important economic species widely cultivated in southern China, have not yet reported on RAPD analysis.

Although the principle of the RAPD method is simple and operated easily, the different results would be amplificated with the PCR conditions varied and instablity of RAPD also would be found in some experiments (Liu Xinghui, etc. , 1992), which can be avoided by controling the testing conditions (Lowe A J, 1996). This paper dealed with the Optimization of RAPD Conditions of *Dendrocalamus latiflorus* Munro to establish the stable system of RAPD that can provide theoretical guidance to understand genetic variation within and among geographical populations of *Dendrocalamus latiflorus* Munro and their clone identification.

1 Materials and Methods

1.1 Plant Materials

The samples of *Dendrocalamus latiflorus* Munro have been collected from eleven natural populations in five Provinces, including Fujian, Guangdong, Guangxi, Guizhou and Yunnan (Table 1). 155 clump individuals have been collected from all the populations and 10g fresh leaves have been sampled from each clump for DNA extraction after cleaned and dried.

Table 1 Collection Localities of Populations of *Dendrocalamus latiflorus*

Location	BHD (cm)	Culm length (m)	Individuals
Liangjiang of Fujian	8.70	11.92	15
Quanzhou of Fujian	9.73	14.75	10
Nanjing of Fujian	6.67	10.30	12
Jiedong of Guangdong	7.69	12.62	15
Qingxin of Guangdong	7.24	11.29	15
Guangning of Guangdong	8.47	15.46	15
Fengkai of Guangdong	8.80	13.01	15
Pingxiang of Guangxi	11.58	17.74	13
Tianlin of Guangxi	11.03	17.34	15
Xingyi of Guizhou	9.38	13.82	15
Mile of Yunnan	10.13	14.14	15

1.2 Experiment Methods

1.2.1 DNA Extraction

DNA was isolated from silica-dried *Dendrocalamus latiflorus* Munro leaves by using sodium 3 dodecyl benzene sulfonate (SDS) methods. After grounded in powders, 1.5g of *Dendrocalamus latiflorus* Munro was put into the 100ml centrifuge tube, and extracted joltily at 65℃ for two hours by the buffer solution that was composed of: 1,000mmol · L^{-1} trishydroxymethlaminomethane – HCl (Tris – HCl), 50 mmol ·

L^{-1} ethylenediamine tetra acetate (EDTA), 1.5% SDS (weight), 1% β-mercapto-ethylamine (β-C_2H_5SH) (volume) and 2% polyvinylpyrrolidone (PVP) (wight) with pH8.0. Then the extraction, mixed with 20ml chilorform and isoamyl alcohol (24:1), was oscillated for 20min in oscillator and swung for 15 min in the centrifuger at 4,000 r · min^{-1}. The separated up- clear liquid was mixed same volume of i-sopropyl alcohol, swung and then persevered in the refrigeratory. Next day the floccule was fished out, washed with 70% ethanol. After dried by airing, the floccule was put into the 10 ml centrifuge tube with 2 ml of TE (10 mmol · L^{-1} Tris-HCl, 1 mmol · L^{-1} EDTA, pH8.0), and after dissolved completely, it was added with same volume of chilorform and isoamyl alcohol (24:1), and then swung for 10 min at 3,000 r · min^{-1}. The separated clear liquid was added one-tenth of its volume of 3 mol · L^{-1} sodium acetate and 2 times of volume of absolute ethyl alcohol, and then preserved in referginator for while. Then the separated deposition was dried by airing, and putted into the 3 ml centrifuge tube and dissolved completely with TE.

1.2.2 Purity Determination of DNA

15 μL DNA solution was added 5 μL of tetrabromophenol sulfonphthalein, and then after shook to uniformity, it was putted into 1.5% agarose gel for electrophoresis at 5 V · cm^{-1} and dyed by EB, and token the photos by FR-200 ultraviolet-visible light analyzing and imaging system for recording the DNA degradation and RNA digestion.

After 100 μL DNA solution were diluted to 1/20 by TE, absorption value was determined by UV-2401PC ultraviolet specteophotometer at 260 and 280 nm. If OD260/OD280 ≥ 1.7 – 1.8, purity of DNA is available for testing.

Calculation of DNA purity (μg · ml^{-1}): OD260 × 50 × times of dilution.

Extraction rate of DNA (μg · g^{-1}): DNA purity (μg · ml^{-1}) × volume/quantity (g)

1.2.3 Optimization of RAPD Conditions

The fine annealing temperature is identified from 16 different temperatures: 35.0, 35.5, 36.0, 36.5, 37.0, 37.5, 38.0, 38.5, 39.0, 39.5, 40.0, 42.0, 45.0, 48.0, 50.0 and 55.0 ℃.

Purity of Mg^{2+}, an important factor impacting the PCR reaction, is identified from 6 different purities: 1.5, 2.0, 2.5, 3.0, 3.5 and 4.0 mmol · L^{-1}.

Tag enzyme density is identified from 7 different dosages: 0.60, 0.75, 0.90, 1.05, 1.20, 1.35 and 1.50 U.

dNTP density is identified from 10 different densities: 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00, 2.25 and 2.75 mmol · L^{-1}.

The primer density is identified from 0.075, 0.100, 0.125, 0.150, 0.175, 0.200, 0.250, 0.300, 0.350, 0.400, 0.450 and 0.500 μmol · L^{-1}.

DNA template density is identified from 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 110 and 120 ng.

20μL PCR reaction system was established for PCR reaction in GeneAmp PCR system PE9600 DNA Amplification Instrument at procedure: initially at 94℃ for 3min, followed by 40 cycles at 94℃ for 1min, at 37.5℃ for 1min, at 72℃ for 1 min and 20sec, and then hold at 72℃ for 8min, last hold at 4℃.

2 Analysis and Results

2.1 Purity Determination of DNA

2.1.1 Gel Electrophoresis Determination

DNA samples from 11 different sites has been determined by Gel electrophoresis at random, and the results are showed in the agarose gel electrophoresis picture (see Figure 1). The extracted DNA is a kind of white floccule deposition, and DNA template has been degraded to some extent, with some impurity such as RNA, which can be removed by RNA degrading enzyme. However, it can be tested for RAPD reaction because most of RAPD reaction does not needs high quality of DNA templates, which is similar with the results founded by Wilklie in shallot family and by Peng Suotang in paddy rice.

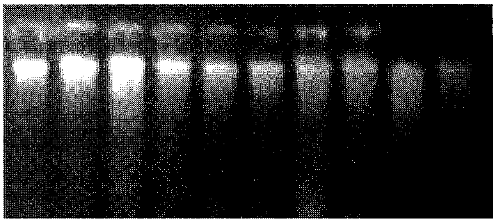


Figure 1 Electrophoresis Determination for Templates

2.1.2 Quality Different

The DNA extractions' absorption ratio of 260 nm ultraviolet to 280 nm lies between 1.8 and 2.0 (see Table 2), which indicate that it can be used for RAPD analysis. The extraction ratio is high, varied between 823.8 μg · g^{-1} and 1,448.0 μg · g^{-1}.

Table 2 Quality of DNA Extracted by SDS Method

Location	A_{260}	A_{280}	A_{260}/A_{280}	DNA density (μg · ml^{-1})	Extracting ratio (μg · g^{-1})
Liangjiang of Fujian	2.117	1.101	1.92	2117.11	1411.4
Quanzhou of Fujian	2.172	1.126	1.93	2172.03	1448.0
Nanjing of Fujian	1.825	0.945	1.92	1825.02	1216.7

(Continued)

Location	A_{260}	A_{280}	A_{260}/A_{280}	DNA density ($\mu g \cdot ml^{-1}$)	Extracting ratio ($\mu g \cdot g^{-1}$)
Jiedong of Guangdong	1.780	0.997	1.78	1779.51	1186.3
Qingxin of Guangdong	1.531	0.857	1.79	1530.80	1020.5
Guangning of Guangdong	1.236	0.683	1.80	1235.76	823.8
Fengkai of Guangdong	1.243	0.676	1.83	1243.16	828.8
Pingxiang of Guangxi	1.456	0.792	1.84	1456.47	971.0
Tianlin of Guangxi	1.606	0.863	1.86	1605.99	1070.7
Xingyi of Guizhou	1.269	0.715	1.78	1269.21	846.1
Mile of Yunnan	1.908	1.046	1.83	1907.92	1271.9

2.2 Optimization of RAPD Conditions of *Dendrocalamus latiflorus*

2.2.1 Impact of Annealing Temperature on RAPD

The Annealing temperature is a most important factor in PCR reaction conditions. 16 Annealing temperatures ranging from 35 to 55 ℃ have been selected for RAPD amplification of DNA of *Dendrocalamus latiflorus* Munro by two primers. The results showed in Figure 2 and Figure 3 that there are many bands amplified by two primers between 36 and 37.5℃, among which amplification at 37.5 ℃ is the best one with clear band, rich polymorphism and well repeatability.

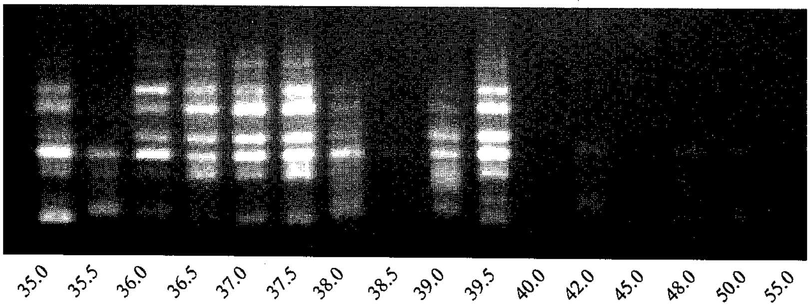


Figure 2 Annealing Temperature Selection (Primer S76)

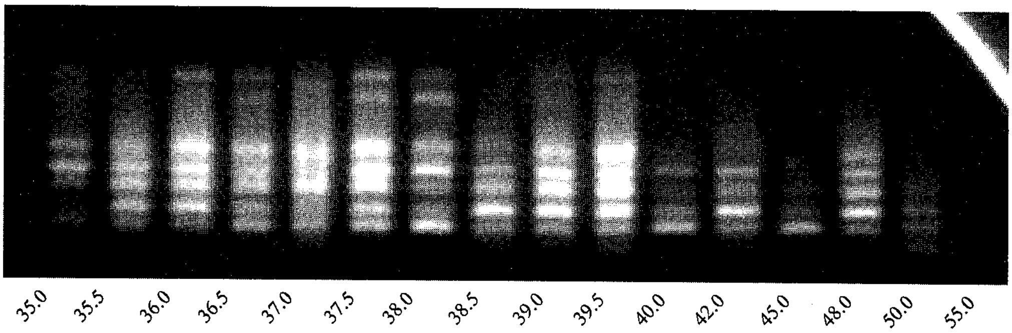


Figure 3 Annealing Temperature Selection (Primer S88)

2.2.2 Mg^{2+} Factor

Mg^{2+} among the bivalent cations that are very important in PCR reaction system has more impact on the idiosyncrasy and PCR producing ratio. The effects of the RAPD amplification using six different densities of Mg^{2+} from 1.5 mmol · L^{-1} to 4.0 mmol · L^{-1} are almost same, but it is a little better by using the 2.5 mmol · L^{-1} Mg^{2+} (Figure 4).

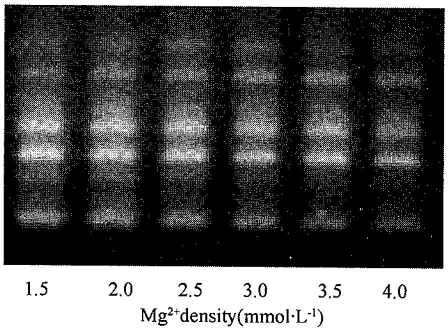


Figure 4 Selection of Mg^{2+} Density

2.2.3 Primer Factor

The primer is also one of the factors that affect the PCR reaction. The Figure 5 indicates that the idiosyncrasy is increased with the increment of primer density, but it is decreased when the density is over 0.45 μmol · L^{-1}. 0.40 μmol · L^{-1} is the most suitable primer density that has clear amplification band.

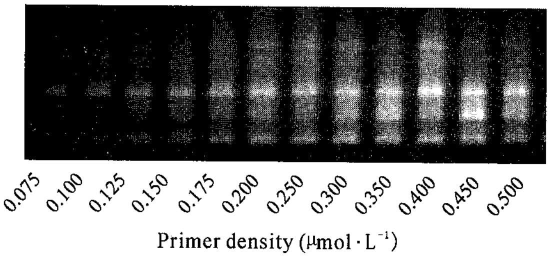


Figure 5 Identification of Primer Density

2.2.4 DNA Template Density Factor

DNA template density is also an important factor for PRC amplification by fact of that the high density results in amplifying non-idiosyncrasy and the low density results in no amplification available. The Figure 6 show that the clear amplification bands can be produced in large range of DNA density; therefore, the factor of DNA template density is not important for the *Dendrocalamus latiflorus* Munro so that trace DNA can get the amplification band. In order to ensure each template can produce the clear band, the suggestion density is 50 $\mu g \cdot \mu L^{-1}$ based on our experiments.

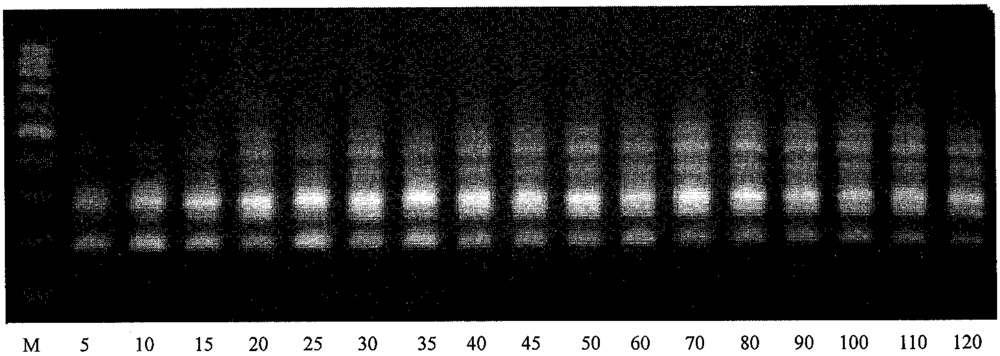


Figure 6 Identification of DNA Template Density (M: Marker of DNA Standard)

2.2.5 dNTP Density Factor

dNTP, as a material of the PCR reaction, works on directly the results. The Figure 7 shows that the number of brighter bands is increased with the increment of dNTP density but there are no different in results, so the dNTP density is not an important factor. Considering meeting the PCR requirement and economic cost, 1.75 $mmol \cdot L^{-1}$ is identified as better density for PCR reaction of *Dendrocalamus latiflorus* Munro.

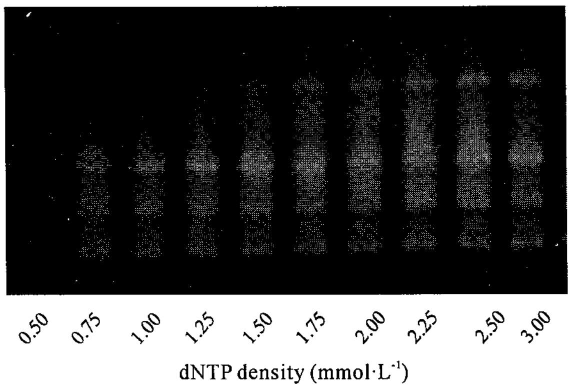


Figure 7 dNTP Density Selection

2.2.6 Tag Enzyme Factor

Tag enzyme density and category affect the PCR amplification reaction. Figure 8 shows that among the selected 6 densities (0.60, 0.75, 0.90, 1.05, 1.20, 1.35 and 1.50 U), the amplification

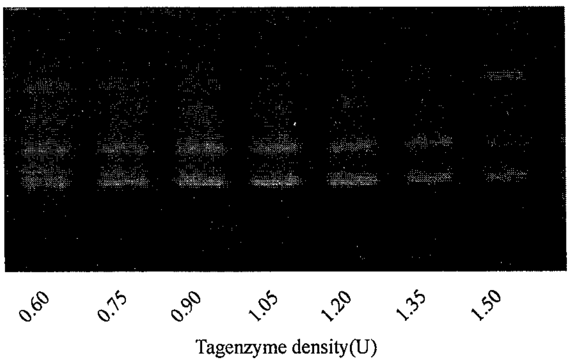


Figure 8 Tag Enzyme's Impact on Amplification

bands are brighter with increment of density, but the band amplified by 1.5 U of Tag density is more clear and rich.

3 Conclusions and Discussions

Although DNA template quality is not so important for RAPD reaction, the experiment result and its repeatability are guaranteed by high quality of DNA, which can be extracted by SDS and CTAB method but it needs to ensure the samples not being contaminated each other. A little of DNA has been degraded in the experiments, which is possibly caused by that some content of leave has been changed when it was dried. The suggestion to improve experiment is to use the fresh bamboo leave for DNA extraction if possible, or to extract the DNA by CTAB method.

DNA template density is one of factors for PCR reaction by fact of that the high density results in amplifying non-idiosyncrasy and the low density results in no amplification available. The clear amplification bands can be produced in large range of DNA density from 10 to 120 ng, so, for *Dendrocalamus latiflorus* Munro, the RADP reaction is not influenced by the DNA template density to some extent. If the primer density were too low, it is difficult to amplify the DNA for EB dyeing because of decreasing the opportunity to touch with the DNA template, while if it is too high, mispairing would be happened. So appropriate primer density is needed for DNA amplification. Mg^{2+} is a indispensable secondary factor that not only influence the activity of Tag enzyme, but also influence the efficiency of primers linking with the DNA template, the temperature of destructing the chain of template and PCR produce, idiosyncrasy and formation of primer dimeric polymer. Low Mg^{2+} density will result in low efficiency of enzyme and decreasing the produce. And high Tag enzyme will result in increasing the produce of the non- idiosyncrasy and nebulous bands. Based our experiments, the best Mg^{2+} density is 2.5 $mmol \cdot L^{-1}$ for amplification. DNTP is a material for DNA synthesis. It is available to use the a little high density to ensure PCR amplification completely. If its density is less than 1.25 $mmol \cdot L^{-1}$, the amplification bands are decreased obviously.

The annealing temperature is the most important factor in PCR amplification procedure. 16 selected annealing temperatures are repeatedly tested by single primer for amplification and the data obtained by same primer is consistent. 37.5 ℃ is suggested as a best annealing temperature at which certain stable results can be well amplified. If the temperature is over 40℃, the idiosyncrasy is decreased, and when it reached 55℃, there no bands amplified all. So high annealing temperature is not suitable to amplify the PCR for *Dendrocalamus latiflorus* Munro. Because of the PCR amplification procedure is also influenced by denaturation temperature, extending temperature and their time, which need to research further.

Single primer in this experiment is used for PCR amplification and satisfactory results have been obtained. In the pre-experiments, bi-primers have been tested for repeat amplification but it is not successful. The PCR amplification procedure established in this experiment and their reaction system for identifying the primers and their amplification can improve the stable of testing.

RAPD Analysis on Genetic Variation of *Bambusa pervariabilis*

Bambusa pervariabilis McClure distributes mainly in Guangdong, Guangxi, Hainan and Fujian, growing on loose and fertile sandy soil in the places of downhill, flat and river bank. It is one of the most important managed timber bamboo species, with straight culm, thick and flexible culm wall. It is used as shed frame, pole, dead stock, furniture and construction material.

During the recent years, there are many reports about the heredity diversity and molecule systematic research about bamboo. Among varied methods of DNA marker, Random Amplified Polymorphic DNA, RAPD technique, has the dominant status in research work about bamboo's population genetic structure, diversity and systematic taxonomy as well as evolvement because the polymorphic analysis of the DNA fragment can be done with this technique without any molecular biologic research on the species in advance. The genetic diversity analysis of *Bambusa pervariabilis* McClure population in six regions with the RAPD technique is reported in this paper so as to provide a scientific basis for the collection, reservation, evaluation and utilization of *Bambusa pervariabilis* McClure germ plasm resources.

1 Material and Methods

1.1 Sample Collecting

The samples were collected in Zengcheng, Huaiji, Fengkai and Gaozhou of Guangdong, and Guilin and Nanning of Guangxi. 30 bamboo clumps of 6 regions were sampled, 5 clumps for each region. 10g of fresh leaf was pick up from each bamboo clump, and placed in a sealed bottle with dry silica gel in it after dust and dew was cleaned.

1.2 DNA Extraction

DNA extraction was done with the method of SDS with a slight modification.

1.2.1 RAPD Analysis

The experiment was undertaken at the Subtropical Forestry Tree Cultivation Key Laboratory in Research Institute of Subtropical Forestry. The 10-base-random-primer and agarose were purchased from Shanghai Bio-engineer Co and the reaction buffer solution, Tag enzyme, dNTP and standard DNA were purchased from Shanghai Huamei Bio-engineer Co. The PCR reaction was undertaken on the GeneAmp PCR System PE9600 DNA which was manufactured by the PE Co of US. The reaction condition has being optimized until the amplified band was clear and repeatable. The PCR reaction system is composed of 20μL, 2μL10 times reaction buffer solution, with template content being 50ng, Mg^{2+} being 1.5mmol · L^{-1}, Tag enzyme being 1.2U, dNTP being1.0mmol · L^{-1}, primer content being 3.75μmol · L^{-1}. The reaction Procedure is: 94℃ 3min → [94℃ 1min → 37.5℃ 1min → 72℃ 1min20sec]40cycles→72℃8min→4℃ keep going. The product after amplification was separated with electrophoresis within 1.5% agarose gel. The buffer solution of electrophoresis and gel is 0.5 times TBE. The picture was taken under ultraviolet lamp.

1.2.2 Data Processing and Analysis

Each DNA electrophoresis band, which is clear and repeatable, was recorded and specified as a locus, with band spectrum marked in 0/1 form. If an amplification product appeared in one sample, 1 was recorded; other wise 0 recorded. The heredity distance, similarity coefficient, the number of valid allelic gene, Ne, gene diversity, H, Shannon genetic diversity index, I, and gene differentiation coefficient, Gst, were calculated with data analysis using POPGENE1.31 (Tools for population Genetic Analysis). The 6 populations were clustered with the method of UPGMA based on the estimation of Nei's unbiased genetic distance among geographic population.

2 Results and Analysis

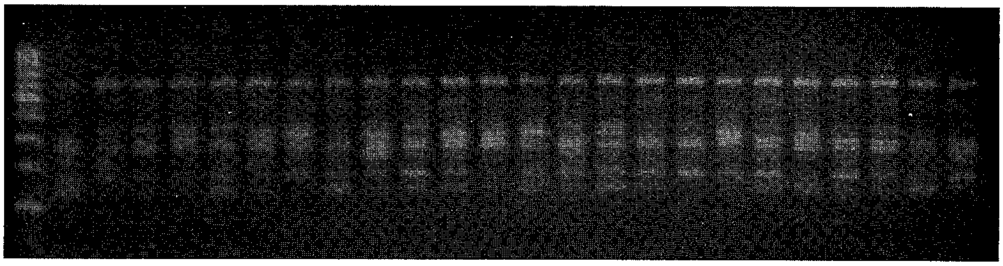
2.1 Primer Filtration

One clump was selected randomly from each population for DNA extraction and total get 6 templates with the PCR amplification procedure determined through pilot experiments. Twenty-eight multimorphic primers with clear amplification bands were selected from 112 random primers for the amplification of all the templates. The amplification of the 28 primers was analysis with RAPD. Table 1 showed the sequence of the 28 primers and the locus of the amplification. Each population has 4 individuals based on the number of hole of the gelatin process. Figure 1 and 2 showed the monomorphic and multimorphic markers of the 24 individuals from 6 populations amplified by the primers of S32 and S37.

Table 1 DNA Fragments of 6 *Bambusa pervariabilis* Geographic Populations Amplified with 28 RAPD Primers

No.	Primer	Sequence (3′-5′)	Number of amplified spectrum band (or multimorphic spectrum band)	No.	Primer	Sequence (3′-5′)	Number of amplified spectrum band (or multimorphic spectrum band)
1	S012	CCTTGACGCA	5(1)	15	S063	GGGGGTCTTT	8(7)
2	S013	TTCCCCCGCT	4(3)	16	S064	CCGCATCTAC	6(4)
3	S016	TTTGCCCGGA	6(5)	17	S066	GAACGGACTC	4(1)
4	S020	GGACCCTTAC	7(4)	18	S067	GTCCCGACGA	7(6)
5	S025	AGGGGTCTTG	4(1)	19	S070	TGTCTGGGTG	6(5)
6	S032	TCGGCGATAG	8(6)	20	S072	TGTCATCCCC	5(2)
7	S034	TCTGTGCTGG	4(0)	21	S076	CACACTCCAG	4(1)
8	S035	TTCCGAACCC	6(1)	22	S094	GGATGAGACC	7(2)
9	S036	AGCCAGCGAA	5(0)	23	S101	GGTCGGAGAA	6(4)
10	S037	GACCGCTTGT	9(6)	24	S142	GGTGCGGGAA	9(3)
11	S052	CACCGTATCC	6(1)	25	S299	TGAGGGTCCC	7(1)
12	S057	TTTCCCACGG	5(3)	26	S2083	TGGACTCGGT	7(2)
13	S059	CTGGGGACTT	6(6)	27	S2084	CCCAAGCGAA	7(3)
14	S061	TTCGAGCCAG	5(2)	28	S2093	TCGGTGAGTC	10(5)
Total			173(85)				

The spectrum bands amplified by 28 primers demonstrated a rich multimorphology, as showed in Table 1. The number of RAPD locus detected by the primers is between 4 to 10, with each primer providing the fragments amount of 6.18 RAPD markers averagely. 173 loci were amplified in 6 populations by 28 primers, among which 85 loci were multimorphic, accounting for 49.13%. This result indicates that there is a rich DNA sequence multimorphic characteristic in 6 populations.



M 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Figure 1 DNA Electrophoresis Result of *Bambusa pervariabilis* Clone in 6 Producing Area Amplified with Random Primer S32

1 – 4 Gaozhou, Guangdong, 2 – 8 Fengkai, Guangdong, 9 – 12 Guilin, Guangxi, 13 – 16 Zengcheng, Guangdong, 17 – 20 Huaiji, Guangdong, 21 – 24 Nanning, Guangxi

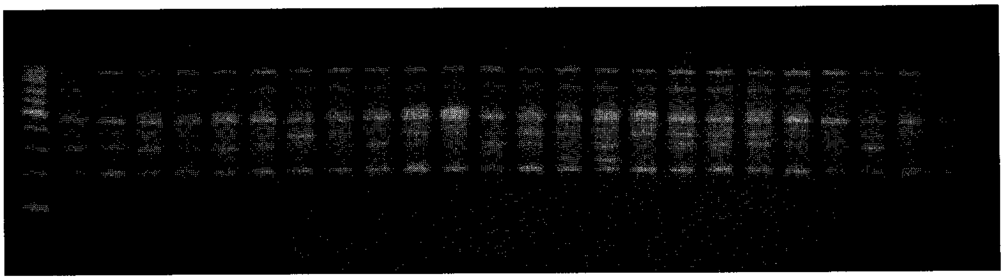


Figure 2 DNA Electrophoresis Result of *Bambusa pervariabilis* Clone in 6 Producing Area Amplified with Random Primer S37

1 -4 Gaozhou, Guangdong, 2 -8 Fengkai, Guangdong, 9 -12 Guilin, Guangxi, 13 -16 Zengcheng, Guangdong, 17 -20 Huaiji, Guangdong, 21 -24 Nanning, Guangxi

2.2 Genetic Diversity and Differentiation of Population

The genetic multimorphology and Shannon genetic diversity index are the important indicator for weighing the genetic diversity of organism. Table 2 shows the number of valid allelic gene, Ne, gene diversity, H, Shannon genetic diversity index, I, etc. calculated with POPGENE1. 31 based on the multimorphic bands amplified with 28 RAPD primers. The gene multimorphology and Shannon genetic diversity index of *Bambusa pervariabilis* population are 0. 2114and 0. 3277 respectively, indicating that it has a high genetic diversity. The gene differentiation coefficient between population is 0. 1853, indicating the variation between the populations of *Bambusa pervariabilis* accounts for around 19% averagely, 81% heretic variation happens within a population.

Table 2 Heretic Diversity and Differentiation of *Bambusa pervariabilis* in 6 Producing Areas

Indicator	Number of allelic gene observed, Na	Number of valid allelic gene, Ne	Gene diversity, He	Shannon genetic diversity index I	Gene diversity of population Ht	Gene diversity within population, Hs	Gene differentiation coefficient between populations, Gst
Mean	1. 7209	1. 3432	0. 2114	0. 3277	0. 2114	0. 1722	0. 1853
Standard deviation	0. 4499	0. 3373	0. 1796	0. 2541	0. 0322	0. 0235	

2.3 The Heretic Similarity between Populations and Clustering Graph

With the gene differentiation coefficient, the extent of population differentiation can be evaluated, but not for the relation between populations. However, with the heretic similarity coefficient and heretic distance, the relation between populations can be illustrated. So, the heretic similarity coefficient and heretic distance were calculated (Table 3). The heretic similarity coefficient between populations varied from 0.9405 to 0.9942, indicating that the genetic relationship between populations is close. The genetic distance of *Bambusa pervariabilis* population ranged between 0.0058 and 0.0613, averaging 0.0350. It is low.

Table 3 Nei's Unbiased Genetic Distance of *Bambusa pervariabilis* Population from 6 Producing Areas

Region	Gaozhou	Fengkai	Guilin	Zengcheng	Huaiji	Nanning
Gaozhou		0.9710	0.9478	0.9405	0.9421	0.9417
Fengkai	0.0295		0.9717	0.9567	0.9675	0.9624
Guilin	0.0536	0.0287		0.9787	0.9825	0.9837
Zengcheng	0.0613	0.0443	0.0216		0.9942	0.9695
Huaiji	0.0596	0.0330	0.0176	0.0058		0.9762
Nanning	0.0600	0.0384	0.0164	0.0310	0.0241	

Note: data on bottom left corner is heretic distance, data on top right corner is heretic similarity coefficient.

The heretic variation was further analyzed with AMOVA in order to evaluate the extent of heretic variation between and within the population. As the Table 4 showed, the difference between population is significant statistically, with 82% of the variation resulting from the difference between individuals and 18% of the variation from difference between population. It is conformed that the usable heretic variation of *Bambusa pervariabilis* population is slight due to its narrow distribution and asexual propagation.

Table 4 AMOVA Analysis of 30 Clump of *Bambusa pervariabilis* Geographic Population from 6 Regions Based on RAPD

Source of variation	Degree of freedom	Sum of squares	Mean square	PHIst	F	Significance test
Between population	5	100.900	20.180	0.068	2.084(17.6%)	<0.05
Among population	24	234.192	9.758		9.758(82.4%)	
Total	29	335.092				

Note: PHIst denotes the index of the correlation of the genotype diversity on the sub-taxonomic level of systematic evolvement.

The tree-like graph of the genetic relationship of 6 *Bambusa pervariabilis* populations has been made with the UPGMA Clustering based on the heretic distance (Figure 3). The *Bambusa pervariabilis* populations from 6 regions have been clustered into 3 classes with the RAPD marker. The population from Zengcheng and Huaiji, Guangdong, fell into a class at the first clustering, because Zengcheng, located in the east of Guangzhou, is an important traffic artery from west to the east of Guangdong Province. And, the two regions possess rich forest resources and easy traffic, which is helpful to the transportation of the tree and bamboo. The population from Guilin and Nanning of Guangxi was clustered into the second class and the population from Fengkai and Gaozhou of Guangdong into the third. The first and second classes get together first and go further with the third class. There is a close genetic relationship between the populations from Guangxi Region and from Fengkai and Huaiji of Guangdong Province because Huaiji is adjacent to Guangxi Region, making bamboo introduction easy. Fengkai and Gaozhou of Guandong are located on the Southwest of Guangdong, neighboring the South Sea, with a complex topography and different forest resources from other places. So, the heretic relationship of the *Bambusa pervariabilis* population between them is far.

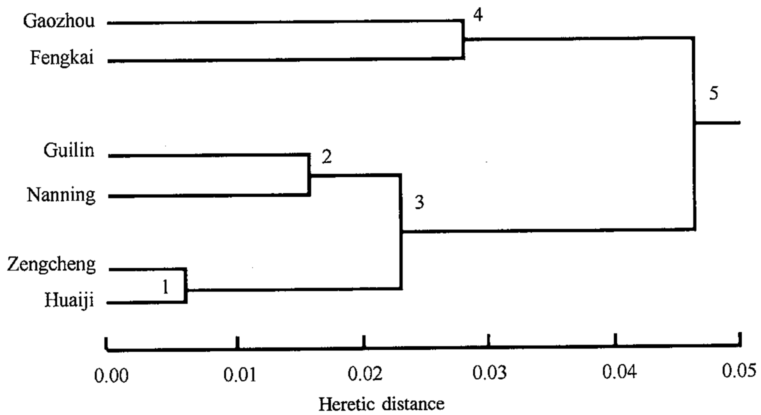


Figure 3 Tree-like Graph of 6 *Bambusa pervariabilis* Populations with UPGMA Clustering

3 Conclusion and Discussion

The reliability of the RAPD technique is controversial when applied in bamboo species identification and purity analysis. Some reports suggested it has bad stability due to its bad repeatability and nonspecific amplification, while others argued that the repeatable results can be available if the reaction condition is well-controlled. The results in this paper showed that the key issue is the primer selection and standard mode establishment in the application of the bamboo germ plasm identification. It is necessary to select appropriate primer and establish a standard mode and graph spectrum for polymorphic amplification according to different material, making the identification method simple and rapid, the result correct and reliable.

The importance is commonly acknowledged of the genetic structure of plant population to its evolvement, introduction and acclimatization and gene conservation. Ellstand & Elam suggested that, when Gst, an indicator of genetic differentiation, is more than 0.1, the variation between population is high. By analyzing the DNA sequence of 6 *Bambusa pervariabilis* populations with 28 random primers, we found that its genetic differentiation coefficient is 0.1853, more than 0.1, indicating *Bambusa pervariabilis* is a bamboo speices with a comparatively large differentiation between populations. The variance analysis also suggested a conspicuous differentiation of the population, with 18% of it occurring between population and 82% of it between the individuals within population. The *Bambusa pervariabilis* resources are suggested to be surveyed overall to determine the role of Guangdong and Guangxi in the origin and evolvement of *Bambusa pervariabilis*, and to make the objectives and strategy for the employment and development of its heredity resources. For a more reliable result, more experiments and more samples are suggested.

The taxonomy of bamboo plant has been confused because of its special biological characteristic, limiting the acquirement, protection and fully utilization of the bamboo gem plasm and decreasing its breeding efficiency. Currently, varied DNA marker can be used in the fingerprint analysis but more on bamboo plant. *Bambusa pervariabilis* is distributed comparatively narrowly and it's different to identified morphologically. We made a clustering analysis to 6 *Bambusa pervariabilis* populations with RAPD technique. Even if the number of sample is small, *Bambusa pervariabilis* population from each producing area is recognized. So, as a genetic marker, RAPD technique is valuable to identify bamboo species and clone, and is probably a good solution for some controversial taxonomic questions.

Bamboo Ecosystem and Carbon Dioxide Sequestration

1 Preface

Population growth and elevation of living standards are placing a greater stress upon the natural environment. The burning of vast quantities of fossil fuels, the large-scale devastation of tropical forest and land-use change have resulted in a gradual increase of atmospheric Greenhouse gas concentration which in turn have led to global warming. Carbon dioxide and other trace gases in atmosphere have a strong absorbency on infrared radiation, which absorb long-wave radiation from the earth and emit part of long-wave radiation to the earth, thus causing the warming of the earth's surface and globe climate. These potential serious problems have evoked many concerns not only from the general public and experts, but also from governments which have taken effective measures to reduce the emission of greenhouse gases. In 1992, about 166 counties have signed in The United Nations Framework Convention on Climate Chang (UNFCCC) in the Earth Summit of Rio de Janeiro. In 1997, Kyoto Protocol has developed in Japan and responsibility and obligation of reducing of Greenhouse gases have drafted.

Because of gas concentration, many studies have showed that Greenhouse effect has resulted in elevation of atmospheric temperature and seawater temperature, thus affecting the global precipitation and soil moisture. In the last one hundred years or so, atmospheric temperature have already crept up to 0.3 – 0.6℃. Based on the model forecast, Greenhouse gas concentration will double in 2050 and the ground temperature will be 1.5 – 4.5℃ higher. According to evaluation reports of the United Nations Intergovernmental Panel on Climate Change (IPCC), if no measures are taken, by the end of the 21st century, the sea level will have risen up to 15 – 95 cm; weather systems will be chaotic and severe rains, storms or droughts will occur in many places; water resource allocation will be uneven, with low ground inundated, while shift ocean currents will relocate fishing grounds. Carbon dioxide concentration has some great influence on energy transform and the biological carbon cycle. The elevation of carbon dioxide concentration will accelerate the growth of plants to some degree and will change vegetation types and terrestrial ecosystems, agricultural product pattern, forest distribution, terrestrial vegetation, pole ice biosphere and frozen earth, seriously affecting the climate.

2 Bamboo Ecosystem Roles in Carbon Dioxide Sequestration

There are three carbon inventories globally, which are ocean, atmosphere and terrestrial ecosystems. So far, we know little about the carbon cycle between ocean and atmosphere. Because we live in this terrestrial ecosystem, which is complex and bigness, we know much about the carbon cycle between atmosphere and terrestrial ecosystem. In the terrestrial ecosystem, forest is the largest carbon inventory and it deposits 1146×10^{15} g carbon which occupies 56 percent of the carbon inventory of the total terrestrial ecosystem.

Bamboo ecosystem is an important part of forest ecosystem and an important carbon source and carbon sinks on the earth. In this system, bamboo biomass, bamboo litter and bamboo soil are carbon sinks, while respiration of organisms and decomposers degrading the dropping or carcasses of animals and plants are the greatest carbon sources on the earth. If the amount of bamboo carbon fixation is larger than that of the decomposition, bamboo ecosystem is a carbon sink, otherwise it is a carbon source. In the global carbon cycle, the bamboo ecosystem is regarded as an carbon sink, but due to the bamboo ecosystem destruction, degradation and other interfering factors, bamboo forest ecosystem will become carbon sources, thus contributing to cause degradation of environment and exasperation of Greenhouse.

In bamboo ecosystem, through the mechanism of photosynthesis, bamboo turn scarbon dioxide into organic carbon and stores it as their structures (G_p: gross of plant). Respiration of plant will emit part of carbon (R_a). Part of organic carbon will store in the litters and forest soil and part of which will gradually decompose, rot and return to the atmosphere (R_h). The Net Primary Production (NPP) of bamboo forest may be formulated as : $NPP = G_p - R_a - R_h$. In the natural situation, the Net Primary Production of bamboo forest is positive, but due to the disturbance by human beings, NPP is negative. So we must take measures to protect the bamboo forest from being a carbon source and to mitigate the Greenhouse effects. Through carbon storage and emission from bamboo stands, litters, bamboo forest soil and bamboo products, the bamboo ecosystem participates in the carbon cycle between bamboo forest and atmosphere.

2.1 Bamboo Forest Biomass

Bamboo forest biomass stores a large quantity of carbon. With a carbon percentage of 40% – 45%, nearly half of the total biomass is carbon. The biomass of bamboo ecosystem in south China is listed in the following Table 1, also in comparison with the biomass of other forest ecosystems. The biomass of *Indosasa sinica*, Maozhu high and middle yield stands are higher than those of *Pinus massoniana* stand, *Cunninghamia lanceolata* stand and natural secondly stands, but lower than those of conifer-broad leaf mixed stands and ever-green broad leaf stands. The biomass of *Neosinocalamus affinit* stand is higher than that of *Cunninghamia lanceolata* stand (Chinese fir). These data show that the bamboo ecosystem possesses a great capacity for carbon dioxide sequestration.

Table 1 Biomass Comparison between Bamboo Forest and Other Ecosystems (t/ha)

Ecosystem Types	Stock	Branch	Leaf	Root	Total	Rank
Maozhu high yield stand	98.89	13.05	4.3	53.13	169.37	4
Maozhu middle yield stand	41.99	8.213	2.886	61.9	114.989	6
Neosinocalamus affinit	38.35	8.46	4.6	10.93	62.34	10
Bambusa rigida	57.49	8.6	5.3	11.6	82.99	9
Dendrocalamus latiflorus	24.82	8.45	5.92		39.19	12
Phyllostachys nidularia cv. Smoth sheath	7.771	4.17		11.941	13	
Acidosasa edutis Wen	5.353	4.8		10.153	14	
Indosasa sinica (better site condition)	143.68	20.07	18.338		182.088	3
Indosasa sinica (poor site condition)	100.66	15.037	11.205		126.902	5
conifer-broad leaf mixed stand	174.938	94.145	22.601	85.839	377.523	2
ever-green broad leaf stand	201.151	58.325	25.921	113.174	398.571	1
Pinus massoniana	70.31	22.7	10.73	5.03	108.77	8
Cunninghamia lanceolata	32.374	6.235	4.968	10.904	54.481	11
Natural secondly stands	56.058	32.412	9.287	16.274	114.031	7

2.2 Bamboo Products

The bamboo culm has its special features of high strength, flexibility, hardness compared with timbers, so it is an ideal raw material for many projects and widely utilized in construction, handicraft, agriculture and fish industry. Because of the high cellulose content, it is suitable for bamboo paper-making, especially for top grade paper. Due to the different production types of bamboo, the length of growing time and also the emission by carbon dioxide after consumption varies. According to production longevity, bamboo products may be classified as short-term products and as medium-term products, for example, fuel and paper pulp belong to short-term products, while bamboo boards and bamboo furniture may be medium-term products. Carbon storage in fuel bamboo may emit in 1 – 2 years; carbon storage in paper and bamboo board may last 5 years or 100 years respectively. Longevity of bamboo products may determine the carbon sink function to a great degree. It is important to decrease the byproduct proportion and to produce durable and medium-longevity products during bamboo processing. Other measures such as bamboo culm modification and bamboo preservation may improve the bamboo products longevity. In a word, utilization of medium-longevity bamboo products may alleviate the emission of carbon dioxide and slow down the increase of carbon dioxide in the global atmosphere.

2.3 Bamboo Litters

Part of bamboo plants are shed and fallen to the ground as litter. A portion of this litter will decompose and rot, and its carbon re-emitted back into the atmosphere, while other portions will become part of the soil organic material. This part of carbon inventory occupies only a little proportion of the total ecosystem, but can not be neglected. To decrease the decomposition may play some role in carbon sequestration. The Main ecosystem litters in China are listed in the following Table 2.

Table 2 Litter Comparison between Bamboo and Other Ecosystems (t/ha)

Ecosystem Types	Litter	Rank
Maozhu stands	7.440	3
Neosinocalamus affinit	2.76	8
Bambusa rigida	2.556	11
Dendrocalamus latiflorus	3.93	7
Dendrocalamus brandisii	2.58	10
Dendrocalamus oldhami	2.62	9
Indosasa sinica (better site condition)	37.00	1
conifer-broad leaf mixed stand	7.66	2
ever-green broad leaf stand	6.9	4
Pinus massoniana	1.79	12
Cunninghamia lanceolata	4.841	5
Natural secondly stands	4.003	6

From the table, we may see that the litter of Indosasa sinica stands is 5 times larger than that of a conifer-broad leaf mixed stand, and the litter of Maozhu stand is higher than those of Cunninghamia lanceolata、Natural secondly stands and ever-green broad leaf stands.

2.4 Bamboo Soil

Bamboo SOC (soil organic carbon) is a most important part of soil organic material (SOM), which affects soil structure, root depth, soil profile characteristics, soil available water and soil biodiversity, etc. The loss of SOC will damage the formation of soil aggregation and its stability. The balance level of SOC is a symbol of the system. In this system, only the carbon flux maintains a suitable level, can it maintain and improve its productivity. Soil is the largest carbon sink in bamboo ecosystem and SOC varies in different bamboo ecosystems. In a Maozhu stand, the SOC content is about 2.0% (0 – 40cm below the soil surface), while in a *Neosino-*

calamus affinit stand, the SOC content is more than 3%. Generally speaking, the SOC content of bamboo is lower than in conifer-broad-leaved stand, ever-green stands and natural secondly stands, but higher than in a *Pinus massoniana stand* and *Cunninghamia lanceolata* stand. See Table 3.

Table 3 The Carbon Storage of Chinese Major Forest Ecosystems and Bamboo Ecosystems (10^8t)

Ecosystem Types	Vegetation	Soil	Litter	Total
Larix forests	5.83	16.13	1.95	23.91
Picea-Abies forests	6.2	27.28	1.57	35.05
Pinus sylvestries var. *mongolica* forests	0.2	0.85	0.04	1.09
Pinus koraiensis forests	1.36	3.7	0.19	5.25
Temperate coniferous forests	1.85	8.12	0.49	10.46
Warm temperate forests	14.17	32.58	1.64	48.39
Coniferous mixed/coniferous and broad-leaved mixed forests	0.86	4.47	0.1	5.43
Deciduous broad-leaved forests	17.24	75.4	2.11	94.75
Sclerophyllous broad-leaved forests	4.02	8.19	0.13	12.34
Evergreen/evergreen-decidous broad-leaved forests	9.29	32.48	0.68	42.45
Tropical forests	0.98	1.03	0.03	2.04
Total	62.00	210.23	8.92	281.16
Bamboo forests	2.511	8.516	0.361	11.388

3 The Dynamic Change of Soil Organic Carbon Storage

3.1 Biomass Carbon

As trees grow up, the biomass is enhanced, thus the storage of carbon increases gradually. The rate of carbon accumulation depends on the relationship between plant photosynthesis, respiration of animals and microorganisms, and death of organisms. These have a close relation with forest types, forest productivity, growth stage of forest and climate condition. Respiration of organisms have a positive relation with forest biomass. As the forest is aging, the biomass increases, but debris increase also, so the respiration of organisms increases. The undisturbed virgin forest (climax stage) absorbs a large amount of carbon dioxide, but due to the intensive respiration by the vegetation, animals and microorganisms, the decomposed organic material releases carbon dioxide greatly. The absorption and the respiration of the climax forest will stay in a balance. Anyway the virgin forest stores a large amount of carbon in the biomass and soil.

Based on the forest biomass and forest resource survey, Canadian scientists estimated the carbon storage and dynamic changes. They collected the forest biomass data and draw the growth curve of forests, according to climate zones, forest types, productivity scale and forest growth stage. According to one proportion, forest cumulation conversed into forest biomass and carbon storage is calculated by forest biomass times carbon conversion index.

3.2 Forest Soil Carbon

Researchers have divided SOC into three parts, quick turnover, middle turnover and slow turnover. Different parts of SOC determine their different remaining time in the soil. The half life of the quick turnover carbon ranges from 3 to 20 years, and is composed of dead leafs and branches with a diameter less than 10 cm. The half life of the middle turnover carbon ranges from 20 to 100 years, composed of dead branches and stocks, above 10 cm. The half life of the slow turnover carbon exceeds 100 years and exists as organic material. According to the analysis, 17 percent of the quick and the middle turnover carbon are converted into slow turnover carbon stock, while 83 percent are emitted into the atmosphere as carbon dioxide.

The soil carbon stock depends on the input of organic material, output of decompose and loss of waters, which is also closely related with climate, disturbance factors and change of vegetation biomass. By modeling decomposing rate, disturbance factors and biomass change, soil carbon stock is estimated.

3.3 Disturbance Factors on Forest Carbon Balance

Forest cutting, land-use change, forest fire, forest plant diseases and insect pests can greatly affect the forest carbon storage. After forest cutting, the biomass and carbon storage is reduced. If reafforestation follows after forest cutting, there is little change about soil organic carbon; but if no reafforestation follows, the remains of forest cutting will decompose in ten years later. In general, soil organic carbon remains at a lower level after 25 years forest cutting.

After forest cutting, the land becomes arable land or ley, as the biomass reduce, the SOC stay a lower level. Soil cultivation will increase the carbon release from soil, so that destruction of forests increases carbon dioxide in the air. If forest plant diseases and insect pests break out, the growth of forest will be affected and carbon storage will decrease. Forest fire will burn the vegetation and emit the carbon dioxide into the air, which were amassed over a long time. Therefore expanding afforestation and forest protection are effective measures to mitigate the rising of carbon dioxide in the atmosphere.

4 Review on Forest Ecosystem Carbon Cycle in China

As the people in the world pay more and more attention to the global warming, caused by Greenhouse effect, China has also conducted some carbon balance study, especially in forest ecosystem carbon inventory. Besides the studies by forest experimental stations, such as Tropical Forest Experimental Station in Hainan Province and artificial forest experimental station in south China, researchers have surveyed the space distribution of forest carbon, based on the statistic data, plot survey and GIS. All these work has established foundation for forest carbon cycle studies in China. Today the forest coverage in China is 18.21% , and as reafforestation steps quicken up and forest management level is improved, in 2050 the forest coverage will reach 27%. Without question, enhancement of forest area will surely improve the forest absorption on carbon dioxide in the air and Chinese forest will have a carbon sink roles in the global carbon balance. There are still many efforts needed to settle Chinese carbon cycle in the future.

To strengthen the fundamental studies on the forest ecosystem in forest experimental stations in order to reinforce the data on forest ecosystems in China;

To study the different vegetations in order to survey the carbon stock and carbon cycle on different forest ecosystems, considering the vast territory and complex vegetations in China;

To estimate the benefits of forest carbon sink.

5 The Future of Bamboo Ecosystems in Carbon Dioxide Sequestration

China has the richest bamboo resource in the world and is one of the bamboo origins and center distributions. The broad natural geographical environment from tropical, subtropical and warm temperate zones has provided 39 genera of more than 500 bamboo species with a favorable growing situation. The total bamboo areas is more than 4.4 million ha, which occupies 3.6% of the total forest land and plays an important role in conserving soil and water, modulating climate and improving environment. Their large amount of biomass determines their important function in carbon dioxide sequestration. People in the world have reached an agreement in improving soil carbon storage, alleviating enhancement of carbon dioxide, protecting soil from being degraded, improving soil quality and productivity and conserving biodiversity. It is estimated that in future 25 years, $14 \pm 7 \times 10^{15}$ g carbon will be stored. If the degraded land in the world be reestablished and if vegetation reestablishment and pasture intensive management are taken into account, carbon dioxide sequestration will be 0.58 - 0.80 $\times 10^{15}$ g yearly, which will be 9% - 12% percent of carbon dioxide emission from human activities. So carbon sequestration projects as an available and economic measure are carried out in many countries in the world to cut down Greenhouse gas content, to improve soil quality and to conserve environment. For example, in United States, four measures are put forward to alleviate carbon dioxide emission, including soil erosion management, land use change and resume, producing bio-fuel to reduce the amount of fossil fuel utilization and intensive arable land management. All of these measures have resulted already in marked ecological benefits.

Bamboo has its features of fast growth, high output, and annually renewable and harvestable vegetable if managed in an intelligent way after planting. It is an important forest resource in tropical and subtropical zones. Its high-resistance and lower demand on site condition determines that it can grow widely, so it is one of the most-selected species in national grain for green projects. The project aims are to reestablish forestry, to improve carbon absorption of vegetation and soil, to reduce the emission of carbon and to enhance the SOC and to extend the storage time of carbon in soil. The exuberate branches and leaves, evergreen, and the excellent conservation of soil and water show that bamboo provides an integration of economical, ecological, and view functions. With the development of national grain for green project and natural forest conservation project, bamboo will surely play ever-greater roles in the future.

Environmental Role of Sympodial Bamboos

Sympodial bamboos one of the bamboo types classified according to its morphological characteristics and breeding habit. There are about 200 sympodial bamboos species with total area of 1.0 million ha in China, where it is mainly distributed in the south and southwest part, such as the Provinces of Sichuan, Yunnan, Guangdong, Guangxi, Taiwan and etc. Sympodial bamboos is not only an ideal economic investment that can be utilized in many different manners but also has enormous potential for alleviating many problems, both environmental and social, facing the world today. The increasing rate of tropical deforestation makes the search for alternative natural resources important. The characteristics of sympodial bamboos make it a perfect solution for the environmental and social consequences of tropical deforestation. Its biological characteristics make it a perfect tool for preventing soil erosion and reducing carbon dioxide levels in the atmosphere. On account of extensive shallow root system and accumulation of leaf mulch, sympodial bamboos serves as an efficient agent in preventing soil erosion and conserving moisture, reinforcement of embankments and drainage channels, etc. Additionally, its qualities of strength, light weight and flexibility make it a viable alternative to tropical timbers that typically supply the furniture and building materials industries.

1 Sympodial Bamboos for Erosion Control

Soil erosion is a major environmental threat to the sustainability and productive capacity of agriculture. It is a worldwide problem approaching disaster proportions in many countries. It is estimated that the world's arable land is lost at a rate of more than 10 million ha per year. 75 billion metric tons of soil is removed from the land each year, causing up to US $400 billion in damage worldwide (Pimentel *et al.*, 1995). One analysis of globe soil erosion estimates that, depending on the region, topsoil is currently being lost 16 to 300 times faster than it can be replaced (Barrow, 1991). In America farms routinely lose tons of topsoil per year. Soil is eroded by wind, water, and gravity aided and hurried by tillage and poor soil management

(Lewis, 1993). In China, soil erosion is increasing and about 1.5 million km^2 (17% of the total area) are affected (Li, 1990).

In addition to many industrial and construction uses, sympodial bamboos also is valuable for controlling soil erosion, it grows well on steep hillsides, road embankments, gullies, or on the banks of ponds and streams. The valuable features of sympodial bamboos for controlling soil erosion are its extensive fibrous root system, the leafy mulch it may produce on the soil surface, its comparatively dense foliage which protects against beating rains, and its habit of producing new culms from underground rhizomes which allows harvesting without disturbing the soil.

1.1 Holding Soil

Sympodial bamboos can form a closely woven mat of roots underground which are effective in holding soil. The soil around bamboo plants is permeated by a mass of intertwining roots. A study showed that 83% of the roots of *Bambusa tulda* were present in the upper foot of soil which is the area where roots serve best in controlling soil erosion, its root can extend horizontally for a distance of 5.2 m (White and Childers, 1945). It has been reported that a single bamboo plant can bind up to 6 m^3 of soil. Because of this, it is perfect for arresting the ravages of water erosion in areas prone to it such as slopes and lowlands. *Guada* bamboo in Colombia has been the one that prevented millions of tons of mountain soil from reaching the ocean bottom. The plant is so effective in binding soil on steep slopes that Malaysia has started planting bamboos on hillsides to block mud and sTonnes sliding onto roads (INBAR, 1997).

Research results indicate that bamboo forest soil shows strong anti-scouribility and anti-erosion. The indices of anti-scouribility and anti-erosion in the upper soil (0 – 40 cm deep) of a moso bamboo stand are measured to 0.998 and 1.051, higher than those (0.92 and 0.98) in black locust (*Robinia pseudoacacia*), 0.93 and 0.52 in *Metasequoia glyptostroboides*, and 0.95 and 0.38 in Poplar (I-69). The dwarf *Pleioblastus argenteostriatus* f. *albostriatus* has well-developed rhizomes and root system, of which indices (1.404 and 1.413) increases by 40% and 34% even than those in larger sized *Phyllostachys pubecens* (Luo *et al.*, 1999). In a *Dendrocalamus latiflorus* forest with a density of 825 culm/ha, the runoff coefficient and soil loss were 2.83% and 0.073t/ha per year respectively (Xie, 1999).

At the Mayaguez Federal Experiment Station of Puerto Rico, *Bambusa longispiculata* was planted in steep hillside. At the time this bamboo had been planted, many ditches caused by erosion were present, however, 4 years later, the ditches were covered with leaves and the soil impregnated with roots. Some ditches are culvert outlet from nearby roadway. A clump of bamboo situated directly in the path of this outlet serves to disperse the flow of water during rains. The slope in this planting is 52%, too steep for comfortable walking. This 4-year-old planting of bamboo served to control erosion on this steep hillside in addition to providing culms for industrial purposes. The planting was made on the square with the clumps spaced 20 feet apart. A better system of planting for steep hillsides may be the hexagonal arrangement in which the staggered clumps further retard fast moving water from torrential rains (White and Childers, 1945).

In the north-central Andes, the rich volcanic soils have been under cultivation for thousands of years, even on steep hillsides (Judziewicz *et al.*, 1999). *Chusquea scandens* and related species appear to aid the control of erosion naturally by stabilizing the soils surrounding their intricate rhizome system and by protecting the soil surface from insolation through shading and deposition of leaf litter (Stern, 1995b). In the lowlands, disturbed sites have been reforested with species of *Guada* to protect exposed soils and to produce timber (Venegas, 1993, cited by Judziewicz *et al.*, 1999).

1.2 Protecting Riverbanks

Bamboo planted along stream and river banks, grows particularly well because of a more even and abundant supply of moisture. The fibrous mass of roots binds the soft banks, and the thick culms arrest strong currents during flood periods. Bamboo's efficacy as a soil binder was successfully used in Puerto Rico. A river used to cause great damage at regular intervals to the trial crop fields at the Mayaguez Federal Experiment Station. Before the bamboo was planted, large areas of the adjoining experimental field were washed away, especially on the sharp curves. At these critical points a bamboo revetment was constructed. A sympodial bamboo, *Bambusa vulgaris*, was used in this case (White and Childers, 1945; INBAR, 1997). The soil behind the revetment is reinforced further by additional plantings of bamboo, thus building a solid wall of living plant material on the banks of the river.

A study sponsored by INBAR (1997) has documented two instances in China, one in Dayingjiang River in Yunnan Province and the other in Jiulongjiang River in Fujian Province, where sympodial bamboo succeeded in protecting river banks after soil-rock engineering efforts and planting of other trees failed to yield results. The mixed bamboo stands that adorn the south-west mountains area were instrumental in ensuring that the quantity of soil that reaches Yangtze River through sheet erosion is just half that of the quantity washed out into the Yellow River. Many undestroyed high mountain bamboo forests with the major species of *Sinarundinaria* grow in its upper reaches (INBAR, 1997; Fu *et al.*, 2000).

1.3 Preventing Landslides

Puerto Rican researchers found bamboo to be one of the most effective in controlling landslides. Puerto Rico has many winding roads through the mountainous interior of the Island. Landslides are a problem both above and below the hillside roads. The Department of Interior has used sympodial bamboos with considerable success to maintain fills and steep road embankments. The bamboo generally used for this purpose is the common species, *Bambusa vulgaris* (White and Childers, 1945; INBAR, 1997). It develops large thick clumps, makes a rapid dense growth, and planting material is readily available.

In Hakone-yama mountain of Japan, the bamboo community of Sasa and *Indocalamus distributed* in the high mountainous area, 1,000 m above the sea level, resulted in little water and soil loss. The Brazilian even introduced *Bambusa blumeana* and *Phyllostachys pubescens* for controlling soil erosion, preventing nutrient loss and improving soil structure (Fu *et al.*, 2000).

For erosion control purpose, the sympodial bamboos is generally planted in the specific places vulnerable to erosion. However, this is not the only way to do it. In south-western Japan introduced *Bambusa multiplex* is widely planted in coastal areas facing the Pacific Ocean. Especially in Kagoshima prefecture, it has been utilized as the material for culm weaving works, a kind of hillside fencing, called 'Karami' for erosion control for more than 100 years (Shibata, 2001).

2 Sympodial Bamboos for Water Conservation

2.1 Litter Fall Accumulation

Sympodial bamboo creates a lot of biomass. In south Fujian Province of China, the current above-ground biomass of *Dendrocalamus latiflorus* is 39.52 tons/ha (Zhou, 1999). Ueda (1960) point out that bamboo leaves usually fall when they are between 12 and 18 months old, and they are quickly replaced by new leaves. Total above-ground litter fall (litter, sheath, and branches) was estimated to be 4.7 tons/ha at 72 months. Rozanov and Rozanov (1964) reported values for total above-ground litter fall for bamboo plantation of 6.6 tons/ha per year for bamboo forest under thinned tropical forest, and of 10.6 tons/ha per year for bamboo forest thinned monsoonal forest. Tripathi and Singh (1994) reported above-ground litter values ranging from 4.1 to 7.2 tons/ha per year for mature bamboo savannas. Seth *et al.* (1963) reported the above-ground leaf litter production of 3.2 tons/ha in a bamboo plantation in India. A 4-year-old *Bambusa longispiculata* forest has accumulated to form a 2 to 4-inch mulch in a study area.

2.2 Moisture Retention

The leafy mulch which accumulates beneath bamboo collects and conserves moistures in addition to preventing soil erosion. The thick leafy blanket also assists the earth to absorb and retain moisture more effectively, and to reduce the rate of evaporation. Leaves, being organic matter, also help increase the organic content of the soil. Bamboo litter has an extremely high water retention capacity. The moisture that bamboo litter can hold weighs 2.75 times as much as itself, topping the other 8 types of vegetation studied in Hunan Province of China (Huang *et al.*, 1997). According to study, sympodial bamboos, such as *Dendrocalamus latiflorus*, has abundant litters and strong self-fertilization capacity. For example, the litter of *Dendrocalamus latiflorus*, with a density of 825 culm/ha, has the capacity to absorb the moisture 2.7 - 2.9 times of its dry weight. The annual litter is measured to 3.6 - 3.9 t/ha, and soil porosity 52%, maximum potential water storage 315 - 326 mm. The annual soil surface runoff, sediment loss and erosion modulus are 21.2mm, 0.07t/ha and 7.1t/ha respectively (Xie, 1999).

The underground porous network structure improves permeability, water holding capacity and soil fixing capacity. Experimental results show that the soil fixing capacity of a bamboo stand increases by 150% than that of masson pine (*Pinus massoniana*). In comparison with Chinese fir (*Cunninghamia lanceolata*), the absorption capacity of precipitation increases by 130% and water holding capacity by 30% - 45% (Zheng *et al.*, 1995).

2.3 Rainfall Interception

Bamboo has evergreen leaves, dense canopy and numeral culms, which can help to intercept considerable amount of rainfall. Falling raindrops change their direction and ways, and reduce velocity, and therefore decreases its direct soil erosion after multiple interception by tens of shoot layers and larger amount of culms. A research in China conclusively proved that the canopy of bamboo stands can intercept up to 25% of rain through fall and the leaf litter up to 0.7 mm of rain-value much higher than those for conifers and pine. The canopy interception is dependent upon quantity of standing culms and leaf area index. For example, the average interception is 0.95mm with interception ratio of 21.3% in a *Phyllostachys pubescens* stand with 2,190 culms, average DBH of 8.12 cm and leaf area of 35,100 m^2/ha. The average interception (1.80mm) and ratio of interception (31.3%) increases by 89.4% and 47.0% respectively in a dense *Phyllostachys pubescens* forest with 6,720 standing culms, average DBH of 7.35 cm and leaf area of 100,000 m^2/ha, compared to the previous sparse bamboo stand (Wu *et al.*, 1997).

The sympodial bamboos also improve water holding capacity, and soil and water conservation. Taking *Dendrocalamopsis latiflorus* as example, the culm quantity measured to 5,000/ha if density is practiced by 3 × 4 and 6 culms are finally left in a clump. Its annual canopy interception is up to 128.1mm, ratio of interception

14.5% , direct precipitation 78.0% , stem runoff 66.0 mm, coefficient of stem runoff 7.47%. A positive correlation exists between canopy interception, stem culm runoff and culm density, as well as between surface runoff and sediment loss with direct canopy precipitation, precipitation intensity, and total precipitation (Xie, 1999).

2.4 Water Holding Capacity and Forest Structure

The capacity of bamboo forest for moisture retention and rainfall interception depends greatly upon the forest structure. Generally speaking, the mixed bamboo forest has better water holding capacity than pure forest because of its larger litter and higher decomposition. For the litter, its water holding capacity is very closely related to composition of the mixed stand, quantity of litter and human activity. According to measurement, the dense pure moso bamboo stand (3,893 culms/ha) produces 5.8 t/ha litter which has maximum water holding capacity up to 231.54% and maximum water holding quantity of 1.11 mm. For a bamboo forest (1,500 culm/ha) mixed with broad-leaved (average height 4.5m, 4,665 trees /ha), the leaf litter is 7.16 t/ha (up 23% than pure *Phyllostachys pubescens* stand), the maximum water holding capacity 262.20% (up 13.2%), maximum water holding quantity 1.90 mm (up 71.2%). As for a mixed forest of moso (1,020 culms/ha) and Chinese fir(705 trees /ha) mix stand, leaf litter is 9.41 t/ha, the maximum water holding capacity 183.67% , and maximum water holding quantity 1.83mm (Wu *et al.* , 1997). The denser pure moso bamboo stand produces larger quantity of litter, but bringing bamboo shoots, bamboo leave and bamboo sheaths out of bamboo land by farmers results in losing accumulative litter and thus reducing lower water holding capacity of litter.

The mixed bamboo forest has the highest capacity of canopy interception, litter and soil moisture retention among the coniferous forest, broad-leaved forests and the mixed stands of conifer with broad-leaved trees. The mixed forest in the south-west mountainous areas, which is composed of *Fagus lacida* + *Chimonobambusa quadrangularis* with *Sinarundinaria nitia*, or the pure *Chimonobambusa quadrangularis* forest, has the highest capacity in terms of all the index of water interception of canopy, water interception of litter, water retention of soil and soil fixation of root system (Fu *et al.* , 2000).

3 Sympodial Bamboos for Land Rehabilitation

The globe store of arable land and grazing lands is under increasing pressure from varied causes, including overuse of fertilizers and pesticides; salinization, acidification or alkalinization, nutrition depletion and etc. In the last five decades or so, 1.2

billion ha of land (11% of the earth's total vegetated land) is reported to have become degraded to the extent that their original biotic functions are damaged (Oldeman *et al.*, 1990). According to a UNEP report (1992), at least one-quarter of the degradation of agriculture lands is human induced (agricultural practices, overgrazing, deforestation, etc.). Bamboo can be a healer of lands wounded through human enterprise. The ability to grow in a wide variety of soils, from marginal to semi-arid, makes bamboo perfect for rehabilitation; it also serves to conserve soil and manage water flows. Bamboo is also a prolific generator of biomass, ideal for regenerating soil. The plant is thus well-positioned to be used as an instrument for land repair and maintenance.

Sympodial bamboos is the main bamboo type in tropical and subtropical areas. With its evergreen canopy, large biomass accumulation and abundant litterfall, sympodial bamboo has been playing a great role in rehabilitation of regarded land in the areas. In China, India and Thailand, appropriate bamboo agro-forestry modes for cultivation on degraded lands have been developed. In China, three types of bamboo-agroforestry models have been established, which includes agro-silvicutural system, (bamboo + tea, bamboo + coniferous or broad-leaves tree for timber, bamboo + crops), silva-pastoral system (bamboo (+ crops) + fish pond (or poultry)) and special agro-forestry system (bamboo + edible fungi, bamboo + medicinal plant) (Fu *et al.*, 2000). With the establishment of the agro-forestry model, rehabilitation effects on land have been attained. These bamboo agro-forestry models improve the microclimate in the stands, helping to increase the formation and accumulation of the photosynthetic product. Meanwhile, the community composed of several different plant populations strengthens its resistibility to calamities such as frost and heavy snow or reduces the attack of disease and pests.

Since the subterranean root systems of different components in the community have different distribution, horizontal and vertical, the bamboo agro-forestry system can fully use the soil fertility, which increases the growth of the populations. The litterfall also increase greatly, resulting in the increment of organic matter, nitrogen, phosphoresces, potassium etc. If the nitrogen fixation plants are planted in the models, a much better effects will be obtained.

In Jabalpur, Madhya Pradesh of India, farmers were willing to plant *Dendrocalamus strictus*, *Bambusa bambos* and *B. nutans* on farm bunds and degraded lands even if it is non-productive. Bamboo seedlings were intercropped with either maize or soybean. In Thailand, the bamboo species were intercropped with maize and peanut (INBAR, 1997).

In India, researchers have tried to develop bamboo-based technologies to rehabilitate land from which topsoil has been removed to depths up to three meters for producing bricks. Also, a novel research project, funded by IDRC and jointly undertaken by Indian researchers, looked at the possibility of using bamboo and coal fly-ash to rehabilitate degraded land. The project successfully proved that using a soil + sludge + fly-ash combination, bamboo can be successfully cultivated to restore degraded land because it can produce the maximum biomass per unit area and unit time (INBAR, 1997).

In Caldas of Colombia and Merida of Venezuala, *Guada angustifolia* has been widely used for reclaiming land degraded by deforestation and poor agricultural practices (Judziewicz *et al.*, 1999). Vietnam has demonstrated the rehabilitation effects by regreening with bamboo vast tracts of land laid wasted by the war (INBAR, 1997). Dwarf bamboo (Sasa) is the most representative forest floor vegetation in Japan and covers 6,910,000 ha of land throughout the country, accounting for 25 percent of the total forest area (Katoh, 1979, cited by Takamatsu *et al.*, 1997). It plays a significant role in preventing soil from acidification in mountainous area in Japan by acting as a biological pump to return basic cations from the lower layer of soil (20-30cm) to the surface, and retaining them within the ecosystem (Takamatsu *et al.*, 1997). In West Java of Indonesia, the bamboo "talun-kebun" agroforestry system had a great success. Bamboo is acknowledged as so important that the farmers kept the old saying "without bamboo, the land dies". The success of the talun-kebun system in maintaining soil fertility appears to be based largely on the "nutrient pumping" action of the bamboo, the slow decomposition, of its silica-rich litter, and the extremely high biomass of bamboo fine roots (Christanty *et al.*, 1996). Singh *et al.* (1999) suggested that *Dendrocalamus strictus* plantation has an efficient restoration potential and positive rehabilitation effect on mine-spoiled land in a dry tropical region in India. The bamboo plantation planted on this land has attained similar biomass and higher net production levers compared to that of native dry forest within a short time.

4 Sympodial Bamboo for Carbon Sequestration

The globe environment debate, which has intensified considerably over the years from the Stockholm Conference on Environment in June 1972 to the Earth Summit in Rio de Janeiro in June 1992 and beyond, has seen international action being taken through the Framework Convention on Climate Change to reduce carbon dioxide in the ambient temperature of the earth. A focus of this climate change debate has been the role of the forests, and especially tropical forests-being they primary, logging and regenerating, secondary, or plantation forests- in sequestering carbon.

There are three carbon inventories in the global, ocean, atmosphere and terrestrial ecosystem. So far, we know little about the carbon cycle between ocean and atmosphere. Because we live in this terrestrial ecosystem, its complex and bigness, we know much about carbon cycle between atmosphere and terrestrial ecosystem. In terrestrial ecosystem, forest is the largest carbon inventory and it deposits $1,146 \times 10^{15}$ g carbon which occupies 56 percent of the carbon inventory of the total terrestrial ecosystem. Bamboo forest ecosystem is an important part of forest ecosystem and an important carbon source and carbon sink on the earth (Li *et al.*, 2003).

In bamboo forest ecosystem, through the mechanism of photosynthesis, bamboos turn carbon dioxide into organic carbon and store it as their structure, part of which will store in the litters or in forest soil. Considering the respiration of bamboos organism and decomposition, the net primary production of bamboo forest is the key issue. In the natural forests of the tropics, sympodial bamboo spreads gregariously where there is disturbance by logging and shifting cultivation activities, and the bamboos are the fastest growing plants, reaching their full height in two to four months, and that branching begins as soon as culms reach their full heights. It is estimated that a bamboo clump can produce in its lifetime up to 15 km of poles of 30 cm in diameter. So, bamboo is very vigorous and dynamic in growth. Due to its rapid biomass accumulation and effective fixation of solar energy and carbon dioxide, the carbon sequestration ability of bamboo is likely to be second to none and if at all, only to a very few. According to an estimate, one quarter of the biomass in tropical regions and one-fifth in subtropical regions comes from bamboo (INBAR, 1997). If one considers the fact that the great majority of sympodial bamboos occur in the tropics within the broad band circumscribed by the Tropics of Cancer and Capricorn, and that about 80% of the area containing bamboo is in the South and Southeast Asian tropical regions, the likely contribution to the globe accounting of carbon sequestration by bamboo alone could be quite significant.

Sympodial bamboo is an important type of bamboo. It is versatile not only in industry utilization and in routine life but also in environment protection. It possesses a great potential either in soil erosion control, water conservation, or in land rehabilitation and carbon sequestration, which is composed to give it a promising future.

Biodiversity and Conservation Strategy of Sympodial Bamboos (I)

As one of the significant natural resources, bamboo forest covers over 20 million ha or about 1% of the total forest area in the world. Benefiting from its geographical position in the bamboo distribution center of the world, China, located in the center of the Southeast Asia monsoon region, ranks first in the world in terms of either bamboo area, standing stock, resources or yields. With the implementation of reform and opening policies adopted in recent years, the China bamboo sector is booming in harmony with economic prosperity of the nation. The rapid growth of the China bamboo sector has been greatly attributed to local economy. In this sense, it is significantly important for the sustainable development of the bamboo sector, and even for ecological environment and healthy national economic development, that the biodiversity of bamboo and its conservation strategy are studied in detail for scientific exploitation.

1 The Germplasm of Sympodial Bamboos in China

China has vast territory with its various geographically and climatically complex mountains and rivers that differ greatly in terms of elevation and topography, and climatic zones that range from frigid to temperate, subtropical and tropical zone, which acts as a haven for a large number of bamboo species that enjoys a wide diversity in China.

According to the systematic survey to the world bamboo resources by Prof. Geng Bojie of the Nanjing University, the bamboo on the globe entails over 1,300 species belonging to 107 genera. Among these, woody species account for approximately 1,200 species within 79 genera and herbaceous species number more than 180 within 28 genera. In China, all the bamboo species are woody ones and none of herbaceous exists. In *The Chinese Flora* (1996, Vol. 9, Book 1), there are more than 502 bamboo species and 100 varieties listed within 37 genera, and 13 unidentified species. The information in *The Chinese Flora* was collected by the end of 1985, though. In *Compendium of Chinese Bamboo* (1994), edited by Zhu Shilin, Ma Naixun and Fu Maoyi, there are more than 509 bamboo species and 96 varieties listed within 39 genera by revising the information of bamboo species in *The Chinese Flora* thanks to new information and knowledge got from the publications during 1985 to 1994. Moreover, there are still new genera and new species of bamboo reported since 1994. According to incomplete survey recently, two new bamboo genus, *Gaoligongshani* (Lin Wantao, 1995) and *Monospatha* (Lin Wantao, 1994) and 45 new species and 5 varieties have been identified again. But Prof. Yi Tongpei has a different view that the *M. triloba* W. T. Lin, as a type species of *Monospatha*, is same species of *Yushania canoviridis* G. H. Ye et Z. P. Wang (Yi Tongpei, 1996).

According to the morphological characteristics and breeding habit, bamboos can be classified into sympodial and monopodial. Sympodial bamboo can be classified into the clumped sympodial and irregular stocking sympodial based on the distribution habit of standing culms. The former is characterized by high-density clumped short culms, while the latter is characterized by scattered standing culms which sprout far distance from mother bamboo. Of 40 genera in China (including *Gaoligongshania* D. Z. Li, Hsueh et N. H. Xia), there are 21 genera of sympodial bamboos, including 16 genera of clumped sympodial which has more than 160 species and about 40 varieties (Table 1). The irregular stocking sympodial basically are *Fargesia* and *Yushania* distributed in alp. All the sympodail bamboos mentioned in this paper are the clumped sympodial.

Table 1 Sympodial Bamboos Species in China (Total Number)

No.	Genera	The Chinese Flora		Compendium of Chinese Bamboo		Identified after 1994	
		Species	Varieties	Species	Varieties	Species	Varieties
1	*Ampelocalamus*	2		2			
2	*Bambusa*	61	23	63	21	4	2
3	*Cephalostachyum*	4		4			
4	*Chimonocalamus*	9		9			
5	*Dendrocalamopsis*	8		9			
6	*Dendrocalamus*	29	8	30	9	2	
7	*Drepanostachyum*	6		5		1	
8	*Gaoligongshania* D. Z. Li, Hsuehet N. H. Xia					1	
9	*Gigantochloa*	5		8		1	
10	*Melocalamus*	2		5			

(Continued)

No.	Genera	The Chinese Flora		Compendium of Chinese Bamboo		Identified after 1994	
		Species	Varieties	Species	Varieties	Species	Varieties
11	*Monocladus* *	3	1	3	1		
12	*Neohouzeaua*			1			
13	*Neomicrocalamus*	2		2			
14	*Neosinocalamus*	2	4	2	4	(1)	
15	*Schizostachyum*	9		9		2	
16	*Thyrsostachys*	2		2			
Total		144	34	153	35	11	2

* According to Xia Nianhe in 1996, Monocladus should be named by *Bonia balansa*.

2 The Distribution of Sympodial Bamboos

Compared with monopodial bamboos, the shoot growth of sympodial bamboos is later, commonly in summer and autumn. The new culm has not been fully lignified when winter is coming, and consequently it is usually not able to endure cold, which is the reason why the sympodial bamboos distribute in the mid-southern subtropical or tropic area in southern provinces of China. The attached table lists over 160 native sympodial bamboos species and their distribution in China (Appendix 1). According to Appendix 1, plus the information reported and our survey on sympodial bamboos resources recently, the Chinese sympodial bamboos distribution has following characteristics:

In general, the arctogea distribution line of sympodial bamboos reaches up to Yangtse River, including Zhejiang, Hunan, Sichuan and so on. Few sympodial bamboos species can grow in the north of Yangtse River, among which the most cold-enduring one is *Bambusa multiplex*, and *Bambusa textiles* var. *fasca*, *Bambusa rigida*, *Bambusa wenchouensis*, *Bambusa textiles*, *Bambusa chungii*, *Dendrocalamopsis basihirsuta*, *Neosinocalamus affinis* and *Dendrocalamopsis vario-striatare* are also able to endure cold, and generally can grow in Wenzhou of the southern Zhejiang.

Yunnan Province has the most abundant sympodial bamboo resource in China, in the 16 genera of sympodial bamboos, 13 ones are naturally distributed there, among which 5 species exist only in Yunnan Province, i. e, *Giganthochloa*, *Gaoligongshania*, *Cephalostachyum*, *Chimonocalamus*, and *Thyrsostachys*. The majority species of *Dendrocalamus* genus are distributed in Yunnan except few cultivatable, great economic species, such as *Dendrocalamus latiflorus*, *D. minor*, etc. As Darwin mentioned in 1859 that each species has its own ancient origin center, it was reported that the ancient origin center of many genera located in a same certain area is the origin center of such flora. Sympodial bamboos are relatively antique and aboriginal monoid in the history of bamboo evolution. Compared with the broad earth continent, Yunnan Province has a small area with 500km distance from the north to the south and 700km from the east to the west, which is so parochial but has so many antique and native bamboos, so it can be undoubtedly inferred that Yunnan is the ancient origin center of bamboos in the world.

Geographic distribution areas of sympodial bamboos.

The Sympodial bamboos plants in China are grouped into two geographic distribution areas: southeastern Asia monsoon sub-area and southwestern monsoon sub-area, which widely accepted by bamboo researchers. The former belongs to the Pacific southeastern Asia monsoon climate area, including Hainan, Guangdong, Guangxi, Fujian, Taiwan and other provinces, where the precipitation varies little from month to month that means no obvious distinct between the rainy season and dry season. The precipitation in winter and spring commonly accounts for 1/4 of total or more in a year, and is usually not less than the evaporation. The typhoon occurs in summer and autumn every year and brings much precipitation. While the latter, where the mountains stretch from north to south, is affected by the Indian Ocean monsoon that go north via the Bengal Bay and the Indian. The southwestern monsoon sub-area includes Yunnan, southern Tibet and Sichuan Province, where there are obvious distinct climate between the rainy season and the dry season, characterized by high humid in summer and dry in winter, even dry all the year or evaporation in excess of precipitation in some place. The dividing line between two sub-areas is located from estuary of Nanpanjiang River to Wenshan. The bamboos, growing and developed in such two different ecological systems for long term, formed their own bamboo population gradually. It can be found in the Appendix 1 that *Bambusa* and *Dendrocalamus* are the biggest genera in China, containing over 60 and 30 species respectively. The majority species of *Bambusa* are distributed in southeastern Asia monsoon sub-area, mainly in the provinces of Guangdong, Guangxi, Taiwan, Fujian and so on, while the species of *Dendrocalamus* mainly are naturally distributed in southwestern monsoon sub-area, especially in Yunnan, and also in the southern Tibet, Guizhou, Sichuan, etc. The species of Bambusa are characterized by short culms but strong wind-resisting ability while the species of *Dendrocalamus* and *Giganthocloa* are characterized by long and large culms and high dry-endure but low wind resistance, which is resulted from the long-time evolution and natural selection.

The distribution of sympodial bamboos shows a big geographically difference. Bamboo plants grow quickly with high yield and versatile use, as well as strong ability of regeneration, especially for some economic species, such as *Dendrocala-*

mus latiflorus, *Bambusa textiles*, *Bambusa chungii*, *Bambusa pervariiabilis*, *Dendrocalamopsis oldhamii* and so on. These economic bamboos species have been cultivated for a long time and introduced to various places. As a result, they are distributed widely. But most sympodial bamboos species are naturally distributed in a poky place and are in endangered. Because of cultivation in long-term but lack of conservation of bamboo germplasm diversity, some of the bamboo species are in endangered, or even in extinction. There are 20 thousand ha of *Bambusa chungii* forest in Xinyi city of Guangdong Province, from which annual export value reached over US $ 100 million by processing/weaving handcrafts and articles in recent years. As a result, the area of *Bambusa chungii* stands are expanded so fast that *Bambusa pervariabilis*, the main species distributed around Guangdong Province, can seldom be found there, and it grows widely all over Gaozhou, though, the neighbor city of Xinyi. One of the ten "China's Bamboo Hometown", Guangning County of Guangdong Province is only sympodial bamboos hometown, where exist almost 60 thousand ha of *Bambusa textilis* that can be found everywhere in river banks and hillside, but few other bamboo species grow there.

The uncertainty of sympodial bamboos' distribution.

The Appendix 1 lists the distribution of sympodial bamboos in various provinces, which is a comparatively large region, but the distribution of bamboo species are reported in province-level domain by Chinese literatures, so it is not clear how many bamboo species distributed there. Although some new sympodial bamboo species has been reported recently, most of them exist only one type specimen or grow in some limited area.

It's complicated to categorize and identify bamboo species, and furthermore few professionals are engaged upon that work. So, it's quite difficult to clearly survey the resources and distribution of sympodial bamboos in such a broad geographical area due to some problems faced by them in time, finance and traffic. That makes the sympodial bamboos distribution uncertainty.

It needs to clarify the conception of "distribution" and "cultivation" here. What we called "distribution" usually indicates natural distribution while "cultivation" means introduction. But the history of bamboo utilization has exceeded thousands of years, as well as the history of introduction that did mostly for production and cultivation and that are lack of records, so the question is raised that how long it should be called "distribution" of some species after they introduced? This question appears in many literatures. For example, *Bambusa rigida*, one of the vital economic bamboo species, can be found in almost every publications about bamboos, which listed in following table (Table 2). Therefore they are so different described that there are no way to know which publication is more correct. Likewise, similar examples can be found everywhere in the taxonomy of bamboos.

Table 2 Distribution of *Bambusa rigida* Reported in Various Publications

Publications	Published by	Publishing date	Distribution
The Chinese Flora	Science Publishing House	1996	Native in Sichuan Province, and introduced to other Provinces
Compendium of Main Chinese Flora (gramineae)	Science Publishing House	1959	Native in Sichuan and Guangdong
Bamboo in Fujian	Science and Technology Publishing House of Fujian	1987	Native in Fujian, Guangdong, Guangxi and Sichuan
The Bamboo Flora in Sichuan	China Forestry Publishing House	1997	Native in Sichuan, and also distributed in northern Guizhou and northeastern of Yunnan
Chinese Forestry	China Forestry Publishing House	2000	Distributed in Sichuan, Guizhou, Hunan, Jiangxi, Fujian, Guangdong, Guangxi and Yunnan, etc.
Compendium of forests in Yunnan	Science and Technology Publishing House of Yunnan	1991	Native in Yunnan, Guangdong and Guangxi, and also distributed in Guizhou, Sichuan, etc.
Bamboo Species and Cultivation in Guangxi	The People's Publishing House of Guangxi	1987	Cultivated in northeastern Guangxi
Bamboo Cultivation	Agriculture Publishing House	1974	Cultivated in Sichuan, Hunan, Jiangxi, Fujian, Guangdong, Guangxi, etc.
Bamboo Cultivation and Management	China Forestry Publishing House	1959	Native in Sichuan Province
Compendium of Chinese Bamboo	China Forestry Publishing House	1994	Distributed in Guangdong, Guangxi, Sichuan, Fujian, Jiangxi etc.

3 Resources of Sympodial Bamboo Forest

According to the lately national statistics, the bamboo forest area reach to 4.5 million ha, but if plus natural distribution of Fargesia in alp and the mixed *Yushania*, it can reach 5 million ha. Among which *Phyllostachys heterocycla* var. *pubescens* is the largest distribution species with 2.8496 million ha that account for two third of the total bamboo forests. But there are no definite data available on areas of other bamboo species.

According to rough survey based on reports, the sympodial bamboos, mainly distributed in the south and south-west China, have total 700 – 800 thousand ha, growing mainly in Provinces of Sichuan, Yunnan, Guangdong, Guangxi, Taiwan and so on (Table 3). And main dominant species are *Neosinocalamus affinis*, *Bambusa textilis*, *Dendrocalamus membranaceus*, *D. latiflorus*, *Bambusa chungii* etc.

Table 3 Bamboo Area in Main Bamboo-growing Provinces (ten thousand ha)

Province	Bamboo area	Sympodial bamboos area	Dominant species and area
Sichuan	40.8	25.0	*Neosinocalamus affinis*: 20; *Bambusa rigida*: 1
Yunnan	33.1	18.0	*Dendrocalamus membranaceus*: 7, *D. giganteus* and *Cephalostachyum fuchsianum*: 8 *S. funghomil*: 1 *Neosinocalamus affinis*: 1
Guangdong	32.0	~15.0	*Bambusa textilis*: 6.6 *Bambusa pervariabilis*: 2 *Bambusa chungii*: 2
Guangxi	24.01	~6.0	*Bambusa chungii*: 2
Fujian	68.0	~4.0	*Dendrocalamus latiflorus*: 1.7 *Dendrocalamopsis oldhami*: 1.03 *Bambusa albo-lineata*: 0.5
Taiwan	18.45	Unknown	Dominated by *Dendrocalamus latiflorus*
Guizhou	6.09	0.44	
Hainan	5.18	~4.0	Dominated by *Bambusa chungii*

Note: A little of bamboos distributed in Zhejiang, Hunan, Jiangxi, Tibet, etc.

4 The Utilization of Sympodial Bamboos

4.1 Bamboo Shoots

There are many sympodial bamboo species that can produce high-yield economically profitable and high quality edible shoots, such as *Dendrocalamus latiflorus*, *Dendrocalamopsis oldhami*, *Dendrocalamus membranaceus*, *Schizostachyum funghomii*, *Dendrocalamopsis beecheyana*, *Dendrocalamopsis vario-striata*, *Dendrocalamus hamiltonii*, *Dendrocalamus brandisii*, *Dendrocalamus giganteus*, etc., and the output of *Dendrocalamus latiflorus* is the largest in China. Nanjing County of Fujian Province is the largest county of *Dendrocalamus latiflorus* production, in which over 66.7 thousand ha of *Dendrocalamus latiflorus* forest grows and 13 shoot processing factories have been established. The high-yield *Dendrocalamus latiflorus* stand can produce more than 40 tonnes of shoots each year. Taiwan is the largest *Dendrocalamus latiflorus* shoots production province with annual output of 30 thousand tonnes. Fu'an city of Fujian Province is the largest *Dendrocalamopsis oldhami* production county where there are about 4,000 ha of *D. oldhami* forest. Many species of *Dendrocalamus*, such as *Dendrocalamus giganteus*, *Dendrocalamus membranaceus*, *Dendrocalamus hamiltonii* and *Dendrocalamus brandisii*, are all derived from Yunnan Province, in which there are abundant bamboos resources for shoot production with large potential to develop bamboos shoots.

4.2 Utilization of Bamboo Timber

The output of sympodial bamboo culms lacks an exact statistical data because its markets in many sympodial bamboo growing areas is not established completely. It's roughly estimated that the yearly output of Chinese sympodial bamboo culms is about 5 million tonnes from the 700 – 800 ha of sympodial bamboo forest in whole China. Compared with utilization of *P. heterocycla* of monopodial bamboos, sympodial bamboos are developed lately, mostly for agriculture and living utensils, such as weaving products: baskets, mats and so on, by using the flexible character of sympodial bamboo culms. In Xinyi city of Guangdong Province, all of the culms produced from 20 thousand ha of *Bambusa chungii* are used for weaving products to export. The brackets, used for vegetable and fruit production in agriculture, and containers for transportation consume large quantity of sympodial bamboo culms. Taking Hainan Province as an example, every year a great deal of fresh vegetables and tropical fruits produced there are exported to the mainland (about 8 million tonnes of fresh vegetable and 2 million tonnes of tropical fruits). If 30% – 40% of those products are packed by bamboo materials for transportation, it would cost 300 thousands tonnes of culms that calculated based on 4 – 5 kilogram of culms for one basket that pack 20 kilogram of vegetable or fruits. It also needs 180 thousand tonnes of culms if most of brackets for 460 thousand ha of banana crops there. The culms output in Hainan is far from meeting the demands of market and it needs to import several hundred thousands of bamboo culms from mainland.

Use of sympodial bamboos in industry is mainly for pulp making. In recent years pulp making from bamboo culms is developed fast by the fact that the bamboo pulp output has increased doubly in the past decade, from 250 – 300 thousand to 500 thousand tonnes. Bamboo pulp are made mainly from sympodial bamboos, which consume 2 millions tonnes of culms calculated based on 4.0 – 4.2 tonnes of fresh culms for one tonne of pulp. Sichuan is the leading province in China of bamboo pulp making, reaching 262 thousand tonnes of bamboo pulp each year that accounts for more than half of the total in China. Majority of culms from large *Neosinocalamus affinis* area are used for the production of paper pulp. Along with the development of the pulp industry, the demand of sympodial bamboos culms will ascend.

Appendix 1 Distribution of Sympodial Bamboo Species in China

Genera	Species	Province												
		Hainan	Guang-dong	Guangxi	Hunan	Fujian	Yunnan	Guizhou	Sichuan	Zhe-jiang	Jiangxi	Taiwan	Hong Kong	Tibet
Ampelocalamus	*A. actinotrichus* (Merr. et Chun) S. L. Chen	√ *												
	A. calcareus C. D. Chu et C. S. Chao							√						
Bambusa Retz. corr Schreber	*B. angustiaurita* W. T. Lin		√											
	B. angustissima Chia et H. L. Fung		√											
	B. arundinacea (Retz.) Willd		o *										o	
	B. aurinuda McClure	√		√										
	B. blumeana Schult. f	√	√	√		√	√					√		
	B. blumeana cv. Wwi – fan Lin											√		
	B. chungii Chia et H. L. Fung												√	
	B. corniculata Chia et H. L. Fung		o	√										
	B. diaoluoshanensis Chia et H. L. Fung	√	√											
	B. dissemulator McClure		√	√		o								
	B. dissemulator var. *albinodia* McClure		√			o							√	
	B. dissemulator var. *hispida* McClure		√			√								
	B. flexuosa Munro	√	√										√	
	B. funghomii McClure		√	√		√								
	B. gibba McClure		√	√		√							√	
	B. glabro – vagina G. A. Fu	√												
	B. indigena Chia et H. L. Fung		√											
	B. insularis Chia et H. L. Fung	√	o	o									o	
	B. lapidea McClure		√	√			√		√				√	
	B. macrotis Chia et H. L. Fung		√											
	B. malingensis McClure	√	o										o	

(Continued)

Genera	Species	Province												
		Hainan	Guang-dong	Guangxi	Hunan	Fujian	Yunnan	Guizhou	Sichuan	Zhe-jiang	Jiangxi	Taiwan	Hong Kong	Tibet
	B. prominens H. L. Fung et C. Y. Sia		o						√					
	B. ramispinosa Chia et H. L. Fung			√					o					
	B. rutila McClure		√	√		√			√					
	B. sinospinosa McClure	√	√	√		√	√	√	√					
	B. subaequalis H. L. Fung et C. Y. Sia		o						√					
	B. ventricosa McClure		√	√		√								
	B. xiashanensia Chia et H. L. Fung		√											
	B. albo – lineata Chia		√			√				√	√	√		
	B. boniopsis McClure	√	o	o					o					
Bambusa	*B. burmanica* Gamble						√							
Retz. corr	*B. contracta* Chia et H. L. Fung		o	√										
Schreber	*B. cornigera* McClure		√	√						o				
	B. dissimilis W. T. Lin		√	o										
	B. dolichoclada Hayata					√						√		
	B. dolichoclada cv. Stripe											√		
	B. duriuscula W. T. Lin	√												
	B. eudulдoides McClure		√	√		√	o						o	
	B. euduldoides var. *basistriata* McClure		√	√		√	o							
	B. euduldoides var. *viridi – vitatta* Chia		√											
	B. gibboides W. T. Lin		√	o			o	o					√	
	B. lenta Chia					√								
	B. longispiculata Gamble ex Brandis		√	o										
	B. mollis Chia et H. L. Fung			√										

(Continued)

Genera	Species	Province												
		Hainan	Guang-dong	Guangxi	Hunan	Fujian	Yunnan	Guizhou	Sichuan	Zhe-jiang	Jiangxi	Taiwan	Hong Kong	Tibet
	B. multiplex (Lour.) Raeuschel. ex Schult. f.					√			√	√	√			
	B. multiplex cv. Alphonse – Karr		√						√			√		
	B. multiplex cv. Fernleaf					√			√	√	√			
	B. multiplex var. *incana* B. M. Yang				√						√			
	B. multiplex var. *riviereorum* R. Maire													
	B. multiplex var. *shimadai* (Hayata) Sasaki											√		
	B. multiplex cv. Silverstripe		√										√	
	B. multiplex cv. Yellowstripe								√					
Bambusa	*B. mutabilis* McClure	√	o	o										
Retz. corr	*B. nutans* Wallich ex Munro						√							
Schreber	*B. pachinensis* Hayata		√	√		√				o	√	√		
	B. pachinensis var. *hirsutissima* W. C. Lin		√	√		√				√		√		
	B. pallida Munro						√							
	B. piscaporum McClure	√	o				o							
	B. pervariabilis McClure	√	√	√		√								
	B. polymorpha Munro						√							
	B. rigida Keng et Keng f.		o	o		o			√		o			
	B. subtruncata Chia et H. L. Fung		√											
	B. textilis McClure		√	√		√				o	o			
	B. textilis var. *fasca* McClure					√				√				
	B. textilis var. *glabra* McClure		√	√										
	B. textilis var. *gracilis* McClure		√	√										
	B. textilis cv. Maculata		√											

(Continued)

Genera	Species	Province												
		Hainan	Guang-dong	Guangxi	Hunan	Fujian	Yunnan	Guizhou	Sichuan	Zhe-jiang	Jiangxi	Taiwan	Hong Kong	Tibet
	B. textilis cv. Purpurascens		√											
	B. tulda Roxb.		√	√			o	o						√
	B. tuldoides Munro		√	√									√	
	B. tuldoides cv. Swolleninternode		√											
	B. utilis W. C. Lin											√		
Bambusa	*B. vulgalis* Schrader ex Wendland		√	√			√							
Retz. corr	*B. vulgalis* cv. Vittata	√	√	√			√					√		
Schreber	*B. vulgalis* cv. Wamin	√	√	√		√				o		√		
	B. cerosissima (McCl.) Chia et H. L. Fung		√	√	√	√								
	B. chungii McClure		√	√	√	√			o	o				
	B. distegia (Keng et Keng t.) Chia et H. L. Fung			o		o	o		√					
	B. guangxiensis Chia et H. L. Fung			√										
	B. hainanensis Chia et H. L. Fung	√												
	B. papillata (Q. H. Dai) Q. H. Dai			√										
	B. remotiflora Kuntze	√	√	√										
	B. surrecta (Q. H. Dai) Q. H. Dai			√										
	B. wenchouensis (Wen) Q. H. Dai					√				√				
	B. intermedia Hsueh et Yi						√	√	√					
	C. fuchsianum Gamble						√							
	C. pallidum Munro						√							√
Cephalostachyum	*C. pergracilis* Munro		o				√							
Munro	*C. virgatum* (Munro) Kurz						√							

(Continued)

Genera	Species	Province												
		Hainan	Guang-dong	Guangxi	Hunan	Fujian	Yunnan	Guizhou	Sichuan	Zhe-jiang	Jiangxi	Taiwan	Hong Kong	Tibet
Chimonocalamus Hsueh et Yi	*C. delicatus* Hsueh et Yi						√							
	C. dumosus Hsueh et Yi						√							
	C. dumosus var. *pygmaeus* Hsueh et Yi						√							
	C. fimbriatus Hsueh et Yi						√							
	C. longiligulatus Hsueh et Yi						√							
	C. longiusculus Hsueh et Yi						√							
	C. makuanensis Hsueh et Yi						√							
	C. montanus Hsueh et Yi						√							
	C. pallens Hsueh et Yi						√							
	C. tortuosus Hsueh et Yi													√
Dendrocalamopsis (Chia et H. L. Fung) Keng f.	*D. basihirsuta* (McClure) Keng f. et W. T. Lin		√	o		√				√	o		o	
	D. beecheyana (Munro) Keng f.	√	√	√										
	D. beecheyana var. *pubescens* (P. F. Li) Keng f.		√	√								o	√	
	D. bicicatricata (W. T. Lin) Keng f.	√	o	o			o							
	D. daii Keng f.		o	√										
	D. edulis (Odachima) Keng f.											√		
	D. oldhami (Munro) Keng f.	√	√	√		√				√		√		
	D. oldhami f. *revolute* (W. T. Lin et J. Y. Lin) W. T. Lin		√											
	D. stenoautila (W. T. Lin) Keng f.		√	o					o					
	D. validus Q. H. Dai		o	√										
	D. vario-striata (W. T. Lin) Keng f.		√	√		√				o				

(Continued)

Genera	Species	Province												
		Hainan	Guang-dong	Guangxi	Hunan	Fujian	Yunnan	Guizhou	Sichuan	Zhe-jiang	Jiangxi	Taiwan	Hong Kong	Tibet
	D. calostachyum (Kurz) Kurz						√							
	D. fugongensis Hsueh et D. Z. Li						√							
	D. giganteus Munro		o	o			√					o		
	D. jianshuiensis Hsueh et D. Z. Li						√							
	D. latiflorus Munro	√	√	√		√	√	√	√	o	o	√	√	
	D. latiflorus cv. Mei – nung											√		
	D. latiflorus cv. Subconvex											√		
	D. minor (McClure) Chia et H. L. Fung		√	√				√		o				
	D. minor var. *amoenus* Hsueh et D. Z. Li			√										
	D. pachystachys Hsueh et D. Z. Li						√							
Dendrocalamus	*D. peculiaris* Hsueh et D. Z. Li						√							
Nees	*D. sinicus* Chia et J. L. Sun						√							
	D. sinicus f. *aequotus* K. L. Wang						√							
	D. tomentosus Hsueh et D. Z. Li						√							
	D. yunnanicus Hsueh et D. Z. Li			o			√							
	D. asper (Schult. f) Backer ex Hayne						o					o	o	
	D. bambusoides Hsueh et D. Z. Li		o				√							
	D. barbatus Hsueh et D. Z. Li		o				√							
	D. barbatus var. *internodiiradicatus* Hsueh et D. Z. Li						√							
	D. birmanicus A. Camus						√							
	D. brandisii (Munro) Kurz		o				√							
	D. farinosus (Keng et Keng f.) Chia et		√	√			√	√	√					

(Continued)

Genera	Species	Province												
		Hainan	Guang-dong	Guangxi	Hunan	Fujian	Yunnan	Guizhou	Sichuan	Zhe-jiang	Jiangxi	Taiwan	Hong Kong	Tibet
Dendrocalamus	*D. hamiltonii* Nees et Arn. ex Munro						√							
Nees	*D. liboensis* Hsueh et D. Z. Li							√						
	D. membranaceus Munro						√		o					
	D. membranaceus f. *pilosus* Hsueh et D. Z. Li						√							
	D. membranaceus f. *striatus* Hsueh et D. Z. Li						√							
	D. membranaceus f. *fimbriligulatus*						√							
	D. mianningensis Q. Li et X. Jiang								√					
	D. parishii Munro						√							
Dendrocalamus	*D. patellaris* Gamble						√							
Nees	*D. pulverulentus* Chia et But		√										√	
	D. rongchengensis Yi et C. Y. Sia								√	o				
	D. semiscandens Hsueh et D. Z. Li						√							
	D. sikkimensis Gamble						√							
	D. strictus(Roxb.) Nees		o	√			√					o	o	
	D. tibeticus Hsueh et Yi						√							√
	D. tsiangii(McCl.) Chia et H. L. Fung		√	o				√						
	D. tsiangii f. *viridistriatus* X. H. Song							√						
	D. loudianense(Yi et R. S. Wang) Keng f.							√						
	D. melicoideum Keng f.								√					
Drepanostachyum	*D. microphyllum*(Hsueh et Yi) Keng f.						√		√					
Keng	*D. naibunense*(Hayata) Keng f.											√	√	
	D. saxatile(Hsueh et Yi) Keng f.						√		√					
	D. scandens(Hsueh et Yi) Keng f.							√						

(Continued)

Genera	Species	Province												
		Hainan	Guang-dong	Guangxi	Hunan	Fujian	Yunnan	Guizhou	Sichuan	Zhe-jiang	Jiangxi	Taiwan	Hong Kong	Tibet
Gaoligongshania D. Z. Li, Hsueh et N. H. Xia	*G. megathyrsa* (Hand – Mazz) D. Z. Li						√							
	G. albociliata (Munro) Kurz						√							
	G. felix (Keng) Keng f.						√							
	G. levis (Blanco) Merr.		o				√							
Gigantochloa	*G. ligulata* Gamble						√							
Kurz ex Munro	*G. perviflora* (Keng f.) Keng f.						√							
	G. pseudoarundinacea (Steud) Widjaja		o				√						o	
	G. rostrata Wong						√							
	G. scortechinii Gamble						√							
	G. migrociliata (Büse) Kurz						√						o	
	M. arrectus Yi			√			√							
Melocalamus	*M. compactiflorus* (Kurz) Benth et Hook f.			√			√							
Benth	*M. elevatissimus* Hsueh et Yi													√
	M. fimbriatus Hsueh et Yi						√							
	M. scandens Hsueh et Hui						√							
	M. amplexicaulis Chia, Fung et Y. L. Yang			√										
Monocladus Chia,	*M. levigatus* Chia, Fung et Y. L. Yang	√												
Fung et Y. L. Yang	*M. saxtilis* Chia, Fung et Y. L. Yang		√	√										
	M. saxtilis var. *solidus* (C. D. Chu ex C. S. Chao) Chia			√										
Neohouzeaua A. Camus	*N. coradata* Wen et Q. H. Dai		o	√										

(Continued)

Genera	Species	Province												
		Hainan	Guang-dong	Guangxi	Hunan	Fujian	Yunnan	Guizhou	Sichuan	Zhe-jiang	Jiangxi	Taiwan	Hong Kong	Tibet
Neomicrocalamus	*N. microphyllus* Hsueh et Yi													√
Keng f.	*N. prainii* (Gamble) Keng f.						√							√
	Neosinocalamus affinis (Rendle) Keng f.			√	√		√	√	√					
	Neosinocalamus affinis cv. Viridiflavus								√					
Neosinocalamus	*Neosinocalamus affinis* cv. Striatus								√					
Keng f.	*Neosinocalamus affinis* cv. Flavidorivens								√					
	Neosinocalamus affinis cv. Chrysotrichus								√					
	N. recto-cuneatus W. T. Lin		√											
	S. annulatus Hsueh et W. P. Zhang						√							
	S. brachycladum (Kurz) Kurz											√		
	S. chinense Rendle						√							
Schizostachyum	*S. diffusum* (Blance) Merr.											√		
Nees	*S. dumetorum* (Hance) Munro		√	o									√	
	S. funghomii McClure		√	√			√							
	S. hainanense Merr. ex McClure	√												
	S. jaculans Holttum	√												
	S. pseudolima McClure	√	√	√			√							
	S. xinwuense Wen et J. Y. Chin										√			
Thyrsostachys	*T. oliveri* Gamble						√							
Gamble	*T. siamensis* (Kurz ex Munro) Gamble		o	o		o	o					o		

* √: Native; O: Introduced.

Biodiversity and Conservation Strategy of Sympodial Bamboos (II)

Sympodial bamboos is defined as the clumped sympodial bamboo species, which is an important part of the bamboo resources and account for 80% of total bamboo area of ten million ha. In the world, which is widely distributed in the Asia – Pacific, Africa and America, while the monopodial bamboo is mainly distributed in some east Asia countries, such as China and Japan. According to the statistic data, there are more than 0. 8 million ha. Of sympodial bamboo resources in China while *Fargesia and Yushania*, distributed in high mountains, are more than 0. 5 million ha. The total area of these two types bamboo is one – fourth of the total bamboo area in China. The abundant resources of sympodial bamboo are fundamental for sustainable development of bamboo. It is necessary for the sustainable development of bamboo sector and ecological conservation and construction to study and recognize the bamboo biodiversity

1 Species Diversity of Sympodial Bamboos

Biodiversity includes four basic aspects of genetic, species, ecosystem and landscape, and species diversity is apparent and easily determined. Species diversity is generally expressed by species abundances, which are the number of species in a defined area.

There are more than two hundred years' dispute about species concept and essence, and the issue is whether a species actually exists in the nature. A great many of scholars believe in the facticity of species and species are discontinuous community between formation and procreation, whether this concept is the concept of taxlogy or biology.

There are more than 1,200 bamboo species in the world, belonging to over 70 genera. There are more than 500 bamboo species in China, belonging to 39 genera, taking nearly one half of the total in the world in terms of the number of bamboo genera and species. Sympodial bamboos species accounts for 50% of the total bamboos species in China; although the total area of sympodial bamboos stand is only one – fourth of the total bamboo area. So, compared with monopodial bamboo species, species diversity of sympodial bamboos is more abundant.

It is the vast territory, the long geological history and the complex habitats with various landforms, climate and soil conditions, as well as the little effects of the Fourth Glacier Movement on bamboo that create the excellent situation for the conservation and development of bamboo species which are typically distributed in China. There are five sympodial bamboo genera, distributed only in China, i. e. *Ampelocalamus* Chen ,Wen et Zheng, *Chimonocalamus* Hsueh et Yi, *Drepanosta chyum* Keng f. , *Gaoligongshania* D. Z. Li,Hsueh et N. H. Xia, *Neosinocalamus* Keng f. These five genera have about 30 bamboo species. Besides, there are some species belonging to other genera and are only distributed in China. For example, more than 30 bamboo species, belonging to genera of Bambusa Retz, have been recognized as new species since 1970's and takes almost one half of the total bamboo species of this genus. 40 species belonging to Genera of *Fargesia* Franch and *Yushania* Keng f. have been recognized as new species and are distributed only in China. A bamboo culm of *Dendrocalamus sinicus* Chia et J. L. Sun recognized in Yunnan Province in 1982 is reported to weight 450 kg with 36 centimeters in diameter and 46 meters in height, so it is called as World Bamboo King.

Species diversity of sympodial bamboos determines their diversity of features, which are listed as follows:

1.1 Dimensional Distribution Types of Bamboo Culms

One types of sympodial bamboos with the culms growing in cluster, has 15 genera, such as *Bambusa*、*Dendrocalamus*、*Schizostachyum.*

Another types with the culms scattering around but still sympodial or degenerated rhizome, has 5 genera, i. e. *Fargesia*, *Yushania*, *Melocanowna*, *Pseudostachyum*, *Thamnocalams.*

1.2 Behavior of Bamboo Culm

Behavior of bamboo culm may be classified as three categories, which are arbor, shrub and cane (Table 1).

Table 1 Behavior of Sympodial Bamboo Culm

Culm types	Bamboo species	Height (m)	Diameter (cm)
Arbor	*Dendrocalamus giganteus*	30	30
	D. sinicus	30 – 46	30 – 36
Shrub	*Yushania baishazhuensis*	1.5 – 2.0	0.5 – 0.8
	Bambusamultiplex var. nana	1.0 – 2.0	0.3 – 0.6
Cane	*Schizostachyum hainanense*	8.0 – 20.0	2.0 – 4.0
	Drepanostachyum luodianense	6.0 – 10.0	0.4 – 1.0

1.3 Culm Character

Different sympodial bamboos species have different culm characters. The color of culm usually is green, but some are yellow or yellow and green, such as *Bambusa vulgalis* cv. Vittata, *Galbociliata pseudoarundinacea*(Steud) Widjaja. Internodes of culm generally is cylinder, while some is abnormal and tumid, such as *Bambusavulgaris* cv. Wamin, *Bambusa ventricosa* McClure, *Bambusa tuldoides* cv. Swolleninternode. The length of culm internode varies. The same diameter of different bamboo species may have one meter length of culm internodes, such as *Schizostachyum xinwuense*, *Cephalostachyum scandens*, *Cephalostachyum fuchsianum*, *Bambusa chungii.*

Bamboo culm is main product of bamboo forest and culm characters have close relation with bamboo forest yield. Different bamboo species have different bamboo yield(Table 2).

Table 2 The High Yield Record of Sympodial Bamboos

Bamboo species	High yield($t \cdot ha^{-1} \cdot a^{-1}$)
Neosinocalamus affinis	20 – 25
Bambusa textilis	25 – 30
Bambusa pervariabilis	40 – 45
Bambusa rigida	45 – 50
Bambusa chungii	45 – 60
Dendrocalamus membranaceus	40 – 50
D. giganteus	60 – 80

1.4 Characters of Bamboo Shoot

There is abundant diversity in character of bamboo shoot. They usually are stable, although there are some variances in character of bamboo shoot in the different bamboo species. Characters of bamboo shoot are important reliance of species determination.

Characters of bamboo shoot include many aspects. Shoot color, texture, dots, whiting, back and margin hair of shoot shield, formation, shape and developing degree of shoot's shell, upper and lower part, front formation and so on.

Bamboo shoot is tender and delicious, which is rich in amino acids, sugar and edible fiber, necessary for human body. Different bamboo species have different adaptation, quality and productivity, which determine their distribution, yield and economical benefit. The high yield records of sympodial bamboos species are listed as Table 3:

Table 3 The High Yield Records of Some Sympodial Bamboos Species

Bamboo species	High yield ($t \cdot ha^{-1} \cdot a^{-1}$)
Dendrocalamus latiflorus	70 – 80
D. hamiltonii	20 – 30
Dendrocalamopsis oldhami	15 – 23
D. beecheyana var. *pubescens*	20 – 27

2 Genetic Diversity of Sympodial Bamboos

Genetic diversity is referred to the gene combined existing in the biology, but generally is referred to genetic variances within a species, to show genetic abundance within a species. It is fundamental for diversity of ecosystem and species and also genetic improvement. For a specific species, the more genetic variance, the more adaptation to environment.

China has thousands of years of history for bamboo management. Bamboo species with high yield and quality are cultivated for the pursuit of economic benefit. Since the increasing of population, irrational utilization of resource and long period of flowering, or flowering without seeds or flowering with seeds but no germination, the bamboo species mainly depends on asexual reproduction. Because of this, many bamboo species have lost a large amount of genetic resource, so genetic diversity of sympodial bamboos reduce quickly and many bamboo specie may rank as genetic single species.

Just based on the above reasons, we know very little about genetic diversity of sympodial bamboos and have great difficulty in researching on genetic diversity of sympodial bamboos. Many sympodial bamboo species are distributed in a narrow district and we cannot identify whether they are originated from the same clone. If bamboo species are widely distributed, the above problem is more difficult. It is difficult to find a good method to carry on the genetic diversity research of bamboo species and many researchers are frustrated about this. So far there is little acknowledgement about genetic diversity in sympodial bamboo fields.

There is little research on heredity diversity of sympodial bamboo in the recent years. With the research project of "sustainable management and utilization of sympodial bamboos in South China" funded by the International Tropical Timber Organization (ITTO), a number of provenances under some priority species such as *Dendrocalamus latiflorus*, *Bambusa chungii*, *Bambusa pervariabilis* etc. have been collected. The Ministry of Science and Technology launched the project of China Bamboo Gene Pool last year and 200 heredity resource pools related to 20 bamboo species have been established in the Forestry Experimental Center of Chinese Academy located in Pingxiang, Guangxi by the International Bamboo and Rattan Center. This is just the beginning of the task. There is a long way to go, and we have to make greater efforts.

3 Ecological Diversity of Sympodial Bamboos

3.1 Ecological Diversity of Population

Population is the aggregate of the individuals of one species within a particular region. Population ecology is the science studying the relationship between the population and the environment. In "China Vegetation Partition" (Science Publishing House, 1980) edited by Wu Zhengyi, bamboo is defined as pure forest composed by a single dominant species. According to the dominant species of the pure forest and the habitat forming the characteristics, bamboo forest in China is divided into 36 formations belonging to 5 formation groups under 3 types. Among them, 19 formations belonging to 4 formation groups under 3 types are sympodial, with *Fargesia* forest, *Yushania* forest and *Fargesia robusta* forest belonging to the formation of mountainous bamboo forest under the temperate bamboo forest type and 4 formations of *Bambusa sinospinosa*, *Bambusa rigida*, *Neosinocalamus affinis* and *Bambusa multiplex* var. *nana* included in the formation group of valley and flat land under the mild temperate bamboo forest type. The other 12 main formations belong to 2 formation groups of mountainous and valley/flat land under the tropical bamboo forest type.

There are over 300 sympodial bamboos species in China, with most of them can form pure forest. Thus, there are over 300 populations under 19 formations supposedly. Sympodial bamboos distributes widely in over 10 Provinces in South China, with varied habitat and different management practice. So, the number of ecological type of bamboo populations in China is supposed to be several times as much as the number of population.

3.2 Ecological Diversity of Community

Organism community is the aggregate of all the living things living in particular environment. Community ecology is to deal with the structure, function and succession of the organism community.

There are hundreds of sympodial bamboos populations composed of one dominant species. Beside the pure forest, there is a lot of mixed bamboo forest and they form different community, which can be divided into following formation:

Bamboo-bamboo mixed formation: community composed of two or more than two bamboo species.

Bamboo-broadleaf mixed formation: community composed of bamboo and broadleaf tree, with varies proportion.

Bamboo-conifer mixed formation.

Bamboo-conifer-broadleaf mixed formation: community composed of bamboo, coniferous and broadleaf tree.

In above-mentioned formations, the organism population may different and the proportion may varied also, which determines the rich ecological diversity of sympodial bamboo in China.

4 Landscape Diversity of Sympodial Bamboos

Landscape is a geographic entity which is made up by different land unit in mosaic way and has visibly obvious characteristics. It is on a medium measure, upper than ecosystem and lower than macroscopically geographic region. It has a multiple value economically, ecologically and in culture. Based on different comprehension of its implication, there are different classification method and system of landscape from the aspect of landscape-geography and landscape-ecology. The internationally influential classification system of landscape include ecology-land, landscape property, ecosystem and disturbance intensity, with the disturbance intensity classification becoming essential. According to the intensity of human disturbance, there are 5 types of landscape, as suggested by Forman and Gordon (1986). Based on this system, the sympodial bamboos landscape can be divided into following types:

4.1 Natural Landscape

The natural landscape is characterized by absence of human disturbance. The sympodial bamboos landscape can be divided further into following types:

4.1.1 Alpine/Subalpine Natural Mixed Sympodial Bamboos Forest

This type forest generally distributed in alpine/subalpine region or plateau with an altitude of above 2,000m, where the bamboo forest is in wildness due to the escape from human activity. Growing in the middle-west part of China and with an high altitude, this type forest is composed of the species in the genera of *Fargesia* and *Yushania* which usually come into being the understory of mixed forest due to its dwarfism.

The region around the border of Sichuan, Shaanxi and Gansu is the utmost north area for bamboo to grow, which is the habitat of giant panda and has a bamboo area of 526.8 thousand ha. It is the largest naturally distributing area for alpine/subalpine natural bamboo forest with the main species including *Fargesia nitida*, *F. spathacea*, *F. rebusta*, *F. dracocephala*, *F. denudata* and *F. rufa* which generally come to be the under story of conifer-broadleaf mixed forest and subalpine dark coniferous forest with the arbor tree being *Abies*, *Cedrus*, *Betula* etc. The understory species include *Lonicera nervosa*, *Euonymus alatu*, *Sorbus pohuashannesis*, *Rubus amabilis* etc. with the bamboo being dominant understory species. The bamboo is generally 2 – 5m high and around 1cm in diameter with a density of 150 – 200 thousand culms per hectare. There are 5 exclusively distributing species, i. e. *Fargesia ferax*, *F. jiulongensis*, *F. emaculata*, *F. adpressa* and *F. canaliculata* in the subalpine area of South-west Sichuan, most of which distribute around an altitude of 2,000 – 3,200m, with F. emaculata at as high as 3,800m. The total area of bamboo forest is over 60 thousand ha in the alpine and above the snow line of Nujiang, Diqin, Lijiang and Dali in North-west Yunnan, with the main species including *F. pagyrifera*, *F. acuticontracta*, *F. yulongshanesis*, *F. contracta*, and *F. sylvestris.* Yunnan is the area where the bamboo distribution is the highest which can be 4,500m in altitude.

4.1.2 Medium/Low Natural Sympodial Bamboos Forest

This type of bamboo forest distribute in the areas where the altitude is low and the human activities are frequent, however, it is essentially on natural state because the forest is not easily accessible or its economic benefit is not high enough to draw human's attention. This type of forest distributes mainly in the west and south part of Yunnan. There are 100 thousand ha bamboos forest in Xishuanbanna, Simao and east Linchuang of Yunnan, with natural Dendrocalamus membranaceus forest being 70 thousand ha, which is the largest big-sized sympodial bamboos forest in China. Besides, there are Melocalamus compactiflorus and other local species such as Gigantochloa felix, Dendrocalamus giganteus etc. There are widely distributed Schizostachyum funghomii and Bambusa textilis natural forest in medium/low mountainous areas in Gaozhou and Guangning of Guangdong, with most of them being pure forest and their area varying from tens of thousand hectares to hundreds of thousand hectares. In Hainan, there are lots of unexploited natural forest or secondary forest mixed with a great deal of Schizostachyum hainanesis, scrambling up and hanging down, presenting a luxuriant sight of tropical seasonal rain forest.

4.2 Managed Bamboo Forest Landscape

Bamboo forest management has thousands of years' history in China. Providing culm and other by-products such as bamboo shoot, bamboo can find a wide utilization in human life. Most of the sympodial bamboo forest in China has been under management.

According to its product and utilization, sympodial bamboo forest can be divided into culm-oriented, shoot-oriented, culm-and-shoot-oriented, soil and water conservation and scenery forest, with each one having further division in terms of species. The shoot-oriented bamboo forest with big area and beautiful scene includes the forest of *Dendrocalamus latifloru*, *Dendrocalamopsis oldhami*, *D. beecheyana* var. *pubescens*, *D. beecheyana*, *D. vario-striata*, *Dendrocalamus hamiltonii* and etc. The culm-oriented bamboo forest includes *Bambusa textilis*, *B. chungii*, *B. pervariabilis*, *B. rigida* etc. Nanjing and Fu'an of Fujian is the main production of *Dendrocalamus latifloru*, and *Dendrocalamopsis oldhami* respectively, each with an area of tens of thousands hectares. The species grow on river beach and the lower slope of hillock and under intensive cultivation. High-yield bamboo forest can produce 20 – 30 tons of shoot per hectare. Guangning County of Guangdong has the largest area of sympodial bamboo forest in China, with 60 thousand ha of *Bambusa textilis* forest. The bamboo forest widely grows on the river alluvium and river bank, and hillock. A clump of bamboo may include hundreds of culms on fertile alluvium, with average DBH of 4 – 5 cm. Meanwhile, *Bambusa textilis* on mountainous area, known as "mountain bamboo", has lower yield, with a diameter of 1 – 3 cm. Besides the bamboo weaving and routines use, most of the bamboo production is supplied to a paper pulp factory with annual production of over 50 thousand tons in Guangning. Xinyi of Guangdong is the largest region for Bambusa chungii growing, with an area of 20 thousand hectares. The culm is mostly used for weaving and the products are exported overseas with an annual production value of over 100 million US dollars. With people's arduous work on bamboo generation after generation, the bamboo forest area keep growing, the productivity keep increasing and the benefit from bamboo keep rising. Bamboo industry has become the economic mainstay in rural area.

4.3 Bamboo Culture

Bamboo culture landscape is a kind of artificial landscape or human civilization landscape, which is made up of bamboo environment and human culture, and the key factor of creation and development of bamboo culture is human activities.

4.3.1 Bamboo Culture Landscape

As an ancient country, China has a long history of bamboo culture and Chinese people love or would be like to enjoying bamboos by using, planting and managing bamboos that are deeply melted into their life. Man can live without meat, but cannot live without bamboo is the best expression of the characteristic of bamboo culture landscape with various traditional customs in different regions.

Bamboo exists everywhere around the villages surrounded by green bamboo. Bamboo buildings are set off one another encircled in bamboo clumps in Tai nationality in Yunnan Province where bamboo culms are used to cook aromatic sticking rice, while Neosinocalamus affinis are planted around the house in many villages of Sichuan Province where many kinds of bamboo farm tools, such as the bamboo baskets, dustpans, flails, harrows etc. are used in threshing grounds. The young married women on paths, roads and in market places put the babies into the bamboo baskets on the backs. All the peoples play the reed pipe wind instruments when the festivals is going on, dancing straightforwardly and warmly around need fire. The people in Li nationality villages in Hainan Province enjoy the bamboo dances joyously and unrestrainedly with the tuneful sounds created by hitting the bamboo culms. However, bamboo culture in bamboo hometowns web up many florid bamboo landscapes.

4.3.2 Bamboo Botanical Gardens and Culture

By collecting and conserving the sympodial bamboos, the environments of the bamboo botanical gardens provide the information and knowledge for scientific researches, teaching, dissemination, enjoying, recreation and other bamboo cultures. The famous bamboo botanical gardens are Wangjianglou Park in Sichuan Province, Xishuangbannan Botanical Garden in Yunnan Province, Bamboo Garden in Kunming City, Xiamen Bamboo Garden, South China Botanical Garden, etc. More than one hundred sympodial bamboo species have been collected in those gardens with bamboo buildings, booth, bamboo corridors, bridges and bamboo paths that took the bamboo as the main characteristic for landscape decorations.

Current Status and Demand Potential of Market for Bamboo Shoot Products

1 Introduction

Bamboo, as one of the fastest growing, highest productivity with lower investment, most versatile, short harvesting circle, and annually renewable and harvestable plants if managed in an intelligent way, is not only with great economic importance in rural communities but also with ecological benefits in environment protection, which has been highly prized by the governments of which countries have rich bamboo resources. It was reported that bamboo area reached to 20 million ha and would tended to expand.

China, one of original producing and earliest countries of bamboo shoots for edibles use by fact of that it was reportedly took as one of the major food ingredients as early as in Zhou dynasty, has over 500 bamboo species belonged to 39 genus and more than 4 million ha of bamboo area. In generally, bamboo shoots are divided into three types, winter shoots, spring shoots and rhizome shoots, based on different growing seasons that are mainly distributed in Zhejiang, Fujian, Jiangxi and Guangdong Provinces. Their uses are so wide in daily life that shoots are sold fresh, or processed and peeled and then tinned, dried or preserved as pickles to meet great demand for consumers in different seasons, which are enjoyed a high reputation in Japan and South-eastern Asia, and has developed fast in past decade.

With the socialist market system continuously being adjusted and national macro-control policies persisting, partly due to international economic crises occurring throughout the world, the bamboo sector is facing problems and serious challenges, such as a sluggish market of the bamboo shoot products that result in negative impact on shoots resources development. Since China entranced to WTO recently, bamboo sector has entered into new stage with challenge and opportunities.

2 Characteristics of Bamboo Shoots

Bamboo shoots were considered as "the titbit among vegetables" since ancient time in China and praised as "the first class among the vegetables" by Li Liweng, a writer in Qing dynasty, who opined that it is better than meat, such as mutton and pork. There are lot of poems and papers for chanting the praise of bamboo shoots by writers and poets, which reflect the high value of bamboo shoots. Bamboo shoots can be used for both the food ingredients and main course, and there are dozens of dishes listed famous menus in China.

2.1 Nutrition of Bamboo Shoots

Table 1 Main Nutrients Components of Bamboo Shoots in Anji County of Zhejiang Province

Items		Winter bamboo shoot	Spring bamboo shoot
Moisture (g)		Nutrients Component	92
Protein (g)		3.07	2.15
Fat (g)		0.7	0.5
Carbohydrate (mg/100g)	Total carbohydrate	6.72	5.6
	Oligose		0.35
	Sucrose		18.36
	Glucose		0.07
	Fructose		0.09
Trace Elements (mg/kg)	Cr		0.44 - 0.12
	Co		0.05 - 0.02
	Cu		0.619 - 3.17
	Ni		0.758 - 0.385
	Zn		3.41 - 1.75
	Fe		5.91 - 2.34
	Mg		48.6 - 28.66
	Mn		1.71 - 0.91
P (mg/100g)		64	44
Ca (mg/100g)		1.9	5.8

Some edible bamboo shoot is tender and delicious, which contains about 90% of water and 3% of protein needed by human body. The bamboo shoot protein contains 17 kinds of amino acids, especially rich in saccharopine, speramic acid and glutamic acid. The total carbohydrate, which can be absorbed by human body, is above 2.5% and lipid is about 0.5%. In addition, there are Mo and Ge elements, which have anticancer and aging-resistant function, and Zn, Cr and other trace elements in bamboo shoots. It can also be used for production of medical products and as a health protection food. Main nutrients of the bamboo shoots are listed in Table 1 and Table 2.

Table 2 Comparison of Main Amino Acid Contents between Bamboo Shoots and Vegetables

Kind	Amino acids (mg/100g)								
	Serine	Leucine	A	Threonine	B	C	Lysine	Systine	D
Moso bamboo spring shoots	97	113	67	66	69	8	70	17	-
Dendrocalamus calamopsis Bamboo shoots	74	85	49	56	43	8	59	16	-
Potato	113	113	70	71	81	30	93	28	32
Carrot	40	35	23	20	24	9	21	5	9
Onion	27	33	16	16	27	6	31	25	9
Lotus root	48	48	26	30	30	10	34	10	15
Chinese cabbage	44	37	24	26	25	9	30	4	8
Rape	51	55	30	34	36	12	40	3	13
Carriage	69	62	37	44	34	12	52	17	8
Amaranth	88	108	57	60	75	18	75	3	23
Pumpkin	22	23	14	11	14	5	16	3	6
Eggplant	34	36	20	19	22	8	23	4	6

Notes: 1. The main amino acids of vegetables are cited from "Component of food".
2. A: Iso-amino acid; B: Phenyl alanine; C: Methionine; D: Tryptophane.

2.2 Health Food and Pharmacy Use

Bamboo can be used for health food or in the medical treatment. Several famous Chinese ancient herb books once stated the health care efforts of bamboo shoots. Chinese traditional doctors all through the ages realized that bamboo shoots are characterized with little sweet flavour, slight cold property of drug and medical functions of slaking thirst, diuresis, lung heat clearing and phlegm reducing, and it has curative certain effect on edema, ascites, acute nephritis, asthma and diabetes. It also reported, by many pharmacological testing in recent years, that bamboo shoots are benefits to health body, such as anti-tumour, anti-ageing, free radical-clearing, etc. Hence, bamboo shoots is one of important kind of health food for dietotherapy.

The folk literatures describe that bamboo shoots has the yin-nourishing and blood-tonifying if one eat frequently the dish of bamboo shoots with pork; promoting digestion with stewing shoots with sesame oil; clearing away phlegm, relieving heat and curing wind syndrome of the head with soup *Phyllostachys glauca* shoots; but it is better for people who suffer the gastric diseases not or to eat little of bamboo shoots. Bamboo shoots contain rich cellulose and hemicellulose that, it has been scientifically testified, that can promote to excrete digestive gland that is benefit to digest of food and excretion, and sequentially to reduce accumulation and ingestion of insalubrious substances in the interior of the body that will reduce incidence of toxinosis and intestinal cancer, as well as accumulation of fat. So, bamboo shoots is considered as a good food for weight reduction, beauty and anti cancer of intestine. It also was found that the cellulose of bamboo shoots can combine with fatty acid in the interior of the body that would prevent production of cholesterin in blood plasma, thereby, which has certain effect on cerebrovascular diseases. The ryrosine of bamboo shoots can inhibit proliferation of cancer cell. In addition, bamboo shoots contain trace elements of Se, Ge, etc. that has an effect on anti-cancer and anti-ageing.

Majority of bamboo resources are distributed in far mountains with no or less pollutions. With continually improvement of people's living standards in China, more attention to health care are paid by people. Various health foods are widely swarming into markets and a great of advertisements for it reach everywhere. But bamboo shoots, a kind of natural cate with functions of health care, reduction of weight, beauty and medical treatment, has been propagandized so poor that few people know the information and knowledge on characteristics of bamboo shoots.

3 Current Status and Problems Being Addressed

3.1 Current Status of Bamboo Shoots Production

It can get high income from bamboo shoots-based earning activities. According to Yearly Statistic of Forestry, the bamboo area in China reached to more than 400 million ha in 1997 and the fresh shoots to over 3 million tonnes in 1999. The Figure 1 and Figure 2 show the yearly change of total output and value of bamboo shoots in China from 1980 to 1999 (sources: Yearly Statistic of Forestry in China, and provided by the China National Forestry economics and Development Research center under the State Administration of Forestry). Since 1980, especially 1990, the production of bamboo shoots has developed fast with average increasing rate of 11.1% of output and 17.6% of output value at 1990 constant price. Because the extensive management area still occupied near 60% of total bamboo area, even if bamboo area would not be expanded, there were a great potential to development of production of bamboo shoots.

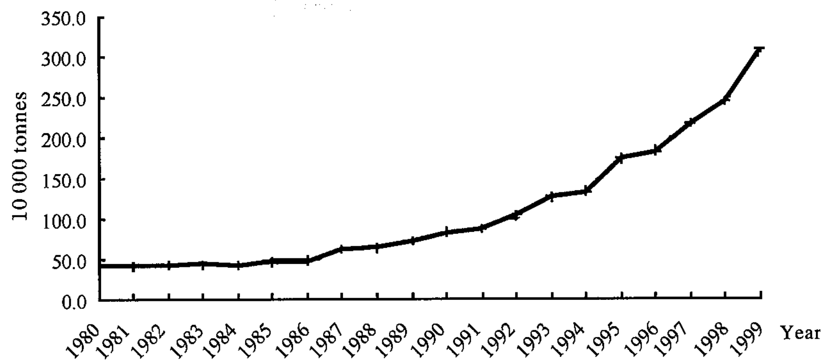


Figure 1 Yearly Total Bamboo Shoots Output in China

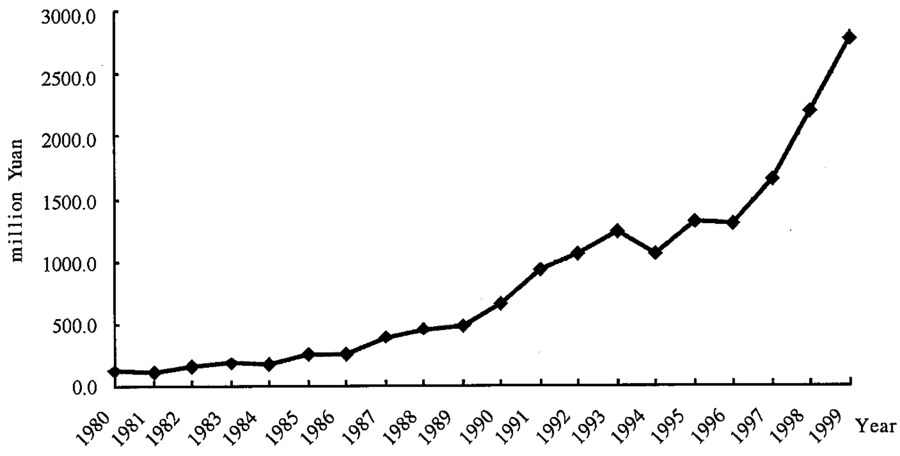


Figure 2 Total Shoots Value in China at 1990 Constant Price

The total export output of processing bamboo shoots products are 65.3 thousand tonnes in 1992 and 77.8 thousand tonnes in 1993 respectively. The total export in 1996 reached 137.5 tonnes of canned bamboo shoots with US $ 145.55 million, 6.4443 thousand tonnes of fresh shoots with US $ 10.037 million and 7.88241 thousand tonnes of salt shoots with US $ 6.47 million. The main international market is Japan where occupied 86.9% , following Hongkong, the United States and Korea. The Figure 3 shows the yearly change of total export value from 1980 to 1999. During the beginning of 1990's, there has been big increase in export of bamboo shoots. Partly because of financial crisis happened in the East Asia in 1997, the export tended to sluggish until in 1999 when it has risen. We can find that the cur-

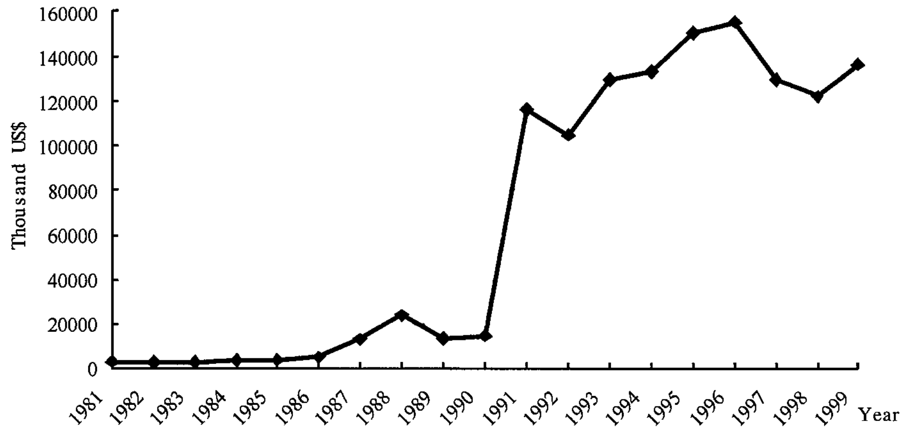


Figure 3 Total Export Value of Bamboo Shoot Products in China

rent price of bamboo shoots is steadily increasing from 1980 to 1999 (see Figure 4, sources: Yearly Statistic of Forestry in China, and provided by the China National Forestry economics and Development Research center under the State Administration of Forestry), while the trend of the price at 1990 constant price is same as that of export output. Hence the price of bamboo shoots in China is dominated by international markets, especially by Japan.

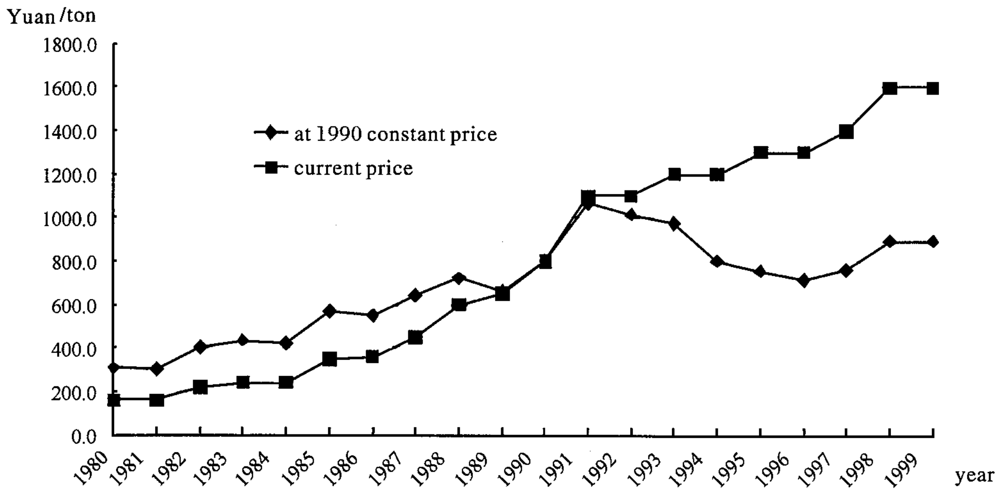


Figure 4 Average Price Change of Bamboo Shoots in China

3.2 Problems Being Addressed

A large amount of boiled canned shoots are currently processed mainly by some small-scale enterprises with 2 thousand tonnes of processing capacity and low-level technology. In the international market, the boiled canned shoots are considered as vegetables. If which are used as raw materials for further finishing processing, the cost will be very high that lead to that the products have difficult access to domestic market. If fresh shoots are processed and stocked in time by local farmers, based on the processing standard, it will keep raw material freshness and quantity well, and thus the highest quality of finishing products will be likely to produce. Meanwhile, it can save the costs of material, transportation and loading and unloading, and reduce the spoilages. So, due to reduction of processing cost in large, the price fluctuation can be avoided in certain degree, such as big drop in price of shoots during shoot-growing seasons and going up largely during off-seasons, which are beneficial to both farmers and consumers and, will promote the farmer's bamboo shoot-based earning activities and consumer's purchase desires. For finishing processing industries it can save circulating funds for stock of the raw material and reduce the costs of finishing products so that their competition can be improved. The accuracy and flexibility of management activities, such as selecting product variety and amounts, setting price and budget, will be improved, which enhance enterprises' advantageous competitiveness in the markets. The markets of flavoring shoot products are mainly located in Europe and America, which are provided by Japan and Taiwan. And China exported only oil-stewed shoots, one of flavoring shoot products with lower standard, poor package and lower price, while majority of boiled canned shoots were exported to Japan as raw materials.

The problems faced by processing factories are as follows: 1) limited varieties of shoot products with lower qualities and high costs that cause weak access to markets; 2) Outdated technology in bamboo processing, high costs of the equipments and the fixed assets and great requirement of circulating funds, which resulted in a higher processing costs; 3) shoots processing industries greatly depend on the international market, especially Japan market; 4) Serious competitions among Chinese export-orient companies acutely led to low price of products without consensus, and due to the establishment of Sino-foreign corporation, the market system is disturbed, which causes price fluctuation.

4 Financial Analysis

Based on the 18 liter-canned bamboo shoot in Anji county, the cost of raw material, accessory material and energy is 3,578.1 Yuan/ton, which occupy 89% of the total cost of products; and the profit rate is 11.03%; added-value is 1,218.95 Yuan/ton, which occupies 25.41% of total yield.

5 Market Analysis

China has the largest quantity and varieties of bamboo shoots in the world. The fresh bamboo shoots are mainly exported to Japan. EU, US and the South-east Asia. In recent years 110 – 130 thousand tonnes of shoots have been exported annually, which mainly are boiled canned shoots and dried shoots. It needs to augment the varieties and qualities of shoot products to develop both domestic markets and international markets. Because China has so large population, 1.3 billion people plus with 0.1 billion increased annually, that if 1 kg of fresh shoot is consumed by average person per year, 1.3 million tonnes of shoots will need to be supplied. Based on 3 million tonnes of fresh shoots produced in 1999, subtracting the exported, only 1.8 kg of shoots are yearly consumed by average capital. Moreover, only because the edible shoots can be got 50% of fresh shoots, so average person consumed only 0.9 kg. As more and more experts and people realized knowledge on health care function of shoots, more and more people enjoyed it in the world. For example, now 3 kg of shoots were consumed by average Japanese, which are as times as that in 1960's. So, besides their domestic output, large quantity of bamboo canned – shoot are imported from china, and southeast Asia where the bamboo bases of *Dendrocalamopsis latiflorus* were established. There would be a large market potential of shoot development by fact of that ordinary people would afford it like other vegetables, if sale price of products declined by improving the preserving techniques and reducing of the processing cost, along with many secure product varieties with high qualities, rich nutrition and convenient use, such as for health care, beauty, reduction of weight, etc. , that can preserved for long time in a normal temperature to meet the demand of different desire of consumers. With the development of food industry in China, the food processing equipments and the functions of security of the package materials have been improved, and it is high time for further development of shoot products. There are also a great market potential of the processing technology by fact of that because the fast technical extend of high-yield cultivation of bamboo shoots in China, the abundant fresh shoots available are supplied, that will promote the processing factories to improve the techniques.

But even if the output of shoot production would not be increased any more, it also would be weak access to markets. For example, in 1997, the price of fresh shoots was lower than 0.3 Yuan/kg during shoot-growing seasons in most regions of Fujian Province and boiled shoots without sheath was 0.7 Yuan/kg, and the fresh shoot Price was even lower than 0.14 Yuan/kg in Xianju county of Zhejiang Province. While in the May of the same year, the retail prices of the boiled canned shoot s and fresh shoots were 4 Yuan and 5 Yuan/kg in Sanmin city of Fujian Province; and the wholesale of 18 litre canned shoots was 65 Yuan/can in Daqiao produce market in Nanjing and the retail price was 7 Yuan/kg, which is higher than the live pig. Although the demand of bamboo shoots in international markets has a little increasing, overlapping blindly construction of the processing factories led to overstock of shoot products. During the Guangzhou Autumn Trade Fair in 1997, when America businessman wanted to order more than ten containers of soft package canned shoots, most enterprises have no ability to produce them, which is evident that there is no actual market saturation of bamboo shoots both in domestic and abroad market. It is outdated processing techniques, overlapping blindly construction of the processing factories, poor qualities and limited product varieties, higher price that cause the weak access to the markets.

6 Market Development Strategy

Just the same as other produces, there are two markets for bamboo shoots, the first is called original market (for raw material), in which bamboo shoots will be sold; the other is called final market, in which bamboo shoots or their products will be purchased. Because those two markets are often much separated in space, they often need to be connected by trade firms or corporations (especially by foreign trade companies) who are in responsible for shoot processing, transportation, distribution, etc. Due to attraction of economy of scale and serious competition, the scales of those firms are being larger, while the number is being reduced. It is well known that in order to keep the stable and high-yield of bamboo shoots, facing the large amount of bamboo shoots during harvesting period, farmers have to sell their shoots at very lower price due to storage problem. It is the outdated technology of preserving, processing, packaging, transporting and selling, which occupy 60 percent of total cost pulsing management cost of 10 month off-seasons, which result in high cost of products. The high price of the shoot products in the final markets is one key issues, which surpass the purchasing power of consumers, which causes the sluggish of bamboo shoot sector. So the shoot producers, processing enterprises and consumers cannot obtain good income/benefits due to lower price of raw materials, high cost of processing and high price of processing shoot products.

In order to solve problems faced by shoot producers and processors that hampers the development of the bamboo shoot sector, there should be a benefit trade-off between raw material producers and processors, and the following market strategy are suggested:

Establishing or reorganizing the key enterprises with modern management mechanism as main body of shoot market and leading them to healthfully development. It needs for them to pay more attention to the relation between resource utilization and cost, based on themselves features and advantages, and to ensure sustainable development of resources to endure serious competition in both domestic and international markets.

The processing enterprises need much maneuverability for finishing products that meet the requirements of markets in accordance with consumption habit in different regions and races and to improve goodwill for further exploiting markets.

Providing conditions for traders, such as product quality, varieties and standards to meet different demands of consumers' desires.

To ensure regular running, enterprises need to manage according to their abilities of supporting finance.

Establishing or perfecting marketing system that needs to connect well with all market-places, such as the wholesale market-places, agricultural and trade market-places, commercial and trade centers, cooperation organization of shoot producer.

Good Manufacturing Practice for Bamboo Shoots Factory

The acronym "GMP" (Good Manufacturing Practice) is used internationally to describe a set of principles and procedures which, when followed by manufacturers of goods, helps ensure that the products manufactured will have the required quality. The aim of good manufacturing practice in the food industry is to provide food that meets the consumers' needs, and also gives them the security of safety and reliability. Good manufacturing practice is based on the knowledge and skills throughout the food system, from primary production of the raw materials, through processing of the industrial ingredients, manufacturing of the consumer products, distribution of the final retail products to the cooking and eating of the final foods.

The Good Manufacture Practice for Bamboo Shoots Factory for establishing quality control system are prepared based on Hygienic Requirement of Export Foods for Factories and Storehouses and the Hygienic Criterion for Processing Factories for Export Canned Foods. The purpose of establishing quality control system is to implement the related international standards and national regulation and to definitize the fundamentals and rules of hygiene and quality control. The contents include:

Introduction

References

Definition and terms

Guideline and objective for sanitation and quality control

Organization and their responsible

Environmental sanitation
Including roads and paths, contaminating objects, treatment and release of waste raw materials and water, sanitation rules, and so on.

Workshop and facility sanitation

Including processing workshops, layout of technological flow, marks of different parts, condition of ground, doors, windows, walls and ceiling inside workshops, light condition, sterilization and air conditioning facilities, tools and other auxiliaries.

Raw and auxiliary materials and water for processing

Including acceptance requirements of raw and auxiliary materials and cans and their procedures, water standard for processing and its analysis and recording, requirements for pumps, taps and tanks for rinse, as well as contamination.

Staffs

Including qualification of all manager and technicians, personnel training, individual sanitation and action, health care, sterilization and management of private articles, etc.

Quality control procedure during processing

Including sanitation, operation procedure and its management, recording etc.

Quality control during sterilization

Checking and testing

Packing, storage and shipment

Management institution

Including production, quality control, sanitation and so on, as well as their recording.

China's Criteria and Indicators (C&I) for Sustainable Management of Bamboo Forests

1 Brief Description of Bamboo Forest Management Units

Forest is a principal part of territory ecosystem and plays an important part in maintaining ecological environment, guaranteeing the development of the national economy. UNCED(United Nations Conference on Environment and Development) confirmed in 1992 that it was required to maintain the sustainable development of forest for meeting the need of the present age and offspring and for performing the Statement on Forest Principles and Chapter 11 of Agenda 21. In order to evaluate whether or not the forest management is in a sustainable state, it was required that a series of criteria and indicators should be established. After the conference, a series of international meeting were convened, discussing the protection and sustainable development of forestry and some criteria and indicators were put forward. Chinese government paid much attention to the protection and sustainable development of forest during the past years, took part in the international activities energetically. In December 2002, National level criteria and indicators of sustainable forest management in China were announced and in national level, sustainable forest management should comply with. Under the guidance of Criteria and Indicators for Sustainable Management of Natural Tropical Forests (1998), the Manuals on Criteria and Indicators for Sustainable Management of Natural Tropical Forests(Part A and Part B, 1999), Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests, national level criteria and indicators of sustainable forest management in China, China's Criteria and Indicators (C&I) for Sustainable Management of Bamboo Forests are put forward initially.

China is the richest bamboo producing country in the world, with over 500 bamboo species belonging to 39 genera and an area of over 4.4 million ha. Bamboo is not only with high economic value, but also with wide utilization. Bamboo culm is widely utilized in the fields of construction, papermaking, furniture, packaging, transportation; some bamboo species are good ornamental materials in horticulture; some edible bamboo shoots are tasty and of high nutritive value. With the development of Chinese economy and increasing of national economy strength, bamboo industry also has gradually flourishingly developed. Bamboo forest area has been extended year by year, and bamboo benefits also have been increased. But improper management measures and weak environmental consciousness have caused many environmental problems, such as land degradation, intensive soil erosion etc. So, it is eagerly necessary to set up the framework of Criteria and Indicators (C&I) for sustainable management of Chinese bamboo forests.

As an important part of the terrestrial ecosystem, bamboo forests are playing even-greater roles in controlling global warming and affecting the biogeochemical circle. Bamboo forests function as the pool for natural resources, living things, water storage, carbon storage, energy etc. Bamboo forests have an effect on climate adjustment, water restraint, soil and water conservation, soil melioration, pollution lessening, environment beautification, biodiversity protection and agricultural development. It plays essential roles in maintaining ecological balance and protecting the environment for human's living and development.

Covering many aspects, such as economy, society, environment, science and education, policies etc., sustainable management of bamboo forest is a complicated tremendous system. Therefore, during the process of designing the indicator system, a guideline has to be set up to establish the indicator system as a whole. While establishing the indicator system for sustainable management of Chinese bamboo forest, we should not only follow the general guideline of sustainable management, but also take a full account of the specific situation in China. According to the systematic theory and systematic analysis method, we make an effort to ensure that the indicator system cover all the aspects of the sustainable management of Chinese bamboo forest, and reflect the characteristic of Chinese bamboo forest and the strategy of Chinese sustainable development.

2 Fundamental Principles

2.1 Systematic

Take the bamboo forest resources in China as an entire system. Study the quantitative relationship between the development and utilization of Chinese bamboo forest resources and the environmental protection. By means of the indicator system, bring together the utilization of bamboo forest resources and environment protection, and establish a description about the status of the sustainable management of Chinese bamboo forest resources.

2.2 Universal

The indicator system should objectively reflect the change within each side and their intrinsic relations. The concept, the method of data collection and calculation of each indicator should be scientific, and its selection should comply with the theory of sustainable development, economic theory, social theory, environmental theory and statistic theory.

2.3 Purposeful

Combine the actual situation in China, establish the strategic objectives of the sustainable management for Chinese bamboo forest, and work as a guideline for the practice of sustainable development. Based on the specific situation in China, put an emphasis on the objective of sustainable economy and moderate economic increasing. Combine with the optimization of industry construction, the increase of economic benefits and the disparity reduction among regions, ensure the harmonic and healthy development of the social system, control population increase, improve the living quality, extend the employment and improve the social security, strengthen the capability build of sustainable development and so on.

2.4 Easily Available and Concise

The indicator system of sustainable management for bamboo forest consists of many aspects. The selected indicators should be of pertinence. The indicators should be simple and concise, with the key ones chosen according to the key issues in the strategic target. The statistics of each type of indicators should be in favor of the data acquirement, and can be calculated, researched and analyzed.

2.5 Sensitive

The indicators in the system of sustainable management should be sensitive to the changes of each aspect. Some indicators, although be probably important, should not be included in the system because they cannot completely reflect the social and economic changes although there is some close relation to the policy issues.

2.6 Stratal

The sustainable management for bamboo forest resources is a tremendous system which comprises a few sub-systems with each being independent and, while on the other hand, interdependent. Those sub-systems should be put into different categories and divided into different levels so as to be analyzed and studied conveniently. The higher level, the more general the indicators would be; and the lower level, the more specific. The system can be divided into seven criteria on the basis of the above-mentioned principles.

3 Criteria and Indicators

3.1 Criterion 1 Precondition for Ensuring the Sustainable Management for Bamboo Forests

This criterion includes the issues, which are related with the sustainable management for Chinese bamboo forest, of policy, legislation and economy, and the mechanism of stimulation, scientific research, education, consultation and participation. Those are the issues to ensure the sustainable management for Chinese bamboo forest, and the fundamental factors for establishing the exterior cycle. Among them, some are descriptive.

INDICATORS:

3.1.1 Policies, Laws and Rules

Laws, policies and rules which are related with bamboo forest

(a) Establishment of permanent bamboo forest reserves and their security
(b) Land ownership and property right related with bamboo forests
(c) Bamboo forest management
(d) Harvesting management of the bamboo forests
(e) Soil and water conservation
(f) Health and safety of the bamboo forester
(g) Participation of the local community

3.1.2 Economic Framework

3.1.2.1 Input of bamboo management, research and human resources

(a) Input from national government
(b) Input from local government
(c) Input from private both from domestic and abroad

3.1.2.2 Economic methods and other stimulation to promote the sustainable management of bamboo forest

3.1.2.3 Condition of the professionals involved in bamboo forest management, research and generalization

3.1.2.4 Techniques of the sustainable management for bamboo forests, processing and utilization of bamboo products

3.1.2.5 Plan and periodic inspection and assessment of sustainable management for bamboo forests; capability and mechanism of feedback to its progress

3.1.2.6 Extent of community participation in plan-making, policy-making, data *collection, inspection and assessment*

3. 1. 2. 7 Public awareness improvement to bamboo forest-related policies, legislation and sustainable management

3. 2 Criterion 2 Security of Bamboo Forest Resources

National forest ecological security means the forest ecological environment in a country is comparatively steady and sustainable. Bamboo forest resources are significant part of national forest resources, which are finite and renewable. It is extremely important how to exploit and utilize the bamboo forest resources reasonably. The bamboo forest resources security can be momentarily monitored and attained with the establishment of the indicator system.

INDICATORS:

3. 2. 1 Bamboo Forest Resources

3. 2. 1. 1 Area percentage of different stand

3. 2. 1. 2 Land area and its percentage covered by different bamboo species

3. 2. 1. 3 Bamboo forest area to which non-bamboo forest was transformed

3. 2. 1. 4 Non-bamboo forest area to which bamboo forest was transformed

3. 2. 2 Protection Law and Regulation of Bamboo Resources

Laws and rules regulating bamboo forest destruct, fire and illegal exploit

3. 3 Criterion 3 Healthiness and Ecological Condition of Bamboo Forest Ecosystem

This criterion relates to the biological functions of bamboo forest and its ecosystem in a region. The healthiness of bamboo forest is affected by various factors and natural accidents such as air pollution, flooding, hurricane, disease and pests etc. The healthiness of bamboo forest ecosystem means a complex status of the ecosystem while serving human being, and can be assessed in terms of soil, water, flora, fauna, ecosystem circling, landscape pattern and non-living being factors etc. However, it is difficult to reflect comprehensively the healthiness and viability of the system.

INDICATORS:

3. 3. 1 Extent and Condition of Damage to Bamboo Forest

3. 3. 1. 1 Human activities

(a) Erosion

(b) Farming practice

(c) Infrastructure such as road construction

(d) Mining
(e) Reservoirs
(f) Fire
(g) Illegal exploit
(h) Unscientific management
(i) Destructive cutting
3.3.1.2 Natural disasters
(a) Wild fire
(b) Drought
(c) Flooding
(d) Diseases and pests
(e) Others

3.3.2 Laws and Rules about Bamboo Forest Resources Conservation
3.3.2.1 Implementation of plant quarantine its procedures
3.3.2.2 Executive procedure of disease and pests prevention of bamboo forest
3.3.2.3 Executive procedure of poisonous chemicals prevention
3.3.2.4 Executive procedure of fire prevention

3.4 Criterion 4 Production Flow of Bamboo Forest Product

This criterion relates to the production of timber and non-timber products.

INDICATORS:
3.4.1 Resources Assessment
3.4.1.1 The status of bamboo forest resources and its survey
3.4.1.2 The extent of the sustainability of bamboo forest
3.4.1.3 The yield of bamboo products

3.4.2 Bamboo Forest Development Plan
3.4.2.1 Bamboo forest development plan
(a) Plan for bamboo forest resource development
(b) Plan for bamboo forest products development
3.4.2.2 Bamboo forest management area
3.4.2.3 Executive program of long-term projects, strategy and plan
3.4.2.4 history of bamboo forest management

3.4.3 Management Principle
3.4.3.1 Management principle of main bamboo forest products
(a) Assessment of natural reforestation

(b) Measure of artificial reforestation

3.4.3.2 The executive program for inspecting and assessing the rules of bamboo forest management

3.4.3.3 Principle of lessening the damage on bamboo forest caused by bamboo cutting

3.4.4 Inspection and Assessment

3.4.4.1 Inspection and assessment

(a) The program of comprehensive assessment to bamboo forest management principle

(b) Evaluation of lessening of destructive cutting on bamboo forest

(c) Assessment of bamboo forest reforestation before harvesting

3.4.4.2 Implementation plan

(a) Bamboo forest under the bamboo forest management principle

(b) Bamboo forest to be cut based on the schedule

3.5 Criterion 5 Biodiversity

This criterion relates to the protection and management of biodiversity which includes ecosystem diversity, community diversity and heredity diversity.

INDICATORS:

3.5.1 Ecosystem Diversity

3.5.1.1 Bamboo Ecosystem diversity

3.5.1.2 Bamboo species diversity

3.5.1.3 Inspection of the bamboo species in the danger of extinguishments and rare species

3.5.1.4 Former distribution of the bamboo species in the danger in extinguishments

3.5.2 Genetic Diversity

Strategies for in and ex situ conservation of commercial species, species in the danger of extinguishments and rare species

3.5.3 Management Rules

Management principle

(a) Undisturbed bamboo forest

(b) Management principle guiding the conservation of the species in the danger of extinguishments

(c) The principle guiding the conservation of the significant species so as to be utilized in the future, such as bamboo seeds, individuals, forest and their living environment

3.5.4 Procedure of Inspection and Assess

Executive program assessment of the biodiversity changes in bamboo forest (compared with other forests disturbed by the human)

3.6 Criterion 6 Soil and Water Conservation

This criterion relates to soil and water conservation of bamboo forest. Bamboo forest plays a great role not only in keeping the productivity and quality of bamboo forest and bamboo forest-related aquatic ecosystem but also in protecting water quality, balance flux, flooding and decrease sediment.

INDICATORS:

3.6.1 Situation of Soil and Water Conservation

The area and percentage of ecological bamboo forest

3.6.2 Procedure of Conservation and Protection

3.6.2.1 The divisional procedure of areas susceptible to erosion

3.6.2.2 The layout of the road in the bamboo forests for the purpose of drainage and protection of the river buffer zone

3.6.2.3 The method and procedure for cutting bamboo culm and harvesting bamboo shoot which can prevent soil erosion

3.6.3 Inspection and Assessment

Implementation procedure of assessing the changes of water quality around bamboo forest, compared with other forests

3.7 Criterion 7 Economy, Community and Culture

This criterion relates to the economy, community and culture of bamboo forest. The bamboo forest possesses benefit in many ways, which, besides providing high-quality bamboo timber, can provide the opportunity of relaxation and ecological tourism, lessen the employment pressure and improve the living quality.

INDICATORS:

3.7.1 Socio-Economic Aspects

3.7.1.1 The importance of bamboo sector in economy

3.7.1.2 Quantity (volume) and value of bamboo products traded

(a) In domestic market

(b) In international market

3.7.1.3 Quantity (volume) and value of bamboo products for subsistence use

3.7.1.4 Ratio of domestic bamboo culm yield to the processing capacity of bamboo-based industries

3.7.1.5 Efficiency of utilization in terms of the percentage of field volume processed

3.7.1.6 Existence and implementation of mechanisms for the effective distribution of incentives and the fair and equitable sharing of costs and benefits among the parties involved

3.7.1.7 Employment in the bamboo sector

(a) Numbers employed

(b) Percentage of total work force

(c) Average wage rate and gender rate

3.7.1.8 Number and extent of bamboo areas available primarily for

(a) Research

(b) Education

(c) The direct use or benefit of local communities

(d) Tours

3.7.1.9 Numbers of people depending on the bamboo forest for subsistence uses and traditional and customary lifestyles

3.7.1.10 Areas of bamboo forest upon which people are dependent for subsistence uses, traditional and customary lifestyles

3.7.2 Cultural Aspects

3.7.2.1 Numbers of visitors to forest for recreational purposes.

3.7.2.2 Number of important archaeological and cultural sites identified, mapped and protected.

3.7.3 Community Participation

3.7.3.1 Policy about the bamboo management rights, land use rights, assignment and inheritance rights

3.7.3.2 Extent to which tenure and user rights over the bamboo forest are documented and recognized

3.7.3.3 Extent of participation by indigenous people and local communities, etc

3.7.3.4 Agreements involving local communities into co-management responsibilities

Production Technologies, Properties, Uses, and Marketing of Bamboo Charcoal

1 Introduction

Bamboo plant grows rapidly and matures about 6 years. During this period, its specific gravity and mechanical strength remains in good status and is the best time for utilization. Generally sympodial species mature earlier than monopodial ones. Moreover, since forming bamboo forests, bamboo culms can be harvested every year. In other words, bamboo is a sort of renewable organic resource for sustainable development.

China is richest of bamboo forest because of locating at bamboo distribution centre region. In china, there are approximate 400 species of 35 genera of bamboo, which is one third of total species in the world. The total bamboo forest area is 7.2 million ha including pure bamboo forest area 4.2 million ha, mixed bamboo forest with trees and bamboo cluster on mountains 3.0 million ha.

Since 1980', because of the rapid reduction of tropical forest, people recognized the significance of bamboo cultivation and utilization, especially in China. Bamboo utilization developed very quickly, and varieties of bamboo processing machines emerged to replace hand jobs. As a result, various bamboo-based panels such as plybamboo, bamboo glued-sliver board, bamboo flooring, bamboo-wood composite products, and bamboo veneer for decoration etc. were successfully developed and a kind of mew bamboo processing industry has formed in China (Zhang *et al.*, 1995).

But making bamboo-based panel doesn't complete overall use of bamboo culms. It only uses the medium portion of a bamboo culm. Moreover, a lot of small diameter bamboo and sympodial bamboo with thin wall can't be used to make bamboo-based panel. Accordingly, people pay more attention to chemical utilization of bamboo that not only utilizes overall bamboo culm, but also almost every bamboo species including enormous amount of sympodial species. At present, main chemical processing methods include distilling from bamboo leaves and pyrolyzing bamboo culm to get bamboo charcoal and vinegar. The later was proved to be a beneficial and practicable way to make bamboo overall use. Besides the tip and base potion of bamboo culms to be made into charcoal, tremendous processing residues left in producing bamboo-based panel and daily articles such as bamboo chopsticks, bamboo mat, bamboo toothpicks etc. can be converted into bamboo briquette charcoal after a series of procedures. Therefore, making bamboo charcoal and related charcoal products is a good way of utilizing bamboo efficiently and widening the field of bamboo use (Zhang *et al.*, 2002).

2 An Introduction to Bamboo Charcoal

Similar to wood charcoal, bamboo charcoal is a micro-holed material with excellent adsorption property because of its large specific surface area. Adsorption of bamboo charcoal is theoretically classified into physical adsorption and chemical adsorption. Physical adsorption is caused by molecule acting force (van der Waals force) between adsorbent and adsorbate that doesn't change the surface composition of adsorbent and the molecular situation of adsorbate. Chemical adsorption is by chemical bond between adsorbent and adsorbate in which the exchange and transference of electrons results in rearrangement of atoms and chemical bond formation or destroying.

Physical adsorption goes fast and is reversible. It usually carries through in lower temperature without selection and acts in monolayer or multilayer because there is van der Waals force on one layer of molecule of adsobate.

Similar to chemical action, chemical adsoption needs activation energy. It is not reversible and usually carries through in higher temperature companying chemical output. It is always monolayer adsorption with distinct selection.

The electric conductivity of bamboo charcoal will be reinforced with the rising of terminal pyrolysis temperature. When terminal pyrolysis temperature reaches 700℃, the resistance in bamboo charcoal becomes very small, only 5.40×10^{-6} $\Omega \cdot M$, meaning good conductivity. Therefore, bamboo charcoal carbonized under high temperature has effective property for shielding electromagnetism.

As the industrialization worldwide speeds up, air pollution and water pollution are becoming serious environmental problems. Bamboo charcoal is functional material for environment protection and developed fast in recent years for the reasons that (1) the woody culm that can be used as high-grade charcoal reduced rapidly and almost exhausted; (2) the harvest cycle of bamboo is short because it grows very fast. So making bamboo charcoal doesn't destroy forest and environment; (3) bamboo charcoal is similar in properties to and can replace the high quality charcoal made of hardwood; (4) bamboo charcoal is good in strength and easy to process into different shapes.

At present, a series of bamboo charcoal products have been manufactured by taking advantage of the excellent adsorption and infrared radiation. These products involve in a variety of fields such as purifying drinking water and indoor air, adjusting humidity in house, health care, odor adsorption, bamboo charcoal arts and so on. Some of products with shielding electromagnetism and anti-radiation are presently researched.

3 Bamboo Charcoal Classification

There are different sorting methods in accordance with the shape of raw material and bamboo charcoal, uses, and pyrolysis temperature. Figure 1 shows the classification according to bamboo charcoal shapes.

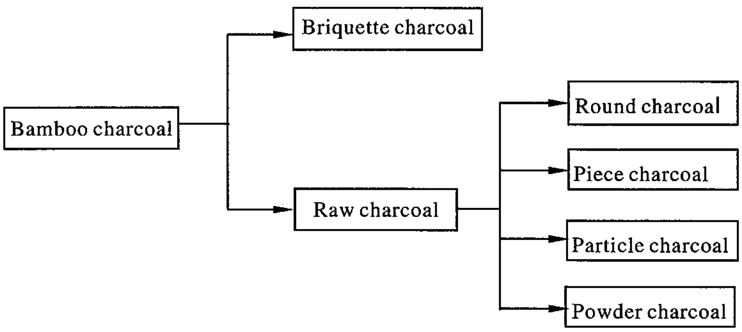


Figure 1 Classification of Bamboo Charcoal

Accordance with the outline of raw material, bamboo charcoal can be divided into (1) raw bamboo charcoal (Figure 2), which is made of bamboo culm, cut into a certain length and then loaded into a kiln to dry, heat and pyrolyze under the condition of absent or little oxygen and (2) bamboo briquette charcoal (Figure 3), which is made up of bamboo particles and processing residue which was broken, dried, formed into briquette, and then pyrolyzed.

According to its shape, bamboo charcoal can be classified into round, slice, particle and powder charcoal. According to its use, bamboo charcoal can be divided into water depuration, humidity adjustment, odor adsorption, health care, agriculture, fuel of barbecue etc.

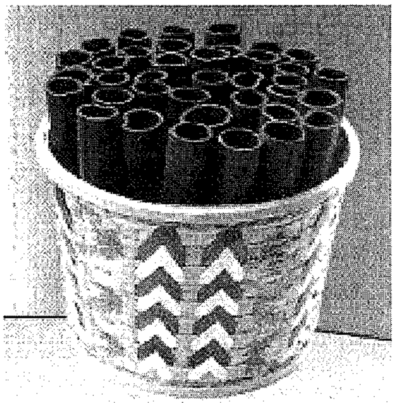


Figure 2 Raw Bamboo Charcoal

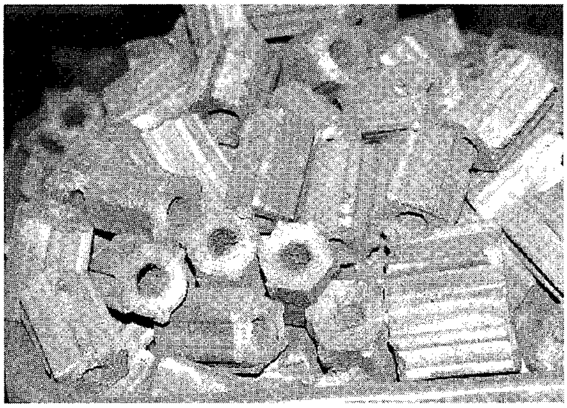


Figure 3 Bamboo Briquette Charcoal

Due to the lack of a national standard, the terms might be different in different regions.

4 Basic Knowledge of Bamboo Pyrolysis

Bamboo represents a renewable biological resource. Compared with most species of trees, bamboo grows faster, so it matures early with high output. As the global environment is worsening, bamboo has become a very important material that is widely used as a good natural material for construction, decoration and so on.

Bamboo pyrolysis, including bamboo carbonization, bamboo destructive distillation, bamboo activated carbon and bamboo gasification, etc. is a manufacturing method which makes bamboo heated to form many pyrolysis products under the condition of isolating air or flowing little air in.

a. Bamboo carbonization: bamboo is heated in brick kilns or mechanical kilns with little air by means of the heat energy generated by burning firewood to pyrolyze bamboo and produce bamboo charcoal.

b. Bamboo destructive distillation: bamboo is heated in a pyrolyzing kettle isolating air to produce bamboo charcoal and bamboo vinegar and so on.

c. Bamboo activated carbon: the bamboo material is heated in a brick kiln and activated kiln to get bamboo activated carbon.

d. Bamboo gasification: bamboo or bamboo residues resulting from the processing are heated to get bamboo gas in a gasification kiln (Huang, 1996).

4.1 Stages of the Bamboo Pyrolysis

Bamboo pyrolysis can be divided into four stages according to temperature and products situation in a kiln or a pyrolyzing kettle.

The first is drying: the temperature is below 120℃ and the speed of pyrolysis is very slow in this stage. It is the main reason that the water in bamboo is evaporated by heat provided from outside, and no change happens in chemical composition of the bamboo. So this stage is called an absorbing heat process and water is the product.

The second is pre-carbonization: the temperature is in the range of 120℃ to 260℃ and there is a distinct pyrolysis reaction in bamboo during this stage. The unstable chemical compounds in bamboo (like hemicellulose) began to decompose into carbon dioxide, carbon monoxide and little vinegar, etc. This stage is also an absorbing heat process.

The third is carbonization: the temperature is in the range of 260℃ to 450℃, and the bamboo is rapidly decomposed to form many products including liquid and gas products. Liquid products contain much acetic acid, methanol and bamboo tar. Flammable methane and ethylene in gas products are increasing while carbon dioxide is decreasing gradually during this stage. Because a lot of heat emits from bamboo, this stage is also named as an exothermic reaction process.

The fourth is calcination (refining stage): the temperature is 450℃ or so. The bamboo turns into charcoal by means of massive heat, emitting the volatile substances from the charcoal and enhancing its content of non-volatile carbon. There is little liquid and gas produced in this stage. Refining stage is the key to define the quality of bamboo charcoal. According to the temperature in this stage, the bamboo charcoal can be divided into three groups (low-temperature charcoal, middle-temperature charcoal and high-temperature charcoal).

It should be noted that it is difficult to delimit the four stages because the different parts of a pyrolyzing kettle are heated differently. Bamboo culms located in different parts of a pyrolyzing kettle (the top or the bottom) might be in different pyrolysis stages; the difference might happen between the outer and the inner parts of bamboo culm. But we can see the distinct change of temperature during the exothermic reaction stage in an intermittent pyrolyzing kettle. The temperature in the pyrolyzing kettle is going up rapidly while heating coefficient keeps stable (Huang, 1996).

4.2 Products of Bamboo Pyrolysis

There are three groups of pyrolysis products: they are solid (bamboo charcoal), liquid (bamboo vinegar) and gas (bamboo gas).

Bamboo destructive distillation is carried out in a one-kilogram-retort in a lab, and the pyrolysis time is about 8 hours. The products of bamboo pyrolysis are shown in Table 1 and Figure 4.

Table 1 The Contents of Products of Bamboo Pyrolyzed at the Terminal Temperature of 500℃

Bamboo charcoal	Bamboo vinegar	Bamboo gas	Loss
30%	51%	18%	1%

Note: Percentage of the products made from oven-dry bamboo.

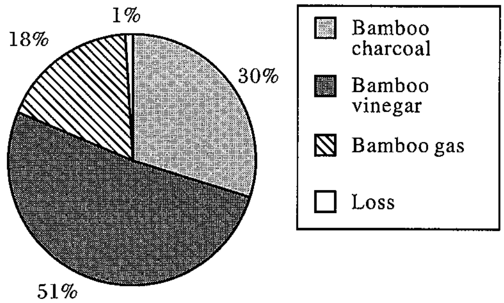


Figure 4 Contents of Pyrolyzing Bamboo at Terminal Temperature 500℃

4.2.1 Solid Products

The bamboo charcoal is the solid product left in the carbonizing kettle after the bamboo culms are pyrolyzed. The bamboo charcoal has a micro-hole in structure and excellent adsorption.

4.2.2 Liquid Products

The compounds including vapor and gas are collected from the pyrolyzing kettle and condensed into liquid products (bamboo vinegar) and gas products (non-clotted gas and bamboo gas).

Crude bamboo vinegar is a brown-black liquid with more than 300 organic compounds except a quantity of water (include reaction water). Some of the compounds are as follows (Huang, 1996).

Saturated acid: acetic acid, formic acid, propanoic acid, and butanoic acid.

Unsaturated acid: propenioc acid.

Hydroxyl-acetic acid: 2-hydroxyl-acetic acid.

Heterocyclic acid: β-furancarboxylic acid.

Alcohol: methanol.

Un-alcohol: allyl alcohol.

Ketone: acetone, methyl ethyl-ketone, methyl propyl-ketone, and cyclopentanone.

Aldehyde: formaldehyde, ethyl-aldehyde, and furol.

Ester: methyl formate, methyl acetate.

ArOH: phenol, methyl-phenol, and O-benzenediol.
Lactone: butyrolactone.
Aromatic substance: benzene, toluene and naphthalene.
Heterocyclic compounds: furan, and α-methyl furan.
Amine: methylamine.

The crude bamboo vinegar can be divided into two layers by setting for two months. The upper layer is clarified bamboo vinegar, which is a light yellow or light brown liquid with special smell, and the lower layer is sediment-bamboo tar.

4.2.3 The Gas Products

The bamboo gas obtained from bamboo pyrolysis is mainly composed of carbon dioxide, carbon monoxide, methane, ethylene and hydrogen, etc. The bamboo gas can be used as fuel.

5 Production Equipment and Process for Bamboo Charcoal

When people began to manufacture bamboo charcoal, they adopted an ancient way of making wood charcoal, which obtained charcoal by building kilns with stick soil. First dig into a certain depth as the base of carbonization room according to the dimension of a kiln on a chosen ground, and then build the carbonization room with stick soil. After that, build burning room in front of carbonization room and then air-dry the kiln. When loading, bamboo culms and briquettes stand in the kiln. To make bamboo charcoal a series of procedures has to carry out such as igniting, heating and drying, pre-carbonizing, carbonizing, calcining, sealing kiln, cooling, and unloading. This method was difficult to ensure the quality of bamboo charcoal.

Because of the development of environment protection and health care functions of bamboo charcoal, its products attract attention of people and the productivity is increasing. To improve and enhance its quality, the production process and equipment are much better after 10 years of improvement. At present, there are two main kilns or furnaces e. g. pear type brick kiln and mechanical furnace, with corresponding processes.

5.1 Structure of Kilns or Furnaces

5.1.1 Structure of Brick Kilns

The vertical and lateral views of the double kilns are shown in Figure 5 (a) and (b), and the dimension measures are 3.8 m in length, 2.8 m in width and 2.5 to 2.7 m in height with wall 24 cm thick. The building process is as follows: first of all, 15 to 20 cm thick stones are levelly paved on the ground, covered by a layer of loess 20 cm thick. Then bricks are laid on the loess. After building the kiln with

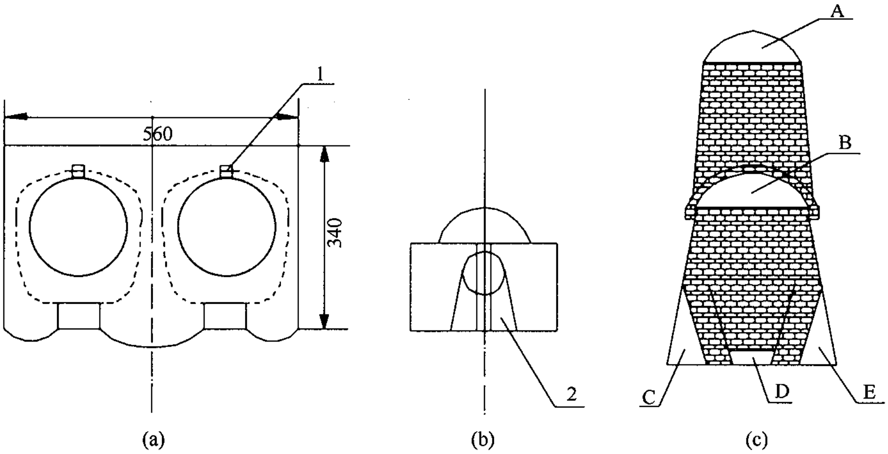


Figure 5 Diagrammatic Sketch of the Structure of a Typical Double Drick Kilns
(a) Planform (b) Front view (c) Side view
1. flue 2. side wall A. B firewood intakes C, D, E air intakes

bricks a layer of loess 20 cm thick is laid on the top, which serves to keep out the moisture and preserves the heat. The flue of 100 cm × 100 cm is situated at the back.

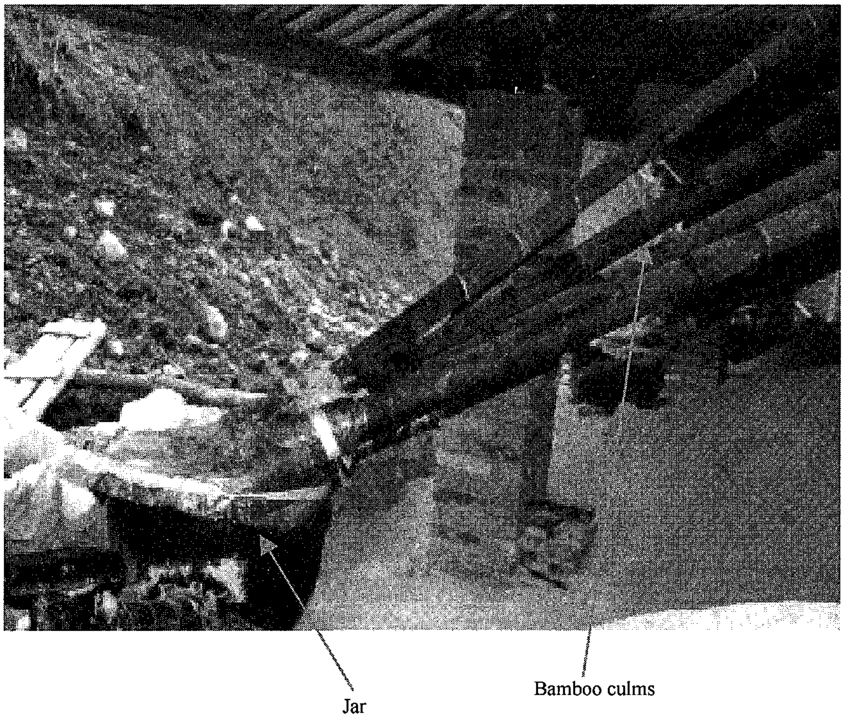


Figure 6 The Instrument for Condensing Smoke and Collecting Crude Bamboo Vinegar

Figure 5 (c) depicts an explicit illustration of a kiln gate, which is 1.5 m high, with 50 cm wide at the bottom and 40 cm wide on the top. There are five intakes on the kiln gate. Intakes A and B serve not only to add firewood, but also to observe flame and burning situation. Intakes C, D and E are mainly used to control the increase rate of interior temperature by adjusting their opening. This type of kiln has a capacity of four to six tons of bamboo and consumes two tons of firewood in a cycle. Measures are taken to prevent the air pollution by smoke emitted in the process of charcoal making. The specific procedures are as follows: Make two holes in a jar, one is square (10cm × 10 cm) and the other is round. Next, build a passageway with bricks connecting the square hole and the flue rim to let smoke go through. Take four or five bamboo culms with eight meters in length, remove the internal joint layers. Then put one end of them into the jar, and fix the other end on the beam. Seal the jar completely with plastic films and earth. After doing so, the smoke coming from the kilns has to pass through the jar and the bamboo culms. Inside the inner walls of bamboos, the smoke condenses into liquid (crude bamboo vinegar) and then drops down into the jar. The liquid flows out through a plastic pipe connected to the round hole on the jar. What is collected is crude bamboo vinegar. See the following Figure 6.

5.1.2 Structure of a Mechanical Furnace

A mechanical furnace is depicted in Figure 7. It is 2.5 m high and 2.3 m in diameter. The body is made of thin steel sheet lined with firebricks and coated with heat preservation material. There are two intakes on the body. One is fixed in the upper part and the other is lower that serve as for raw material loading. Near the bottom is a fuel feeding intake and a hole for ash exit. There are 4 thermocouples in the furnace for measuring the temperature at different points. Two of them are situated at the upper part and

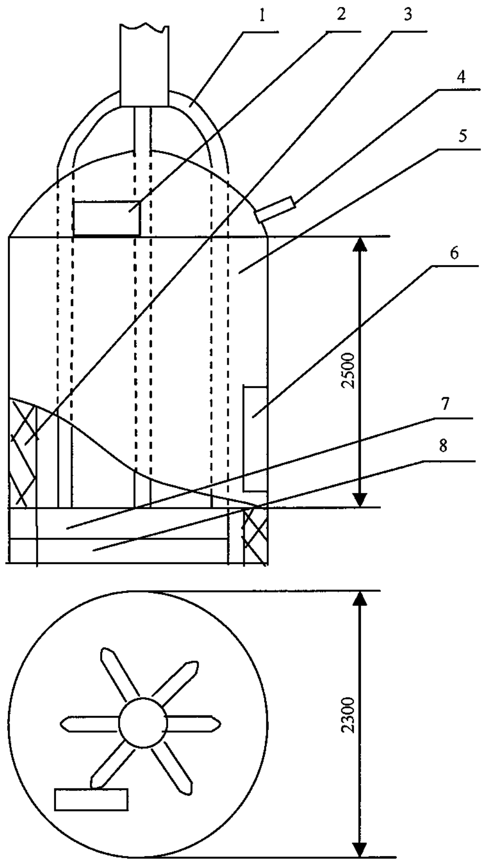


Figure 7 Structure of a Mechanical Furnace
1. smoke channel 2. top intake 3. firebrick
4. thermocouple 5. body 6. bottom intake
7. fuel feeding 8. ash exit

the other two at the bottom. So workers can adjust the combustion situation and master the product quality in accordance with the feedback temperature from the thermocouples. There is a grid with protuberant center below the fuel intake in the furnace. So the furnace can burn either coal or firewood. The outline of mechanical furnaces is shown in Figure 7.

5.2 Production Process

A practice production process of bamboo charcoal is shown in Figure 8:

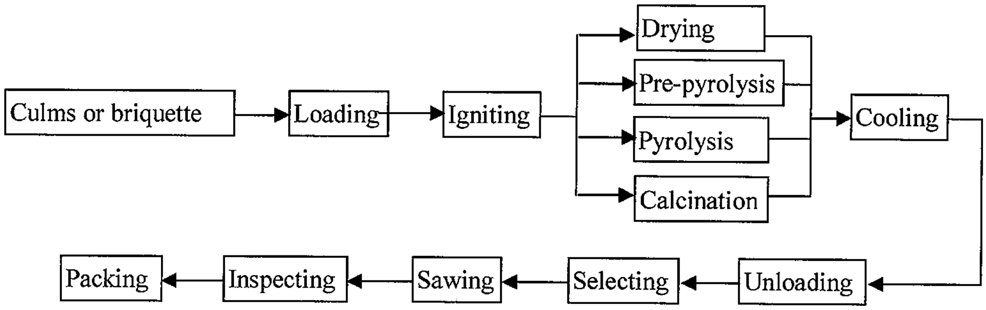


Figure 8 Production Process Flow Chart of Bamboo Charcoal

5.3 Raw Material Requirements

5.3.1 Raw Bamboo Charcoal Material Preparation

Raw bamboo charcoal is made of bamboo culms, branches and rhizomes/roots. The products made of bamboo culm can be divided into bamboo tube charcoal, bamboo slice charcoal, particle charcoal according to their outlines. Bamboo particle charcoal is made from bamboo tube charcoal and bamboo slice charcoal.

To enhance quality and productivity of bamboo charcoal, the bamboo culms must be matured (growing over 4 years) and fresh. Punk culms can't be used as raw material because the bamboo charcoal made from punk culms is loose and brittle and apt to self-ignited. Moreover, the density, cavity structure and tissue composition of bamboo culms differentiate from bottom portion to tip. Meanwhile, the quality of bamboo is influenced by its age, land and soil condition, and climate. So it is reasonable to divide the culms into three parts (the upper, the middle and the lower) for processing. If possible, the culms may be divided with the consideration of age and soil conditions. There are abundant nutrient substances in bamboo, so it is apt to be moldy. Therefore the storage time of bamboo materials should be strictly controlled, especially in summer. The newly cut bamboo culms should be processed and dried rapidly and loaded into kiln as soon as possible to protect their quality.

The moisture of bamboo influences bamboo production. The drying period of bamboo pyrolysis will prolong if the moisture content is too high, and as a result, the carbonizing process will extend with more fuel consumption. On the other hand, the bamboo culms are easy to cracks because of not being heated uniformly in the kiln when drying rapidly, and this degrades bamboo charcoal. Natural dry and manual dry methods are usually adopted. In small plants, the natural or air dry method is popular, e. g. place bamboo culms on the bases and let them air dry for a certain time to the moisture content of 15% to 20%. Some of plants first cut open the culms into slices, and then manufacture sliced bamboo charcoal.

5.3.2 Raw Material Preparation for Bamboo Briquette Charcoal-Bamboo Briquette Making

Bamboo briquettes are usually made of the bamboo processing residues such as particles, powder, sawdust, truncation portions, different threads etc. and a little of the tips and base of bamboo stem. The moisture content of the raw material should be dried to the standard of air-dried material. Besides that, the soil and stones mixed in the raw material should be removed. See Figure 9 and 10.

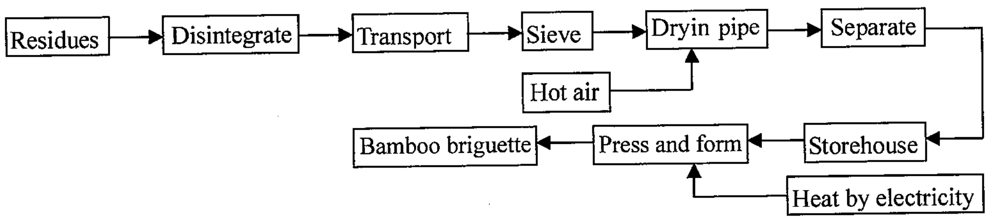


Figure 9 Production Process Flow Chart for Bamboo Briquette

The main procedures of making bamboo briquettes include the following:

5.3.2.1 Disintegrating and Conveying

It is the process of feeding the raw material into a disintegrator to break them down, and then the disintegrated particles will be conveyed on a belt into a sieve to be screened. The fine particles with the size of 10 meshes are carried into the vertical pipeline by belt transporter. The coarse particles will be turned back to the disintegrator again. Regular particles will be transported into a vertical pipeline where they are mixed with hot air coming from a heating furnace. They are to be dried and transferred into a hopper by an air current transportation system. The temperature of hot air is 85 ℃. The belt deferent speed is 50 m/min and the diameter of roller of transporter is 0.7 m.

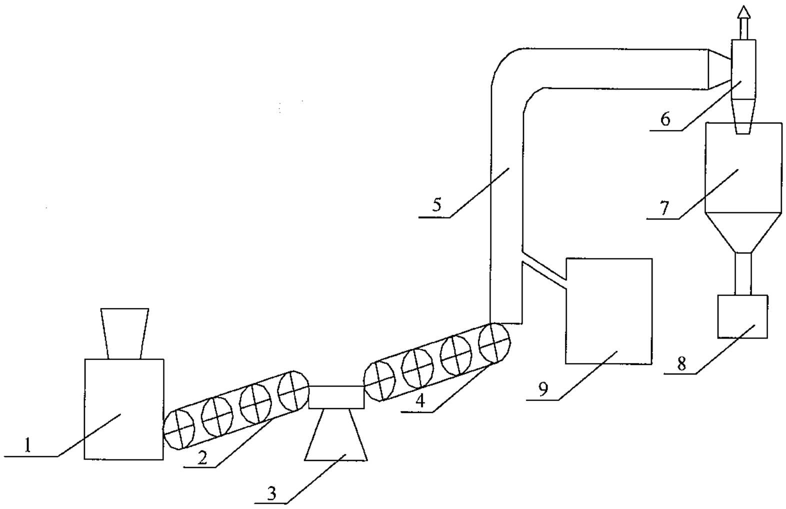


Figure 10 Diagrammatic Sketch of Bamboo Briquette Production Line
1. disintegrator 2、4. belt conveyor 3. screen 5. pipeline 6. cyclone separator
7. hopper 8. particle forming machine 9. heating furnace

5. 3. 2. 2 Drying

The regular bamboo particles will be dried in the vertical pipeline and transported to the hopper by air current transportation system and then pass through the cyclone separator to fall into the hopper. The moisture content of particles after drying should be within the range of 4% to 6% before feeding into a screw-forming machine.

5. 3. 2. 3 Extruding into Briquettes

The regular particles in the hopper are fed into the screw-forming machine, which is heated by electricity to 160℃, and extruded into briquettes. They are the raw material of briquette charcoal. It can be pyrolyzed in both brick kilns and mechanical furnaces. Figure 11 shows the outline of bamboo briquette.

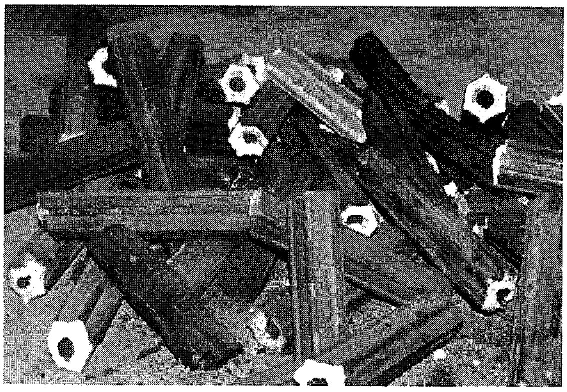


Figure 11 Outline of Bamboo Briquettes

5.4 Main Procedures Explanation

5.4.1 Loading

Cut bamboo culms into segments or pieces according to inner height of the kiln and load them into the kiln. The bamboo segments are arranged vertically with the tip portion downward. Loading begins from tail of the kiln toward the gate, leaving 0.5 m between the bamboo stack and kiln gate for combustion of firewood. Then the door is sealed with bricks and clay, leaving the arc intake for igniting and feeding firewood.

5.4.2 Igniting

It means to ignite the firewood lying behind the kiln gate and then close the top two intakes on the gate when the firewood is burned, leaving two intakes at the bottom of the gate to keep the hot flow circulating in the kiln and go out through the flue at the tail of kiln. At beginning, a small hole at the top of gate is necessary to let the smoke out and firewood burning easily. When the inflammation goes, seal the top small hole.

5.4.3 Heating (Dry and Pre-carbonization Stages)

It is a process raising the temperature inside the kiln by dismounting the arc-feeding intake on the gate everyday and feeding firewood to keep burning. Once finished feeding, the feeding intake should be sealed again. Usually the feeding keeps 2 to 3 times according to combustion that can be adjusted by changing the opening of bottom air intakes on the gate. To avoid feeding firewood at midnight, it is necessary that not only the feeding intake but also the air intakes should be sealed after last feeding in the evening every day. Of course, the air intakes couldn't be sealed completely and leave a small portions to remain slow combustion. The bamboo in the kiln will crack if the temperature escalates quickly. The temperature in the kiln should be controlled under the self-igniting point of bamboo in seven to eight days after igniting. Firewood feeding should be decreased or stopped if the temperature is enough. Blocking the intakes and flue rim with bricks can regulate the temperature in the kiln.

5.4.4 Carbonization and Refining

When the temperature in the kiln reaches 260℃, bamboo will be decomposed rapidly and gives out a lot of offspring and reaction heat. When it is over 450℃, bamboo pyrolysis enters into refining or calcining stage. In fact, it is a contracting process of high temperature pyrolyzation for improving the quality of bamboo charcoal and enhancing its hardness as well. After the end of heating open the intakes on the gate and feed more firewood quickly to raise the temperature inside the kiln. In this process, the intakes of kiln gate shouldn't be opened wholly in a short time, and they are to be opened gradually within twenty-four hours or so to make the bamboo charcoal contracted absolutely. At the end of refining stage, all the intakes should be opened again for one or two hours to raise the temperature of the charcoal in the kiln to 1,000℃ or more. The beginning and ending of refining process will be controlled according to the temperature on the curve.

In practice, workers, especially in small plants, determine the carbonization stages by watching the color and smelling the smoke coming out from the flue. At the beginning of drying, the smoke shows white color containing a lot of steam, and then with a slight acid smelled. Beginning carbonization, the smoke shows slight yellow companying with tar smell. When smoke color turns to slight blue, it indicates the end of carbonization and the start of refining.

5.4.5 Sealing for Cooling and Unloading

The kiln gate must be fully sealed with brick and mud pile at the end of refining, and let the bamboo charcoal in kiln cools naturally. If the kiln is not sealed well, bamboo charcoal inside will be easily oxidized. The cooling time depends on weather. Usually it takes five to six days. When temperature in the kiln is lower than 50℃, it is the time to take out the bamboo charcoal. At first the gate should be opened little to note if the bamboo charcoal re-burns and then opening the gate completely.

6 Properties and Quality Targets of Bamboo Charcoal

In this experiment, it was implemented to make bamboo distillation under different temperature (300 - 1,000℃), measure and analyze the fundamental properties of bamboo charcoal. The result indicated that the properties of bamboo charcoal change at different carbonizing temperature.

6.1 Bamboo Charcoal's Fixed Carbon

Fixed carbon is a supposed conception, it is a ashless bamboo charcoal which burns without air under the high temperature of 850℃ ±20℃.

If the ash and volatilization content are known, then the fixed carbon content can be calculated with the formula blow:

$$C = 100 - (A + V)$$

Where: C—percentage of the fixed carbon (%);

V—volatilization content (%);

A—percentage of ash (%).

Due to the difference in terminal temperature and pyrolysis method, bamboo charcoal could contain fixed carbon from 60% t to 93%. The corresponding percentage of fixed carbon in bamboo charcoal will increase with the rising of carbonizing temperature. The corresponding percentage of fixed carbon will increase dramatically with the rising of carbonizing temperature before the temperature reaches 600℃. However, it will change little after the temperature reaches 600℃.

The percentage of fixed carbon in bamboo charcoal grade 1 made at medium and high temperature is more than 88%, and grade 2 more than 85%. For bamboo briquette charcoal, grade 1 is over 86%, and grade 2 over 82%.

The relationship between fixed carbon and terminal pyrolysis temperature is shown in Figure 12.

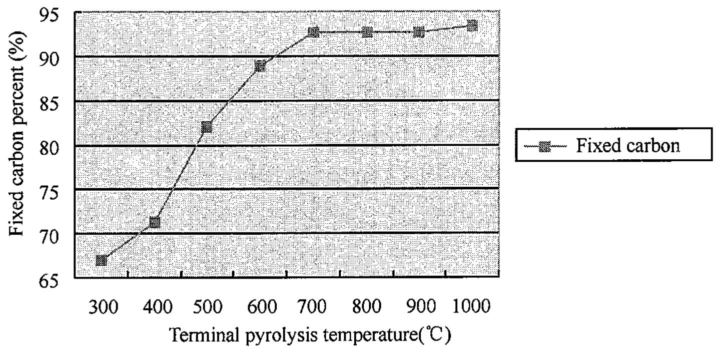


Figure 12 Relation Ships between Fixed Carbon Content and Terminal Pyrolysis Temperature

6.2 The content of Volatile Matter of Bamboo Charcoal

When heated under high temperature (850 ±20℃), the bamboo charcoal emits gaseous offspring such as CO, CO_2 H_2, CH_2 and other hydrocarbons which are called volatile matter. Measurement of volatile matter complies with the standard ASTM D1762 - 84 (R2001) Standard Test Method for Chemical Analysis of Wood Charcoal. The measure procedures are as follows: Heat the muffle furnace to 950℃. Preheat the crucibles used for the moisture determination, with lids in place and containing the sample, as follows: with the furnace door open, for 2 min on the outer ledge of the furnace (300℃) and then for 3 min on the edge of the furnace (500℃) (Individual nichrome wire baskets to hold the crucibles are convenient). Then move the samples to the rear of the furnace for 6 min with the muffle door closed. Watch the samples through a small peep-hole in the muffle door, if sparking occurs, results will be in error (If the sparking sample does not check the results of its non-sparking duplicate within ±0.5%, the analysis shall be repeated.). Cool the samples in a desiccator for 1 h and weigh.

Calculate the percentage of volatile matter in the sample as follows:

$$\text{Volatile matter, } \% = [(B - C) / B] \times 100$$

Where: B — grams of sample after drying at 105℃;

C — grams of sample after drying at 950℃.

Figure 13 presents the relationship between volatile matter in bamboo charcoal and the terminal pyrolysis temperature. It can be seen in Figure 13 that the volatile matter percentage decreases from 30.38% to 2.11% with the rising of pyrolysis temperature, the volatile matter percentage decreased rapidly with the rising of temperature up to 600℃, this might be caused by the almost completed volatilization of the volatile matter at the temperature below 600℃.

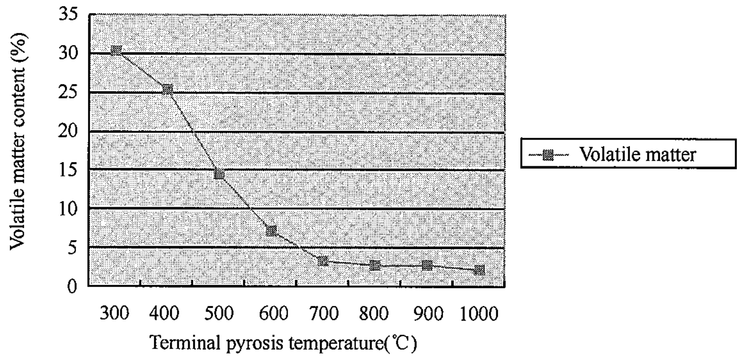


Figure 13 Volatile Content Changes with Pyrolysis Temperature

For the bamboo charcoal made in medium and high temperature, the volatile matter content should be less than 8%. In the final phase of making bamboo charcoal, it's very important to keep the equipment sealed during calcining and cooling, otherwise, it will influence greatly the volatile matter percentage. Because under heating condition, bamboo charcoal will absorb large amount of oxygen and produce at the same time a lot of surface oxygenate. The process is not necessary to be carried out under very hot condition, and it will be enough when the temperature reaches 200℃ to 300℃.

6.3 Ash of Bamboo Charcoal

The ash of bamboo charcoal is its inorganic constituent, which is a white or shallow red substance left when bamboo charcoal has been burned completely at high temperature. Shown in Figure 14, the ash percentage in bamboo charcoal increases from 2.93% to 4.69% with the rising of pyrolysis temperature. The ash elements

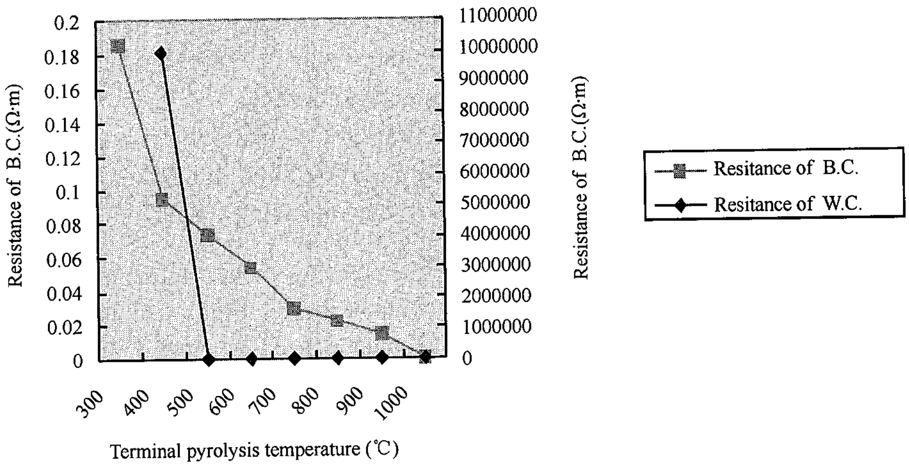


Figure 16 Relationships between Resistance of Bamboo Charcol and Terminal Pyrolysis Temperature

As shown in Figure 16, the resistance rate of bamboo charcoal reduced apparently before the carbonizing temperature reaches 700℃, while above 700℃ the reduction speed descended. Probably, this is because the volatile in bamboo charcoal released completely at that temperature.

Different target use requires different electric conductivity of bamboo charcoal. High temperature bamboo charcoal has excellent electric conductivity and can be used for shielding electromagnetism.

6.6 The Specific Surface Area of Bamboo Charcoal

The surface area of bamboo charcoal in 1 gram is called specific surface area of bamboo charcoal that is determined by the inner area of holes. It is one of important parameters that indicates the macrostructure of bamboo charcoal and reflects the reaction and adsorption abilities. Like wood charcoal, in high temperature, all kinds of porosities will form inside bamboo charcoal, which results in a certain specific surface area, reaction and adsorption capacity. The relationship between specific surface area and pyrolysis temperature is shown in Figure 17.

The maxim specific surface area ($385m^3/g$) is formed when the pyrolysis temperature reaches 700℃, the specific surface area value is much smaller when pyrolyzing under lower temperature (<500℃) due to the less porosity resulted from incomplete carbonization. Under higher temperature (>800℃), the porosity reduces too, the reason might be that some cavities have been burned and the surface area correspondingly reduced. So when carbonizing temperature reaches 1,000℃, the surface area value is small too.

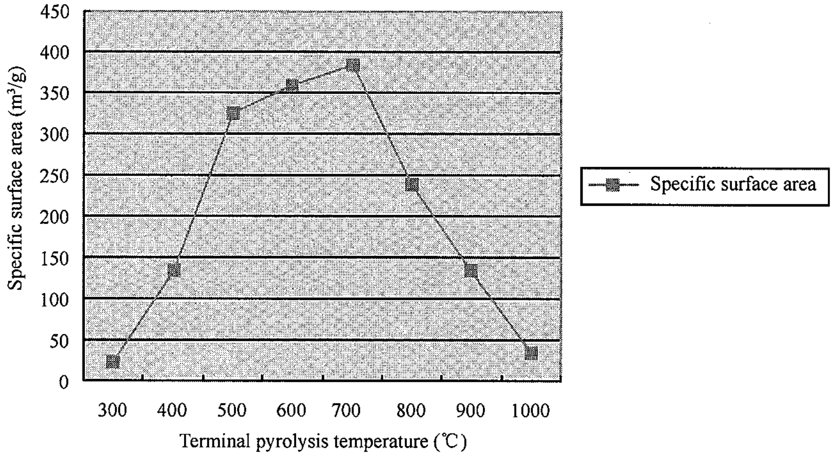


Figure 17 Relationships between Specific Surface Area of Bamboo Charcoal and Terminal Pyrolysis Temperature

There are different methods to measure the specific surface area; the BET capability way is most popular.

7 Factors Influencing Bamboo Pyrolysis Process

7.1 The Terminal Temperature of Bamboo Pyrolysis

The terminal temperature of bamboo pyrolysis has great influence on the output and composition of bamboo pyrolysis products. The results of experiments demonstrated that the output of bamboo charcoal descends as the pyrolysis temperature goes up, and the descending speed at the temperature below 400℃ is more distinct than that above 500℃.

The yield rate of bamboo charcoal descends while the pyrolysis temperature goes up, but the relative content of fixed carbon in bamboo charcoal increases. The yield rate of the liquid products and gas products are increased with the temperature raising.

The specific surface area of the bamboo charcoal is the biggest ($385m^2/g$) at pyrolysis temperature 700℃. The specific surface area increases with the pyrolysis temperature going up till 700℃, then it descends with the pyrolysis temperature going up further. The temperature can't be too high for producing the bamboo-based activated carbon.

7.2 The Speed of Pyrolysis

The speed of pyrolysis influences the productivity of pyrolysis equipment. In other words, high pyrolysis speed and low processing time can increase the utilization ratio of the pyrolysis equipment. The speed of pyrolysis is influenced by the speed of heating, the dimension and quality of raw material, the pyrolysis method and the carbonizing equipment, etc.

The bamboo vinegar's output distinctly increases and the bamboo charcoal's output remarkably decreases in high-speed pyrolyzing process. It might be the reason that the second reaction during the pyrolyzing process may reduce.

When the exothermic reaction of raw material is taking place rapidly, a great quantity reaction gas emits abruptly from the bamboo vessels causing cracks that will reduce the mechanical strength of bamboo charcoal (Huang, 1996).

7.3 The Moisture Content of Bamboo

The moisture content of bamboo directly influences the pyrolysis time and the consumption of fuel. The drying period of bamboo pyrolysis will prolong if the moisture content is too high, and as a result, the carbonizing process will extend with more fuel consumption. On the other hand, the bamboo culms easily crack when not being heated uniformly in the pyrolyzing kettle due to rapid drying, and this degrades bamboo charcoal. At the same time, the concentration of bamboo vinegar becomes lower and will increase the consumption of fuel while the bamboo vinegar is further treated.

A lower moisture content of bamboo speeds up the bamboo pyrolysis process. But the output of bamboo charcoal will be decreased and its mechanical strength reduced by the vigorous exothermic reaction if the moisture content of bamboo is too low.

So suitable moisture content of bamboo is important for pyrolysis, and the 15%-20% moisture are favorable for carbonization in an outside-heating pyrolyzing kettle.

7.4 Bamboo's Dimensions

Because of low thermal conductivity, bigger dimension of bamboo pieces, will require a longer period for the gas compounds emitting. Due to much subsidiary reaction causing loss during the pyrolyzing process, the output of charcoal will be reduced. It should be mentioned that bamboo material's conductivity value is low, and it should be considered how to speed up the heating process uniformly.

8 Utilization of Bamboo Charcoal

Because of the many pores and the high specific surface area, bamboo charcoal has strong adsorption capacity. Also its physical and chemical properties are very stable. It isn't soluble in water and other solvents and it demonstrates high stability in various working conditions except strong oxidants in high temperature, ozone, chlorine and salts of dichromate. So bamboo charcoal can be used in a wide range of pH and in many solvents. Moreover, it can be used under high pressure and high temperature.

8.1 The Exploitation of Adsorption Capacity of Bamboo Charcoal

8.1.1 The Use of Bamboo Charcoal Indoor

8.1.1.1 Main Sources of Indoor Air Pollution

Due to the economical development and improvement of society, more and more activities of human being such as work, study and entertainment are often performed indoor. But indoor environment is relatively closed and the air is polluted. The main sources of indoor pollution are indoor decoration, human bodies and oil-smoke in kitchen.

Indoor decoration. People are investing more and more money into indoor decoration to improve living environment. Meanwhile, tremendous wood panels and decorative stones are placed into houses. This means some harmful substances such as formaldehyde, ammonia, benzene etc. are mixing in indoor air. If the decorative products are of bad quality, the air pollution indoor might exceed the state standard regarding indoor decoration.

Formaldehyde is a colorless, gaseous compound used to make glue due to its adhesive and is also a certain pesticide with antiseptic capacity. Gaseous formaldehyde has strong stimulation to people. It comes from wood-based panels, plastic and furniture when a house has just been decorated. The results of studies demonstrate that when indoor formaldehyde content is 0.1 mg/m^3 people feel the odor and uncomfortable; when it is 0.5mg/m^3, people will be stimulated to tear, when it reaches 0.6mg/m^3, the throat of people will be uncomfortable or irritated; with higher content, it can cause illness, emesis, cough, suffocation and emphysema pulmonary. When formaldehyde content in air is 30mg/m^3, it can cause death. People contacted with lower dose formaldehyde for long time, might suffer from chronic respiratory diseases, female illnesses, harm to newly born babies, chromosomal anomaly, even a nasopharyngeal cancer. To control indoor formaldehyde polluting, besides selecting good material for decoration, and ventilating house, we can use bamboo charcoal for its good adsorption because formal formaldehyde's releasing period ranges from 3 to 15 years.

Ammonia in house comes from cement antifreeze additive. Ammonia stimulates eyes and breathing channel.

Painting and coating release benzene and so on, which are harmful to blood forming organ of human body. At the beginning of touching benzene, persons show the symptoms of leukocyte continuous decrease and dizziness, but a person might suffer from cancer if he is in contact for a long time.

Human body. Human being respires air that is exchanged in the lung, and carbon dioxide and other harmful substances are exhaled. Study results show that people excrete beyond 20 harmful substances by breathing, sweating urinating and defecating. So people often feel dizziness, difficulty in breath, even suffocation, and illness in a crowded unventilated house.

The smog smoker exhale is also an important source of indoor air pollution. Active ingredients of tobacco are decomposed at high temperature, and sometime they also form new chemical substances. It is demonstrated that there are tens of substances harmful to human body by analyzing the components in smog. For example, carbonic oxide, ammonia, formaldehyde, benzopyrene, nicotine, tar etc. are found in smog. These are severely harmful to human organs.

Oil-smoke in kitchen. Burning LPG that residents use daily consumes oxygen and releases carbonic oxide, carbon dioxide, nitrogen oxide, aldehyde, benzopyrene and so on. Vegetable oil gives out volatilizing chemical compounds (for example: acrylic acid) when it is heated at high temperature. These chemical compounds diffuse indoor and are harmful to human body.

8.1.1.2 Preventing Indoor Air Pollution

There are two ways for improving indoor air. The first is to use environment friendly material. The second is to use indoor deodorizer correctly.

Research results demonstrate that bamboo charcoal is a good product of indoor deodorizer because of good adsorption, long time efficacy to indoor harmful material and being regenerative and reusable easily. If product of bamboo charcoal is modified, its effect will be even better.

8.1.2 The Use of Bamboo Charcoal in Purifying Water

Everyone knows the seriousness of water pollution. To protect environment, it is an important task to dispose wasted water and drinking water.

8.1.2.1 Bamboo Charcoal Adsorbs 2,4-dichloro-hydroxybenzene

2,4-dichloro-hydroxybenzene is one of the main components of pollution in drinking water. Study on the purifying water capacity indicates that the adsorption properties of bamboo charcoal on 2,4-dichloro-hydroxybenzene are favorable.

Material and Methods. Test material includes bamboo charcoal which is grounded into particles with diameter of 0.06 – 0.9 mm, 2,4-dichloro-hydroxybenzene for analysis, and analytic ether.

Test process consists of 3 steps:

a. Compounding of standard 2,4-dichloro-hydroxybenzene solution: 0.0101g 2,4-dichloro-hydroxybenzene is dissolved into 100ml ether in a volumetric flask, then shooked up and placed in a refrigerator.

b. Static balance adsorption is adopted in the test: 0.02 - 1.000g bamboo charcoal particles and is added into 2,4-dichloro-hydroxybenzene solution with different concentration contained in 250ml conical flasks, then they are shook up and laid in vibrating machine keeping in 20℃ for a while so as to filter them easily. Finally the solution is filtered by ether twice, and 50ml. Constant volume solution is ready to measure the content of 2,4-dichloro-hydroxybenzene with gas chromatograph.

c. Gas chromatography measurement: the instruments and test conditions are as follows: HP5890 GAS CHROMATOGRAPH (electron capture detector), quartz capillary column (inner diameter 0.53mm, 10m long, solution film thickness 2.65 μm) with temperature 95℃; vaporization room temperature of gas chromatograph keeps 150℃ and test room 250℃; Feed speed of N_2 is 30.5ml/min and 1μL. sample volume is entered.

Results and Discussion. Dynamics of bamboo charcoal adsorption reaction to 2,4-dichloro-hydroxybenzene: Figure 18 is the kinetics curve of bamboo charcoal adsorption reaction to 2,4-dichloro-hydroxybenzene. It shows that adsorption volume of 2,4-dichloro-hydroxybenzene increases with treatment time. At the same time, the adsorption speed of 2,4-dichloro-hydroxybenzene by bamboo charcoal is fast at the beginning of adsorption, then becomes constant in 30 minutes, finally declines. According to the results the relation of adsorption volume of bamboo charcoal and 2,4-dichloro-hydroxybenzene can be expressed as the following equation:

$$\text{Ln } C = -0.896 - 0.00185t$$

Where the coefficient of correlation is $r = 0.863$. The equation shows that the adsorption of 2,4-dichloro-hydroxybenzene by bamboo charcoal accords with the first order reaction dynamics. The action between bamboo charcoal and 2,4-dichloro-hydroxybenzene caused mainly by van der Waals force.

Effect of the various concentration of 2,4-dichloro-hydroxybenzene on adsorption volume: it is shown in Figure 19 that volume of 2,4-dichloro-hydroxybenzene absorbed by bamboo charcoal shows good linear relation with concentration of 2,4-dichloro-hydroxybenzene. It indicates bamboo charcoal has a good nature of adsorption of 2,4-dichloro-hydroxybenzene that is shown in Table 2. With 1.0g of bamboo charcoal in this test, the maximum adsorption volume of 2,4-dichloro-hydroxybenzene is 1,500mg. When concentration of 2,4-dichloro-hydroxybenzene solution is in the range of 2.5 - 640mg/L, the adsorption rate of 2,4-dichloro-hydroxybenzene absorbed by bamboo charcoal is between 88.2% and 99.2%.

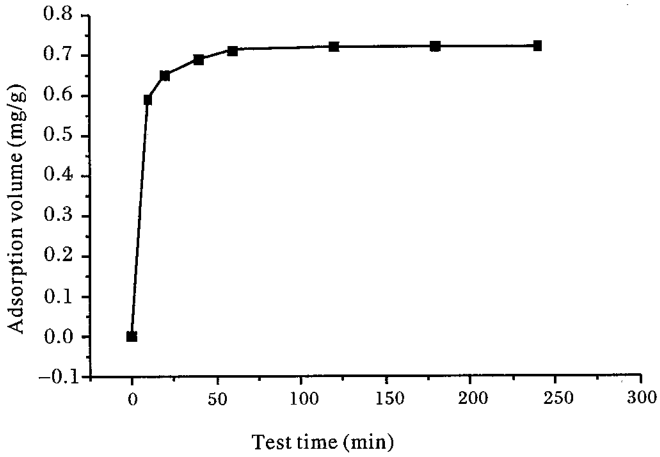


Figure 18 Effect of Treatment Time with Bamboo Charcoal on Adsorption Volume of 2,4-dichloro-hydroxybenzene

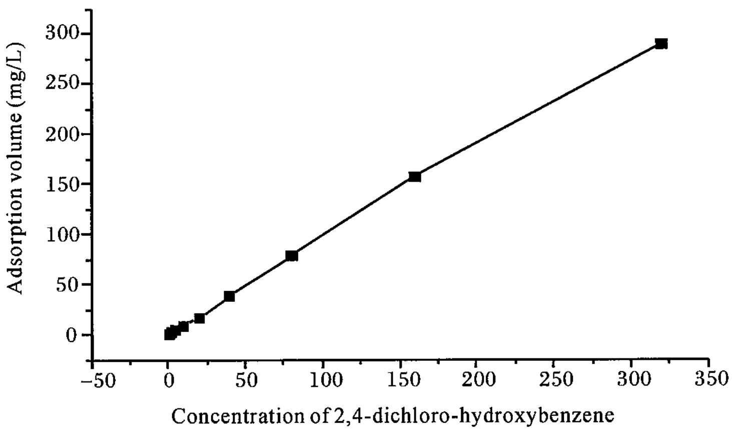


Figure 19 The Relation of Adsorption Volume and Concentration of 2,4-dichloro-hydroxybenzene

Table 2 Adsorption Rate of 2,4-dichloro-hydroxybenzene in Bamboo Charcoal Solution

No.	Concentration of 2,4-dichloro-hydroxybenzene (mg/L)	Test value (mg/L)	Adsorptivity (%)
1	2.5	0.02	99.2
2	40	1.2	97.0
3	160	3.1	98.0
4	640	69.1	89.2

Effect of diameters of bamboo charcoal particles on adsorption of 2,4-dichloro-hydroxybenzene: size of bamboo charcoal particle samples ranges from 0.06mm to 0.90mm which is divided into four grades, the first grade 0.8 – 0.9mm, the second one 0.25 – 0.35mm, the third one 0.15 – 0.155mm, and the last one 0.055 – 0.06mm. The solution concentration of 2,4-dichloro-hydroxybenzene is 1mg/L with pH value 6.4. The quantity of bamboo charcoal sample is 0.2g. The temperature in test keeps 20℃. The results are shown in Table 3.

Table 3 Function of Different Diameters of Bamboo Charcoal Particles

Size of bamboo charcoal particle (mm)	Particle size grade	Adsorption (mg/g)	Absorptivity (%)
0.8 – 0.9	1	1.1	22
0.25 – 0.35	2	1.7	34
0.15 – 0.155	3	2.5	50
0.055 – 0.06	4	4.9	98

Effect of pH value on adsorption of 2,4-dichloro-hydroxybenzene. We can see, under the test conditions that bamboo charcoal has a good ability of absorbing 2,4-dichloro-hydroxybenzene. With the pH value is at the range of 2.0 – 10.0, the adsorption rate of 2,4-dichloro-hydroxybenzene reaches 99%.

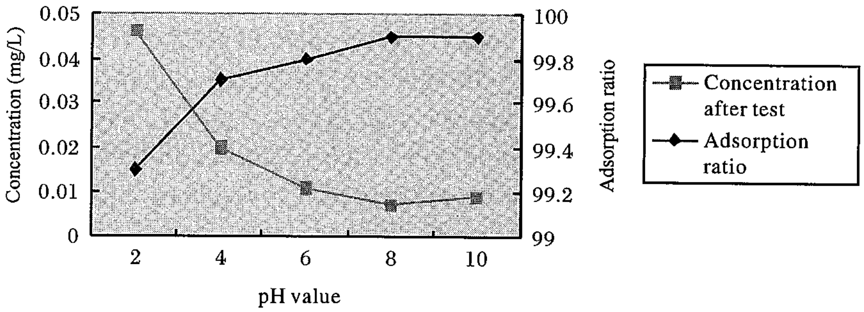


Figure 20 Effect of Acid Value on Adsorption Ratio of Bamboo Charcoal

Conclusions:

(1) Bamboo charcoal has a good capability for absorbing 2,4-dichloro-hydroxybenzene from water, whose reaction abide by the first order reaction kinetics.

(2) Under this test conditions, the maximum amount of 2,4-dichloro-hydroxybenzene absorbed by bamboo charcoal reaches 1,500mg/L

(3) The adsorption properties of bamboo charcoal on 2,4-dichloro-hydroxy-

benzene are closely related with size of bamboo charcoal particle, specific surface area, and adsorption temperature.

(4) When the acid value is at range of 2 – 10, bamboo charcoal has good properties on absorbing 2,4-dichloro-hydroxybenzene.

8.1.2.2 *Use of Bamboo Charcoal in Cooking and Boiling*

Bamboo charcoal not only eliminates harmful substances such as surplus chlorine, chloroform etc., but also contains rich natural mineral, for example, potassium, magnesium, sodium, calcium etc. Study result shows that if bamboo charcoal is dipped in water, metal ions can be absorbed (Table 4). So water quality can be improved when bamboo charcoal is used in cooking and boiling.

Table 4 Result of Metal ion Dissolving out in Bamboo Charcoal (mg/L)

Boiling No.	K	Na	Al	Mg	Ca
First dissolved	11.4	0.84	0.032	0.079	0.5
Second dissolved	6.1	0.82	0.02	0.055	0.37
Third dissolved	5.6	0.78	0.02	0.053	0.2

8.1.2.3 *Use of Bamboo Charcoal in Adjusting Humidity*

Because bamboo charcoal is activated under the condition of very little oxygen and high temperature, it contains almost no water and has a lot of pores. This makes its high effectiveness in adjusting humidity. When humidity of surroundings exceeds that of bamboo charcoal, bamboo charcoal can adsorb mass of moisture from air. When humidity of surroundings becomes lower than that of bamboo charcoal, it can give out moisture into air to keep a dynamic equilibrium. So bamboo charcoal is usually used to make different health care products for adjusting micro-surroundings of human beings. In practice, bamboo charcoal is usually laid under indoor floor or placed behind wallboards.

8.2 Use of the Emitting Infrared Ray Property of Bamboo Charcoal

Because of the nature of emitting infrared ray, bamboo charcoal can be used in health care. Massaging bodies with bamboo charcoal is favorable to promote blood flowing. Putting it into oil not only can fry delicate food but also can prevent oil oxidization. Sinking bamboo charcoal into a piscine before bathing, when water temperature rises, the wavelength of bamboo charcoal will become shorter and the quantity of absorbed heat will enlarge. So persons absorb the infrared ray coming from the bamboo charcoal to warm them up.

8.3 Use of Bamboo Charcoal in Deodorant and Preservative

Refrigerators are used to store fresh foods. Their capacities are so big that they store almost all kinds of food ranged from crude food to ripened food: vegetable, fruit, fresh fish, meat and so on. Although refrigerators are designed considerately, for example, it has many departments, but it is not able to exclude mixed odor because of the cold air flowing. If we use bamboo charcoal or its modified product in a refrigerator, the mixed odor can be excluded for its adsorption action. At the same time, because of bamboo charcoal's effect of adjusting humidity, it can prolong the preservative period of vegetables and fruits. Moreover, bamboo charcoal can be reused after washing and sunning.

8.4 Other Uses of Bamboo Charcoal

8.4.1 Bamboo Charcoal is Activated to Produce Bamboo Active Carbon

Being a good adsorbent, active carbon can be used as a decolourant and purifier in food, medicine, chemical industry, environment protection, and military engineering. Demand of its market is increasing. Wood is a sort of material for making active carbon, but the productivity of wood is decreasing because of the efforts for preserving forest. So it is an important subject to develop new material, which can be used to produce active carbon at present. Bamboo is a fast growing grass plant distributed in many areas worldwide. The quality of bamboo charcoal is similar to that of wood charcoal. So bamboo charcoal can be activated to produce bamboo active carbon. Activation process in lab was as follows (Wu *et al.*, 1999):

Bamboo charcoal (which is carbonized at 500℃) was activated at 900℃ by conducting steam to get good bamboo active carbon. The main adsorption index was as follows:

Adsorption value of iodine (mg/g): 1,000
Adsorption value of methylene blue (mg/g): 180
Yield rate of active carbon (%): 30

8.4.2 Use of Bamboo Charcoal in Conductivity

The conductivity of bamboo charcoal produced at different carbonizing temperature differentiates greatly. Bamboo charcoal gets very little resistivity, high conductivity and effect of electromagnetic shield when it is carbonized at 700℃. The relationship between the conductivity of bamboo charcoal and its carbonizing temperature, porosity, and degree of graphytization are to be studied.

9 Market and Cost Analysis on Bamboo Briquette Charcoal Made from Sympodial Processing Residues

9.1 Background

Guangning is one of 10 bamboo hometown counties in China and is also the only one sympodial species bamboo predominates. There is bamboo forest 69,300 ha. The predominating species is *Bambusa textilis* McClure approximately 52,000 ha with a yearly productivity of 150,000 tons (*Bambusa textilis* McClure is a sort of sympodial bamboo with 5 to 6 cm in diameter and 8 to 12 m in height). Being flexible and easy to be split, it is used as the raw material of making the skeletons of joss sticks that are burnt in temples when pilgrims worship Buddha. These products are exported to Japan, Taiwan, and Southeastern Asia. There are 37 factories that produce over 500 kg skeleton of joss sticks a day spotting the suburb of the county and around Gushui town (19 km northwestern of the county). Most of them are near the road and convenient to transport products.

According to the statistics approximately 10,000 ton skeletons of joss sticks are exported yearly from Guangning. Because the utilization rate is only 20% to 25% in production of skeletons of joss sticks (as some owners of factories told us and confirmed by the observations on site), there is 30,000 ton processing residues yearly. There are two small paper factories taking use of the residues to manufacture paper products, but they utilize only 4,000 to 5,000 ton one year. So there exist tremendous bamboo processing residues heaping up around these factories causing environment pollution and hiding the danger of fire.

According to the facts outlined above a decision building a bamboo briquette charcoal mill to utilize the residues had been made. This would be a good way not only for the benefit of the local people but also to protect environment. For this purpose, Fuda Bamboo and Wood Co. Ltd, Xinchang City, Zhejiang Province was invited to participate in the investigation activities. This company has successfully produced and sold this bamboo charcoal for several years.

9.2 Market

Japan and South Korea are the main importing countries. Bamboo charcoals made in China are almost always exported to the two countries. There was over 7,000 ton of various bamboo charcoals freighted to Japan and South Korea in 2001.

Bamboo briquette charcoal is used to sear or cake food in South Korea and to purify water from stream in Japan. The volume consumed in the two countries is too large to supply enough according to the words told by Mr. Chen xiaoan, manager in chief of Fuda Bamboo & Wood Co. Ltd, Xinchang City, Zhejiang Province. Mr.

Chen also told us that he dared not receive the order with large amount for insufficient productivity restricted by raw material. In order to keep steady relation with oversea consumers and export sufficient product, it is necessary that Fuda expands its supply capacity by combining Guangning Forest Bureau to build a bamboo briquette charcoal taking use of local processing residues.

9.3 Instrument and Cost

9.3.1 Instrument

The equipment for a production line of bamboo briquette charcoal includes the following: breaking devises for breaking down and transport, dry system, extruding and forming machines, carbonizing equipment, and sawing machines. There are two sorts of carbonizing equipment: brick kiln and mechanical kiln. The former is easy to build and has low cost. But it also has the disadvantages of low productivity and shift quality if a bad brick kiln is used. The later is easy to control, more investment and longer building time.

Consideration of the above elements, and the economical capacity of Guangning Forest Bureau, we made the decision to select the new brick kiln designed by " Wenzhao" Company, Suichang County, Zhejiang Province to be assembled on the production line and the product cost is analyzed on the base of such a line. The investment to set up a production line of capacity 360 ton a year is approximately 40,000 USD, including the expense of installation and regulation.

9.3.2 Cost Analysis

The cost of raw material, salary, and management per cubit meter are shown in the Table 5.

Table 5 Cost List of Per Cubic Meter Bamboo Briquette Charcoal

No.	Item	Unite price (USD)	Quantity	Amount (USD)	Note
1	Bamboo residues	12 per ton	3.5 ton	42	Arriving at factory
2	Electricity	0.96 per kWh	550 kWh	52.8	—
3	Fuel	—	—	30	—
4	Salary	3.6 per day	15 persons	54	8 for forming; 3 for kiln; 4 for load and package
5	Depreciation of equipment	—	—	12	—
6	Maintenance	—	—	12	—
7	Management	—	—	24	—

(Continued)

No.	Item	Unite price (USD)	Quantity	Amount (USD)	Note
8	Package	—	—	24	—
9	Short distance transport	—	—	5.3	From Guangning to Shanshui harbor
	Total			256	—

At present, the selling price (FOB) of bamboo briquette charcoal is USD400 per ton. So the profit of it reaches USD144 per ton and the profit rate is over 30%. All investment could be reclaimed during 2 to 3 years. It is obvious that building a factory to produce bamboo briquette charcoal at Guangning would bring beneficial result in economy and society.

9.4 Market Strategy

A joint venture company should be set up which invested jointly by Fuda Co. Ltd and Guangning Forest Bureau and supported by Bamboo Engineering Research Center of Nanjing Forestry University in technology. Guangning Forest Bureau will supply the demanded site and house, and Fuda will furnish the equipment. The product will exports to Japan and South Korea by taking use of existent consumers of Fuda after the factory comes out. On the other hand, the joint venture company will develop new consumers abroad, and set up second line to sufficiently utilize local bamboo resource when the time comes up.

High Pressure Sap Displacement Used Against Splitting and Insect

1 Introduction

Conventional bamboo preservation methods such as immersing, spraying or brushing have the advantage of easy operation, but their preservation effect lasts for a short period because the outside wall of bamboo culms is lined with epidermal cell coated a ply of wax and the inside is composed of numerous scelerenchyma cells. Moreover, there are no ray cells that facilitate the radial movement of liquid in bamboo culms. Accordingly, preservative penetrates neither from the outside nor from the inside of a bamboo culm, and the only pathway is in the vessel or vascular bundle direction, i. e. axial direction. In another words, the liquid preservative gets into bamboo culms on one end and flows out on the other end. Soaking a bamboo culm for 24 hours in indoor temperature, the liquid usually penetrates only 5 – 10 mm in depth and 1 – 3 mm by brushing or spraying. If the treated bamboo were planned or sanded, the treated layer with preservative would be removed and the outer surface of bamboo would be vulnerable to fungal or insect attack. For pressure treatment, special plant and equipment are needed, and the air or the liquid in bamboo can't change with the preservative solution under the surrounding pressure (Lieses W, 1997)

The high pressure sap displacement (HPSD) preservation was used in this experiment, and the pressure was 0. 3 – 0. 4 MPa (42 – 56 psi) (Choo and Gan, 1998).

2 Material and Methods

2.1 Material

2.1.1 Bamboo Culms

The species of bamboo was *Phyllostachys heterrocycla* var. *pubescens* (Mazel) Ohwi, from the bamboo garden of Nanjing Forestry University, 6 – year – old. The diameter of the culms' base end is about 80 mm. Because diameter sizes of the base end change too much, and the shape of their cross section aren't firm circle, the end of the culms were cut off 200 – 300 mm from the ground.

For soon after the bamboo felling, the vessels are filled by a blockage due to cellular outgrowths (tyloses) and slimes. The bamboo culms were treated after a week of their felling with length 1,000 mm (Weiner G, Liese W; 1996).

2.1.2 Bulking Treatment Agents

Polyethylene Glycols (abbreviated PEG). The average molecular weight of PEG in the experiment is 1,000.

Thermosetting Phenolic Resin (abbreviated PF). The amount of use has relation to dimensional stabilization: the more they are, the higher the anti swelling and anti shrinking effect is.

Inorganic Salts. Sodium Chloride, Magnesium Chloride and Calcium Chloride were selected to be using.

Polymeric Compounds. Polyvinyl Alcohol (abbreviated PVA), Polyvinyl Butyral (abbreviated PB) and Elhycellulose (abbreviated EL) were also selected.

2.1.3 Insecticides

In order to compare the effect of the bulking agents, the insecticide Sodium Fluoride and Sodium Pentachlorophenolate were used.

2.2 High Pressure Sap Displacement Treatment and Equipment

2.2.1 High Pressure Sap Displacement Treatment (HPSD)

The outside round wall of the bamboo culm is lined with epidermal cells, and the inside of the culm is composed of numerous sclerenchyma cells. The vessels of freshly cut culms run straight without any branching or obstructing connections of single vessel along the culm length. The preservative solution in the vessel can diffuse into the surrounding fiber sheaths and vascular bundles as well as the parenchyma through the pits, so the treatment is more effective in bulking the cells' walls.

2.2.2 HPSD Equipment

The equipment is composed of an air compressor, solution container, valves and rubber cap (Figure 1). The rubber cap's design is the key of the apparatus, because the dimension and the section shape of the round culms are different, and it is difficult to obtain a tight joint between the cap and the culm without leakage.

2.3 Bulking Treatment

The bamboo culms must be treated as fresh as possible, because soon after their felling, the vessels are filled by a blockage due to cellular outgrowth (tyloses) and slime. Therefore, both ends have to be cut off 100 mm in length immediately and wash off the duty on ends before the treatment (Weiner G, Liese W;1996). All of the bulking treatment agents and the effects were shown in Table 1.

Table 1 The Bulking Treatment Agents and Effects

No.	Chemical	Solvent	Concentration (%)	MC of before drying culms (%)	MC of dried culms (%)	Average shrinkage in percent of culms (%)	Effect
Ⅰ-1	—	water	—	86.6	7.5	5.4	N check
Ⅰ-3	$CaCl_2$, Na_2CO_3	water	28.6,25	55.0	17.3	1.3	N check
Ⅱ-2	$CaCl_2$, Na_2CO_3	water	28.6,25	63.9	9.1	2.7	N check
Ⅱ-3	PEG	water	25	115.4	4.0	8.8	N check
Ⅱ-4	PVA	water	7.5	99.2	10.4	8.6	N check
Ⅲ-1	PVA	water	3	82.3	16.7	3.5	O check
Ⅲ-2	PVA, $Na_2B_4O_7 \cdot 10H_2O$	water	1.5	74.9	10.5	4.5	N check
Ⅲ-3	PEG	water	25	75.9	9.8	3.6	N check
Ⅲ-4	PB	alcohol	2	58.3	5.7	4.4	N check
Ⅲ-5	EL	70% xylene 30% alcohol	1.2	55.1	3.7	3.9	O check
Ⅳ-1	PF adhesive	water	25	66.0	10.3	2.9	three checks
Ⅳ-2	PF adhesive	water	34	60.4	10.7	2.7	N check
Ⅳ-3	PF adhesive	water	40	58.6	11.3	3.3	O check
Ⅳ-4	PF adhesive	water	44.5	55.4	12.1	3.0	O check
Ⅴ-1	NaCl	water	25	62.4	10.8	2.3	N check
Ⅴ-2	$MgCl_2 \cdot 6H_2O$	water	55.6	52.0	14.7	1.3	four checks
Ⅴ-3	$CaCl_2 \cdot 6H_2O$	water	34	44.4	17.8	—	four checks

2.4 Toxicity Experiments

In order to compare toxicity effect, the same insecticide was pressed into a green bamboo culm and an air-dried one. All the treated bamboo culms were cut into strips with 80 mm length and 25 mm width, and the strips were put in plates in the lab. There are 20 beetles were put in every plate. The treatment effects were observed after 20 days (Table 2). The toxicity was checked with the number of galleries, died insects and the weight of bore dust. The full value marks is 100 in every item, indicating no galleries, no bore dust and no living beetles, and there are not mark as the same of the contrast's gallery, bore dust and died beetles.

Table 2 The Treatment Agents and Their Against Insect Effects

No.	Chemical	Solvent	Concentration (%)	Beetles number	Dead beetles	Dying beetles	Galleries number			Weight of bore dust (g)
							shallow	deep	total	
Ⅰ-3	$CaCl_2$, Na_2CO_3	Water	28.6,25	20	4	0	0	0	0	0.006
Ⅱ-2	$CaCl_2$, Na_2CO_3	Water	28.6,25	20	4	0	0	4	4	0.049
Ⅱ-3	PEG	Water	25	20	1	0	0	12	12	0.217
Ⅲ-2	PVA, $Na_2B_4O_7 . 10H_2O$	Water	1.5	20	3	2	3	1	4	0.031
Ⅲ-3	PEG	Water	25	20	8	0	1	4	5	0.143
Ⅲ-4	PB	alcohol	2	20	1	0	0	13	13	0.247
Ⅳ-1	PF adhesive	Water	25	20	1	1	0	8	8	0.187
Ⅳ-2	PF adhesive	Water	34	20	2	4	0	8	8	0.197
Ⅳ-3	PF adhesive	Water	40	20	2	2	0	9	9	0.202
Ⅳ-4	PF adhesive	Water	44.5	20	3	0	0	9	9	0.156
Ⅴ-1	NaCl	Water	25	20	7	1	1	5	6	0.034
Ⅴ-2	$MgCl_2 \cdot 6H_2O$	Water	55.6	20	1	1	0	6	6	0.141
Ⅴ-3	$CaCl_2 . 6H_2O$	Water	34	20	11	3	2	2	4	0.036
A4	NaPCP	Water	4	20	4	0	2	1	3	0.012
A5	MBT	Water	0.4	20	1	1	2	6	8	0.063
A6	NaF	Water	3.5	20	1	3	6	0	6	0.008
A7	NaF	Water	3.5	20	10	2	2	0	2	0.010
Untreated	—	—	—	160	16	0	1	98	100	1.78

Table 3 The Effect Against Beetles

No.	Effect	No.	Effect	No.	Effect
Ⅰ-3	208	Ⅳ-1	47	Ⅴ-3	235
Ⅱ-2	157	Ⅳ-2	71	A4	198
Ⅱ-3	7.5	Ⅳ-3	55	A5	124
Ⅲ-2	195	Ⅳ-4	64	A6	208
Ⅲ-3	138	Ⅴ-1	145	A7	251
Ⅲ-4	0	Ⅴ-2	89	Untreated	0

3 Results and Analysis

3.1 The Diffusion of HPSD Treatment

In order to observe the diffusion, the section of 44.5% solid content of PF treated bamboo (No. Ⅳ-4) and the untreated bamboo were taken photos with the scanning electron microscope (SEM). Figure 1 is a 6-year-old untreated bamboo's parenchymas. Figure 2 is the No. Ⅳ-4 bamboo's parenchymas. Figure 4 is a 2-year-old untreated bamboo's pith periphery. Figure 5 is the No. Ⅳ-4 bamboo's pith periphery. It is shown: (1) the Figure 1 parenchymas' cell section shows many holes and rough, but Figure 2 shows few holes and smooth. The section shows there is PF adhesive in the cell's wall and in the starch which usually shows little balls (Figure

1); (2) the pith periphery's cells showed in Figure 4 are filled with PF adhesive, but there are empty in Figure 3.

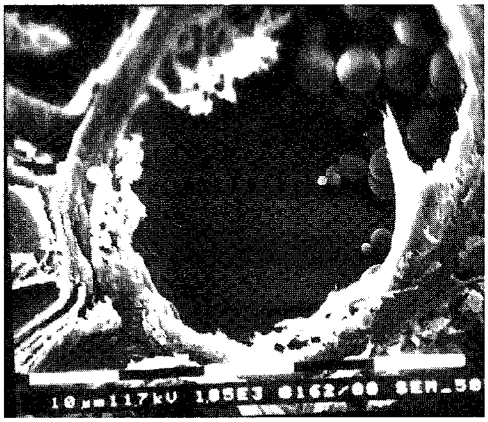


Figure 1 Parenchymas, ×1850

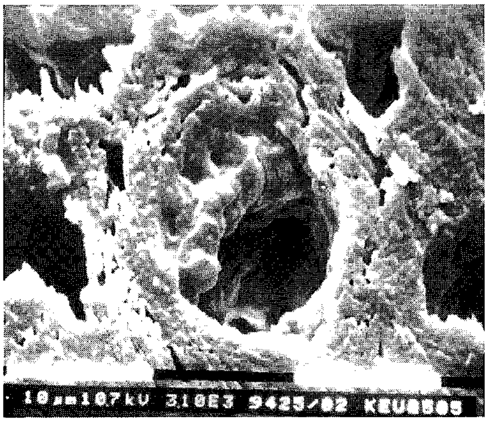


Figure 2 No. Ⅳ-4 parenchymas, ×3100

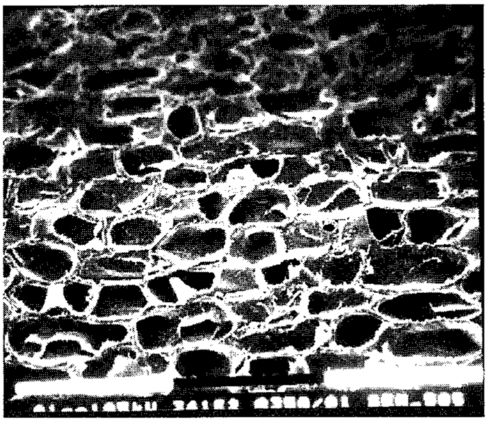


Figure 3 Pith Periphery, ×341

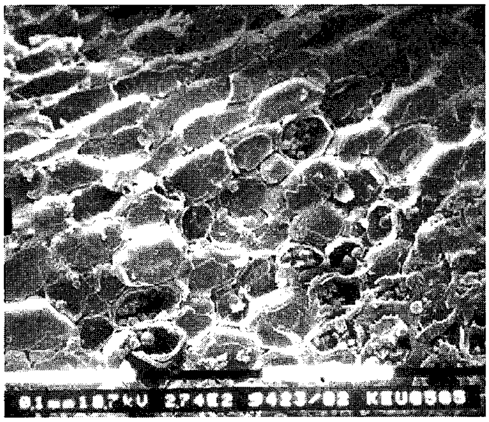


Figure 4 No. Ⅳ-4 Pith Periphery, ×274

3.2 The Results of Bulking Treatment

In order to check the treated bamboo's bulking effect, there are three methods to be used, such as drying in drying box, natural weathering and cleavage strength. The bulking effect in Table 1 were checked after 15 days drying with temperature 40℃ and relative humidity 30% in the drying box. The results of bulking treatment was as follows:

Inorganic salts treatment has the best bulking effect, and the tangential shrinkage in percent of the round culms is 1.34% -2.68%.

The bamboo treated by PEG (No. Ⅱ-3) with 115.4% moisture content shows a little collapse in drying, and the outer tangential shrinkage is up to 8.79%, but the bamboo treated by PEG (No. Ⅲ - 3) with 75.9% moisture content is only 3.7%. All the above treated round bamboo culms have no check after drying.

The bamboo treated with PF has lower shrinkage percentage which is 2.66% - 3.26%. among them, the shrinkage percentage of bamboo treated by 34% solids content of PF(No. Ⅳ - 2) is the lowest, and there is no check on the culm.

The shrinkage percentage of bamboo treated with 1.5% PVA is 4.52%, and there is not check after drying in the drying box. The bulking treatment effect will be checked in the natural weathering later.

3.3 The Toxicity of the Insecticide

According to Table 2 and Table 3, it was shown:

3.5% solution of sodium fluoride has the best treatment effect as an insecticide against bamboo powder post beetles, and the effect of HPSD with green bamboo is better than that with the air-dried one.

34% solution of calcium chloride shows the second best treatment, and gets the marks of 235.

4% solution of sodium pentachlorophenolate is also good with a mark of 185.

The marks of solution of sodium chloride are not high, but there are 7 beetles died, but sodium chloride is no toxicity to human, so it can be used in cooking.

3.4 Other Result of the Experiment

The cleavage strength means the characteristic to resist the split, and it depends on the strength of being split. Because there is not cleavage strength testing method in the standard of "testing methods for physical and mechanical properties of bamboos", and the culm wall is thinner than 20 mm, the thickness prescribed in the standard GB1942 - 91 "the testing method of wood cleavage strength". In the experiment, the treated bamboos were sawed as the need of GB1942 - 91 except for the thickness being the same as the walls of the bamboo culms.

The cleavage strength is the property of the tension perpendicular to grain, and may influence the check in the bamboo culms. Most the bulking treated bamboo's cleavage strength are less than the untreated ones except for those treated by the PF adhesive(No. Ⅳ - 3 and Ⅳ - 4) and cured. So the cleavage strength can't be as the property to forecast the bulking effect of the treated bamboo culms.

4 The Results

The penetration effect of HPSD is better for the round bamboo culms with high effective, inexpensive installation and easy operation than any other treatment. The

HPSD is suit for bamboo preservation, especially for the big diameter sympodial bamboos species, which can be used as posts.

The bamboos treated with inorganic salts have the best bulking effect, and treated by PEG and PF have good bulking effect also. Among the inorganic salts, calcium chloride has the better bulking effect than magnesium chloride and sodium chloride have.

Because the cleavage strength of treated bamboos has less effect to the check, it can't be as the property to forecast the bulking effect of the treated bamboo culms.

The effect of HPSD treating green bamboo is better than that of air-dried bamboo.

Calcium chloride has the best treatment effect of resistance against checking and bamboo beetles, and sodium chloride has a good treatment effect also. As there is not insecticide in PEG and PF adhesive, the bamboos treated with them only have the effect of resistance against checking. Compound chemical that has resistance against checking and beetles were not tested in the experiment, expecting to do in the next experiment.

A Case Study of Production-to-consumption System of Bamboo Weaving Industry in Xinyi City

Bamboo is one of the most important forest resources in tropical and subtropical areas. There are more than 1,200 bamboo species worldwide, which belong to over 70 genera, and are widely distributed over Asia, Africa and South America. China is the richest bamboo producing country in the world, with over 500 bamboo species belonging to 39 genera and 4.21 million ha of bamboo plantations and improved natural bamboo stands (Shidong L and Chuande X, 1998). Bamboo is a fast growing, versatile, and annually renewable plant, with high productivity, if managed in a sustainable way.

China has long history of cultivation and utilization of bamboo resources. Bamboo, among all plants, has a distinctive status in the Chinese culture and history. Bamboo has deeply colored the lives of Chinese. The usefulness of bamboo in the daily lives of people in China, especially in the rural areas, has been well eulogised in literature, both scientific and popular.

This paper describes the significance, function, characteristics and trends of the bamboo production to consumption system in Xinyi City, Guangdong, China. It was found in this study that bamboo contributes a great deal to the local economy and the farmers' income. With the change from collective to private management and property rights, the bamboo sector has increased considerably since 1990. The establishment of bamboo plantations has also had a positive effect on the local ecological, as bamboo stands can be established around road sides, river banks and hilly sides, and the trend is towards more intensification of production, which at the same time implies that bamboo plantations might not occupy the remaining natural forests in the area. The government needs to improve their institutional support, for example by providing the right incentives to stimulate trade and the processing of higher value products.

1 History of Bamboo Weaving

The history of bamboo weaving in China can be traced to the Neolithic Age, in the both primeval Hemudu Ruin of Yuyao City and Yanliangchu Ruin of Zhejiang Province more than 200 bamboo woven articles have been unearthed, which demonstrated comparatively skilled weaving techniques. According to archaeological records, the weaving and potting were invented soon after the human being started to get ecesis. The baskets and other appliances for food store were woven with bamboo, rattan, willow and straw, which were cut with stone knives, stone axe and so on. Some moulage of weaving, most of which are bamboo weaving moulage, were found on pottery excavated in the famous Banpo Neolithic relic in Xi'an City. The line shapes include baskets, mats, cases, and so on. During the Yin and Shang Dynasty, the technology of bamboo weaving had been well-developed and various products were woven with bamboo culms, which was testified by that colored bamboo mats and small suitcases, found in Chu Ruin of the Warring States Period (403-221 B. C.), of Hubei Province, were ornamented greatly and woven delicately. These various bamboo-weaving products, mainly mats, shades, suitcases, fans, baskets etc., were widely used in daily life or as decorations. Among them, a bamboo fan was woven of thin bamboo strips into rectangle pattern, showing fine workmanship. The Weaving methods differed in thousands ways, for example, mats are woven by placing bamboo strips across one another either diagonally or longitudinally, baskets woven in three directions loosely with holes or in circle pattern and bamboo cans woven in rectangle lines pattern. As yet these methods are applied continually up to now. The bamboo woven products in Shen County of Zhejiang Province enjoyed a high reputation early in East Jin Dynasty (317 - 420 A. D.), which were famous for their thin bamboo strips as transparent as a cicada's wing. Bamboo woven products diversified step by step during Ming (1368 - 1644 A. D.) and Qing (1636 - 1911 A. D.) dynasties, with improved techniques; they became quite popular among ordinary people. The fork weaving artists continuously increased and weaving skill improved greatly, from stitching weaving to monofilament cross. Kinds of calligraphy and patterns can also be woven. Some 120 threads could be cut out from one bamboo culm. On the surface of bamboo woven articles propitious pictures could be drawn with gold lacquer and single lines.

As the technology of weaving run to modern times, it had been further developed in all of southern provinces of China. Various products like boxes, cases, trays, fans, lantern, folding screen, awnings for litter, jars, as well as large mounts of subtle baskets were produced, part of which have been exported to other countries of Europe and America. Bamboo weaving products were closely linked to people's living and production that time. These various colored products had more usage than before. The weaving technology has been developed so well that more than 100 threadlike strips had been put into only one cubic inch where several hundreds of patterns had been woven.

2 Regional Setting

Near the Guangxi Province, and between longitude 110°40′36″ – 111°40′39″ east and latitude 22°11′16″ – 22°42′26″ north, Xinyi city is located in the southwest Guangdong Province with a total area of 3,080.5 km^2. Xinyi is a typical mountainous region with south subtropical monsoon climate. Xinyi's annual mean temperature is 16.5 – 22.8℃ with annual rainfall of 1,477 – 1,941mm. There are 371 hills of above 500 m a. s. l. with the highest peak, Datianxiang Mountain, reaching 1,704 m a. s. l. According to the forest inventory carried out in 1998, the hilly land in Xinyi City covers 239.2 thousand ha, of which the forested area amounts to 207 thousand ha with forest cover rate of 68.1%. In this, bamboo forests account for 26.7 thousand ha, 12.9 % of the total forested area.

3 Bamboo Resurces

3.1 Resource Base

The majority of bamboo stands have been in existence for a long time in Xinyi City. The dominant species in Xinyi is *Bambusa chungii* McClure, a sympodail bamboo, which has been cultivated in the region for centuries. The bamboo area, bamboo standing culms and bamboo production are increasing continuously.

Large – scale planting of bamboo in Xinyi began in 1958, mainly in hilly land in Dongzhen town. The bamboo culm seedlings has been successfully used to plant bamboo in 1965. Since 1980, the fast development of bamboo weaving industry has largely promoted the plantation of bamboos, and local farmers planted the *Bambusa chungii* McClure around the road sides, river banks, hilly sides and nearby the villages and houses (see Figure 1), increasing to 26.7 thousand ha, which includes 23.33 thousand ha of *Bambusa chungii* McClure, 2 thousand ha of *Phyllostachys heterocycla* var. *pubescens* (moso bamboo) and 1.33 thousand ha of other bamboo species. Four bamboo bases, huaixiang, Dongzhen, Gaopo and Heshui, has been established and annual output of bamboo culms reached 60 thousand tonnes, but it has not meet the demands of local weaving development.

3.2 Biological Characteristics of *Bambusa chungii*

Bambusa chungii belongs taxonomically to sub-genus of *Lingnania* of *Bambusa* genus. Its formal Chinese name is *Fendan Zhu*, with many local names depending on different regions where it grows, such as *Dan Zhu*, *Zhuti Zhu* and *Gaojie Dan Zhu* etc.

Bambusa chungii is a sympodial bamboo species, with as many as 40 or 50 culms in a clump. The culm height varies from 3 to 10m and its diameter ranges between 4.5 and 6cm. The culm is usually covered with whitening with 40 to 80cm long internodes. Its branches grow in clusters with a similar size.

Bambusa chungii is distributed specially in South China, including the provinces or regions of Guangdong, Guangxi and Hunan. It usually grows on the banks of rivers and brooks, as well as other places with fertile and moist soil. *Bambusa chungii* is common in South China, with versatile use. The culm wall is thin and flexible, easy to be weaved into handicrafts. The culm can also be the raw material of papermaking. With whitening on the culm and its elegant shape of the clump, *Bambusa chungii* is a good choice for ornamental purpose.

Figure 1 *Bambusa chungii* Planted Near House and Around Roadsides

3.3 Cultural and Management Techniques

The way of seedling-raising for *Bambusa chungii is* asexual propagation, with several methods such as culm or branch cutting, culm burying and rhizome burying. The period for seedling-raising usually is between middle February and middle March in South China.

The methods for *Bambusa chungii* planting include parent culm planting and culm node burying planting. The planting site should have deep, loose, fertile soil and moist such as river's bank, roadside, lower hillside, site around house etc. The soil on the planting site should be prepared in advance. The whole site should be loosened and all the shrubs, and weeds burned or cleaned. The planting spacing generally is 4m × 5m, with a density of 30 culms per mu. The one- or two-year-old culm with large and robust shoot eyes and well-developed fibrous root can be selected as parent culm to be planted. Some tending measurements need to be applied in next two year after planting, which include weed cleaning, soil loosening and fertilization. Fifty gram compound fertilizer needs to be applies to each culm in the current year and one hundred gram in the coming year. The appropriate planting season in South China is between March and April.

The culm of *Bambusa chungii* is usually felled down when it is over 3 years old, leaving 12 – 14 culms in a clump, which is regarded as an appropriate clump density. Since 1 – 2 year-old culms have a good ability to shoot new culms and 3 – 4 year-old culms reduce sharply its ability to shoot, culms over 4 years are generally selected to be harvested. With the way of harvest year by year, a rational age structure of *Bambusa chungii* forest remains for the coming years.

4 The Socio-economic Importance of Bamboo

The weaving industry in Xinyi has long history, and is famous for miles around. At the beginning of 1960's, the bamboo weaving products started to export to foreign countries, with 10 million pieces of weaving products every year. The economic importance of bamboo has been increasing steadily and the annul export value exceed the 10 million Chinese Yuan since the late of 1970's. According to the Xinyi Forestry Bureau, an estimated over 170 thousand of the county farmers managed bamboo as part of their daily activities in 2003. The Xinyi Foreign Trade Bureau has stated that the total export of bamboo products, from the county, amounted to US $186.1 million in 2003.

The average total annual household income (subsistence + barter + cash) in Xinyi city in 2003 was US $504.23 (Figure 2).

In the research area, the farmers find bamboo to be an interesting option, and it is frequent that they participate in its processing either as part-time contracted labour in factories or by doing some semi-processing at home, thus increasing the value added to the raw material at the farm gate. The combination of a high demand for bamboo with an associated local industry has been one of the major success factors in Xinyi's rural development. In the last two decades, the farmers' per capita net income has multiplied by 5.29 in real terms.

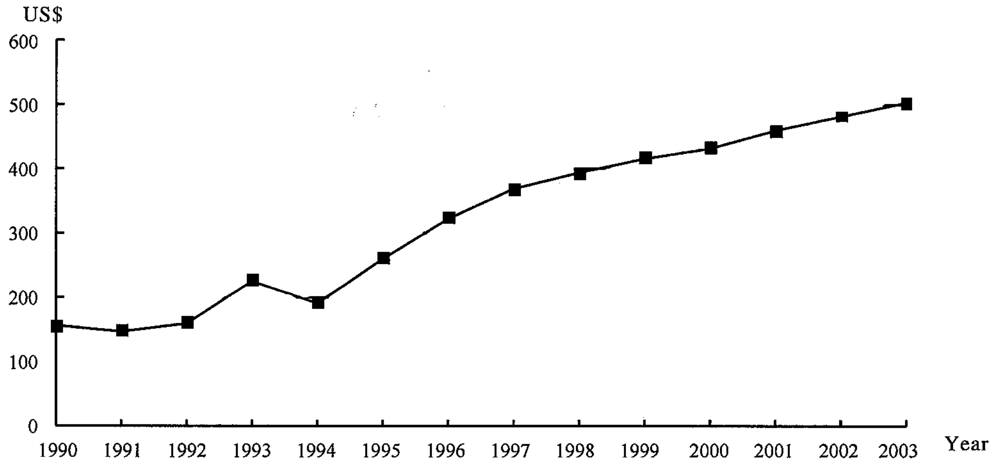


Figure 2 Average Net Income Change of Xinyi's Farmers from 1990 to 2003

5 Processing Industry

Figure 3 Weaving in the Family

The majority of the bamboo weaving industries is either of one-man show style, family oriented or part-time type of businesses and thrives on traditional manual work procedures. Bamboo is widely used because of its excellent features. The strength of bamboo culms, their straight and light characteristics combined with hardness, easiness to split and cut; range in size, hollowness, easy working and transportability make them suitable for a variety of multifarious traditional uses. The weaving of baskets is mainly a cottage industry in Xinyi City, as well as in other parts of China. The traditional weaving industry was, in the past, governed by certain social and cultural norms, such as agriculture and utensils. Individual groups or castes of people had their own particular skills and thereby became associated with a particular type of products. See Figure 3 and 4.

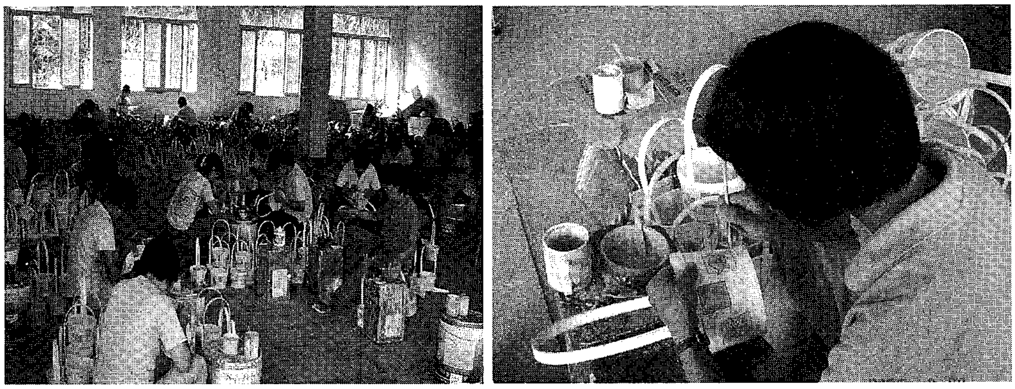


Figure 4 Decorating in the Factory

At present, the utilization of bamboo is no longer confined to private use; bamboo-weaving products are selling well on both the domestic and international markets. The most important use is for baskets that are mainly exported to west countries for decoration use, such as packing the flowers on Christmas or the Thanksgiving.

Before the reform and opening up of China to the outside world, the majority of bamboo raw materials were used for construction, agriculture and utensils. The bamboo processing industry was very outdated. In Xinyi the bamboo-weaving industry, which includes most of the main bamboo products, has expanded enormously over the last 20 years, particularly since the reform of the rural industry and the establishment of private bamboo processing enterprises. The bamboo weaving industry has been growing at an average annual rate of 46.2 % for the period 1990 – 2003. According to the Xinyi Forestry Bureau (2004) in 2003 there were 170 thousand workers participating in bamboo weaving-based activities, with a production value of US $ 186.1 million①. A total of more than 30 processing enterprises and over 80 trade companies are currently operating, with a focus on production for export markets.

Xinyi Hechaheng Bamboo Handicraft Co. Ltd. is a private enterprise with normally 200 staffs, of which include 120 female and 8 managers and technicians. The main products are various woven baskets including small bowls, flower baskets, trays and so on. This factory owns about 7,000 square meters of buildings. The total fixed capital is more than 8 million RMB Yuan, and the total circulating fund is about 4 – 5 million Yuan that includes 1.3 million Yuan loaned from bank. The total annual output value reached to about 10 million Yuan last year. The average wages of employee, calculated based on piece rate, is about 600 – 700 RMB Yuan/

① Exchange rate 2003: US$1 = Chinese Yuan 8.27

person for one month.

The raw materials (bamboo culms) are from both local communities and neighbour counties where it is cheaper than that of local communities. The local farmers weave the articles in their own houses if they have spare time.

Based on survey in this factory, the economic benefits are listed in the Table 1. Main cost of woven products in this factory comes from wages, which occupied about 60% (see Table 1).

Table 1 The Percentages of Economic Component in Total Output Value (%)

Raw materials	Wages	Energy	Rent charge	Tax	Others	Profits
12	60	3	1.5	14	2.5	7

6 Weaving Procedures

6.1 Making Strips and Threads

The bamboo strips and threads are basic materials for weaving various bamboo crafts. Raw materials treatment is a very important procedure that affects the quality of final goods. The processing technology for bamboo strip-making are briefly described as follows:

Bamboo culms ⟶ Cross-cutting ⟶ Knot removal ⟶ Splitting ⟶ Striping ⟶ Width-size ⟶ Thicken-size ⟶ Smoothing

The small size bamboo tip and stout bamboo root ball are removed before bamboo culms are crossly cut to certain length based on requirements of woven products.

Remove waxy epidermis and nodal flange: the waxy epidermis and nodal flange should be removed from culm surface timely, preferable in the same day of cutting, which guarantees the brightness and smoothness of culms. At first remove the nodal flange, and the fix culms on the frame, remove waxy epidermis with a sharp knife quickly, slightly and evenly, without any damage to the surface appearance.

There are two procedures of splitting bamboo culms into pieces. One is that firstly 2 – 3cm vertical line opening are marked out when arranging pieces are carried on in whole bamboo culms, and then split into pieces with knife. Another method is that firstly the culms are split to half-and-half, then split into pieces based on size of strips, close attention should be paid mainly to the smooth pass of nodes through the edge of knife. This operation can be carried out manually or on a machine. Dissected bamboo parts should be put on frames in open air to be dried under the sun with skin side upward. The air-drying process continues until the bamboo skin turns slight yellow or yellowish white. The bamboo parts should not be exposed to the rain for retaining the natural beauty of bamboo surface.

Produce bamboo strips and threads: split bamboo parts vertically along the radius of the cross section into bamboo strips. Cut bamboo strips into bamboo threads according to the requirements of the final products. All the bamboo strips should be of same width and same thickness.

To make whole strip the same width, which avoid to be occurred that one side of strip is width and another side narrow or thickness is asymmetrical.

To make whole strip the same thickness.

To make the strips straight and smooth.

6.2 Weaving Means/Methods

The bamboo thread-weaving method is mostly used for making such articles as baskets, boxes, bottles, jars, dolls and so on. All these goods are woven from their bottom part to up part. After the bottom part is finished, the weaving goes on spirally. Bamboo strip-weaving is used for making bamboo mats and curtains. This kind of goods is usually woven from the middle to borders and corners.

Weaving is key procedure to take shape for final products. There are two sorts that are classified based on whether the threads or strips are used. Products made with threads mainly are subtle one like flask, vase, jar and so on. Products made with strips mainly are case, box, bowel, tray, bag, mat, etc. However, some products are woven with both strips and threads. The means of weaving are classed three sorts that are solid weaving, plane weaving and both solid and plane weaving. The products such as baskets, tray, flask, vase and jar are woven by means of solid weaving, the products like mat for solarization, painting and calligraphy arts by means of plane weaving and that like decoration vase, words and pattern of figures by means of both solid and plane weaving.

Generations of masters of bamboo weaving, by means stitching, layering, inserting, winding stringing and pining, have created hundreds of pattern, most popular of them are cross weaving, V-weaving and circular weaving.

6.3 Procedures of weaving

The main procedures of weaving products (it varies from different products) are design and imagination (especially for handicrafts), selection of raw materials, weaving, decoration, assembly, colouring and painting, which are briefly introduced or prescribed as follows:

To design appearance and pattern of products (especially for woven handicrafts) based on its function and size.

To select bamboo strip based on the precision and size of products. It needs to use fine threads for fine woven products and is available to use thick strips for coarse products.

To choose suitable way and means of weaving based on the characters of designing products. It has different ways and means of weaving from different products, even from same product.

Decoration, a common procedure for woven bamboo handicrafts, aims to gain aesthetic feeling.

To assemble various woven components together as an integrated woven product. Locking stitch is a very important operation in weaving. All kinds of woven goods can not be finished without locking stitch.

The strips or threads are coloured commonly that finished products need before woven. However, sometimes the woven products are coloured after woven. Painting aims mainly for preservation and antimoth (see Figure 5).

Figure 5 Final Bamboo Products

7 Trade and Marketing

Bamboo products have been traded from the raw material production area for centuries, but before 1980, the main commercial bamboo products were raw bamboo materials for construction and some hand-made products such as handicrafts and woven products like baskets. Since 1990, the bamboo weaving industry has developed fast.

The production to consumption system includes producers, intermediates or traders of raw materials, semi-processors, traders of semi-products, final-processors and traders of finished products. Bamboo culms are harvested/collected primarily from bamboo stands, bundled and skidded to the roadside, by the farmers. Here the traders or middlemen may transport the bamboo culms directly to factories, or to someplace near the consumers to sell the bamboo culms to farmers who weave the baskets for semi-products. Then the farmers carried it to collection stations where the factories asked the middlemen to collect the semi-products and convey to factories for final products. Bamboo final weaving products are made in factories. The majority of the finished bamboo products, except for few of that used domestically, are exported, or through trade companies, to foreign countries around the world. The product flows are as shown in Figure 6.

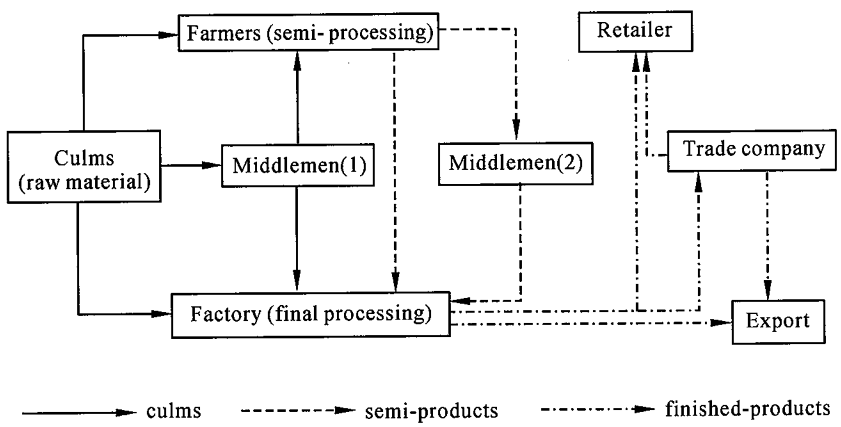


Figure 6 The Distribution Line of Bamboo Raw Materials and Products

A significant component of Xinyi's bamboo production is that the most bamboo weaving products in Xinyi are exported to other countries. It can be seen in Figure 7 that the total exports of Xinyi have grown almost exponentially since 1990, and the bamboo weaving products contributed to the total city exports largely, and has increased in parallel (according to the Xinyi Foreign Trade Bureau). The total export amounted to US $ 186.08 million in 2003. However, partly due to the Asian economic crisis in 1998, and New York terrorism attack on September. 11, 2001, the export value has begun to decline and has recovered since then, and the bamboo weaving products output value has changed in parallel.

Although Xinyi has been, in the past, the city with the rich bamboo resources for the production of raw materials in China, at present the city cannot continue to meet the increasing demands made on the processing industry. Middlemen played an important role in production-consumption of bamboo weaving industry in Xinyi. Information gathered during the survey by Xinyi Forestry Bureau indicates that there are about more than 1,000 special households or cooperate households who participate in trade and transportation of bamboo culms, which are usually collected from neighbour counties, such as Luoding and Gaozhou county of Guangdong Province and Beiliu and Liangxi County of Guangxi Zhuang Autonomous Region. Figure 8 shows the place of raw materials for sale by middlemen who transplanted the bamboo culms from the neighbour counties. The collecting price of bamboo culms in 2004 is about 0.25 - 0.3 Chinese Yuan/kg and the sale price is 0.4 Chinese Yuan/kg averagely, the bigger one may reach to 0.7 Chinese Yuan/kg. They usually transported one time in three days, and only in Huaishan township, 300 - 400 tonnes of bamboo raw materials were imported from neighbour counties.

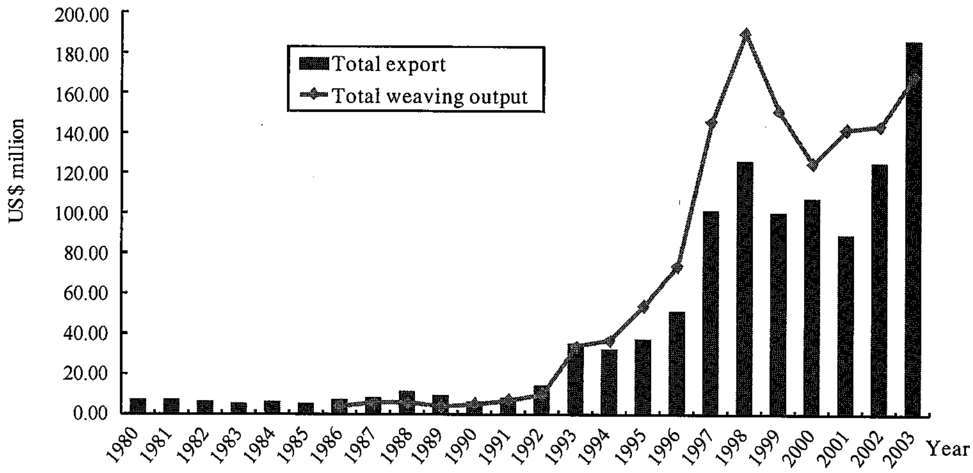


Figure 7 Total Export and Output of Xinyi

Figure 8 Bamboo Raw Materials for Sale

Figure 9 Weaver Carrying to Collection Station

Figure 10 Collection Station

In addition, there are also more than 1,000 semi-product collection stations in whole City, and just in Huaishan Township there are about 150 stations where the middlemen collect the semi-products that the weavers (farmers) carried to (see Figure 9 and Figure10), and then it transported to factory for further processing, such as preservation, decoration and packing.

8 Social Aspect

8.1 Labour

The weaving industry for bamboo products has mostly small-scale and labor intensive for both men and women. Its role in employment generation has been significant and particularly beneficial to the social economic development of rural sector. Bamboo weaving work, like other bamboo handicraft work, provides supplementary income for many villagers in Xinyi City. There are shortages of agriculture lands but abundant hilly lands and labor resources in the mountainous areas. The development of bamboo sector in both forest management and product processing can generate income for local community and provide employment opportunities for rural and suburban surplus labors.

8.2 Gender and Children

The role of women in meeting their household's basic food needs varies from society to society. Generally, men have greater access to the cash economy and often generate cash as their primary activities, while women's activities revolve more around the subsistence needs of the households' most particularly food production, feeding livestock and child care. In fact, the women (as well as old person) are often involved in bamboo weaving industry-based income earning activity in Xinyi City due to its easy extension of technology with low investment and generating income fast. Most of farmers in Xinyi City realized that it is a good way to improve the living condition by developing bamboo sector.

9 Efforts to Promote the Bamboo Sector

Although bamboo has numerous uses, partly due to widely utilization of plastic and metal products, most of woven commodities are traditional and low-value products in Xinyi City. The potential for high value addition has not been fully explored by now. Further development of bamboo weaving industry needs to develop new products, improve the utilization rate of bamboo raw materials and value addition so as to enhance the competence and easy access to international markets.

The majority of bamboo weaving-based manufacturers in Xinyi, either of one-man-show style, family oriented or part-time type of businesses, can neither expand technological capabilities effectively and acquire permanent business sites owing to their minimal academic background and lack of capita, nor conduct market surveys to keep abreast with business trends and accepted products. In the export market, low prices offered (even though for bigger volume) for a relatively high quality product deterred them from entering these markets. So, it is essential to help market development and effective linkages, enhancing technology adoption and commercialisation, and strengthening institutional networking to share knowledge for manufacturers by government.

In addition, in order to transform what used to be looked upon as lowly material into attractive woven handicrafts that caters to the sophisticated tastes of urban consumers showcases, the designs and imagination, creativeness and technology like preservation technology of anti-decay and antimoth should be improved. Aside obtaining various knowledge and designs on manual artistic skill work from other sources to be delivered to the interested local work-force, more diversified value-added products integrated from different cultures could also be expected. And continuing research and development in response to dynamic changes in markets, and to address medium and long term objectives, is necessary.

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