BAMBOO, PEOPLE AND THE ENVIRONMENT
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and the IV International Bamboo Congress
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Volume 1
Propagation and Management

General Editors
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## Contents

**Foreword** v

**Preface** vii

**The Global Environmental Debate: the Role of Bamboo**
Salleh Mohd. Nor 1

**Enhancing the Availability of Improved Planting Materials**
I.V. Ramanuja Rae and Alfinetta B. Zamora 6

**Bamboo Production Systems and their Management**
FuMaoyi and R.L. Baniak 18

**Propagation of *Guadua angustifolia***
Hormilson Cruz Rios 34

**Growth of Phyllostachys sp. in Peninsular Malaysia**
Abd.Razak Othman and Aminuddin bin Mohamad 39

**Propagation of *Gigantochloa levis* by Branch Cuttings**
Abd.Razak Othman and Normah Mohd.Noor 44

**Cultivation Techniques for *Dendrocdamopsis oldhamii***
Lin Quingyi 50

**Mass Propagation of Tropical Sympodial Bamboos through Macroproliferation**
Adarsh Kumar 56

**Commercialization of Bamboo Tissue Culture**
Sanjay Saxena and Vibha Dhawan 62

**Studies on Micropropagation of *Dendrocalamus giganteus* and *Bambusa vulgaris var. striata***
S.M.S.D.Ramanayake, K.Yakandawala, P.K.D.NilminiDeepika and M.C.M. Iqbal 75

**Effects of Fertilizing and Harvesting Intensity on Natural Stands of *Gigantochloa scortechinii***
AzmyHj. Mohamed 86
Shooting Period of Sympodial Bamboo Species: an Important Indicator to Manage Culm Harvesting
Achmad Sulthoni

Effects of Mulching on the Shoot Production of *Phyllostachys praecox* Stands
Cao Qungen, Feng Shixiang and He Yuexiang

Seasonal Change of Photosynthesis Rate and its Relation to the Growth of *Phyllostachys bambusoides*
Hiromichi Koyama and Etsuzo Uchimura

Anatomical Studies on the Rhizome of some Pachymorph Bamboos
Ding Yu-Long, Tang Geng-Guo and Chiao Chison

Ageing of Bamboo Culms: a Review
W. Liese and G. Weiner

Malaysian Bamboo: Research Priority Areas
Aminuddin bin Mohamad

Recommendations
The Vth INBAR International Bamboo Workshop was jointly held with the IV International Bamboo Congress from 19 to 22 June 1995 in Ubud, Bali. The Workshop was organized under the auspices of the International Network for Bamboo and Rattan (INBAR) and the Congress under the banner of the International Bamboo Association (IBA).

Over 600 people from different walks of life - scientists, engineers, architects, designers, crafts people, environmentalists, rural development experts, government officials and plain bamboo enthusiasts-congregated at Ubud to partake in the five-day event of the year. Several representatives of the Indonesian government, international organizations, diplomatic community, and local and foreign media attended the Bali Congress. A large number of scientists participated in the intensive and keen scientific discussions at the 15 scientific sessions.

That the event was such a huge success was largely due to the painstaking efforts put in by a number of people from the organizations involved, particularly by Dr Elizabeth Widjaja, Ms Linda Garland and their team at the Environmental Bamboo Foundation, which was the local host. It also made a great difference that the International Plant Genetic Resources Institute (IPGRI) and the Government of the Netherlands actively supported some of the scientific sessions. It would only be appropriate here to thank all of them.

The Bali Congress was held at a time when bamboo and other forest resources were being increasingly subjected to overexploitation and unsustainable use. This aspect was integral to the theme of the event - Bamboo, People and the Environment. Several papers and posters were presented at the Congress on subjects ranging from bamboo propagation techniques to anatomical studies on pachymorph bamboos, from the role of bamboo in rural development to use of bamboo in religious rituals, from bamboo conservation strategies to use of molecular markers, and from design input into bamboo crafts to bamboo building codes.
In compiling the proceedings, we decided to make a departure from the previous practice of gathering all the papers in one large volume. We felt that segregating the papers presented at the sessions into different subject areas would provide a sharper focus, and presenting them as handy volumes would serve the readers better. Consequently, the proceedings are being published in four volumes: Propagation and Management, Biodiversity and Genetic Conservation, Engineering and Utilization, and Socio-economics and Culture. The last volume, Socio-economics and Culture, also contains the list of participants.

These proceedings are being published with financial assistance from the International Development Research Centre, the International Plant Genetic Resources Institute, the Government of the Netherlands and the Environmental Bamboo Foundation, which is gratefully acknowledged.

We have taken care to ensure that this publication imbibe the essence of the Bali Congress. Dr Elizabeth Widjaja, Dr P.M. Ganapathy, Dr Jules Janssen, Dr V. Ramanatha Rao, Mr. Brian Belcher and Prof. Trevor Williams have very kindly assisted with the technical editing of the papers, and we thank them for their time. We hope that you, as reader, would derive as much satisfaction as we did in bringing *Bamboo, People and the Environment* to you.

I.V. Ramanuja Rao  
Cherla B. Sastry  
*General Editors*
Preface

This volume is the first of the four-volume series *Bamboo, People and the Environment*, which cover the proceedings of the Vth INBAR International Bamboo Workshop and the IVth International Bamboo Congress, jointly held in Indonesia from 19 to 22 June 1995. It contains papers presented in the subject areas of propagation and management of bamboo.

Although the papers are not grouped into sections, it is apparent that they cover aspects of basic science—anatomy and ageing of culms, shootting periodicity and growth rates, etc.—which are essential to applying research to development of more efficient and better production systems.

Several papers address applied research, particularly in relation to propagation, cultivation techniques and management of bamboo stands. Great strides have been made in the past decade on modifying traditional methods of propagation to ensure better success, and techniques have been made applicable to a wider range of species. At the same time, the increasing demands for planting materials have resulted in research on mass propagation, making the propagation process more rapid. It is evident that the process can be commercialized for a number of major economic species, and this must be implemented speedily in view of the current scarcity of planting materials.

Increased production can result from several interventions, from simple management of stands to more intensive cultivation with its attendant inputs such as fertilizers. However, improved production can only be sustained into the future by paying strategic attention to improvement of planting materials. All these aspects were touched upon when an INBAR workshop in 1994 addressed the constraints to production.

I.V. Ramanuja Rao
Elizabeth Widjaja
Editors
It is heartening to see continued research in so many countries addressing diverse constraints to production. At the level of national programs, however, a more integrated approach is needed, so that production in the early years of the 21st century will meet the expected demands and will be sustainable.
The Global Environmental Debate: 
the Role of Bamboo

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Abstract

The paper explores the role of bamboo as an eco-friendly material in addressing environmental problems. Bamboo - and research and development in bamboo - has the potential to provide the technological and hence the economic options that developing countries need. The characterisitics of bamboo desuibeds of a rmake it a promising all yinenvironmental conservation efforts. If its full potential could be realized, bamboo will no longer be just “the poor man's timber”, but a material with very valuable and diverse applications. Research must be made to play its crucial role in achieving this end.

The Need for R&D

Bamboo – a word that conjures up different images in the mind; images of construction material, furniture, handicrafts, basketware, matting, rayon, paper, food, fodder and fuel wood. No wonder then, that this resource has been variously called “the poor man's timber”, “the cradle-to-coffin timber” and “green gold”. Although bamboo is found growing naturally in all continents except Europe, it is in the developing world that it has had the greatest impact on humankind; hence, its identification with the poor. In Asia, the history of bamboo is so inextricably interwoven with human history that one could describe a bamboo civilization in the continent. Globally, 2.5 billion people -almost half the world population-are estimated to use bamboo in one form or other.

The Need for Options

Research and development (R&D) hold out the possibility that bamboo can replace wood and steel, and need no longer be identified
solely with the poor. It has been said that science and technology is like a
steamroller, and that countries are either part of the steamroller or part of
the road on which the steamroller runs. Most countries in the developing
world are not considered part of the steamroller but of the road. This is
basically because of poor organizational capabilities in R&D in these coun-
tries, and this state of affairs needs to be critically examined.

It is not from the perspective of bamboo alone but from all perspec-
tives that one needs to consider options, since people become victims of
circumstances usually because of poor management options. The under-
lying reasons for investing in R&D must be the belief that totally new options
are created through R&D, and that new options are needed because the
future is not going to be the same as the past. Old skills and products
become obsolete, traditional resources get depleted, and social changes
may be unpredictable and unstoppable. Countries that have not taken the
proper steps to develop such options have inevitably stagnated. Many
primacy commodity countries—the so-called coffee countries, banana coun-
tries, cocoa countries, and tin countries—are unable to do anything except
hope for prices to rise, and in the meantime survive at subsistence levels
owing to lack of options. Expansion of production of whatever these coun-
tries already produce hardly helps because price may merely be driven
downwards. To quote from a special message by President Truman to the
US Congress on the day the atom bomb was dropped on Hiroshima:

"No nation can maintain a position of leadership in the world of
today unless it develops to the full its scientific and technological
resources. No government adequately meets its responsibilities
unless it generously and intelligently supports and encourages
the work of science in universities, industries and its own labora-
tories." (Truman, cited in Morin 1993).

It is now 50 years since that message was delivered, and science and
technology has become the great divider separating the technological lead-
ers and the followers, between countries that generate change and countries
that are victims of change. While all countries have made some attempt to
develop national scientific and technological resources, most have done
badly. The blame is usually put on the lack of financial resources for
research. Indeed, if we compare the national expenditure on research, it
is evident that industrial countries spend a lot, while developing countries
spend little on research. The perception that money is the main factor
controlling research effectiveness has given rise to a number of prescriptions, the more familiar of which are:

- Avoid basic research;
- Concentrate on adaptive and applied research;
- Follow standard methodologies;
- Rediscover traditional and indigenous knowledge;
- Privatize and concentrate on fewer projects;
- Avoid duplication; and
- Get end-users to determine what research should be done.

All these prescriptions have been tried but with little success and therefore, one begins to suspect that the remedies must be wrong. They are wrong because they have reduced options in R&D and therefore in economic development. In the industrial countries, there is a prolificacy of research - basic, applied and reductive. Uncontrolled duplication between research organizations and individuals, as well as the range of research topics, keeps expanding and changing. They have a profusion of options, and R&D generates plenty of new ones continuously. This is the route that must be followed in R&D in any area, including on bamboo.

The Role of Bamboo

Can bamboo, through innovative efforts, have further environment-friendly use in the construction industry? Is a paradigm shift possible, whereby expensive and environment-unfriendly materials like steel, for example, could be substituted by bamboo in the road construction sector? We already know that bamboo has the mechanical and strength properties to withstand considerable stress. Could we not make innovative use of this knowledge to reinforce soil structures and hence, the stability of slopes in road embankments, particularly along highways, using bamboo rather than steel? Road and highway construction is an expensive necessity in developing countries and success in the use of bamboo in reinforcing soil structures would cut down costs considerably. Initial studies at the Forest Research Institute Malaysia (FRIM) have shown that bamboo could be used to reinforce embankments, and this option needs to be explored further.

Bamboos are known to have strong and long fibres, which are widely used for pulp and paper. With fibres being increasingly used in industry, one needs to examine whether bamboo fibres can be used singly or in combination with modern materials for new uses. Can bamboo fibres play a role in the new high-technology industries, incorporating the natural
strength and characteristics of bamboo with modern materials, such as plastics and ceramics?

The global 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 atmosphere and consequently, to limit the rise in the ambient temperature of the earth. A focus of this climate change debate has been the role of forests, and especially tropical forests – be they primary, logged and regenerating, secondary, or plantation forests – in sequestering carbon. While data available are generally estimates, net primary productivity involving carbon sequestration is accepted to be highest in logged and regenerating forests. No information is available on the carbon sequestration potential of any single species in a natural forest, but one could predict on the relative rates of certain species by knowing something about their growth. For example, we know that in the natural forests of the tropics, bamboo spreads gregariously where there is disturbance by logging and shifting cultivation activities. We also know that 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. Add to this the estimate that a bamboo clump can produce in its lifetime up to 5 km of poles of 30 cm in diameter, and one gets a plant species that is vigorous and dynamic in growth. The carbon sequestration ability of such a species is likely to be second to none and if at all, only to a very few. If one considers the fact that the great majority of 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 global accounting of carbon sequestration by bamboo alone could be quite significant.

An aspect that requires further investigation is the role of bamboo in soil conservation. Soil is the most important resource in tropics. It is the soil that allows for the luxuriant vegetation that one sees throughout the non-seasonal and-seasonal tropics. But it is also that which is most easily lost when exposed to the high-intensity rainfall of the tropics. Bamboo, with its fine mat of fibrous root system, is efficient in binding soil particles together. How can this knowledge be used effectively in soil conservation programs in the tropics? What are the technological advances that are
required to produce cost-effective planting materials of useful bamboo species which can be transported cheaply to badly exposed, impoverished areas that abound in the tropics, so that satisfactory planting programs can be initiated to rehabilitate the land that has ceased to be directly useful to the people?

As said earlier, in the tropics bamboo spreads gregariously where there is disturbance of the natural forest. This brings up the question: can bamboo be used as an indicator species with regard to biodiversity? There is one school of thought which says that biodiversity is highest in tropical forests that are in an intermediate state of disturbance compared to forests in the secondary or climax state. What species of bamboo in any regional setting characterize what levels of disturbance and, by extension, the state of biodiversity in any forested area? This and other related questions are worthy of consideration in the overall context of forests and the environment.

**Conclusion**

Although bamboo has been called “the poor man’s timber” and is associated mainly with the poor, there is no reason why there should not be a change in perception. Application of science and technology can provide further options in the use of bamboo. Bamboo could replace wood and steel in some uses with the right approach in R&D. There is need for a paradigm shift, for increased options in R&D, in both basic and applied research, and ultimately in our economic development. This paradigm shift should take cognizance of the fact that bamboo is an environment-friendly resource that fulfills environment-friendly functions, as illustrated by the few examples given earlier. Most of all, this paradigm shift should be one that moves away from the feeling of being ashamed of bamboo as an inferior resource to the feeling of pride of a resource that, through proper R&D, would be able to replace the presently more popular materials as reinforcement structures.

When compared with other produce such as rice, potato or corn, the amount of funds spent for bamboo R&D is minuscule. There needs to be a greater infusion of funds and resources for R&D in bamboo. The recent recognition of non-wood forest products (NWFPs) as an important potential resource by the Ministers of Forestry Meeting, organized by the Food and Agricultural Organization in Rome, was long overdue. But action must follow words. The list of NWFPs is long, but bamboo definitely is a leader in that list. It awaits our attention.
Enhancing the Availability of Improved Planting Materials

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Abstract

The availability of improved planting material of bamboos can be enhanced by applying the best available propagation techniques that overcome the restrictions imposed by the nonavailability of seeds and other factors influencing the propagation system, and identifying better sources of seeds or elite planting stocks. But above these technical considerations, is the need for an orchestrated program to determine the requirement for planting material and of motivating the private sector to produce and use the planting material.

Introduction

Bamboo has been traditionally harvested from public lands in Asia. Very little intervention in terms of purposive planting, in comparison with areas harvested, has been done in the past. In rural areas, homesteads may have a few clumps of one of the many species of bamboo for household use such as construction of homes, sheds and fences.

The demand for bamboo has increased in recent years in several Asian countries as a raw material for furniture making, as panel boards in lieu of wood, as a vegetable, and for other uses apart from the traditional agriculture and construction-related uses. Plantation development has come to focus on high-demand bamboo species, including *Dendrocalamus latiflorus* (in China, for bamboo shoots), *Bambusa blumeana* (in the Philippines, for furniture making), and *Bambusa philippinensis* (in the Philippines, for banana props) (Alfonso 1988; Caasi 1988). Furthermore,
the loss of forested areas that has led to soil erosion, the difficulty in replanting degraded areas with trees and the desire of communities and governments to rehabilitate such degraded areas have all contributed to bringing bamboo to the fore as a reforestation plant material. However, factors associated with traditional types of planting materials for bamboo limit the acceptance and use of the plant for reforestation.

**Supply and Demand Scenario**

The supply and demand scenario in bamboo-producing countries indicates that demand is greater than the supply (Ramanuja Rao 1994). It is only in Japan that demand for bamboo has declined (Watanabe 1994) because many traditional uses of bamboo have been replaced with petrochemical derivatives, and also because lifestyles have changed. In the Philippines, for example, the demand and supply balance sheet for *Bambusa blumeana*, *Dendrocalamus merrillianus*, *B. vulgar-is* and *Schizostachyum lumampao* indicated that self-sufficiency of the particular region understudy was only 32%, 36%, 49% and 59%, respectively, for the different species (Uriarte and Pinol 1992). The disparity between demand and supply was met by imports from other regions of the country. Unless purposive plantation establishment is done to meet the needs of the bamboo industry, the present situation may lead to rapid loss of natural stands of bamboos.

**Current Methods of Propagation**

Plant propagation techniques of bamboo, recently reviewed by Banik (1994), include the use of seeds, seedlings or juvenile plant stocks, as well as mature clumps. Techniques of asexual propagation in the nursery or planting sites have been in place for sometime, using conventional methods such as divisions, macroproliferation, rhizomes, offsets, layering, marcotting, and culm and branch cuttings.

In the last 10 years, advances in plant morphogenesis, particularly in tissue culture, have enabled *in vitro* propagation of bamboo. Table 1 summarizes the application of various propagation techniques in the laboratory and in the nursery for the INBAR priority species. Perhaps, an assessment of the INBAR priority species is in order, considering that the absence of reports on some of the species may indicate that other species are of greater importance to bamboo-producing countries in Asia.
### Table 1: Propagation techniques applied to various INBAR priority bamboo taxa

<table>
<thead>
<tr>
<th>Bamboo taxa</th>
<th>Laboratory</th>
<th>Methods of propagation</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Somatic embryo-germination</td>
<td>Multiple shoot formation</td>
</tr>
<tr>
<td><strong>Bambusa bambos</strong></td>
<td>X</td>
<td>X</td>
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<tr>
<td><strong>B. blumeunu</strong></td>
<td>X</td>
<td>X</td>
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<tr>
<td><strong>B. polymorpha</strong></td>
<td>X</td>
<td>X</td>
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<tr>
<td><strong>B. textilis</strong></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>B. tufida</strong></td>
<td>X</td>
<td>X</td>
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<tr>
<td><strong>B. vulgaris</strong></td>
<td>X</td>
<td>X</td>
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<tr>
<td><strong>Cephalostachyum perigracile</strong></td>
<td>X</td>
<td>X</td>
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<tr>
<td><strong>Dendrocalamus asper</strong></td>
<td>X</td>
<td>X</td>
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<tr>
<td><strong>D. giganteus</strong></td>
<td>X</td>
<td>X</td>
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<tr>
<td><strong>D. latiflorus</strong></td>
<td>X</td>
<td>X</td>
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<tr>
<td><strong>D. strictus</strong></td>
<td>X</td>
<td>X</td>
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<tr>
<td><strong>Gigantochloa oryzoptera</strong></td>
<td>X</td>
<td>X</td>
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<tr>
<td><strong>G. levis</strong></td>
<td>X</td>
<td>X</td>
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<tr>
<td><strong>G. pseudvarundinaria</strong></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Guadua angustifolia</strong></td>
<td>X</td>
<td>X</td>
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<tr>
<td><strong>Melocanna baccifera</strong></td>
<td>X</td>
<td>X</td>
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<tr>
<td><strong>Ochlandra</strong></td>
<td>X</td>
<td>X</td>
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<tr>
<td><strong>Phyllostachys pubescens</strong></td>
<td>X</td>
<td>X</td>
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<tr>
<td><strong>Thysostachys siamensis</strong></td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

1 Including pre-rooted, pre-rhizomed branch cutting; X = Applied; NI = No information.

Source: Papers by Banik (1994) and Zamora (1994)
Nursery techniques

Nursery techniques include divisions, macroproliferation, rhizomes, offsets, layering, marcotting, and culm and branch cuttings. The application of a propagation technique is influenced by the bamboo species (Banik 1994), the ease of the technique, the availability of moisture and the availability of seed. With regard to choice of plant material for propagation, in general, it becomes more difficult to propagate bamboo as the propagator goes from the rhizome, to the culm and to the branch (Ramanuja Rao 1994). The nursery techniques lead to planting materials of different sizes; with seed/seedling-derived plants being smaller and compact than those derived from culm cuttings, dump divisions and other techniques making use of bigger plant stocks. In general, the conventional methods of propagation lead to bulky and heavy plant propagules, making them difficult to transport to reforestation areas. Nurseries are often not strategically located to facilitate transport and planting. The choice of the location is usually based on workforce and water availability and thus, the nursery is generally sited near the experiment station.

Laboratory techniques

Tissue culture methodologies have been sufficiently developed for a few species of bamboo- such as Dendrocalamus strictus, D. longispathus, Banzbusa bambos and B. tulda – so that the whole protocol can be repeated on a larger scale as needed for commercialization.

The methodologies successful for micropropagation include somatic embryogenesis for D. strictus and B. bambos using seed-derived explants (Ramanuja Rao and Usha Rao 1990; Zamora and Gruezo 1990), multiple shoot formation using in vitro germinated seedlings for B. tulda (Saxena 1990), D. strictus (Preetha et al. 1992) and D. brandisii (Vongivitra 1990) and forced axillary branching from adult clumps in D. longispathus (Saxena and Bhojwani 1993). Reviews on the status of micropropagation research, worldwide and in South Asia (Saxena and Dhawan 1994; Zamora 1994) have highlighted the many attempts on bamboo tissue culture using various approaches.

Considerations on Selecting the Propagation Method

The primary consideration is the availability of choices among the propagation methods. Table 1 indicates the available procedures for INBAR priority species. It appears that some species, but not others, are amenable
to particular propagation techniques and/or that the propagation technique have not been tested/applied for some of the species. Among the species, *D. strictus* is the best studied for laboratory and nursery techniques, followed by *B. bambos*. There is also a relative lack of knowledge on a few priority species, such as *Cephalostachyum pergracile*, *Gigantochloa pseudoarundinaria*, *Guadua angustifolia* and *Ochlandra*.

In bamboo, the choice of the propagation technique should be influenced by the objective of the plantation. For reforestation projects, wherein vast areas need to be planted, a rapid propagation technique is desirable, and the planting materials produced by the technique should remain vegetative for as long as possible. The basis of this consideration is the observation for some species where flowering of the mother clump and the asexual propagules from this clump simultaneously occurred (Ramanuja Rao et al. 1990). Ramanuja Rao (1994) cites the example of *Dendrocalamus asper* flowering in Thailand. Therefore, the latter requirement is met when the propagation technique employed is seed-based, or makes use of seedling or juvenile materials. It has also been suggested that propagules derived from somatic embryogenesis would live their whole life span (Ramanuja Rao and Usha Rao 1988).

In cases where the objective of the plantation is to harvest as soon as possible for income generation, the approach has to consider generating planting materials from mature dumps which yield propagules with a very short “waiting period” before harvestable culms can be obtained. Community-based reforestation projects should therefore take this consideration into account. When the objective of the plantation is to establish clones of a superior or elite bamboo, only mature clumps need be considered for propagation.

**Improved Planting Material**

The constraints in the production and transport of bamboo planting material produced by conventional methods lead us to ask, “What do we consider as an improved planting material? How do we enhance their availability?”

Improvement in planting material can be perceived from the point of view of better populations and selected mother stocks (elite plants), or from the point of view of the propagation technique by which it results. Technically, an ideal propagule must have a well-developed root system, rhizome and shoots. Many propagation techniques would yield
propagules that meet these requirements. However, an ideal planting material should also address the needs of the end-user, a consideration which is limited by the present level of technical expertise on a per species basis.

**Seeds**

Bamboo seeds are very convenient for propagation and transport, particularly to areas difficult to reach by road. Where numbers are the primary concern of the end-user, seeds are the ideal planting material to be used. In species that flower gregariously, seeds can be collected. However, many important species flower infrequently or are considered sterile and other propagation techniques, used either independently of the seed or coupled to seed germination to increase propagants, need to be considered.

The approximate number of seeds/kg varies with species: for example, 90,000 seeds/kg for *Bambusa bambos*; 26,000 seeds/kg for *B. tulda*; 150,000 seeds/kg for *Dendrocalamus longispathus*; 40,000 seeds/kg for *D. strictus*, and only 70 pieces/kg for the pea-like seeds of *Melocanna bambusoides* (Ramanuja Rao 1994). Based on the studies of Zamora and Gruezo (1994) on *Gigantochloa levis*, it is estimated that there would be 30,000 seeds/kg for the species.

**Asexual propagation**

Asexual propagants would most likely make use of mature clumps or seedlings, when available. The seedling-based propagation would be most useful even if the quantity of seed available is limited. For asexual propagants, the characteristics of an ideal planting material include weight, compactness, sufficient vegetative growth, presence of strong rhizome growth and good root system. These characteristics would permit ease of packing and transport, high survival upon field transplanting and good growth rates. Among the types of propagules offered by different propagation techniques, these characteristics are met by tissue culture-derived materials, seed/seedling-based propagules, macroproliferation, and to a certain extent, by branch cuttings, pre-rooted/pre-rhizomized branch cuttings and branch marcottage.

**Micropropagation**

Plants arise from calli, somatic embryoids, aseptically germinated seedlings, and rooted shoots derived from multiple shoot cultures *in vitro*. These
can be made available to the public at several stages ranging from cultures and unhardened ex vitro plantlets to hardened plants which are two or more months old (from potting) (Ramanuja Rao 1994).

The plants obtained through micropropagation based on methodologies using seeds and seedlings are similar to the seedling material, juvenile in appearance with “weedy” stems, and progress through growth phases akin to seedlings. However, plantlets of *Dendrocalamus latiflorus*, obtained adventitiously from callus generated from rhizome and internode calli, shifted to a culm growth habit similar to cutting-derived planting material within a year in the greenhouse (Zamora et al. 1991).

The tissue culture-derived plants form rhizomes even in culture (Ramanuja Rao and Usha Rao 1988). These structures are also favoured by the use of potting mixes with high organic matter for the tissue-cultured plants; well-formed rhizomes were obtained in soil:compost (1: 1, v:v) and soil:sand:compost (2:2:1, v:v) at three months after potting out from culture vessels (Zamora et al. 1992). The development of rhizomes in tissue culture-derived plants enabled their early planting in the field (four months after transplant) in the monsoon season (95-100%). Plants transported to the site at four months of age showed higher survival (100%) compared to those at eight months of age (97.5%). At three to four months of age, tissue cultured plantlets are still in small plastic cups. This compact size and low weight (mean weight of 168 g/potted plant) greatly facilitate transport of greater numbers needed in mass planting. Volume and weight of traditional planting materials are two factors that reduce the quantities that can be transported at any one time. Banik (1994) estimates that the weight of rhizome offsets ranges from 4-30 kg each, making them difficult to handle and transport. This weight would approximate 21-160 potted tissue culture-derived plants.

**Seed and seedling-based propagation (nursery)**

Seedlings may be multiplied by rhizome separation (Banik 1987) leading to smaller-sized planting material. Banik (1987) subsequently called the technique as macroproliferation, and projected that the application of this technique on *Bambusa tulda* seedlings of 5-9 months would increase the number of propagules by 3-5 times per year, with 90-100% survival of propagules. This method has been demonstrated in *B. bambos, B. tulda, Dendrocalamus strictus* and *D. hamiltonii* (Banik 1994). In the Institute of Plant Breeding (Philippines), rhizome division technique has been
applied on Schizostachyum lumampao (Zamora and Gruezo 1994). It was noted that the source plants with small mean stem diameters (1.3-1.8 mm) yielded propagules that produced new culms earlier than source plants with bigger stem diameters (3.2 mm), and that more stems were developed with the smaller-stemmed source plants than bigger-stemmed source plants. Propagules need have only one stem as long as the rhizome is intact.

However, seed/seedling-based propagation is limited to seed-bearing species and leads to planting material with a longer juvenile phase, a characteristic which commercial enterprises may not find desirable as this prolongs the gestation period of a project. It is because of this consideration that those engaged in livelihood prefer traditionally produced planting material.

Other propagation methods

Among the traditionally produced materials, the pre-rooted/pre-rhizomed branch cutting methods may produce smaller propagules. These approaches have been noted by Banik (1994; Table 1) to have been used on nine out of the 20 INBAR priority species. These techniques are difficult to use on thin-walled bamboo species (Banik, 1987).

Smaller-sized propagules are also possible with branch marcottage, a technique wherein the base of the branches are wrapped with moist spagnum moss and enclosed in plastic to permit rooting during monsoon months. This was developed by Alfonso (1988) for Bambusa blumeana.

Enhancing the Availability of Planting Material

How do we enhance the availability of improved planting materials? How can we view the problem of production of planting materials? Aside from the technical aspects, namely the propagation techniques and source of propagules, the availability of improved planting material can be influenced by an orchestrated program to determine the requirement for planting material and of motivating the private sector to produce and use the planting material.

Communities, in general, utilize the forest in a sustainable manner. However, business – the bigger user of bamboo – should be encouraged to engage in plantation development instead of harvesting from public land to meet its demand for poles. Ensuring the involvement of the community residing near the site of reforestation or plantation development, greatly increases the possibility of project success. Existing clumps of the targeted
species are potential initial resources for application of improved propagation techniques.

A community-based nursery, within the framework of a cooperative is exemplified by a project on bamboo dispersal in Davao (Caasi 1988). Initiated because of increasing difficulty in gathering poles of *Bambusa philippinensis* to support the banana industry, bamboo plantation development proved to be a solution to Caasi and those in their cooperative. Not only did he organize a cooperative but also experimented to improve traditional methods of propagation using culm cuttings and offsets by the “incubation approach”, in which the cuttings are sprouted and rooted in the nursery in a high-humidity environment created using plastic covers or misting. In 1988, the Davao Bamboo Development Cooperative Inc. had 231 members who had planted 372 hectares of bamboo from January to December. Members availed of loaned sprouted cuttings, payable in poles/planting materials upon harvest.

Another example in the Philippines of private sector initiative is that of Alfonso (1988) who experimented to develop his own propagation technique akin to air-layering for *Bambusa blumeana* in order to produce planting materials for bamboo plantation establishment. His motivation was to help government and private sector “green” the land and to have a supply of culms of the bamboo for the family enterprise on furniture.

In the examples of private sector intervention cited above, the proponents not only had monetary interests in the undertaking but also a commitment to improve their environment.

Government incentives to business, and raising the social consciousness of business in terms of resource depletion and renewal, are two strategies that could lead to greater private sector intervention.

In the case of new technologies, such as tissue culture, as well as improving traditional technologies of propagation, support to research and pilot projects would hasten technology development. However, a cooperative effort would have to be made by scientists, government foresters and communities for these techniques to be taken out from the laboratories to the field.

**Significant Research Achievements on Planting Material Production**

Significant research works on production include the development of tissue culture technique and technologies for propagation for several economically important species as reviewed by Saxena and Dhawan (1994)
and Zamora (1994), in vitro flowering (Ramanuja Rao and Usha Rao 1990; Nadgauda et al. 1990; Chambers et al. 1991) and artificial seeds (Mukunthkumar and Mathur 1992), and further refinement of nursery-based propagation using seedlings and young plants as reviewed by Banik (1994).

Research on the use of somatic embryogenesis technique on various bamboo species leading to the production of somatic embryoids, when coupled with research on artificial seeds, could provide “seeds” for bamboo species which flower infrequently or are considered sterile/highly sterile.

**Specific Gaps in Research Coverage**

**Micropropagation studies**

Basic research on bamboo tissue culture propagation for priority species should be encouraged. Micropropagation has, advanced in the case of a few species of bamboo, but many priority species remain to be subjected to research in order to develop appropriate micropropagation systems.

**Biological clock**

The so-called “biological clock” in bamboos should be further documented with several agencies and countries participating in this long-term research, particularly since this aspect influences research and production programs. Whether or not somatic embryo-derived populations are similar to embryo-derived populations is best answered by actual comparisons.

**Acceptability of the product**

The general unacceptability of tissue cultured propagules, specially among foresters, is a problem that need to be resolved in bamboo-producing countries. In countries such as India, where tissue cultured plantlets were put in the field earlier, monitoring results from foresters could encourage foresters in other countries.

**Redirection of focus on type of planting material**

Research on conventional methods of propagation that result in smaller-sized propagules akin to tissue culture-derived materials should be encouraged. The limitations of existing technologies need to be faced with fresh initiatives in the area of nursery propagation.

**Enhancing biodiversity**

Lastly, possible introduction, propagation and field trials of bamboo species in other countries would enhance their bamboo diversity.
References


Bamboo Production Systems and their Management

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Abstract

Based on bamboo production in China, Bangladesh, India and Thailand, the paper introduces, reviews and evaluates the production systems and the management of monopodial and sympodial bamboo stands in the tropical and subtropical parts of the world. The discussion covers bamboo stands which have single or multiple purpose – for timber, shoot, pulp, ornamental use, soil and water conservation, etc. The management of bamboo in homesteads and agroforestry, as well as significant research covering the different disciplines involved in bamboo production in Asia are also reviewed. Specific gaps in current bamboo research are identified, and the ways in which these gaps can be filled are explored.

Introduction

Bamboo occurs naturally in four of the five continents (except Europe) of the world and is found mainly in the wide belt between the Tropics of Cancer and Capricorn, as well as the adjacent temperate and subtropical areas. Over 70 genera of bamboo with about 1,200 species have been reported to be growing in natural stands or plantations, covering an area of more than 14 million hectares globally (Table 1). The bamboo-growing areas in the world are divided by oceans into three natural distribution regions – the Asia-Pacific region, the American region and the African region.

Morphologically, all bamboo species can be categorized as monopodial, sympodial or amphipodial, with each group containing species grown
for industrial, agricultural, ornamental and/or ecological purposes. Although there are some general principles that can be followed in bamboo cultivation, it is essential that the management, cultural practices and research methods adopted be suitable to the growing area, the species cultivated and the purpose of cultivation. This paper will be discussing the present status and future prospects of bamboo cultivation and research, based on experiences in the Asia-Pacific region, particularly in China, India, Myanmar, Thailand and Bangladesh where 80% of the global bamboo resources – in terms of species as well as growing area – are concentrated.

Table 1: Estimated bamboo resources in the world

<table>
<thead>
<tr>
<th>Country/Region</th>
<th>Area (‘000 ha)</th>
<th>No. of genera</th>
<th>No. of species</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ASIA</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>4 000</td>
<td>39</td>
<td>500</td>
</tr>
<tr>
<td>India</td>
<td>2 980</td>
<td>19</td>
<td>136</td>
</tr>
<tr>
<td>Myanmar</td>
<td>2 170</td>
<td></td>
<td>90</td>
</tr>
<tr>
<td>Thailand</td>
<td>510</td>
<td>12</td>
<td>50</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>510</td>
<td>13</td>
<td>30</td>
</tr>
<tr>
<td>Vietnam</td>
<td>287</td>
<td>15</td>
<td>101</td>
</tr>
<tr>
<td>Cambodia</td>
<td>130</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>123</td>
<td>13</td>
<td>230</td>
</tr>
<tr>
<td>Indonesia</td>
<td>60</td>
<td>9</td>
<td>30</td>
</tr>
<tr>
<td>Malaysia</td>
<td>20</td>
<td>7</td>
<td>44</td>
</tr>
<tr>
<td>Korea</td>
<td>8</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>The Philippines</td>
<td>8</td>
<td>12</td>
<td>55</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>2</td>
<td>7</td>
<td>30</td>
</tr>
<tr>
<td><strong>PACIFIC ISLANDS</strong></td>
<td>200</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td><strong>AMERICAS</strong></td>
<td>1 500</td>
<td>40</td>
<td>400-500</td>
</tr>
<tr>
<td><strong>AFRICA</strong></td>
<td>1 500</td>
<td>14</td>
<td>50</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>14 008</td>
<td>72</td>
<td>1 225</td>
</tr>
</tbody>
</table>
**Production System**

Given favourable conditions, bamboo will be the first plant to colonize in a new site in a seed year and the last to leave it. Once established in soil, it is difficult to eradicate it. The rhizomes are found throughout the area where bamboo grows. Bamboo rhizomes give out new shoots to take the place of felled trees, even if bamboos are also felled along with the trees. It is often noticed that a forest is appropriated by a bamboo species when tree regeneration fails to occur. If tree regeneration happens, then bamboos come up as the undergrowth. Clear cutting, burning or any other disturbance of forest environment tends to help the expansion of bamboo stands since bamboo regenerates itself by sending up new culms from its perennial subterranean rhizomes.

Bamboos are gregarious in habit, and in some localities pure bamboo forests can be seen to the exclusion of other timber species. Normally, in a natural forest, bamboo grows as an understorey plant under other timber species. Generally, only one species of bamboo grows in pure condition; a mixture of two species or more is rare.

**Regeneration**

1) Natural regeneration

Given adequate protection, natural regeneration of bamboos occurs profusely after each gregarious flowering. Gregarious flowering starts at some point in the bamboo forest and gradually spreads in waves to cover the whole area in up to 3-4 years. Masses of fertile seeds are shed in the immediate vicinity of the clumps and they germinate profusely at the onset of rains. Seedlings are particularly numerous on bare or freshly exposed soil. Banik (1988) reported that the density of naturally occurring seedlings of *Bambusa tulda* and *Dendrocalamus longispathus* after one to two months was higher (about 45/100 cm²) in depressions and valley areas, and lower on the slopes (about 3/100 cm²). There is intense competition among the seedlings themselves, resulting in a natural thinning. Clusters begin to form in three to four years and in about six years or more, the area will have a homogenous crop of more or less evenly spaced-out young clumps.

It is reported that factors such as shade and weeds influence the density and survival rate of the regenerating seedlings. Bamboo seedlings are found to thrive better in partial shade and low-weed condition than in full shade and high-weed condition. Under full shade, almost all seedlings
gradually degenerate. The influence of light is comparatively more important than weed competition to seedling health and mortality, at least in the early stages of growth. Felling of the dead mother clump within one to three months of seed germination is highly detrimental to the regeneration process. The effect is not so hazardous if burning is done after the seedlings are at least nine months old, since the seedlings generally produce underground rhizomes after four to six months of age. Grazing is also a limiting factor for natural regeneration of bamboos. Combined with burning, or even alone if severe enough, grazing can wipe out the entire seedling bank. In heavily grazed areas, seedlings may survive inside dead bamboo clumps and, in the absence of burning of the dump, eventually grow up into clumps.

2) Artificial regeneration

Bamboo can be raised artificially for planting by any of the following methods:

- Direct sowing of seeds;
- Raising seedlings from seeds in the nurseries and transplanting them;
- Planting rhizomes, offsets;
- Planting stem, rhizome or branch cuttings; and
- Through layering, marcotting, etc.

With over-exploitation and shrinkage of habitat, bamboo resources are depleting at an alarming rate. Sustained availability can be ensured only by raising bamboo plantations. It is, therefore, necessary to raise plantations of selected bamboo species, particularly in:

- Denuded hills and degraded areas;
- Logged-over forest; and
- Marginal farmland in agroforestry programs.

Management of Bamboo Stands Grown for Different Purposes

According to the currently prevalent intensive production management practices, bamboo stands can be categorized into five end-use types: timber stand (including timber-and-shoot stand), shoot stand, pulp stand, ornamental stand, and water/soil conservation stand. The species involved and the management system will vary with the intended end-use.

Timber stand: grown for culm timber

The planned end-product of large-sized monopodial species, such as *Phyllostachys pubescens*, is 7/8-year-old culms. The recommended age
The structure of culms in the stands after harvesting is 1 to 2 years old : 3 to 4 years old : 5 to 6 years old : over 7 years old in the ratio 3:3:3:1. The density for high, medium and low production is about 3 000, 2 225 and 1500 culms per hectare, respectively, with the relative annual yield per hectare of culm timber in fresh weight being 7-10 tonnes, 3.5-7 tonnes and below 3.5 tonnes, respectively. Harvesting is done in the winter season of the “on year”. Culms will be felled at four years of age for mid-sized monopodial species such as l? viridis, P. glauca and P. bambusoides. The stand after felling is preferably kept at the density of 10 000 to 15 000 culms per hectare, with an age structure of 3:3:3:1 for 1 to 4-year-old culms.

The end-product of sympodial species, such as Dendrocalamus strictus, Bambusa bambos and B. textilis, is 3/4-year-old culms. Culms are harvested at the rate of 30% in winter or dry season. The recommended stand density is 700 clumps per hectare, each clump containing 10 to 20 culms at 1 to 3 years of age. The annual yield of culm timber generally ranges from 3 to 10 tonnes, sometimes reaching 15 to 33 tonnes, per hectare.

Some species can be grown for both culm timber and edible shoots, thus leading to the term “timber-shoot stand” or “multi-purpose stand” (some timber stands even serve an ornamental purpose). Cultural measures for multi-purpose stand differ somewhat with those employed for single-purpose stand. In the case of Phyllostachys pubescens, multi-purpose stands are usually kept at mid-level density (2 225 culms/hectare) and managed more intensively for ensuring that the yield of edible shoots contributes over 10% of the total output of intended end-products. Among sympodial species, No. 1 of Bambusaprevariabilis < female > x (Cephalostachyum latiflorus + B. textilis) < male > - a fine hybrid bamboo with edible shoots and beautifully coloured timber culms - can be grown as a multi-purpose species. Only nine culms at 1 to 3 years of age are retained for each clump. A well-managed stand can annually produce 3 tonnes of shoots and 9 tonnes of culm timber per hectare.

**Shoot stand: grown for edible shoots**

Edible bamboo shoots, rich in proteins and cellulose, are traditionally regarded as quality natural food in many Asian countries, and are gradually finding acceptance in Europe and the Americas. Over 500 bamboo species can produce edible shoots, including such monopodial bamboos as Phyllostachys pubescens, P. praecox, P. iridescens and P. dulcis, and sympodial species such as Dendrocalamus latiflorus, D. hamiltonii,
D. asper, Dendrocalamopsis oldbamii, D. beecheyana, etc. The cultural measures for shoot stand differ from those for timber stand because the former needs better site conditions in terms of light, heat and water. A shoot stand also consumes more mineral nutrients from the soil than a timber stand and hence, the application of organic or chemical fertilizers is important. In the case of chemical fertilizer, NPK fertilizers (without silicon) should be used. The ratio of N, P and K will vary with site conditions. In Asian regions, where the potassium content in the soil is generally high, the NPK ratio could be 4:3:1 or 5:2:1. Up to 1.5 tonnes per hectare of NPK fertilizer will be needed annually (application 1 to 3 times). Irrigation might be required for intensively managed shoot stands when there is no rain for more than 10 days, especially during shooting period.

The reasonable stand density would be 2,225 culms (1 to 6-year-old) per hectare for large-sized monopodial species such as P. pubescens, and 9,000 to 12,000 culms (1 to 3-year-old) for medium and small-sized ones. Sympodial species can be planted at 4x5 m or 5x5 m spacing, and each clump can have 6 to 8 culms of 1 to 2 years of age. A few 3-year-old culms may be retained in the case of some species, such as Dendrocalamus latiflorus. Bamboo stands managed in this way can produce 10 to 20 tonnes of edible shoots per hectare annually for monopodial species or 10 to 30 tonnes for sympodial ones.

**Pulp stand: grown as raw material for pulp production**

To obtain high-quality paper, the raw materials for pulping must have long fibres and low silica and lignin content. Chinese scientists have tested more than 100 sympodial and monopodial bamboo species in order to rate them according to their properties suitable for pulping. Although the different sampling and testing methods employed in various studies made accurate comparisons impossible, the general trend was that the large-sized species of Bambusa and Phyllostachys show better pulping properties than medium-sized species, such as Dendrocalamus and Sinarundinaria bamboos. Small-sized species, such as Pleioblastus and Pseudosasa bamboos, were found unsuitable for pulping.

Since ancient times, people in China, Japan and Korea had been using 1-year-old culms for handmade paper. However, the practice had a harmful effect on the bamboo population. Moreover, the low quality of the end-product, as well as the inefficiency and high cost of the production method allowed it to be slowly pushed out by mechanical production,
though handmade papers are still used by artists for paintings. Since the
maximum fibre content in a culm is already achieved by the time the culm
is one year old, and since lignin and silicon accumulation increases with
age, the culms for pulping should be harvested when they are young; that
is, 5 years for large-sized monopodial bamboos and 3 years for sympodial
ones. A high stand density - 3 000 to 4 500 culms per hectare for large
monopodial bamboos, and clumps spaced at 3-5 metres apart for sympo-
dial ones - is recommended. It is necessary to remove old stumps and
rhizomes periodically. In the case of monopodial bamboos, stumps and
rhizomes above 8 years old must be removed every 2 or 3 years, while
4-year-old stumps and rhizomes of sympodial bamboos are to be removed
every 1 or 2 years. Cutting of the top parts should be avoided since this will
make the culm very fragile and is detrimental for pulping.

Ornamental stand: grown for gardening/landscaping

Bamboos grown for ornamental purpose are often characterized by
beautiful appearance and colour combination of clump, culm and foliage.
There are nearly 100 species - such as Phyllostachys heteroclada, P. nigra,
P. viridis, P. vivax, Bambusa ventricosa, B. vulgaris cv. wamin, B. vulgaris
cv. vitata and some Sasa varieties. These bamboos are usually planted
individually or in small lots, and maintenance mainly involves irrigation in
dry season, pruning and pest control.

Soil/water conservation stand: grown for prevention of soil erosion or for
embankment protection

Some medium and small-sized species of Sinarundinaria, Yushania,
Chimonobambusa, Bambusa and Dendrocalamus occur naturally with
various trees on high lands along the upper reaches of rivers. Such natu-
really mixed bamboo stands not only play an important role in soil/water
conservation, but also provide habitats for wild animals. Some countries
such as India, instead of selective felling of these stands once every four
years, practise clear felling to the detriment of the growth and develop-
ment of bamboo. The biggest challenges in maintaining such stands are,
perhaps, the prevention of gregarious flowering and the regeneration
after the death of the clumps after flowering. Some large and medium-sized
species of Bambusa and Dendrocalamus are planted on lands suscep-
tible to floods, and along river banks for embankment protection. Methods
of cultivation are similar to the ones adopted for timber stands, except that
higher clump and culm densities are maintained. Surveys of such stands along Jiulongjiang and Dayingjiang rivers in China have shown that each clump can protect up to 12 m$^3$ of river embankment, besides yielding shoots and timber.

**Tending**

Intensively managed plantations usually require various tending operations according to: (1) the plantation density, and the planted species and their growth characteristics; (2) the intended end-use of the stands; (3) site conditions such as topography, soil fertility, rainfall, etc.; and (4) labour and economic factors.

**Tending of the young stand**

Agroforestry techniques may be applied after one to three years of planting. Such techniques include intercropping, especially with nitrogen-fixing plants, and application of green manure, usually from the intercrop itself. Watering once in three to five days will be required if there is no precipitation during the first 15 days after planting. Weeding is best done in late spring and summer, or during wet seasons. The soil needs to be loosened up to a depth of 10-15 cm in winter or dry season.

**Tending of the mature stand**

Damage from people and animals to shoots and mother culms must be avoided, and grazing must be prevented during the shooting stage. Weak shoots need to be cut off in the early and last stages of shooting to ensure enough nutrients to healthy shoots. Shoots are cut below the soil level. After cutting off the shoots, it is necessary to leave the part remaining in the ground exposed for three to five days if there is enough sunshine, or for five to seven days if the sky is cloudy. The exposed part is then covered with soil, to prevent excess sap flow and bacterial infection.

The soil must be loosened to a depth of 10-15 cm near the clump and 30 cm away from the clump. Shoot quality and yield will be improved if the loosened soil can be covered with more soil to a height of 15-30 cm. The soil at the base of the culm may be opened just before the shooting stage and the shoot buds allowed to receive sunlight for about 10 days. This will ensure adequate soil temperature for better shoot growth, and also facilitate fertilizer application. If there is no rainfall for 15 days during the growth season, watering will be necessary, especially for shoot stands.
Fertilizing

Fertilizing is an important measure to ensure high and sustainable yield. Organic fertilizer is best applied during winter or dry season, while chemical fertilizer may be used in early spring and late summer, or during wet season. An NPK fertilizer can be applied for shoot stand and an NPKSi one for timber stand, at the rate of 3 790 kg/ha. Application is by spreading on the ground as well as in ditches of 15 cm depth dug around the stands. If the stands are situated in steep slopes, it is better that the fertilizer is directly applied at the base of the clumps. Excess chemical fertilizer (above 7 500 kg/ha) will decrease the yield.

Pest and disease control

There are several pests that attack bamboo leaves, shoots, culms, rhizomes and even harvested culms, sometimes damaging entire stands. These include 40 families of leaf-feeders, 50 borers, 130 scales, 30 aphids, 60 bugs, 5 families of timber insects, as well as 73 species of fungi such as Aciculosporium spp., Ceratosphaeria spp. and Fusarium spp. Timely control of pests and diseases are an essential part of sound management practice. The control measures may be silvicultural (such as weeding or soil loosening), biological, behavioural or chemical.

Bamboo Agroforestry

Bamboo agroforestry models

In many Asian countries, bamboos are planted by farmers in courtyards, homesteads or small-scale farm lands, and managed as groves or following some agroforestry model. Advanced agroforestry involves design principles, different models, and their components and structure, as illustrated in Figure 1.

Bamboos involved in agroforestry models are mainly Phyllostachys and Dendrocalamus species of high economic value. Bamboo agroforestry models may be divided into the following three groups according to their functions and end-products:

Group 1: Bamboo-Agriculture (forestry) Model
(1) bamboo + tea plant
(2) bamboo + conifer and broadleaf timber trees
(3) bamboo + agricultural crops
Group 2: Bamboo-Fishery Model
(1) bamboo + fish pond

Group 3: Special Purpose Model
(1) bamboo + edible fungi (*Dictyophora* sp., *Plenrotus ostreatus* and *Auricularia auricula-judoe*)
(2) bamboo + medicinal plants (such as *Cayratia japonica*, *Premna microphyla*, *Tetrapanax papyrifers* and *Astragalus chinensis*).

Fig. 1: The establishment procedure of agroforestry models

**Establishment techniques**

Following the five design principles mentioned in Figure 1, the establishment of bamboo agroforestry models will combine one or more of the four components in a reasonable structure on a given site.

1) **Bamboo + tea plants**

Sympodial species grown for either culm timber or edible shoot can be employed in this model, but in the case of monopodial bamboos only timber-producing species may be planted. Since the rhizomes of monopodial species can grow all around the stand and adversely affect the other crop, it is essential that the culm density and distribution be regulated through selective felling.
Bamboo is often planted at a spacing of $6 \times 4$ m and tea plants at $2 \times 0.5$ m. Intercropping of seasonal agricultural crops, such as soybean and vegetables, can be done for one to three years after planting. But intercropping should leave enough space for the unhindered growth of bamboo and tea plants and ensure adequate nutrition supply to them.

2) **Bamboo + conifer and/or broadleaf trees**

This model can be established by either converting semi-naturally mixed stands or planting new ones. The ratio of bamboo to trees is important, and in semi-naturally mixed stands this may be 7:3 or 8:2 for bamboo and broadleaf trees, and 6:1:3 or 7:1:2 for bamboo, and conifer and broadleaf trees. In planted bamboo and broadleaf tree stand, the ratio can be 6:4, and crops such as watermelon, soybean, sweet potato, sugar cane and vegetables can be intercropped within three years after planting. The planting time for bamboo and trees should be determined based on the growth rate of the tree species involved.

3) **Bamboo + agricultural crops**

This model exists until bamboo plants develop and occupy the whole site, and its final products will be culm timber or edible shoots. Bamboo is planted at a spacing of $4 \times 4$ m for large-sized species or $3 \times 2$ m for small ones. Intercropping, with crops employed in bamboo + trees model, should allow a bamboo plant to have $1 \text{ m}^2$ in area to ensure nutrition supply, and can be done for a maximum of four years after bamboo planting.

All the three models mentioned above involve agricultural crops or trees. In planting trees or bamboos, full soil preparation may be employed on plain land. On sloped land, strip preparation—leaving alternate unprepared strips to prevent water and soil erosion—is recommended. It is necessary to place adequate fertilizer in the planting pits before planting is done.

4) **Bamboo + crops + fish pond**

This model is usually made on plain, or lower and wetter lands where fish ponds are built. One to three rows of shoot-producing sympodial bamboos may be planted on the banks of the pond, and crops such as soybean and rye intercropped between bamboo clumps to form a complete food chain. Crops can be harvested as food of fish feed. Bottom mud from the ponds may be dug out in winter and used as fertilizer for bamboo clumps. The clumps need to be replanted at 8-10 years of age.
5) **Bamboo + edible fungi**

There are a large number of edible fungi regarded as natural food rich in vegetable proteins. Among these, *Dictyophora tomentosa*, *Plenrotus ostreatus* and *Aurricularia auricula-judoe* can be cultured in bamboo stands, which satisfy the fungi’s need for humidity, shade and a fertile bed. A bed of decayed bamboo litter and cotton shells, placed evenly on the ground up to a height of 10 cm, is used as the substrate. Inoculation of *Dictyophora* sp. is done in September for varieties that grow in normal temperature and in May-June for those that require a higher temperature. Harvest is after 4-8 months, depending on the fungus variety. *P. ostreatus* is inoculated in March and harvested two months later. *A. auricula-judoe* needs to be cultured in bags filled with the growth medium and hung on the bamboo.

6) **Bamboo + medicinal plants**

This model is suitable for hilly areas in the sub-tropical, monsoon climatic zone which has a mild climate and adequate rainfall. The medicinal plants should be chosen to suit the topography of the site. Some plants (*Cayratia japonica*, *Premna microphylla* and *Tetrapanaxpapyriferus*) can be grown without much tending since they have good adaptability. Some others (such as *Paris polyphylla* and *Curnma domestica*) need to be planted in valleys at altitudes of 800-900 m. A few (such as *Allizia kalkora* and *Mentha haplocalyx*) need slopes which get adequate sunshine, while others (*Mahonia japonica* and *Holboellia cariacea*, for example) need shaded sites.

**Bamboo Research: a Review**

In the past few decades, extensive research has been carried out on bamboo production in all major bamboo-growing countries in Asia, in order to get a better understanding of bamboo resources and develop more bamboo products. Particularly since the 1980s, international organizations such as the International Development Research Centre (IDRC), International Fund for Agricultural Development (IFAD) and more recently, the International Plant Genetic Resources Institute (IPGRI), as well as international cooperation agencies of countries such as Japan and UK, have contributed greatly to the advancement of bamboo research and drawn the world’s attention to the bamboo industry. Bamboo research has received encouragement in most bamboo-producing Asian countries. Some of the major past and current bamboo research activities are summarized below.
Studies on resources, taxonomy and biology

These are perhaps the fields in which the earliest and most extensive bamboo research studies have been carried out in bamboo-growing Asian countries, as well as in USA and some European countries. Most of these studies have followed the methodology adopted in western countries. In biological studies, Asian countries usually focus on local species of economic importance, while the western countries give priority to ornamental bamboos.

Since the beginning of bamboo research networking by the IDRC and the International Network for Bamboo and Rattan (INBAR), significant progress has been made in bamboo research. For example, large living collections of bamboo species have been established in China and Thailand, and the various bamboo species of high economic value in the region have been identified and programs launched for their development.

Studies on silvicultural techniques

These applied techniques (including pest management), which are employed mainly to increase the productivity of bamboo stands, have enjoyed prime attention in all major bamboo-growing countries. Supported by the IDRC, some studies were undertaken in Bangladesh, China, India and Malaysia in the last dozen years or so. These studies, making the best use of human and financial resources, achieved significant results and were successful in solving some critical technical problems in bamboo cultivation.

Studies on ecology, physiology, breeding and biotechnology

These deal with a wide range of disciplines, and involve basic science and applied techniques. In developing countries, which have limitations in terms of funds and facilities, such studies are restricted to small scale or are included as part of broader silvicultural projects. The IDRC has financially supported the initiation of bamboo tissue culture research in Thailand, the Philippines and Singapore, and bamboo forest ecology research in China. Some research studies in China on the cross-breeding of bamboos have met with success. In general, studies in these fields have not been systematic and have lacked the desired depth; nevertheless, they are important in the sense that they have made a beginning that can later be capitalized on.
Studies on bamboo agroforestry

Agroforestry, which developed in the 1970s, is still a developing science, although it has been in existence as farming practices in many Asian countries for over a thousand years. It was not until two years ago, that systematic research on bamboo agroforestry has been initiated as a regional cooperative project, funded by the INBAR and involving China, India and Thailand. This project is expected to find ways to improve lands that have degraded because of the large-scale destruction of traditional bamboo agroforestry.

Although bamboo research has taken roots in the Asian region and has contributed greatly to the development of the bamboo industry, it still needs to grow in scope and depth, particularly in the following areas.

1) Biodiversity and conservation techniques

As science develops, we become more aware that humans alone cannot inhabit the earth and that we need a vibrant organic world with diverse living organisms. We realize that the biodiversity of our environment is important. Bamboo resources, a part of that biodiversity, have played a major role in the evolution of the society, culture and history in many Asian countries. Considering this, it would be rewarding to conduct studies on bamboo biodiversity and conservation techniques.

Bamboos and the insects that thrive on them are the most abundant groups of living things in a bamboo-based ecological system. Although many studies have been carried out, several key aspects - such as the species resources, their biology, the interspecific relationship of bamboos and insects, etc. - still remain to be explored. For instance, there is a serious confusion about the names of bamboos and the insects that live on bamboos. There are only a very few reports on the natural bamboo resources in many remote areas and on the 400-plus insect species that make bamboo stands their home. A better understanding of all these through further research is essential for the study of biodiversity and conservation techniques.

2) Advanced techniques for bamboo cultivation

Although relatively high productivity in bamboo has been achieved today, it is much less than the theoretical possibility: dry weight yield of 32-38 tonnes per hectare per annum, an estimation based on the efficient use of solar energy. The reason might be the inadequate understanding of
Bamboo, People, and the Environment

the details of bamboo ecological system, resulting from the more qualitative but less quantitative analyses of investigations in the past. Therefore, in order to obtain a higher productivity than what is achieved at present, various techniques including molecular biotechniques need to be employed in future studies designed to identify the optimum biological and ecological conditions of bamboo growth. Besides, as a superior approach of land management, bamboo agroforestry needs to be investigated on a wider scope, especially in terms of interspecific relationships and optimum combinations.

3) Crossing, selection of superior clones and their cultivation

Breeding in bamboo is much difficult and takes a long period because of the long cycle of flowering and pollen abortion. Only a few varieties or hybrids have been identified in the past research works. Effort in the future, following traditional or advanced breeding technology, can be emphasized on cross-breeding, selection of superior clones and their cultivation.

Conduct of Research in the Future

The study of basic science establishes the essential basis for the development of advanced field techniques, but is often ignored because it takes a long time, costs much and has no direct economic profits. A conscious combining of basic and applied studies would be an effective approach to improve both basic science and applied techniques. Such an approach would follow the cycle: development and extension of applied techniques $\Leftrightarrow$ supporting basic studies with funds from extension+ improving applied techniques $\Leftrightarrow$ extension.

Drawing more attention and seeking the assistance of international organizations and various national governments, as well as paying a closer attention to the role of voluntary organizations, are important measures for upgrading bamboo research. Only by bringing every positive factor into play, and obtaining adequate human and financial resources, can we achieve results through meaningful research. Depleting forest resources have focused the attention of international organizations and national governments on bamboo resources. This is a valuable opportunity that should not to be missed.

Expanding international cooperation and initiating regional and global research projects are the other urgently required steps. International
cooperation in terms of personnel and information exchange should be encouraged with a view to improve research quality and to avoid research duplication.

Further reading


Propagation of *Guadua angustifolia*

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**Abstract**

*Guadua angustifolia* is considered by the International Network for Bamboo and Rattan (INBAR) as a high-priority bamboo species. As a result of extensive research in Colombia and Mexico, two economical and simple vegetative macroproliferation techniques have been developed for the propagation of this species. One of the techniques – the basal branch method – involves the use of plagiotropic basal branches as propagules, while the other – the “chusquin” method – employs selected plantlets generated from the rhizome buds when mature culms are felled. The former method has achieved up to 100% survival rate of the plantlets, while the latter has been able to attain a survival rate of 98% and above. The “chusquin” method also proved to be an excellent mass production technique with great commercial benefit.

**introduction**

*Guadua angustifolia* Kunth is a gigantic bamboo, native to Colombia and Ecuador. In Colombia, under optimum conditions, it grows to a height of more than 20 m and a diameter of 12 cm. It is found in the central zone of the country located at 4° 4' 44" N and 75° 26' 54" W, 800 to 1 800 m above sea level. The country has about 40 000 ha of the species, and is the largest reserve of *G. angustifolia* in the Americas.

*G. angustifolia* displays many useful environmental traits, such as protection of river embankments, conservation of water resources, reduction of soil erosion, etc. Moreover, it has very desirable physical and mechanical properties, and good resistance to pests such as rot fungi and wood-eating insects. The species, however, was exploited so irrationally that it came very near to extinction, and prompted active research on artificial propagation methods.
In 1993, G. angustifolia was introduced in Mexico. In the State of Chiapas, Pulsar International Inc. created the International Center of Research and Development in Agriculture (CIICA), where, besides the research on tropical crops, the development of a suitable propagation technique for G. angustifolia was taken up. Today, CIICA is the world’s largest production centre for Guadua angustifolia plantlets.

Reproduction

Both in Colombia and Mexico, G. angustifolia flowers sporadically, but a high percentage of spikelet florets show low fertility index. Consequently, it is very difficult to start a reforestation program using seeds or seedlings. The low efficiency of the natural propagation system of G. angustifolia has forced researchers to look for new propagation methods.

The development of vegetative propagation of G. angustifolia had taken the following route: direct transplant → rhizome plus culm section → rhizome alone → culm cuttings → layering. Although, in general, the first three propagation methods mentioned above yield good results (the shoots are numerous and vigorous in growth), they are not widely prevalent because of cost considerations and the likelihood of causing damage to the clumps. Culm cuttings and layerings have, at best, shown only 50% efficiency.

Two other methods developed for the propagation of G. angustifolia are the basal branch method and the “chusquin” method.

Basal branch method

It is a common occurrence that from the basal part of the culm of G. angustifolia, branches grow plagiotropically. Later, these basal branches reach down into the soil and plantlets are formed from nodal buds. This field observation was the basis for a study conducted under greenhouse conditions in the National Center of Bamboo Research in Colombia.

Materials and methods

Basal branches were removed from the culm below its 18th node. The branches were segregated as upper, middle and lower, depending on their position on the culm. Each branch was subdivided into three equal parts – the basal third, the middle third and the distal third – to form the propagules. Each propagule was 4-5 cm in length, and had a node, a bud and three or four thorns.
The propagules were disinfected with a benomyl solution (1 g/litre), and planted in plastic bags filled with disinfected soil-sand mixture (3:1 ratio). The planted materials were kept in a greenhouse at a temperature of 30°C and a relative humidity of 75%. Irrigation was carried out using a mist sprayer.

Results

Fifty percent of the propagules from the middle third of the middle branches produced plantlets 20 days after planting. The remaining 50% of the propagules produced plantlets 20 days later. The rest of the propagules obtained from other different basal branches gave less than 50% plantlets after 40 days.

"Chusquin" method

Under field conditions, when culms of more than seven years of age are harvested, the buds of the rhizomes bring up small plants of no more than 30 cm in height, locally called "chusquines". Normally, in the absence of seeds, these plants are a natural way to preserve the species. This observation prompted the development, over a period of 25 years, of a method to produce G. angustifolia plantlets commercially.

The "chusquines" are similar to basal shoots, and have a well-developed system of roots, with a diameter of 0.1 to 1.5 mm. The stem is thin and varies in colour from clear green to dark red. The height is 10-30 cm and the stem diameter ranges from 1.0 to 1.5 mm. These plantlets may have a few branches, with a few leaves averaging 7 cm in length and 1 cm in width.

Materials and method

The "chusquines" were first collected from natural forest conditions. After a careful selection based on vigour and healthiness, the selected "chusquines" were separated carefully from their rhizomes using a shovel, taking care to maintain its roots and rootlets in good condition.

The "chusquines" were then planted in plastic bags filled with vermiculite, and kept under greenhouse conditions for 15 days, at a regulated temperature of 30°C and a relative humidity of 95%. When the "chusquines" were adapted, they were transplanted on a propagation bed. Each planting pit measured 30 x 30 x 30 cm, and the transplanting was one "chusquin" to a pit. (In Mexico propagation banks are made under greenhouse
Propagation and Management

The propagation beds were kept free of weeds. The plants were irrigated (4 mm/day) and fertilizer applied (76 g of N/m² every 12 days). After three months, each "chusquin" produced eight to ten new plantlets in clumps. The growth of the plantlet stem was normal and the root system well developed, indicating that the plantlets were ready for field transplanting.

The plantlets, along with the new plantlets they generated, were pulled up from the propagation bed. Each plantlet was manually separated and planted in plastic bags filled with vermiculite (in Mexico; soil in Colombia) and again kept under greenhouse conditions at 95% Rh and 30°C temperature for 15-20 days. Some of these plantlets were then transplanted in the field, while the others were again transplanted in the propagation bed to repeat the regeneration process.

Results

With this method, the survival rate of the plantlets was 95-98% under greenhouse conditions. When propagation was done under field conditions, however, the survival rate was as low as 25-30%. The main advantages of the method are that each plant can be made to generate 4,000 to 10,000 plantlets per year, and that the process is a continuous one.

Acknowledgements

The two propagation methods for G. angustifolia have been developed over several years, and many people have contributed to the success of the experiments. The author wishes to thank the staff of the National Center for Bamboo Research in Colombia, especially Dr Julian Sema G., Dr Aureliano Sabolgal, Dr Faber Martinez Rodriguez, Dr Jorge Enrique Arias, Dr Oscar and Dr Edgar Giraldo H. Special gratitude is due to Dr David Manzur M., Professor of Botany in Caldas University, Manizales, Colombia.

The author also thanks the staff of the International Center of Research and Training in Agriculture (CIICA) in Mexico, particularly Ing. Alejandro Rodriguez Graue, Dr Eduardo Alvarez Luna, Dr Federico Sanchez Navarrete, Dr Velitchka Bagoeva Nikolaeva, M.C. Julian Barrera Sanchez, Ing. Marcelino Martinez Rodriguez and Lorenzo Meza Garcia.

Further reading


Cruz Rios, H. 1993. Morfologia de la Guadua angustifolia. Armenia, Colombia


Growth of Phyllostachy sp. in Peninsular Malaysia

Abd. Razak Othman and Aminuddin bin Mohamad
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Abstract

The culm characteristics and above-ground biomass of eight-year-old temperate Phyllostachys bamboo species - *P. glauca*, *P. nigrahexonis*, *P. pubescens* and *P. viridis* - planted in Peninsular Malaysia are discussed in the paper. Growth performance of these species has been found to be poor when compared with the same species of bamboos in China, their country of origin.

introduction

In mid-1986, *Phyllostachys*, a temperate zone monopodial genus, was introduced into Malaysia from the bamboo garden in Nanjing Forestry University, People’s Republic of China. The species introduced were *P. glauca*, *P. nigrahexonis*, *P. pubescens* and *P. viridis*.

The planting materials were brought in as rhizome offsets and planted in plastic containers for a year before being transplanted in the field at Bukit Fraser and Genting Highlands, in the state of Pahang. Christmas Island rock phosphate (CIRP, 150 g) and an organic fertilizer (1.5 kg) were applied in the 30 x 30 x 30 cm planting pit. Altogether, four clumps of each species were planted.

Abd. Razak (1989) reported on the initial growth performance of these bamboos. *P. glauca* grew best, producing an average number of 12 culms, with a mean height of 171.8 cm, 24 months after transplanting. *P. nigrahexonis* and *P. viridis* produced seven to ten culms each, while *P. pubescens* produced the lowest number of culms.

This paper describes the performance of these species eight years after being planted in the field.
Materials and Methods

Both planting sites are 1,000 m above sea level and their mean annual rainfall, relative humidity and temperature are similar at 2,432 mm, 87% and 19°C, respectively. At Nanjing Forestry University where the bamboo originated, the temperature is much colder with an annual mean temperature of 15°C. The mean annual rainfall is 1,038 mm and the relative humidity is 80%.

All the culms in the clumps were numbered. The height of the culms and diameter at breast height (DBH) were also measured. Ten culms of age between three and five years were randomly felled for the determination of green weight of the culms, branches and leaves. Small samples of culms, branches and leaves were then oven-dried at 103 ± 2°C to constant weight. Conversion to total dry weight was based on the method used for moisture content determination.

Results and Discussion

Growth performance and culm characteristics

The growth performance and culm characteristics are summarized in Table 1. The average number of culms per clump was found to be 33-95. *P. glauca* produced the highest number of culms with an average of 95, followed by *P. nigruhexonis* (Figure 1) and *P. pubescens* (Figure 2) producing an average of 85 and 52 culms/clump, respectively. *P. viridis* (Figure 3) produced the lowest with an average of 33 culms/clump.

*Fig. 1: Phyllostachys nigrahexonis*
As regards the culm characteristics, it was found that *P. nigruhexonis* had the highest mean culm height of 6.8 m compared with *P. glauca*, *P. pubescens* and *P. viridis* which showed 5, 4.9 and 5.5 m, respectively. The average mean range of DBH was 2-3 cm. It is interesting to note that *P. viridis*, which had the least number of culms/clump, showed the highest DBH of 3 cm, while *P. glauca*, with the most number of culms/clump, had the lowest DBH of 2 cm. The mean number of internodes produced by *Phyllostachys* species was 31-36 and the mean internode length 12.2-16.1 cm. *P. nigruhexonis*, which produced an average of 36 internodes with a mean internode length of 16.1 cm, produced more internodes that the other three species.

In comparison, the growth rates of *Phyllostachys* in China (Table 1) was generally superior than those planted in Peninsular Malaysia.

**Above-ground biomass**

Table 2 shows the mean above-ground biomass of 3 to 10-year-old culms of *Phyllostachys* species planted in Peninsular Malaysia. The highest mean
Table 1: Growth performance and culm characteristics of 9-year-old *Phyllostachys* propagated by rhizome offsets

<table>
<thead>
<tr>
<th>Species</th>
<th>Average culms/ clump</th>
<th>Mean height (m)</th>
<th>Mean DBH (cm)</th>
<th>Mean no. of internode</th>
<th>Mean internode length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>In Peninsular Malaysia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>P. glauca</em></td>
<td>95</td>
<td>5.0</td>
<td>2.0</td>
<td>32</td>
<td>13.3</td>
</tr>
<tr>
<td><em>P. nigrahexonis</em></td>
<td>85</td>
<td>6.8</td>
<td>2.6</td>
<td>36</td>
<td>16.1</td>
</tr>
<tr>
<td><em>P. pubescens</em></td>
<td>52</td>
<td>4.9</td>
<td>2.2</td>
<td>34</td>
<td>12.2</td>
</tr>
<tr>
<td><em>P. viridis</em></td>
<td>33</td>
<td>5.5</td>
<td>3.0</td>
<td>31</td>
<td>15.4</td>
</tr>
</tbody>
</table>

In China *

<table>
<thead>
<tr>
<th>Species</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><em>P. glauca</em></td>
<td>10-12</td>
<td>2-5</td>
<td>-</td>
<td>30-40</td>
<td></td>
</tr>
<tr>
<td><em>P. nigrahexonis</em></td>
<td>-</td>
<td>8-12</td>
<td>4-8</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><em>P. pubescens</em></td>
<td>20</td>
<td>6-15</td>
<td>-</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td><em>P. viridis</em></td>
<td>10-15</td>
<td>4-10</td>
<td>-</td>
<td>20-45</td>
<td></td>
</tr>
</tbody>
</table>


Table 2: Mean above-ground biomass of 3 to 5-year-old culms of *Phyllostachys* sp.

<table>
<thead>
<tr>
<th>Biomass weight (g)</th>
<th><em>P. glauca</em></th>
<th><em>P. nigrahexonis</em></th>
<th><em>P. pubescens</em></th>
<th><em>P. viridis</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh weight of culms</td>
<td>626.00</td>
<td>1638.00</td>
<td>878.00</td>
<td>1326.00</td>
</tr>
<tr>
<td>Fresh weight of branches</td>
<td>346.00</td>
<td>481.00</td>
<td>422.00</td>
<td>432.00</td>
</tr>
<tr>
<td>Fresh weight of leaves</td>
<td>348.00</td>
<td>430.00</td>
<td>656.00</td>
<td>325.00</td>
</tr>
<tr>
<td>Dry weight of culms</td>
<td>381.27</td>
<td>1022.12</td>
<td>520.81</td>
<td>800.81</td>
</tr>
<tr>
<td>Dry weight of branches</td>
<td>179.96</td>
<td>264.00</td>
<td>193.81</td>
<td>237.04</td>
</tr>
<tr>
<td>Dry weight of leaves</td>
<td>130.18</td>
<td>211.14</td>
<td>228.96</td>
<td>167.88</td>
</tr>
<tr>
<td>Total dry weight</td>
<td>691.41</td>
<td>1497.26</td>
<td>943.58</td>
<td>205.73</td>
</tr>
</tbody>
</table>

Above-ground biomass per culm recorded was for *P. nigrahexonis*, followed by *P. viridis, P. pubescens*, and lastly *P. glauca*. The total dry weight produced by *P. nigrahexonis* was 1497.26 g composed of 1022.12 g of culm, 264 g of branches and 211.14 g of foliage. Although *P. glauca* produced the highest number of culms/clump, the total above-ground biomass per culm was the
lowest. The total dry weight was 691.41 g, and the dry weights of culm, branches and leaves produced were 381.27 g, 179.96 g and 130.18 g, respectively.

Conclusion

From the above discussion, it is clear that in terms of culm production, *P. glauca* performed better than the other species planted in the same area. *P. nigruhexonis* gave the highest culm height, while *P. viridis* had the highest DBH. On the whole, growth performance was poor when compared with bamboos of the same species planted in China, the country of origin. In terms of above-ground biomass per culm, *P. nigruhexonis* performed the best, followed by *P. viridis*, *P. pubescens* and *P. glauca*.

References


Propagation of *Gigantochloa levis* by Branch Cuttings

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### Abstract

Propagation by branch cuttings of *Gigantochloa levis* in the nursery showed that there is no significant difference in survival between growing in nursery beds and in polybags. However, cuttings prepared in nursery beds showed better growth rate in terms of root length, im/shoot and rhizome production. The use of commercial hormone helped to promote growth of cuttings. IBA 2000 powder (400 ppm concentration) applied by contact method was the best, followed by IBA 100 ppm applied by soaking method, when compared with other IBA hormone treatments.

### Introduction

The main problem faced in establishing large-scale bamboo plantations is the availability of the planting materials. Bamboos can be propagated by seeds and vegetative parts. Propagation by seed is impractical because a large number of Malaysian bamboos produce sterile seeds and show infrequent flowering. The most common method is by planting offsets. However, bamboo offsets are also very limited in availability, expensive, and difficult to extract and transport.

Although propagation by branch cuttings is not quite successful (Banik 1984), a preliminary study showed that some Malaysian bamboos can be propagated by branch cuttings. The branch cutting method is limited to bamboo species with a large and dominant primary branch, with root-primordia and dormant buds at the base of the branch (Abd. Razak and Hashim 1993).
Materials and Method

Branch cuttings of G. levis obtained from bamboo clumps planted in Forest Research Institute Malaysia (FRIM) research plots were extracted from two to three-year-old culms. The branches were carefully removed from the culm sections to prevent damage to the delicate dormant buds. They were subsequently cut to 50 cm lengths (consisting of four nodes) and then planted in nursery beds and polybags filled with top soil. The spacing of the cuttings planted in nursery beds was 9 cm between cuttings and 9 cm between rows, while the polybags size used was 9 x 12 cm.

A randomized complete block design with three replications was used. The main plot consisted of cuttings planted in nursery beds and polybags. The hormone treatments, on a sub-plot, consisted of: control, 100 parts per million (ppm), 200 ppm, 300 ppm and 500 ppm diluted IBA and two commercial IBA hormones (Seradix 2 and IBA 2000 powder). IBA hormones of 100 ppm, 200 ppm, 300 ppm and 500 ppm and control were applied by the soaking method (the basal part of the cuttings was soaked for 24 hours in the hormone before planting). For Seradix 2 and IBA 2000 powder, the contact method was used (the hormone was applied just before planting). For each treatment method, 10 experimental units were kept under observation. All cuttings were placed under 60% shade and watered twice a day (morning and evening).

The percentage of survival and culm production were assessed five months after planting in the nursery. Data on number of new culms and survival rate of propagules were subjected to Analysis of Variance (ANOVA) using SAS software program version 6.03. Means were compared using Duncan’s Multiple Range Test (DMRT).

Results and Discussion

Growth of cuttings in the nursery

Results on the percentage of survival, rooting, culm/shoot produced and rhizome formation of branch cuttings are given in Table 1. The results showed that the cuttings planted in the nursery beds and polybags did not give any significant difference on the percentage of survival and percentage of rooting. However, the percentage of culm/shoot and rhizome production were highly significant.

The branch cuttings planted in polybags gave a better percentage of survival and rooting compared with cuttings in nursery beds (Table 2).
Table 1: Analysis of variances on percentages of survival (PH), culm/shoot production (PRb), rooting (PA) and rhizome formation (PRz) of G. levis branch cuttings

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Df</th>
<th>PH</th>
<th>PA</th>
<th>PRb</th>
<th>PRz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beds</td>
<td>1</td>
<td>0.51ns</td>
<td>088ns</td>
<td>7.00**</td>
<td>9.09**</td>
</tr>
<tr>
<td>Hormone</td>
<td>6</td>
<td>2.05ns</td>
<td>1.97ns</td>
<td>1.73ns</td>
<td>1.88ns</td>
</tr>
<tr>
<td>Beds x Hormone</td>
<td>6</td>
<td>0.90ns</td>
<td>0.82ns</td>
<td>0.39ns</td>
<td>1.73ns</td>
</tr>
</tbody>
</table>

Note: ns = not significant at P<0.05; * - highly significant at P<0.01.

The percentages of survival and rooting of cuttings planted in polybags and nursery beds were 57.7% and 54% and 56.6% and 51.7%, respectively. Planting of branch cuttings in nursery beds produced a significantly a higher percentage of culms/shoots and rhizomes (17.4% and 13.4%, respectively) compared with planting in polybags. The results indicate that nursery beds can produce more vigorous cuttings than polybags.

Table 2: Percentages of survival, rooting, culm/shoot and rhizome production of G. levis branch cuttings

<table>
<thead>
<tr>
<th>Planting treatment</th>
<th>Survival Mean values</th>
<th>Rooting Mean values</th>
<th>Culm-shoot Mean values</th>
<th>Rhizome Mean values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beds</td>
<td>54.0a</td>
<td>51.7a</td>
<td>17.4a</td>
<td>13.4a</td>
</tr>
<tr>
<td>Polybags</td>
<td>57.7a</td>
<td>56.6a</td>
<td>8.9b</td>
<td>5.1b</td>
</tr>
</tbody>
</table>

Note: Values with the same letter are not significantly different at P<0.05.

Further analysis comparing the effect of nursery beds and polybags planting of cuttings on rooting, and culmshoot and rhizome production are presented in Table 3. Results showed that root production on cuttings was highly significant in terms of root length produced but not in number. The analysis also showed that there are highly significant variations in culm shoot and rhizome production by the cuttings. Cuttings planted in nursery beds produced a better root and rhizome system compared with polybag planting (Table 4). Branch cuttings planted in nursery beds produced comparatively longer roots (34.86 cm) and higher number of culm/shoot (0.44) and rhizome (0.30) than those in polybags.
Table 3: Analysis of variance on number of root (NR), length of root (LR), number of culm/shoot (NCS) and number of rhizome (NRz) of G. levis branch cuttings

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Df</th>
<th>NR</th>
<th>LR</th>
<th>NCS</th>
<th>NRz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beds</td>
<td>1</td>
<td>0.76ns</td>
<td>10.77**</td>
<td>10.18**</td>
<td>9.59**</td>
</tr>
<tr>
<td>Hormone</td>
<td>6</td>
<td>21.81**</td>
<td>18.43**</td>
<td>2.92*</td>
<td>2.17*</td>
</tr>
<tr>
<td>Beds x hormone</td>
<td>6</td>
<td>2.11ns</td>
<td>7.40**</td>
<td>3.21**</td>
<td>3.08**</td>
</tr>
</tbody>
</table>

Note: ns = not significant at P<0.05; *highly significant at P<0.01; **-significant at P<0.05

Table 4: Number of roots, root length, number of culm/shoot and number of rhizome produced by branch cuttings of G. levis

<table>
<thead>
<tr>
<th>Planting treatment</th>
<th>Mean values</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of root</td>
<td>Root length (cm)</td>
<td>No. of culm/&quot;shoot&quot;</td>
<td>No. of rhizome</td>
</tr>
<tr>
<td>Polybags</td>
<td>46.23a</td>
<td>34.86a</td>
<td>0.44a</td>
<td>0.30a</td>
</tr>
<tr>
<td></td>
<td>43.00a</td>
<td>27.00b</td>
<td>0.17b</td>
<td>0.10b</td>
</tr>
</tbody>
</table>

Note: Values with the same letter are not significantly different at P<0.05.

Effect of IBA Hormone Treatments on Bamboo Cuttings

IBA hormone treatments were not significant on the percentage of survival, rooting, culm/shoot and rhizome formation of G. levis branch cuttings (Table 1). However, as shown by the DMRT (Table 5), compared with other IBA hormones, the contact method of application using IBA 2000 powder on cuttings gave better success, while using IBA with 500 ppm concentration produced the lowest success rate. Mean percentage of survival, rooting, and culm/shoot and rhizome production varied mostly between 50-60%, 49-59%, 9-16% and 5-13%, respectively, for the IBA hormone treatments used. With IBA 2000 powder, the percentage of survival, rooting, and culm/shoot and rhizome production were the highest - 69, 68, 23 and 18%, respectively - while IBA 500 ppm gave the lowest results of 38, 37, 5 and 3%, respectively.

The responses to IBA hormone treatments are highly significant on the number and length of roots produced, and only significantly different
(P<0.05) on the culm/shoot and rhizome formation (Table 3). Results showed that IBA 2000 powder gave the highest mean number of roots, root length, and culm/shoot and rhizome production of 87.55, 59.1 cm, 0.55 and 0.40, and this is followed by IBA 100 ppm which produced 63, 36.25 cm, 0.50 and 0.30, respectively (Table 6). There were no notable differences in the other treatments.

**Table 5: Effect of hormone treatments on percentage of survival, rooting, and culm/shoot/rhizome production of G. levis branch cuttings**

<table>
<thead>
<tr>
<th>IBA hormone treatments</th>
<th>Mean values</th>
<th>Survival</th>
<th>Culm/shoot production</th>
<th>Rooting</th>
<th>Rhizome production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td></td>
<td>52.0ab</td>
<td>14.0ab</td>
<td>52.0ab</td>
<td>9.0ab</td>
</tr>
<tr>
<td>100 ppm</td>
<td></td>
<td>59.0ab</td>
<td>16.0ab</td>
<td>59.0ab</td>
<td>13.0ab</td>
</tr>
<tr>
<td>200 ppm</td>
<td></td>
<td>52.0ab</td>
<td>9.0ab</td>
<td>49.0ab</td>
<td>5.0ab</td>
</tr>
<tr>
<td>300 ppm</td>
<td></td>
<td>62.0ab</td>
<td>12.0ab</td>
<td>57.0ab</td>
<td>9.0ab</td>
</tr>
<tr>
<td>500 ppm</td>
<td></td>
<td>38.0ab</td>
<td>5.0ab</td>
<td>37.0ab</td>
<td>3.0ab</td>
</tr>
<tr>
<td>Seradix 2</td>
<td></td>
<td>59.0ab</td>
<td>130ab</td>
<td>57.0ab</td>
<td>8.0ab</td>
</tr>
<tr>
<td>2000 powder</td>
<td></td>
<td>69.0a</td>
<td>23.0a</td>
<td>68.0a</td>
<td>18.0a</td>
</tr>
</tbody>
</table>

Note: Values with the same letter(s) are not significantly different at P<0.05

**Table 6: The mean growth parameters of G. levis branch cuttings with hormone treatments**

<table>
<thead>
<tr>
<th>IBA hormone treatments</th>
<th>Mean values</th>
<th>No. of roots</th>
<th>Root length (cm)</th>
<th>No. of culm/shoot</th>
<th>No. of rhizome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td></td>
<td>36.20c</td>
<td>24.10cd</td>
<td>0.45ab</td>
<td>0.25ab</td>
</tr>
<tr>
<td>100 ppm</td>
<td></td>
<td>63.00b</td>
<td>36.25b</td>
<td>0.50ab</td>
<td>0.30ab</td>
</tr>
<tr>
<td>200 ppm</td>
<td></td>
<td>24.85c</td>
<td>19.05d</td>
<td>0.15bc</td>
<td>0.10b</td>
</tr>
<tr>
<td>300 ppm</td>
<td></td>
<td>28.60c</td>
<td>24.15cd</td>
<td>0.05c</td>
<td>0.05b</td>
</tr>
<tr>
<td>500 ppm</td>
<td></td>
<td>35.15c</td>
<td>23.60cd</td>
<td>0.20abc</td>
<td>0.10b</td>
</tr>
<tr>
<td>Seradix 2</td>
<td></td>
<td>36.95c</td>
<td>30.25bc</td>
<td>0.25abc</td>
<td>0.20ab</td>
</tr>
<tr>
<td>2000 powder</td>
<td></td>
<td>87.55a</td>
<td>59.10a</td>
<td>0.55a</td>
<td>0.40a</td>
</tr>
</tbody>
</table>

Note: Any two values having the same letter(s) are not significantly different at P<0.05.
The interactions between planting beds and IBA hormone treatments were found highly significant on root length and number of culm/shoot and rhizome produced (Table 3). In general, for all IBA treatments, the cuttings planted in nursery beds had longer roots and produced higher number of culm/shoot/rhizome when compared with cuttings planted in polybags (Table 7).

As shown in Table 7, the best interaction was between cuttings planted in nursery beds and IBA 2000 powder followed by IBA 100 ppm. Results from cuttings treated with IBA 2000 powder gave the longest mean root length, and the highest mean number of culm/shoot and rhizome of 66.59 cm, 0.79 and 0.6, while IBA 100 ppm produced 41.14 cm, 0.72 and 0.45, respectively.

**Table 7:** Comparison of the hormone and planting treatments in terms of mean growth parameters of *G. levis* branch cuttings

<table>
<thead>
<tr>
<th>IBA hormone treatments</th>
<th>Control</th>
<th>100ppm</th>
<th>200ppm</th>
<th>300ppm</th>
<th>500ppm</th>
<th>seradix2</th>
<th>IBA2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root length (cm) P</td>
<td>21.6c</td>
<td>31.86b</td>
<td>16.47d</td>
<td>21.06c</td>
<td>20.79c</td>
<td>26.46cb</td>
<td>51.57a</td>
</tr>
<tr>
<td>B</td>
<td>27.13cb</td>
<td>41.14b</td>
<td>21.62c</td>
<td>27.19cd</td>
<td>26.85cb</td>
<td>34.17bc</td>
<td>66.59a</td>
</tr>
<tr>
<td>Rhizome number P</td>
<td>0.13bc</td>
<td>0.15bc</td>
<td>0.05c</td>
<td>0.03c</td>
<td>0.05c</td>
<td>0.10bc</td>
<td>0.20b</td>
</tr>
<tr>
<td>B</td>
<td>0.38b</td>
<td>0.45ba</td>
<td>0.15b</td>
<td>0.08c</td>
<td>0.15b</td>
<td>0.30b</td>
<td>0.60a</td>
</tr>
<tr>
<td>Culm/shoot number P</td>
<td>0.25b</td>
<td>0.28b</td>
<td>0.09c</td>
<td>0.03c</td>
<td>0.11b</td>
<td>0.14b</td>
<td>0.031b</td>
</tr>
<tr>
<td>B</td>
<td>0.65a</td>
<td>0.72a</td>
<td>0.22b</td>
<td>0.08c</td>
<td>0.29b</td>
<td>0.36b</td>
<td>0.79a</td>
</tr>
</tbody>
</table>

Note: Any two values having the same letter(s) are not significantly different at P<0.05
P = polybag; B = bed.

**Conclusion**

The results indicate that nursery beds provide better growing conditions for branch cuttings compared with polybags in terms of root length, and culm/shoot and rhizome production. The growth can be further enhanced using commercial IBA 2000 powder hormone with 400 ppm concentration applied by the contact method.

**References**


Cultivation Techniques for 
*Dendrocalamopsis oldhamii*

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Abstract

*Dendrocalamopsis oldhamii* is a sympodial bamboo species that grows in the southern subtropical regions, in a wide variety of habitats. Its shoots are sweet, reported to have a cooling effect and to alleviate hypertension and hyperlipaemia; its leaf is a traditional medicine; and its culm is used to produce paper pulp and to make a wide variety of articles. *D. oldhamii* is also a good species for afforestation, and for water and soil conservation.

This paper describes a successful study for the development of suitable cultivation techniques for the species. The four-year-old experiment has resulted in achieving 80% survival rate, and raising 5 million clumps in plantations.

Introduction

*Dendrocalamopsis oldhamii* is a superior sympodial bamboo species that grows in the southern subtropical regions. It favours warm and humid conditions, and grows in a variety of habitats such as river hanks, foothills, homelots, and edges of fields, parks and roads. *D. oldhamii* grows within a short period, requires a low level of inputs, and is a high-yield species. Its shoots are sweet, reported to have a cooling effect and to alleviate hypertension and hyperlipaemia. Its leaf is also a traditional medicine, while its culm is used to produce paper pulp and to make a wide variety of articles, including plywood, particle board and handicrafts. *D. oldhamii* is also a species suitable for afforestation, and for water and soil conservation activities.

In order to develop the cultivation techniques and to enlarge the population of *D. oldhamii*, a study was started in 1986. After four years of
intensive experiments, a plant survival rate of up to 80% was achieved. At present, there are 16-30 culms/clump in several three-year-old stands, and a total of over five million clumps have been planted in about 50 townships in the mountainous area of northern Fujian province. In some places, the bamboo shoot yield has reached 12-15 t/ha, with the highest production level being 100 kg/clump. The cultivation techniques and tending practices developed for *D. oldhamii* are briefly described in this paper.

**Afforestation Techniques**

**Site preparation for plantation**

The best land for planting this species is loose and fertile sandy loam, with sufficient sunshine, water and humidity. The planting pits should be twice as big as the width of the rhizome (size 50 x 50 x 40 cm). A spacing of 5 x 5 m and a planting density of 600 clumps/ha are recommended. Where conditions permit, base fertilizing should be done (15-25 kg of organic fertilizer, mixed with fine top soil).

**Planting season**

The best planting season for *D. oldhamii* in northern Fujian is February or March, because in these months the mother bamboo is still in dormancy period with comparatively lower physiological activity, less sap flow and higher nutrient accumulation. At this time, the digging up of rhizome, its transportation and planting are more convenient.

**Planting methods**

**Rhizome-division method**

Rhizome-division planting is used widely in production since it tends to give a higher plant survival rate, high shoot yield, large-sized shoots and early stand establishment (three to four years).

The mother culm selected should be one year old, healthy with strong growth, and with thick branches and leaves, well-developed basal buds, strong footing and a diameter at breast height (DBH) of 2-5 cm. Digging of the culm should start along the periphery and around the clump, in a circle of about 30 cm in diameter, deepening gradually to prevent damage to basal buds and root system of the clump. The mother culm is then cut off at the point where the culm neck joins the culm base of the old bamboo. The rhizome attached to the mother culm is dug up, taking care to keep some
soil with it. The culm is cut obliquely at 2 m height at the mid-point of the internode. If transported to long distances, it is necessary to wrap the bamboo rhizome with wet grass or moss to prevent damage to basal buds and root failure.

Before planting, the bamboo rhizome is coated with thick mud to prevent dehydration and increase its chances of survival. When the mother culm is planted, care should be taken to ensure that the rhizome is well below the ground level and the culm is perpendicular to the ground. After planting, the soil at the base of the culm should be pressed firm and then topped up to prevent base rotting.

Culm cutting method

Select the middle part of the mother bamboo culm and cut it into one-metre lengths (the cuts at both ends should be oblique and parallel to each other) with three internodes each. Plant two culm cuttings in a pit, at an angle of 30° to the ground, with the cut on the top portion parallel to the ground and one node on the upper part clearly above the surface. Press down the soil around the planted culms, and fill the cut internode on the upper end with water.

Plantlet method

Dig up a one-year-old plantlet raised from a branch cutting, and plant it in a prepared site immediately. Care should be taken to ensure that the root system of the plantlet is intact. Some branches and leaves may be cut off to decrease transpiration and prevent dehydration of the plantlet. The planting pit should be large and deep enough to allow the root system to expand naturally.

Management Techniques

The newly planted culm/plantlet should not be shaken. Care should be taken to ensure that the planted material is protected from damage by people and animals.

Loosen the soil to a depth of 6-12 cm and remove weeds around bamboo clumps every summer or autumn, without damaging bamboo rhizomes or buds on them. Soil-loosening and weeding could be combined in established stands.

In midwinter, every year, rake the top soil of bamboo clumps in order to expose bamboo buds to higher temperatures and sunlight,
loosen soil, stimulate shoot sprouting, prevent bamboo roots from getting crossed and entangled, ensure proper growth of bamboo branches and leaves, and increase nutrient supply for shoot production.

**Fertilizing**

A suitable fertilizer should be applied twice every year. The first application should be done in June, about six weeks after raking the soil. Application is directly at the base of the bamboo clumps. About 10-25 kg of composted organic manure (15-25 kg of human waste or 10-15 kg of barnyard manure) or 150-200 kg of pond silt may be applied per clump. The second fertilizing, called top dressing, is carried out between June and August, when bamboo shooting is most active. Application is in ditches dug around the clumps. Each clump may receive 10-15 kg of human waste or 0.5 kg of chemical fertilizers (such as urea or ammonium sulphate) or 10-12.5 kg of fermented barnyard manure. After application, the ditches must be covered with earth. Strong fertilizers should not be allowed to come in direct contact with young shoots lest the shoots wither and die. Watering should be done at this stage to ensure proper nutrient distribution.

**Covering with soil**

Shoots must be covered with soil before the middle of May when the temperature goes up by 15-20°C. Covering the shoots with wet soil will prevent damage from excessive heat and sunlight, and improve their quality and grade.

**Disease and pest control**

The main diseases and insect pests that afflict *D. oldhamii* are bamboo leaf roller, bamboo shoot weevil, bamboo aphid, cutworm, bamboo soot disease, etc. The best way to protect the bamboo is to combine adequate tending measures with suitable disease/pest prevention and control measures. The onset of disease/pest and their prevention and control are briefly described below.

**Bamboo leaf roller**

It usually affects the plant in one generation-cycles every year. The larvae mature over winter in soil cocoons and pupate in early May of the following year. Moths emerge in late May and lay eggs on the back of bamboo leaves. The larvae of the second generation hatch in 3-5 days. In
middle and late June, the larvae roll the bamboo leaves with silk and feed inside, thus damaging the leaves and yellowing the infested branch. Heavy defoliation may occur during the following year’s shooting and rhizome growth periods. Larvae mature in middle and late July and over winter in the loose top soil near the bamboo rhizome. The control methods include digging up the earth in winter to wipe out maturing larvae, using lamps towards the end of May to lure and kill moths, and spraying a 1:500 dilution of 90% triclorophon on the affected leaves to kill the larvae.

**Bamboo shoot weevil**

It also occurs in yearly one-generation cycles. The adult weevils survive the winter in soil cocoons, emerge out in the following May, and show peak activity from early June to early July. The adult usually rests in the shaded sides of bamboo clumps. Female weevils lay eggs in feeding holes of 1-1.5 cm in length on the upper part of bamboo shoots. In about one week, larvae of the second generation hatch, bore through the shoot and feed on the inside, leaving wide worm channels full of feculae and making the damaged shoot susceptible to mould and rot. The control methods are to turn the earth over in the winter to destroy the soil cocoons, catch weevils manually in the morning or dusk, and cutting open the affected shoot sheath to take out and destroy the larvae.

**Bamboo aphid**

Aphids often herd on the back of the leaf or stem and feed on the sap, leading to bamboo soot disease and stem damage. The control measure is mainly to spray 1:2 000 - 1:3 000 dilution of 50% dimethoate emulsion to kill it.

**Cutworm**

Cutworm eats tender shoots, leaving a worm channel, making the shoot to be malformed or even wither and die. To control the pest, 1: 1000 dilution of 90% triclorophon is sprayed. Application of tea-seed cake, plant ash and quick lime also kills the worm.

**Bamboo soot disease**

It often occurs on leaves and branches. Irregular, black, soot-like spots are seen on the front side of bamboo leaf which soon spread all over the leaf. The affected leaves will fall off, reducing photosynthesis rate and
weakening the plant. The control measure is mainly to kill the aphid and the soot pathogen with lime-sulphur. Besides, felling bamboo at a reasonable rate could increase ventilation and sunshine within the bamboo grove, and thus decrease the incidence of the disease significantly.

**Harvesting of shoots**

The shooting period of *D. oldbamii* lasts for about five months, starting in middle May and reaching the peak from early July to late August. Shooting activity decreases from early September and ends around late October. Normally, the annual shoot yield is 5-6 t/ha, but intensive management could give much higher yields.

Before harvesting the bamboo shoots, the top soil around the shoot should be raked off. The shoots must be cut short, using a special chisel, upward and along the culm base, to leave the cut surface flat. Care should be taken to not damage other young shoots nearby. According to the traditional practice of the peasants, spraying a little low-density human urine or urea in the place where the bamboo shoot is cut, and covering it up firmly with earth would facilitate regeneration and sprouting, as well as prevent the tender shoots from termite attack. The growth of *D. oldhamii* culm and shoots increase with temperature, relative humidity and precipitation. So spraying bamboo clumps with water will favour the shoot-culm growth if drought conditions prevail during the shoot harvesting period.

**The Regeneration of Bamboo Stands**

After germination, the large basal buds of *D. oldbamii* usually make an angle of 40-70° with the mother bamboo, grow forward from one side, emerge from the ground and grow into a new bamboo culm. The culm neck of the new bamboo is always higher than the culm base of the mother bamboo. Thus, the location from which new bamboo grows gets raised year after year. Space restrictions that hamper of roots and culms, and excessive exposure of basal buds would adversely affect clump development. Besides fertilizing and covering the shoots with soil, measures such as cutting taller shoots and retaining shorter ones, keeping at least 4-6 culms/clump annually, etc. are all some of the basic measures required to guarantee vigorous growth of bamboo stands.
Mass Propagation of Tropical Sympodial Bamboos through Macroproliferation

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Abstract

Macroproliferation for the continuous production of field-plantable saplings of *Bambusa bambos*, *B. tulda*, *Dendrocalamus hamiltornii* and *D. strictus* in large numbers has been achieved. The technology is simple, easy to apply and involves the use of locally available materials. The field planting stocks thus produced, remain small in size, which is an additional advantage as these are easy to handle and transport.

Introduction

Bamboo plays an important role in the rural economics of the developing countries. Tewari (1988) therefore called bamboo a poverty alleviator. No other plant is known in the tropical zone which gives to people as many technical advantages as bamboo (Kurz 1876). More than 4,000 traditional uses have been estimated for bamboos. For many centuries, bamboo has been closely related to the daily life of more than half the world’s population (Hsiung 1991). It is a very important raw material for several small to large-scale industries, besides its use as a construction material. Several thousands of rural people are engaged in the traditional crafts of making bamboo mats, baskets, etc. to earn their livelihood. Intensive bamboo propagation is necessary not only to promote biomass and species conservation, but also to cultivate economically important species for financial gains and to supply bamboo to meet the market demands (Rao 1992). But increasing demand and overexploitation are continuously depleting the bamboo stocks in most Asian countries.

The best method of bamboo propagation is by seed. There are bamboos which flower annually. But in most species within the tropics,
the vegetative phase is a prolonged one - 15, 30 (the most usual), 60 or even 120 years - followed by the death of the clump. The aftermath could be truly apocalyptic: rotting culms collapse in heaps, fire rages and hordes of rats forage on the seeds that lie up to 15 cm thick on the ground (Hanke 1990). The main hurdle in raising a bamboo plantation is the relatively limited seed production in nature owing to very long seeding intervals. Secondly, the seeds are short-lived and hence, cannot be stored for future use. The traditional methods of vegetative propagation of bamboos appear to be inadequate to meet the demand for field-plantable saplings in massive numbers for raising large plantations.

Vegetative propagation by culm, branch or rhizome cuttings is commonly practised. For all practical purposes, however, the degree of failure is still rather high, especially for establishing large plantations. In spite of intensive efforts made at various institutes, a universally applicable method for vegetative propagation of bamboo is not yet available (Liese 1985, 1991). Similarly, Ramanuja Rao and Usha Rao (1990) remarked that vegetative methods of bamboo propagation - offset planting, rooting of culm and branch cuttings - are of limited value for the large-scale propagation of clump-forming sympodials. Secondly, the propagules produced are bulky, heavy, and difficult to handle and transport.

The macroproliferation technique of vegetative propagation was first developed by Banik (1987). According to Tewari (1992), the method has the potential for universal application, and can be used for mass production of field-plantable saplings of sympodial bamboos. Liese (1992) has described this technique as most remarkable and stated that it can solve the existing difficulties of vegetative propagation of bamboos.

**New Technology**

The mass-production of planting material through macroproliferation utilizing young seedlings/saplings, field-plantable saplings has been achieved for *Bambusa bambos* (L.) Voss, Besch. [Syn. *B. artrndinacea* CRetz.1 Willd.], *B. tulda* Roxb., *Dendrocalamus hamiltonii* Nees et Am. ex Munro and *D. strictus* (Roxb.) Nees (Anon. 1992). The method (Adarsh Kumar 1991, 1992; Adarsh Kumar et al. 1992; Adarsh Kumar and Pal 1994) ensures that each propagule possesses shoot, root and rhizome parts even at the time of propagule production, guaranteeing rapid establishment and almost 100% survival of the propagated material. A detailed plan (Figure 1) has been developed for the continuous production of field-plantable
Fig. 1: Plan for the mass production of field-plantable stocks of tropical sympodial bamboos vegetatively through macroproliferation

In the first year, field plantable saplings in massive numbers are available through stages 1-2-3. From second year onwards, the same number of field plantable saplings are available from stages 3-4.5-2 and so on.

AUGUST 4th Stage
- SEPARATE PROPAGULES
  - BY CUTTING RHIZOME
  - AND PLANT IN POLYBAGS
  - BB-7,000; BT-5,000
  - DH-4,000; DS-6,000

AUGUST 1st Stage
- RAISE SEEDLINGS BY SEED SOWING OR PICK OUT FROM FOREST AND PLANT IN POLYBAGS
  - BB-7,000; BT-5,000
  - DH-4,000; DS-6,000

MARCH 5th Stage
- SAPLINGS
  - BB-7,000; BT-5,000
  - DH-4,000; DS-6,000

APRIL 2nd Stage
- SEPARATE PROPAGULES BY CUTTING RHIZOME AND PLANT IN POLYBAGS
  - BB-49,000; BT-25,000
  - DH-16,000; DS-36,000

JULY 3rd Stage
- 1,000 SAPLINGS FOR FUTURE MULTIPLICATION

- SAPLINGS FOR FIELD PLANTING
  - BB-48,000; BT-24,000
  - DH-15,000; DS-35,000

BB = Bambusa bambos; BT = Bambusa tulda; DH = Dendrocalamus hamiltonii; DS = Dendrocalamus strictus.
Propagation and Management

Saplings vegetatively in massive numbers through macroproliferation, reducing the dependence on bamboo seeds for raising plantations.

Young seedlings of 3-5 leaf stage of Bumbusa bambos (7 000 seedlings), B. tulda (5 000), Dendrocalamus hamiltonii (4 000) and D. strictus (6 000) were raised in August by sowing seeds in July or were pricked out from the forest floor. They were planted in August in polybags (24 x 18 cm size), each of which was filled with a 2-kg mixture of sieved soil, sand and farmyard manure in 1:1:1 ratio. NPK treatment was applied by localized placement of the first dose of fertilizer. The first dose consisted of: urea (N = 46.4%) = 0.05 g/polybag @ 25 kg N/ha; super phosphate (P₂O₅ = 16%) = 0.59 g/polybag @ 100 kg P₂O₅/ha and muriate of potash (K₂O = 56-60%) = 0.04 g/polybag @ 25 kg K₂O/ha, mixed in 30 ml of water/polybag. A solution of NPK (30 ml) was poured 10-12 cm deep into the planting hole of each polybag, prior to planting of 1-month old bamboo seedlings. The second dose of fertilizer-urea (N = 46.4%) = 0.05 g @ 25 kg N/ha and muriate of potash (K₂O = 56-60%) = 0.12 g @ 75 kg K₂O/ha in 30 ml of water - was applied in the top dressing of soil of each polybag at intervals of one month from the day of planting of young seedlings in polybags.

In the first week of April, the seedlings consisting of tillers, rhizome and roots were carefully removed from the polybags. Each proliferated tiller, along with part of rhizome and roots, was separated by cutting the rhizome with a sharp secateur to act as a propagule (B. bambos = 49 000; B. tulda = 25 000; D. hamiltonii = 16 000 and D. strictus = 36 000). These were planted in fresh polybags of 24 x 18 cm size, each containing a 2-kg mixture of sieved soil, sand and farm yard manure. Localized placement of first NPK dose and the second dose of N and K were applied as mentioned above. By July, 3-10 tillers of field-plantable size had proliferated in each polybag of B. tulda, D. hamiltonii and D. strictus. In the case of B. bambos, 6-14 tillers had developed in each polybag Out of these, 1 000 seedlings/saplings were retained in the nursery for future multiplication and the remaining saplings (48 000 of B. bambos, 25 000 of B. tulda, 15 000 of D. hamiltonii and 35 000 of D. strictus) were made available for field planting.

In the first week of August, the proliferated tillers of 1 000 bamboo saplings retained in the nursery, were separated out for production of propagules and further raising of a large number of saplings by March (B. bambos = 7 000, B. tulda = 5 000, D. hamiltonii = 4 000 and D. strictus = 6 000). It was thus established that the whole cycle could be repeated every year for producing field-planting stocks for large plantations.
The seedling multiplication should not be continued for a long period as the time gap between the last multiplication and the subsequent flowering gets shorter. Multiplied seedlings are clones and become physiologically older as time passes from the date of germination of the mother seedling. The result is that the last multiplied seedlings are likely to start flowering because of their physiological maturity before attaining the marketable culm size (Banik 1987). Hence, from the second year onwards, various operations were carried out sequentially (Figure 1 - through stages 3-4-5-2 and so on) for the production of field-plantable saplings in massive numbers perpetually for any desired number of years, depending on the facilities available and the targets set.

References


Commercialization of Bamboo Tissue Culture

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Abstract

Bamboos are an important constituent of India's forest produce. The high utility of this woody grass has made it very vulnerable to felling by the rural communities, and paper manufacturing units where it is consumed as a basic raw material. Currently, the demand for bamboos vastly exceeds supply. Increasing production by raising industrial plantations is imperative. Tissue culture offers a rapid and reliable means of producing large numbers of bamboo plants required to undertake this task. Micropropagation protocols for various bamboo species are now available. The Tata Energy Research Institute, under the sponsorship of the Department of Biotechnology, Government of India, has set up a Tissue Culture Pilot Project (TCPP) for large-scale production of forest tree species including bamboos. So far, more than 60,000 plants of various bamboo species (Dendrocalamus strictus, D. longispathus, and Bambusa tulda) have been produced at TCPP. They have been successfully planted at different locations for field testing. This paper highlights some of the observations made by the authors during the mass propagation of D. strictus.

Introduction

In India, bamboos occupy an area of 10.03 million hectares, which is nearly 12.8% of the country's total forest cover (Tewari 1992). During 1991, the production of bamboo from all sources was about 4.045 million tonnes, a quantity which is significantly lower than its projected demand of about 7 million tonnes by 2000 A.D. With existing resources, the supply of bamboo is expected to remain more or less static in the coming years. Therefore, if this gap between demand and supply is to be narrowed, bamboo production will have to be increased. The supply of bamboo can be augmented either by raising large-scale (industrial) plantations or by enhancing the yield per unit area.
Raising Large-scale (Industrial) Plantations

Since the Indian paper industry consumes nearly two-third of the country’s annual bamboo production, it is also required to take some initiatives to secure the availability bamboo. While some of the leading paper mills have already established their own plantations or have made arrangements with local farmers to grow bamboos for them, others are in the process of doing so. However, non-availability of land and scarcity of planting material are the two major impediments in raising large-scale plantations. Even where land is not a limiting factor, various constraints associated with conventional methods of propagation (sexual as well as vegetative) have restricted the availability of propagules.

Enhancing Yield per Unit Area

It would be rather difficult to divert agricultural land for forestry use, including bamboo cultivation, because of the mounting population pressure. Therefore, besides increasing the bamboo cover, efforts must also be made to increase yield per unit area by breeding high-yielding clones or planting superior germplasm. Except for a couple of reports by Chinese researchers (Guang-chu and Fu-qiu 1987, 1994), breeding of bamboos has not met with much success. This is due to the long and erratic flowering cycle of bamboo (30-60 years in most species), and geographical and climatic barriers. Moreover, the factors responsible for flowering in bamboos have largely remained unknown.

Since sexual hybridization in bamboos is difficult, another approach towards increasing productivity could be the selection and large-scale clonal propagation of superior genotypes already growing in the field. However, even the vegetative methods of bamboo propagation are constrained by the restricted availability of culm cuttings, season specificity and the voluminous nature of the propagules. Also, vegetatively raised plants tend to retain their physiological age and thus carry the risk of early flowering.

Application of Tissue Culture

Tissue culture overcomes most of the drawbacks that affect conventional methods of propagation. Through tissue culture, a large number of plants could be produced with just a few seeds, and the demand for planting material for raising industrial plantations could easily be met. Micropropagation, if performed with adult tissue, would also enable mass
multiplication of superior genotypes. This would lead to both quantitative and qualitative gains. With the advancement of other tissue culture techniques, such as somatic hybridization and induction of in vitro flowering, even high-yielding bamboo hybrids may soon be a reality.

**Current Status of Bamboo Tissue Culture**

The growing awareness about the utility and scarcity of bamboo has prompted many researchers to take up studies on tissue culture of bamboos. During the last few years, there have been a large number of reports dealing with different aspects of tissue culture including micropropagation, somatic embryogenesis, and in vitro flowering. Interestingly, many of these reports came from European and American countries regarded as non-traditional bamboo areas. Although there have been several reports that describe regeneration of plants under in vitro conditions, barring the exception of Usha Rao et al. (1990), none of them deal with mass propagation of bamboos. Some probable reasons for this are: (1) lack of infrastructural facilities; (2) most research protocols published in various journals are purely of academic value and are not truly suited for large-scale propagation; and (3) usually, the research studies are performed by doctoral students whose main objective is to obtain a degree, and once that is accomplished they switch over to another plant species or move to some other institution to pursue their career. As far as the use of tissue culture technology for mass propagation is concerned, this activity is largely confined to private companies operating in this area. However, in order to safeguard their commercial interests, the knowledge generated in such laboratories is never disseminated.

In India, till the beginning of this decade, very little progress was made in the commercialization of tissue culture technology for forest species, including bamboos. This was mainly because the government institutions lacked adequate infrastructure to take up such an activity, while the private entrepreneurs, in the absence of any concrete proof of the technical soundness and economic feasibility of the technology, felt it risky to venture into this area.

In a major initiative in 1989, the Department of Biotechnology, Government of India, set up two pilot-scale national facilities for the large-scale production of superior genotypes of various woody species, including those which are difficult to multiply by conventional methods of propagation, such as bamboos. One such unit has been established by Tata Energy
Research Institute (TERI) while the other one has been set up at the National Chemical Laboratory, Pune. The ultimate objective in establishing these facilities was to assess, and if found effective then to promote, the use of tissue culture technology for increasing biomass production.

TERI’s Tissue Culture Pilot Plant (TCPP) is located in Gurgaon District (Haryana), about 30 km to the south of Delhi. It has an annual capacity of two million plants. From 1991, when it became operational, till December 1995, nearly two million plants have been produced in this unit, including more than 60,000 plants of bamboos (Dendrocalamus strictus, D. longispathbus and Bambusu tulda). These plants were distributed to various state forest departments to conduct field trials.

Of the three species mentioned above, the emphasis has largely been on D. strictus as the other two species have a narrow geographical distribution and their natural habitat is far away from the production unit. The transportation cost involved in such venture would be exorbitant and would render the production process commercially nonviable. In contrast, D. strictus grows well under relatively warm and dry conditions that are widely prevalent in Haryana, Delhi, Madhya Pradesh, Uttar Pradesh and other adjoining states. Moreover, because of absence or very narrow lumen (a highly desirable trait from transportation point of view) and multiple uses, this species is in great demand.

The methodology for in vitro propagation of D. strictus through somatic embryogenesis was first developed at the University of Delhi (Usha Rao et al. 1985) and was subsequently passed on to TERI for mass multiplication in 1991. However, when the same protocol was applied for mass propagation at TCPP, somehow, it did not work very satisfactorily. This may be due to genotypic variability in the seed lots used. Subsequently, intense research activities were launched, and besides the vigorous selection of the genotypes, many refinements were made in the original protocol to improve its overall efficiency.

**Protocol for Mass Propagation of D. strictus through Somatic Embryogenesis**

Seeds of D. strictus were obtained from the forests in Maharashtra and Uttar Pradesh, India. After de-husking, they were surface sterilized with 0.1% mercuric chloride for 10 minutes. On agarified MS medium (Murashige and Skoog 1962) supplemented with $3 \times 10^{-5}$ M 2,4-D, the seeds formed calli at the embryonic end of the seeds within six weeks of culturing.
Embryoids showed rapid multiplication on semi-solid MS + 2,4-D (1 x 10^{-5} M) + Kn (5 x 10^{-6} M) + soluble PVP (250 mg/l) [Figure 1a] or MS + 2,4-D (1 x 10^{-5} M) + BAP (1 x 10^{-5} M) + PVP (250 mg/l) at a rate of 2-5 fold every four weeks. Whereas 70-80% of the genotypes yielded higher multiplication rates on medium containing kinetin, only 20-30% of the genotypes performed better on BAP. On being transferred to MS + NAA (5 x 10^{-6} M) + Kn (5 x 10^{-6} M) + PVP (250 mg/l) the chlorophyllous embryoids developed into healthy plantlets (Figures 1 b, c, d). Although, in majority of the genotypes (more than 90%) embryoids formed both shoot/s and roots, in a few genotypes embryoids produced only shoots. Such shoots were rooted on modified MS (major salts reduced to half strength) + NAA (3 x 10^{-6} M) + IBA (2.5 x 10^{-6} M). The rooted plants were transferred to Soilrite in plastic trays and irrigated with inorganic salt solution of MS medium (major salts reduced to half strength). The plants were reared inside the glass house maintained at 28 ± 2°C for seven days. Thereafter, the plants were transferred to polybags containing equal quantities of soil and organic manure (v/v) inside a polyhouse. Depending on the weather conditions prevailing outside, the plants were kept inside the polyhouse for two to three weeks (Figure 1e) and then transferred to nursery in shade. Following this procedure, more than 85% plants survived (results refer to the experiments performed during monsoon, i.e. July to September).

Fig. 1a: Magnified view of a cluster of Deudrocalamus strictus embryoids obtained in semi-solid MS containing 2,4-D (1 x 10^{-5} M) + Kn (5 x 10^{-6} M) + PVP (250 mg/l)

Fig. 1b: Different stages of D. strictus embryoid germination in MS + NAA (5 x 10^{-6} M) + Kn (5 x 10^{-5} M) + PVP (250 mg/l)
Fig. 1c: A magnified view of germinating *D. strictus* embryoids (early stage)

Fig. 1d: Culture showing advanced stage of *D. strictus* embryoid germination wherein embryoids have developed into complete plantlets

Fig. 1e: A group of in vitro raised *D. strictus* plants after two weeks of transfer to soil inside the polyhouse
During the course of the study, certain critical factors influencing the production process were identified. These are as follows:

**Explant**

The availability of explant is a crucial factor in the success of micropropagation. In *B. tulda*, in spite of an efficient micropropagation protocol developed at the laboratory (Saxena 1990), only 1700 tissue cultured plants could be produced at TCPP. This was because, in the absence of fresh seeds, only those few cultures that were initially raised to develop the protocol were available for plant production. However, the wider distribution made it relatively easier to procure seeds of *D. strictus* than of any other bamboo species with restricted habitat.

Besides availability, the quality of seeds performs a vital role in the initiation and establishment of cultures. Usually, freshly collected seeds yield better performance. Also, much variation was observed within and among different seed lots with regard to (1) microbial contamination, (2) amount and type of calli (embryogenic or non-embryogenic) formed, (3) regeneration potential of the calli to form embryoids and their further multiplication, and (4) conversion frequency of embryoids into plantlets.

1. In some seed samples microbial contamination was extremely low while in others it posed a major problem.
2. Generally the seeds produced both embryogenic (yellow and compact) and non-embryogenic (white and friable) calli. However, at least 10-20% of genotypes produced only non-embryogenic calli. Such genotypes were discarded in the early stages of culture establishment. The quantity of a particular type of callus formed was highly variable.
3. Embryoid multiplication rate varied between 2-5 folds every four weeks. Some genotypes were more vigorous than others (Figure 2a).
4. Not only there was a high degree of variability in the germination frequency of embryoids (Figure 2b), but also in the nature of plantlets produced. Usually the embryoids formed both shoot/s as well as roots. However, in some genotypes the embryoids did not produce any shoots at all or the shoots were extremely small. In contrast, in some cases rooting was scanty or altogether absent. Such shoots had to be rooted on a separate medium. Efforts should be made to avoid this rooting stage (through rigorous screening of genotypes) as any additional step in the regeneration process would increase the plantlet cost and production time.
Optimization of media for multiplication and germination of somatic embryos

To eliminate any possibility of monoculture on account of tissue culture, it is always desirable to keep the genetic base as broad as possible. However, it was observed that for the multiplication and germination of somatic embryos, the nutritional requirements varied markedly from...
genotype to genotype. This virtually amounted to standardizing the medium for individual genotypes which made the production process very tedious and cumbersome.

**Handling of cultures**

While establishing the protocol for in *vitro* propagation of any species, the ‘cultures are invariably managed by the scientist concerned. Therefore, the results obtained are fairly consistent. However, for mass propagation, large numbers of cultures are required which are handled by many operators, each possessing different operational skills. This often results in variable response even within the replicates of the same genotype. During this study, this variability was only in terms of amount and kind of callus produced, variable germination frequency, etc. and had nothing to do with any genetic change.

**Hardening of plants**

During the rainy season, weather conditions are extremely favourable for the growth of the plants and hardening does not pose any problem. In summer also, one may get high survival provided the plants are irrigated regularly and grown under shade. However, heavy losses were incurred when the plants were taken out of laboratory during winters (October-February). With decline in temperature, survival frequencies also dropped. The most probable reason for such heavy losses could be that *D. strictus* is a inhabitant of warm areas, and therefore, susceptible to low temperatures. The smaller the plantlet, the higher the number of casualties. Under natural conditions also, the leaves become dry and are often shed, but the plant still manages to survive because of underground growth of the rhizome that had taken place in the earlier months (July-October). Tissue cultured plants usually take 6-8 weeks after transplantation to develop rhizomes. However, those plantlets which were transferred to soil in October or later months get exposed to low temperatures much before they are able to form rhizomes and as a result, they die off. Growing plants in glass houses and/or polyhouses can bring down the hardening losses to some extent, but ideally, the production of this species should be suspended during winters.

**costs**

At the protocol development stage the entire research is targeted towards obtaining an efficient regeneration system and the cost factor is
invariably ignored. However, from the commercial point of view, this perhaps is the most important aspect. Although the best way to economize the production process is to improve the overall efficiency of the protocol, at some stage, this becomes a limiting factor. Once the optimal efficiency of a protocol has been attained, efforts should be made to cut down the direct cost of the production. Some of the cost-effective measures adopted at TCPP are as follows:

- Use of ordinary jam jars instead of highly expensive Corning or Borosil glassware;
- Use of refined sugar as carbon source instead of Analytical grade sucrose commonly used in research labs;
- Replacing highly purified agar with food-grade agar; and
- Substituting expensive growth regulators with less expensive ones without compromising on the quality of the plants.

Along with somatic embryogenesis efforts were also made to regenerate plants by shoot proliferation. The idea behind this study was to assess the technical and economical feasibility of this approach vis-à-vis somatic embryogenesis.

**Methodology for regeneration of D. strictus plants by axillary branching**

Seedlings were raised from the same seed lots (Maharashtra and Uttar Pradesh) that were used earlier to obtain embryogenic cultures. To initiate cultures, the de-husked seeds were given a quick rinse in rectified spirit and washed with a detergent (Teepol) for about 10 minutes. After surface sterilization with 0.1% mercuric chloride solution for 10 minutes followed by four washings with sterilized filtered water, the seeds were cultured on semi-solid and liquid MS basal medium. While the semi-solid medium was gelled with 0.8% agar, in liquid medium the seeds were rested on filter paper bridges (Whatman No. 1). Depending on the seed sample, the germination frequencies varied from 60-80%. Generally, the germination rate and shoot growth was better in liquid medium than on semi-solid medium.

For multiplication, shoots derived from three-week-old seedlings were transferred to semi-solid B₅ (Gamborg et al. 1968) or MS medium. However, the shoots failed to proliferate on either of the basal media and turned brown over a period of time. Incorporation of BAP at various concentrations (4 x 10⁻⁶M - 1.3 x 10⁻⁵M) resulted in shoot proliferation. At all concentrations of BAP, MS medium was superior to B₅ medium in terms of shoot multiplication rate. However, irrespective of the basal medium used,
the proliferating shoots turned brown within two to three weeks of culturing. This problem was successfully overcome by culturing the shoots on the support of filter paper strips (Whatman No. 1) dipped in liquid medium. Thereafter, in all the experiments related to shoot multiplication liquid MS medium was used. Of the various concentrations of RAP tried, 9 × 10⁻⁶ M BAP yielded the highest multiplication rate (2.2 times in three weeks). In order to enhance the proliferation rates, BAP was used in conjunction with Kn (1 × 10⁻⁶ M - 5 × 10⁻⁶ M) or IBA (1 × 10⁻⁶ M - 5 × 10⁻⁶ M) or coconut water (5% and 10%). On the optimal medium containing MS + BAP (9 × 10⁻⁶ M) + IBA (1 × 10⁻⁶ M) + coconut water (5%), recurrent shoot multiplication at an average rate of 3.5-fold every three weeks was obtained (Figure 3a) for more than 14 passages.

Fig. 3a: Multiple shoot formation achieved in 3 weeks after transferring a propagule into shoot multiplication medium (MS + 9 × 10⁻⁶ M BAP + (1 x 10⁻⁶ M) IBA + 5% coconut water

Fig. 3b: A cluster of shoots rooted in liquid MS medium containing 6 × 10⁻⁶ M IAA, 5 × 10⁻⁶ M IBA and 7 × 10⁻⁶ M coumarin

For rooting of shoots, IAA, IBA, NAA and coumarin were tested individually and in various combinations. About 70% of the shoots rooted in liquid MS
medium containing \(6 \times 10^{-6}\) M IAA, \(5 \times 10^{-6}\) M IBA and \(7 \times 10^{-6}\) M coumarin (Figure 3b). Often the plantlets formed a distinct "rhizome-like" structure in the multiplication and rooting medium. Because of this reason, the plantlets could be directly transferred to a potting mix in polybags inside a glass house with over 80% success (Figure 3c). So far, more than 500 plants have been produced using this methodology. However, when compared with somatic embryogenesis, this process of plantlet production is less efficient and more expensive, and therefore, not favoured for mass propagation. After the success with juvenile explants (see cis), the research is now focused on an efficient micropropagation protocol with adult tissue, which would enable the multiplication of clones with proven superiority. Preliminary experiments in this regard are underway.

References


Studies on Micropropagation of
Dendrocalamus giganteus and Bambusa vulgaris var. striata

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Abstract
The initiation of axenic cultures was done using Benlate, a broad-spectrum fungicide, for pretreatment during surface sterilization, as well as in the culture medium during the first few passages. There appears to be an inverse relationship between bud break and contamination which were seasonally affected. Continuous shoot proliferation was achieved. However, it needs to be improved in mature culm explants. Root induction is necessary in order to use this as a method of micropropagation to produce planting stock. Embryogenic callus was induced from excised zygotic embryos of Dendrocalamus giganteus.

Introduction
Bamboos are distributed from tropical to temperate regions, but are more widely distributed and utilized in the tropics. Sri Lanka has 17 species, of which 10 are native. The two species under investigation, Dendrocalamus giganteus (giant bamboo) and Bambusa vulgaris var. striata (yellow bamboo) are amongst the more widely utilized species in Sri Lanka. Tissue culture investigations were carried out to develop methods of micropropagating the two species. This study reports on the results achieved using single node segments and excised zygotic embryos as the initial explant.

Materials and Methods
In vitro axillary bud break and shoot multiplication
Single node segments of secondary branches from mature culms of D. giganteus and B. vulgaris, and from four to five-year-old juvenile plants of D. giganteus were used to initiate cultures.
Mercuric chloride and bleaching powder were used in the surface sterilization procedure. The nodal segments were soaked for one hour in a 1 g/l suspension of Benlate (Benomyl) during surface sterilization. Benlate was also incorporated at 1 g/l in the culture medium, which consisted of semi-solid MS medium (Murashige and Skoog 1962) with 2 mg/l 6-benzylaminopurine (BAP) and 0.1 mg/l kinetin.

The effect of Benlate in reducing fungal contaminants and its possible adverse effects in reducing bud break were investigated. Benlate-treated single node segments of *B. vulgaris* were cultured in a medium incorporated with Benlate. As control, untreated single nodes were cultured in Benlate-free medium. Forty single segments were used in each treatment and the experiment repeated five times.

To investigate the effect of seasonal and environmental changes that affect bud break, single node segments of the two species were cultured every fortnight, and their bud break and contamination observed.

Nodes, which had at least one sprout and an open leaf, were transferred to a liquid medium with higher levels of BAP (6-10 mg/l). Proliferating shoots in both species were separated from the mother nodes and subcultured every 10 to 15 days.

**Callus differentiation**

Inflorescence from flowering clumps of *B. vulgaris* and *D. giganteus* were collected. Seeds were separated from a flowering clump of *D. giganteus*. These were dehusked, surface-sterilized, and the excised zygotic embryos cultured in a modified MS medium with 2,4 dichlorophenoxyacetic acid (3,5 and 8 mg/l) and BAP (0 or 1 mg/l). A total of 250 embryos were cultured. The proliferating callus was subcultured every 2-3 weeks.

**Results and Discussion**

**In vitro axillary bud break and shoot multiplication**

Fungal contaminants, mainly systemic type, began to appear in single nodes segments of *B. vulgaris* after 7-10 days in culture (Table 1). The number of contaminated cultures in the first and third weeks after culture was significantly higher in the control than in the Benlate-treated single nodes. After the fourth week, all nodes in the control were contaminated while a few aseptic cultures remained in the Benlate treatment. There was
no significant difference in the number of nodes that were induced to sprout between the control and Benlate treatment. This indicated that Benlate effectively reduced culture contaminants without adversely affecting *in vitro* bud break. This treatment was therefore used to initiate cultures of single node segments in the two species of bamboo under investigation.

**Table 1:** Bud break and contamination in single node segments of *Bambusa vulgaris*

<table>
<thead>
<tr>
<th>Month</th>
<th>Treatment</th>
<th>Bud break (%)</th>
<th>Contamination (%)</th>
</tr>
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<tbody>
<tr>
<td>May</td>
<td>B+</td>
<td>72.5</td>
<td>17.5</td>
</tr>
<tr>
<td></td>
<td>B-</td>
<td>77.5</td>
<td>85.0</td>
</tr>
<tr>
<td>June-1</td>
<td>B+</td>
<td>47.5</td>
<td>22.5</td>
</tr>
<tr>
<td></td>
<td>B-</td>
<td>27.5</td>
<td>67.0</td>
</tr>
<tr>
<td>June-2</td>
<td>B+</td>
<td>42.5</td>
<td>45.0</td>
</tr>
<tr>
<td></td>
<td>B-</td>
<td>12.5</td>
<td>95.0</td>
</tr>
<tr>
<td>June-3</td>
<td>B+</td>
<td>80.0</td>
<td>20.0</td>
</tr>
<tr>
<td></td>
<td>B-</td>
<td>77.5</td>
<td>57.5</td>
</tr>
<tr>
<td>July</td>
<td>B+</td>
<td>47.5</td>
<td>20.0</td>
</tr>
<tr>
<td></td>
<td>B-</td>
<td>52.5</td>
<td>80.0</td>
</tr>
</tbody>
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B+ : Nodes treated with Benlate  
B- : Control

Axillary bud dormancy was observed during certain periods of the year when they did not develop into shoots in *vitro* (Figure 1). The highest mean bud break of 30.6% was in *B. vulgaris* and the lowest of 9.6% in nodes of *D. giganteus* mature clumps. Nodes from juvenile clumps of this species had a higher mean bud break of 17%. Ramanuja Rao and Usha Rao (1990) reported that it was relatively easier to get the axillary buds in the nodes of *B. vulgaris* to sprout than those of *D. strictus*. In general, juvenile plant material responds better than mature culm explants to *in vitro* manipulations. This is shown by the juvenile nodes of *D. giganteus*, which had the highest bud break of 88% during April 1994, while its low mean bud break could be due to seasonal effects.

During April-July 1994, all three types of nodes showed a relatively high bud break. In *B. vulgaris*, it was greater than 40% during this period.
Fig. 1: Bud break in *Dendrocalamus giganteus* and *Bambusa vulgaris* during April 1994-April 1995
when the highest bud break of 85% recorded. Nodes from juvenile D. gigunteus clumps had the highest bud break of 88% in April 1994, and mature nodes of this species too had a relatively high bud break of 32% in June 1994.

Nodes from juvenile clumps showed peak periods of bud break again in April and September 1994 when mature culm nodes of this species were dormant. *B. vulgaris* nodes showed peak periods of bud break in July and September 1994 and in February and March 1995, when the mature nodes of *D. giganteus* were dormant. But during the period extending from January to April 1995, bud break in the mature nodes of both species was high, while that in the juvenile clumps was low.

There appeared to be an inverse relationship between in *vitro* bud break and culture contaminants in all three types of nodes (Figures 2, 3 and 4). The juvenile tree nodes had the lowest mean number of contaminations. Although a seasonal effect was evident in in *vitro* bud break and culture contaminants, its pattern was not clear. Bud break in all three types of nodes synchronized only during March to July 1994. Ramanuja Rao and Usha Rao (1990) reported that the axillary buds in the nodes of bamboos remain dormant most of the year and generally sprout during the rainy season. Saxena and Bhojwani (1993) have also made a similar observation in *D. longisputbus*. However, such a relationship between rainfall pattern and bud break was not observed during the period under investigation. This may be due to the anomalous pattern of rainfall received during this period, with precipitation occurring in every month.

The natural or characteristic behaviour of buds with respect to dormancy and the breaking of dormancy varies with the position of the buds, the species and the season (McClure 1966). Therefore, this investigation needs to be carried out over a longer period and compared with environmental factors such as rainfall and temperature in order to identify seasonal effects that trigger in *vitro* bud break in the two species. Nodal material for initiating cultures can then be collected at times favourable for in *vitro* bud break.

The number of axillary buds that developed into shoots ranged from one to four in the two species (Figure 5). They turned brown if they were not transferred to fresh medium when the shoots elongated and the leaves expanded.

More shoots sprouted when nodes with at least a single shoot and an expanded leaf were transferred to liquid medium. The number of shoots
Fig. 2: Bud break and contamination in *Bambusa vulgaris* during April 1994-April 1995
Fig. 3 Bud break in the nodal segments of mature *Dendrocalamus giganteus* during April 1994-April 1995
**Fig. 4**: Bud break in the nodal segments of juvenile *Dendrocalamus giganteus* during April 1994-April 1995.
per node ranged from 7 to 50 (Figure 6). These needed to be transferred to a fresh medium at frequent intervals of 7-10 days to prevent browning and vitrification. The shoots that multiplied were separated from the mother node into clusters and subcultured. Shoots multiplied continuously by forced axillary branching. A maximum number of 73 shoots per node developed in mature culm nodes and 366 in juvenile culm nodes of D. giganteus within a period of 120 days. This species showed an average of a four-fold multiplication at each subculture. Although a large number of nodes of B. vulgaris were induced to sprout initially, very few of them multiplied on transfer to a liquid medium. Many of the shoots that multiplied, vitrified and turned brown. Shoots induced from B. vulgaris nodes have been reported to multiply at a slower rate than those from D. longispathus (Saxena and Dhawan 1994).

Although some species of bamboo have been micropropagated by axillary branching from seedling material (Nadgir et al. 1984; Saxena 1990), only a few reports are available on the micropropagation of bamboo from mature culm nodes. Saxena and Bhojwani (1993) have successfully produced plants from four-year-old D. longispathus. Chaturvedi et al. (1993) were able to induce sprouting and elongation of shoots from 10-year-old D. strictus, but could not achieve continuous shoot multiplication. In this study, it was possible to achieve continuous shoot multiplication from nodes taken from mature clumps of D. giganteus that were over 50 years old.

Seeds were found only in a few clumps of D. giganteus that flowered. Out of seven clumps of B. vulgaris that flowered, none set seed.

Callus was induced in some of the embryos that were cultured (Figure 7). These proliferated on subculture. There was a variation in the number
Fig. 6: A proliferating cluster of shoots in *Derldrocalamus giganteus*

Fig. 7: Callus induced from an excised zygotic embryo

of embryos that were induced to develop callus between and within treatments. Callus proliferation too varied. The callus that developed was creamy white in colour. Some of these had associated mucilage. In the callus that proliferated, globular structures that resembled somatic embryos developed. Some of these turned green and shoots and roots differentiated. Further investigations need to be carried out on media constituents and physical factors that will promote consistent
callus induction, proliferation and somatic embryogenesis. Propagation of D. strictus from plantlets, which germinated from somatic embryos derived from seeds, has been reported by Usha Rae et al. (1985).

**Acknowledgments**

We are grateful to Dr A. Kovoor, who initiated culture studies in bamboo at the Institute of Fundamental Studies, for his suggestions and keen interest at all times. The support received from the Royal Norwegian Embassy for participation in the Congress is gratefully acknowledged. The Bamboo project is financially supported by the Norwegian Agency for Development Cooperation (NORAD).

**References**


Effects of Fertilizing and Harvesting Intensity on Natural Stands of *Gigantochloa scortechinii*

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Abstract

At present, there is no study done on the management of natural bamboo stands of *G. scortechinii* in Malaysia. Being one of the most important species found in forest fringes and logged-over areas, *G. scortechinii culms* and shoots are extracted regularly by local people for various uses. This paper describes a study on the effects of NPK (15: 15: 15) fertilizing and felling of mature culms at intensities of 0, 40, 60 and 80% practised on *G. scortechinii* natural stands at Nami, Kedah, Peninsular Malaysia, over a two-year period. This can be a guide to managers and entrepreneurs in the management of the natural bamboo stands.

Introduction

In Malaysia, most sympodial bamboos are found in forest fringes and on logged-over forests (Ng 1980). Natural bamboo stands, composed mostly of *Gigantochloa scortechinii*, exist in abundance throughout the central and north-western areas. *G. scortechinii* is an important species because it is utilized in the making of chopsticks, toothpicks, blinds, joss sticks and skewers on an industrial scale.

At present, there are no proper conservation measures in sustaining the raw material in the forests. Most of the activities in exploiting the supply of the resources are unsystematic and haphazard, and the practices include the felling of bamboo culms annually.

It is important to have a systematic management of bamboo resources to ensure adequate and continuous supply of raw materials over a long period of time. Systematic exploitation increases the production of
bamboo stock (Fateh Mohammad 1931; Numata 1979; Liese 1985). In order to ensure maximum quality and volume, it is essential to enforce correct felling practices (Omar Ali 1981, Ueda 1960). Equally important are correct tending practices, including the use of fertilizers which increase the yield from natural bamboo forests.

In this paper, the effects of various rates of felling intensity (0, 40, 60 and 80%) and a fertilizer regime on G. scortechinii natural stand are analyzed.
Materials and Methods

The study was carried out at Chebar Forest Reserve, at Nami, Kedah, Peninsular Malaysia (Figure 1), from August 1989 to August 1991. The monthly rainfall and temperature were recorded within the forest reserve.

Based on a split-plot design, an area of 1 ha containing a G. scortechinii natural stand was chosen for the experiment. The experimental area was divided into two replicates (0.5 ha each). Each replicate was divided into 12 plots, each plot consisting of eight clumps. Each clump had a minimum of eight mature culms. Thus, there were a minimum of 96 clumps for each replicate.

Four felling intensities - 1, 40, 60 and 80% - were randomly assigned to each replicate. A felling intensity of 40% means 40% of the total mature culms in each clump in the assigned plot were felled.

The felling was done in August 1989. Six months later, in February 1990, NPK (15:15:15) fertilizer was applied at the rates of 2 kg and 5 kg, using a ditch system around every assigned clump. The silvicultural treatments were done alternately for 2 years. Only mature stems of 3 years or older were selected for felling, and some were left for the next felling. The culms that were felled were all well-spaced and from within the clump, and not from the clump periphery. The culms were cut at a height of about 15 cm above the ground using a small chain saw. All malformed, diseased or otherwise useless culms were also removed. The total number of shoots and culms before and after treatments were compared and analyzed. Shoots of 30 cm and below were monitored during the experimental stage. From August 1989 to December 1990, monthly data were obtained. Later, observations were made after 2 and 4 months.

Results and Discussions

As shown in Table 1, the mean number of shoots for July 1990 alone showed a significant increase at the felling intensity of 80%, though not for fertilizer application and their interactions. It was found that fertilizer application has no substantial effect, but the various felling intensities did show notable effects on bamboo dumps (Tables 2-5). Significantly different values, which were greater than ‘F’ tabulated at 0.01 level, were found over the months monitored, particularly for the felling intensity. By using Duncan’s Multiple Range Test, it was found that the means for 0% and 40% harvesting intensities showed significant difference in their respective values. There was no notable effect for the fertilizer applied.
Table 1: Mean number of shoots (1989-91) for *Gigantochloa scortechinii* natural stands (Nami, Kedha, Malaysia) following the application of fertilizer (NPK 15:15:15) and different felling intensities

<table>
<thead>
<tr>
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<td>September</td>
<td>October</td>
</tr>
<tr>
<td>Fertilizer (F)</td>
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</tr>
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<td>0 kg</td>
<td>36.875</td>
<td>4.000</td>
<td>1.375</td>
</tr>
<tr>
<td>2 kg</td>
<td>44.625</td>
<td>4.500</td>
<td>2.625</td>
</tr>
<tr>
<td>5 kg</td>
<td>42.500</td>
<td>2.625</td>
<td>3.000</td>
</tr>
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<tr>
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<td>47.667</td>
<td>4.167</td>
<td>1.833</td>
</tr>
<tr>
<td>40%</td>
<td>44.500</td>
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<td>1.500</td>
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<td>60%</td>
<td>30.500</td>
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<td>2.833</td>
</tr>
<tr>
<td>80%</td>
<td>42.667</td>
<td>3.833</td>
<td>3.167</td>
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Corresponding analysis of variance

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</tr>
<tr>
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Note: * = P <0.05; ns = not significant; ab, a, b = values sharing a common letter do not differ significantly.
Table 2: Mean number of culms (1989) for *Gigantochloa scortechinii* natural stands (Nami, Kedha, Malaysia) following the application of fertilizer (NPK 15: 15: 15) and different felling intensities

<table>
<thead>
<tr>
<th>Fertilizer (F)</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>November</th>
<th>December</th>
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<tr>
<td>0 kg</td>
<td>101.25</td>
<td>95.75</td>
<td>95.75</td>
<td>92.25</td>
<td>95.37</td>
</tr>
<tr>
<td>2 kg</td>
<td>130.37</td>
<td>125.75</td>
<td>121.37</td>
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<td>132.12</td>
</tr>
<tr>
<td>5 kg</td>
<td>93.12</td>
<td>91.75</td>
<td>90.87</td>
<td>90.50</td>
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<th>October</th>
<th>November</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 %</td>
<td>167.50&quot;</td>
<td>166.50&quot;</td>
<td>164.83&quot;</td>
<td>159.50&quot;</td>
<td>184.33&quot;</td>
</tr>
<tr>
<td>40%</td>
<td>116.50&quot;</td>
<td>111.50&quot;</td>
<td>106.33b</td>
<td>109.67&quot;</td>
<td>112.33&quot;</td>
</tr>
<tr>
<td>60%</td>
<td>75.00c</td>
<td>71.83c</td>
<td>73.17c</td>
<td>71.83c</td>
<td>73.83&quot;</td>
</tr>
<tr>
<td>80%</td>
<td>74.00c</td>
<td>67.83c</td>
<td>66.33c</td>
<td>64.17c</td>
<td>69.83&quot;</td>
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<td>ns</td>
<td>ns</td>
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<td>ns</td>
</tr>
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<td>Intensity (I)</td>
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First order information

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<th>Total</th>
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</tr>
<tr>
<td>12</td>
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<td>ns</td>
</tr>
<tr>
<td>23</td>
<td>ns</td>
<td>ns</td>
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</tbody>
</table>

Note: ** = P < 0.01; ns = not significant; a, b, c = values sharing a common letter do not differ significantly
**Table 3**: Mean number of culms (1990) for *Gigantochloa scortechinii* natural stands (Nami, Kedha, Malaysia) following the application of fertilizer (NPK 15:15:15) and different felling intensities

<table>
<thead>
<tr>
<th>Culms 1990</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kg</td>
<td>97.87</td>
<td>94.87</td>
<td>117.12</td>
<td>95.87</td>
<td>108.75</td>
<td>117.50</td>
</tr>
<tr>
<td>2 kg</td>
<td>131.37</td>
<td>139.00</td>
<td>157.12</td>
<td>150.00</td>
<td>147.62</td>
<td>174.75</td>
</tr>
<tr>
<td>5 kg</td>
<td>93.87</td>
<td>101.37</td>
<td>106.12</td>
<td>127.25</td>
<td>113.00</td>
<td>132.87</td>
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**Fertilizer (F)**

<table>
<thead>
<tr>
<th>Fertilizer (F)</th>
<th>0%</th>
<th>40%</th>
<th>60%</th>
<th>80%</th>
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</thead>
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<tr>
<td>0 kg</td>
<td>177.50</td>
<td>169.83&quot;</td>
<td>181.67&quot;</td>
<td>179.67&quot;</td>
</tr>
<tr>
<td>2 kg</td>
<td>113.33b</td>
<td>122.83'</td>
<td>126.50b</td>
<td>129.17&quot;</td>
</tr>
<tr>
<td>5 kg</td>
<td>73.00&quot;</td>
<td>73.00&quot;</td>
<td>112.33'</td>
<td>93.83&quot;</td>
</tr>
</tbody>
</table>

**Felling intensity (I)**

<table>
<thead>
<tr>
<th>Felling intensity (I)</th>
<th>0%</th>
<th>40%</th>
<th>60%</th>
<th>80%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>180.83a</td>
<td>196.00&quot;</td>
<td>169.83&quot;</td>
<td>181.67&quot;</td>
</tr>
<tr>
<td>40%</td>
<td>131.83'</td>
<td>150.83a</td>
<td>127.25</td>
<td>150.00</td>
</tr>
<tr>
<td>60%</td>
<td>84.00c</td>
<td>104.50c</td>
<td>127.25</td>
<td>157.12</td>
</tr>
<tr>
<td>80%</td>
<td>95.83'</td>
<td>115.00c</td>
<td>127.25</td>
<td>157.12</td>
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**Corresponding analysis of variance**

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<td>Intensity (I)</td>
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<tr>
<td>Residual</td>
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<tr>
<td>Total</td>
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</tbody>
</table>

Note: ** = P < 0.01; ns = not significant; a, b, ab, c = values sharing a common letter do not differ significantly
Table 4: Mean number of culms (1990) for *Gigantochloa scortechinii* natural stands (Nami, Kedha, Malaysia) following the application of fertilizer (NPK 15:15:15) and different felling intensities

<table>
<thead>
<tr>
<th></th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>November</th>
<th>December</th>
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<tr>
<td>Fertilizer (F)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>0 kg</td>
<td>122.00</td>
<td>121.87</td>
<td>125.37</td>
<td>118.75</td>
<td>118.75</td>
<td>112.12</td>
</tr>
<tr>
<td>2 kg</td>
<td>162.75</td>
<td>170.87</td>
<td>182.37</td>
<td>182.37</td>
<td>181.00</td>
<td>167.87</td>
</tr>
<tr>
<td>5 kg</td>
<td>123.25</td>
<td>128.00</td>
<td>137.25</td>
<td>142.75</td>
<td>142.75</td>
<td>128.62</td>
</tr>
<tr>
<td>Felling intensity (I)</td>
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<tr>
<td>0%</td>
<td>189.00&quot;</td>
<td>196.00a</td>
<td>206.33&quot;</td>
<td>196.67&quot;</td>
<td>194.83&quot;</td>
<td>182.00&quot;</td>
</tr>
<tr>
<td>40%</td>
<td>147.50&quot;</td>
<td>146.33&quot;</td>
<td>158.33b</td>
<td>160.83'</td>
<td>160.83&quot;</td>
<td>144.50&quot;</td>
</tr>
<tr>
<td>60%</td>
<td>99.33c</td>
<td>104.50c</td>
<td>111.50c</td>
<td>113.50'</td>
<td>113.50c</td>
<td>106.83'</td>
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<tr>
<td>80%</td>
<td>108.17</td>
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<td>120.83'</td>
<td>120.83'</td>
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**Corresponding analysis of variance**

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<td>Intensity (I)</td>
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**First order information**

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</table>

Note: * * = P<0.01; ns = not significant; a, b, c = values sharing a common letter do not differ significantly
**Table 5:** Mean number of culms (1991) for *Gigantochloa scotetchinii* natural stands (Nami, Kedha, Malaysia) following the application of fertilizer (NPK 15:15:15) and different felling intensities

<table>
<thead>
<tr>
<th>Fertilizer (F)</th>
<th>February</th>
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<th>August</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kg</td>
<td>143.2</td>
<td>138.12</td>
<td>140.62</td>
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<td>2 kg</td>
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</tr>
<tr>
<td>5 kg</td>
<td>155.12</td>
<td>158.50</td>
<td>149.37</td>
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<table>
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<th>February</th>
<th>March</th>
<th>August</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>220.17&quot;</td>
<td>229.33'</td>
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</tr>
<tr>
<td>40%</td>
<td>117.83&quot;</td>
<td>180.33&quot;</td>
<td>199.67ab</td>
</tr>
<tr>
<td>60%</td>
<td>117.83'</td>
<td>132.67c</td>
<td>139.00'</td>
</tr>
<tr>
<td>80%</td>
<td>143.83c</td>
<td>143.17bc</td>
<td>151.33bc</td>
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</tbody>
</table>

**Corresponding analysis of variance**

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<tr>
<th>Main factors</th>
<th>df</th>
<th>Fertilizer (F)</th>
<th>Intensity (I)</th>
<th>FxI</th>
<th>Residual</th>
<th>Total</th>
</tr>
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<tbody>
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<td></td>
<td></td>
<td>2</td>
<td>3</td>
<td>6</td>
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<td>23</td>
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First order information

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<tr>
<th>FxI</th>
<th>6</th>
<th>ns</th>
<th>ns</th>
<th>ns</th>
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</thead>
</table>

Residual | 12 |

Total | 23 |

> Note: ** = \( p < 0.01 \); ns - not significant; a, b, c, ab, bc * values sharing a common letter do not differ significantly

Twelve treatments - different combinations of fertilizer and felling intensity - as described below were applied:

- Treatment no. 1 (T1) - 0 kg of fertilizer, 0% felling intensity;
- Treatment no. 2 (T2) - 0 kg of fertilizer, 40% felling intensity;
- Treatment no. 3 (T3) - 0 kg of fertilizer, 60% felling intensity;
- Treatment no. 4 (T4) - 0 kg of fertilizer, 80% felling intensity;
- Treatment no. 5 (T5) - 2 kg of fertilizer, 0% felling intensity;
- Treatment no. 6 (T6) - 2 kg of fertilizer, 40% felling intensity;
- Treatment no. 7 (T7) - 2 kg of fertilizer, 60% felling intensity;
- Treatment no. 8 (T8) - 2 kg of fertilizer, 80% felling intensity;
Treatment no. 9 (T9) - 5 kg of fertilizer, 0% felling intensity;
Treatment no. 10 (T10) - 5 kg of fertilizer, 40% felling intensity;
Treatment no. 11 (T11) - 5 kg of fertilizer, 60% felling intensity;
Treatment no. 12 (T12) - 5 kg of fertilizer, 80% felling intensity.

T12, i.e. treatment with 5 kg fertilizer and 80% felling intensity, gave a higher increment on the mean number of shoots in comparison to other treatments after 2 years observation (Tables 2-5).

Based on the increment of the mean number of culms, it was found that T6 (2 kg, 40%) and T12 (5 kg, 80%) did show a significant effect.

The effect of fertilizer do not show up in the statistical analyses, and this may be due to the time of fertilizer application (the fertilizer was applied at the end of the drought month, i.e. February 1990 and 1991). With the absence of rain water, the fertilizer granules, which were covered back with soil, could not release their nutrients as expected. It may be noted that the statistical results showed a significant effect for 40% felling intensity only. However, the combined effect of fertilizer application and felling intensity are non-significant. Thus, the timing of fertilizer application is an important aspect to be considered for bamboo natural stands.

The increase of 30% in the new shoots sprouted per clump was calculated by averaging the number of new shoots sprouted and comparing it with the number of shoots the clump had one year earlier.

**Conclusion**

From the analyses, it was found that fertilizer treatment favourably affects shoots sprouting. For example, 2 kg of NPK 15:15:15 applied to every clump in the trial plot resulted in a 30% increase in the sprouting of the shoots. Based on the statistical results and figures available, it may be concluded that a 40% felling intensity can be applied as a standard for *G. scortechinii* plantations in Malaysia when the intended end-product is the culm. For shoots production, an 80% felling intensity can be applied.

**Acknowledgements**

Financial support for the field investigation connected to this study was provided by the IDRC under its Bamboo and Rattan Research Network in Asia. The author would like to thank the Forestry Department and their staff at Kedah for their cooperation in making this study possible.
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Shooting Period of Sympodial Bamboo Species: an Important Indicator to Manage Culm Harvesting

Achmad Sulthoni
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Abstract

Sympodial bamboo species always grow in a clumpy form and their shoots mostly sprout at the peripheral zone of the clump. Starch content of the mother culm fluctuates during the year, reaching the highest peak in the "young season" and the lowest level in the "old season". Accumulation of starch in the mother culm also signifies energy saving to regenerate new shoots. In the rural areas of Yogyakarta, the "young season" would be November or December, and in these months shoot production takes place.

Introduction

A natural forest of about 30,000 ha existed in the 1960s in West Banyuwangi Forest District, East Java. This very healthy bamboo forest consisted purely of the sympodial species of Gigantochloa apus (Bl. ex Schult. f.) Back. ex Heyne. Lack of knowledge on the extraction of this natural resource led to mechanized harvesting using tractors. This improper harvesting practice resulted in serious damage to the clumps, leading to a ceasing of the natural regeneration and eventual destruction. Now, that natural forest has changed into a man-made forest of Pinus merknsii.

Shoots of sympodial bamboo species mostly break the surface in the peripheral zone of the clump. In the case of G. apus, the clump is usually large in diameter and consists of old culms crowding in the middle of the clump. The shoots are therefore formed in the relatively free spaces between the younger mother culms in the outer periphery of the clump.

Shoot formation corresponds with the fluctuation of the starch content in the mother culms. This phenomenon was studied by Sulthoni (1987,
The rural Javanese in Yogyakarta and Central Java traditionally harvest bamboo during the old season which they call mangsa tua. The Javanese in Yogyakarta avoid the harvest of bamboo culms during the early shooting period in the belief that at that time, the mother culm is taking care of its young shoots. They manage their agricultural activities based on Pranata Mangsa (rules of climatological phenomena), a traditional solar calendar system that they developed. Pranata Mangsa is divided into 12 uneven mangsa. Mangsa muda or young season consists of six mangsa known as kaji, karo, kateku, kapat, kalima and kanem (season 1, 2, 3, 4, 5 and 6), while mangsa tua or old season consists of the remaining six mangsa, kapitce, kawolu, kasanga, kasepuluh, desta and sada (season 7, 8, 9, 10, 11 and 12). This Javanese seasonal calendar could roughly be transformed into months in the Gregorian Calendar, beginning with July for season 1. According to this, July-December will be the young season, and January-June will be the old season.

In his study, Sulthoni (1988) proposed that the higher starch content in bamboos and the consequent serious attack by powder post beetle relate to the young season (July-December). He found that in the month of November, the starch content was at its highest level, while the month of May registered

![Fig. 1: Relationship between starch content and intensity of powder post beetle attack on four bamboo species.](image)

\[
\log Y = 0.095 + 0.157x \\
\text{r} = 0.71
\]
the lowest level. It has been noted that felling of bamboo in May ensured the least damage from the powder post beetle *Dinoclerus minutus* Fabr. It was evident that there was a positive correlation between starch content and beetle attacks; the higher the starch content, the higher the damage intensity (Figure 1).

**Table 1:** Average starch content (percent/culm) of four bamboo species in relation to the shoots delivery (number/clump) observed in four villages in Yogyakarta.

<table>
<thead>
<tr>
<th>Felling month</th>
<th><em>Bambusa vulgaris</em></th>
<th><em>Dendrocalamus asper</em></th>
<th><em>Gigantochloa atter</em></th>
<th><em>Gigantochloa atter</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>1.408</td>
<td>0.9</td>
<td>0.37</td>
<td>0.53</td>
</tr>
<tr>
<td>June</td>
<td>1.369</td>
<td>0.56</td>
<td>0.3</td>
<td>0.41</td>
</tr>
<tr>
<td>July</td>
<td>1.96</td>
<td>0.4</td>
<td>0.38</td>
<td>0.3</td>
</tr>
<tr>
<td>August</td>
<td>2.66</td>
<td>0.46</td>
<td>0.29</td>
<td>0.54</td>
</tr>
<tr>
<td>September</td>
<td>3.58</td>
<td>2.07</td>
<td>0.27</td>
<td>0.27</td>
</tr>
<tr>
<td>October</td>
<td>4.73</td>
<td>0.49</td>
<td>0.26</td>
<td>0.32</td>
</tr>
<tr>
<td>November</td>
<td>6.22</td>
<td>0.45</td>
<td>0.49</td>
<td>0.31</td>
</tr>
<tr>
<td>December</td>
<td>2.82</td>
<td>0.48</td>
<td>0.31</td>
<td>0.33</td>
</tr>
<tr>
<td>January</td>
<td>0.51</td>
<td>0.48</td>
<td>0.26</td>
<td>0.32</td>
</tr>
<tr>
<td>February</td>
<td>1.54</td>
<td>1.23</td>
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<td>0.3</td>
</tr>
<tr>
<td>March</td>
<td>3.95</td>
<td>2.08</td>
<td>0.28</td>
<td>0.36</td>
</tr>
<tr>
<td>April</td>
<td>1.99</td>
<td>0.32</td>
<td>0.41</td>
<td>0.39</td>
</tr>
</tbody>
</table>

1 = Average starch content (%); 2 = Average shoot delivery (number).
Fluctuation of Starch Content and Shoot Production

Bamboo felling in the old season, as practised traditionally in Yogyakarta, is based on two important reasons: avoidance of the powder post beetle attack, and the termination of the shooting period of the bamboo clumps. Around the month of November, when precipitation occurs in Yogyakarta, starch content of bamboos is at the highest peak. The starch accumulation also signifies the preparation by the mother culm for shoot generation (Table 1).

Harvesting the culm

It is easy to understand why felling of bamboo is avoided in the months of October to December: during that time the young shoots are still in the process of growing. In the months of March to May, the young culms are considered to be strong enough to not suffer damage, and the threat from powder post beetle is at a low. The young culms will reach their full length within one year, and mature in the following year. After four years, the culms will be mature enough to be harvested.

Management of Sympodial Bamboo Forest

It would be advisable to learn from the traditional methods of bamboo management as practised by the rural community in Yogyakarta, and follow their empirical experience. Bamboo culm harvesting should be done selectively since the clumps of sympodial tropical bamboo species are composed of unequally aged culms. To avoid crowding of culms in the clumps, selective harvesting from the middle (oldest culms) should be done every year. Younger mother culms should be left untouched so as to not disturb the shooting activity. Annual selective harvesting will be the practical way to ensure adequate interspacing of the culms. The number of culms to be harvested from a clump would depend on the annual average of shoots produced by the clump.

Gigantochloa apus and G. atter produce more shoots annually than Dendrocalamus asper and Bambusa vulgaris. Hence, growing G. apus and G. atter would be more economically viable if the purpose is to produce culms, especially for construction use. If, on the other hand, the purpose is to harvest shoots, then D. asper and Bambusa vulgaris would be more profitable since both species produce high-quality shoots.
Conclusion

The harvest practice of the rural people in Yogyakarta of felling the bamboo culms only in old season based on the Javanese Pranata Mangsa, is scientifically justified since during this season the starch content of the bamboo culm is low, making it least susceptible to attacks by powder post beetle. Also, by this time, the bamboo shoots would be strong enough to not suffer damage from culm harvesting.

Crowding of sympodial bamboo clumps could be managed by annual selective cutting of the oldest culms, in relation to the annual average number of shoots produced by any individual bamboo clump.

References


Effects of Mulching on the Shoot Production of Phyllostachys praecox Stands

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Feng Shixiang
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He Yuexiang
Cixi Agro-forestry Bureau, Zhejiang, China.

Abstract

Adopting the method of randomized block design, the effects of mulching with eight kinds of materials on the stands of Phyllostachys praecox were studied. The results showed that mulching increased the soil temperature, made the shoots emerge earlier, prolonged the shooting period, and raised the yield and value of the shoots. The results of comprehensive evaluation showed that rice chaff was the best among the eight mulches tested. With regard to the control, it raised the soil temperature by 3.83°C, advanced the shooting time by 41 days, prolonged the shooting period by 40 days, and increased the shoots yield by 29.4%, the shoot production value by 270.3% and the stand’s economic benefit by 310.2%.

Introduction

Phyllostachys praecox Chuet Chao is one of the superior bamboo species valued for its shoots, which emerge early, are tender and delicious, and give high economic benefits. Apart from the natural stands in its originating region of the northern part of Zhejiang Province where the stands area total 7 000 km², P. praecox has also been extensively grown in the places where it was introduced – Fujin, Jiangxi and Anhui. Mulching has been adopted as an essential part of intensive management of the species for shoot production. This study was designed to evaluate the effects of mulching on the stand’s shoot production.
Materials and Methods

Study sites

Three study sites were established at Cixi, Yuyiao and Fenghua in Zhejiang Province, which has an annual rainfall of 1 400 - 1 500 mm and a mean annual temperature of 16.1-168°C. The slope gradients of the sites were 0 to 16, and the site elevations 15 to 71 m. The experimental stands had a density of 13 000 to 18 000 culms/km². The soil was of the red-yellow type.

Method

Following the randomized block design method, 27 plots of 30 m² each were laid out evenly in three blocks at the three sites mentioned above. At the beginning of winter in 1992 and 1993, eight kinds of mulches were laid to a thickness of 25-30 cm on the floor of the experimental stands. The data on soil temperature, shooting time, shooting period and the market price of the shoots were collected during the December and March 1994.

Results and Analysis

Effect of mulching on soil temperature

Different mulches increased soil temperature to varying degrees (Table 1). The average soil temperature at 10, 20 and 25 cm depths was increased by 5.33, 3.83 and 1.75°C by rice stalk, rice chaff and bamboo leaves, respectively. Notable temperature increases occurred during December-January.

Effect of mulching on shooting time

The soil temperature increase boosted the physiological activity of the bamboo plants and stimulated the sprouting of shoots. Compared with the control, all mulching treatments made the shoots emerge earlier and prolonged the shooting period. Rice chaff and bamboo leaves in particular were very effective in that they advanced the shooting time by 41 and 96 days and prolonged the shooting period by 40 and 97 days, respectively (Table 2).

Effect of mulching on shoot yield/value

Compared with the control, the mulches greatly enhanced the shoot yield and value (Table 3). The highest yield increase of 117% was obtained
Table 1: Soil temperature (°C) increase of stands brought on by mulching

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<th>Covering material</th>
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<tr>
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<td>dffe</td>
<td>dffe</td>
<td>dffe</td>
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<td>Pine leaves</td>
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<td>Bamboo leaves</td>
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<td>9.6</td>
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<td>7.5</td>
<td>9.4</td>
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</tr>
</tbody>
</table>

Note: st = soil temperature in °C, dffe = difference from control in °C
### Table 2: Comparison of shooting time and period among the various mulches

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Rice Chaff</th>
<th>Rice stalk</th>
<th>Wood particles</th>
<th>Pine leaves</th>
<th>Bamboo leaves</th>
<th>Pig manure</th>
<th>Cut grass</th>
<th>Rapeseed chaff</th>
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</tr>
</thead>
<tbody>
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<td>Shooting duration (d)</td>
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<td>79</td>
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<tr>
<td>Advancing of shooting time (d)</td>
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<td>36</td>
<td>34</td>
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<td>96</td>
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</tr>
<tr>
<td>Prolongation of shooting period (d)</td>
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<td>97</td>
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</table>

### Table 3: Relation between mulches, and the yield and value of shoots

<table>
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<tr>
<th>Parameters</th>
<th>Rice chaff</th>
<th>Pine leaves</th>
<th>Bamboo leaves</th>
<th>Rice stalks</th>
<th>Wood particles</th>
<th>Rapeseed chaff</th>
<th>Pig manure</th>
<th>Cut grass</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoot yield (kg/km²)</td>
<td>30000</td>
<td>50</td>
<td>235</td>
<td>43</td>
<td>500</td>
<td>27278</td>
<td>21210</td>
<td>39</td>
<td>225</td>
</tr>
<tr>
<td>Early shoot yield ratio</td>
<td>72.0</td>
<td>19.0</td>
<td>32.0</td>
<td>31.0</td>
<td>37.7</td>
<td>18.7</td>
<td>26.0</td>
<td>17.4</td>
<td>7.8</td>
</tr>
<tr>
<td>Shoot production value (10 yuan/km²)</td>
<td>34.23</td>
<td>21.24</td>
<td>20.01</td>
<td>17.27</td>
<td>15.14</td>
<td>12.56</td>
<td>17.68</td>
<td>12.43</td>
<td>9.24</td>
</tr>
<tr>
<td>Early shoot production-value ratio (%)</td>
<td>91.0</td>
<td>38.4</td>
<td>42.0</td>
<td>61.3</td>
<td>59.5</td>
<td>27.0</td>
<td>43.0</td>
<td>23.6</td>
<td>15.6</td>
</tr>
</tbody>
</table>
with Pine leaves, while the highest value increase of 270% was recorded with rice chaff. The value increase was determined by taking the ratio of early emerged shoots to the total shoot yield. Higher market price of early emerged shoots gave the stands, in general, a higher shoot production value.

As shown in the variance analyses in Tables 4 and 6, mulching had a significant effect on the early emergence and the total yield of shoots. The LSD examinations of total shoot yield and early emergence of shoots are given in Tables 5 and 7.

Table 4: Variance analysis of shoot production

<table>
<thead>
<tr>
<th>Item</th>
<th>df</th>
<th>ss</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks</td>
<td>2</td>
<td>49.60</td>
<td>24.80</td>
<td>0.74</td>
</tr>
<tr>
<td>Treatment</td>
<td>6</td>
<td>4354.95</td>
<td>725.80</td>
<td>21.9**</td>
</tr>
<tr>
<td>Error</td>
<td>12</td>
<td>397.70</td>
<td>33.14</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5: LSD examination of shoots yield

<table>
<thead>
<tr>
<th>Mulches</th>
<th>Yield</th>
<th>Xi-87.9</th>
<th>Xi-90.0</th>
<th>Xi-105.5</th>
<th>Xi-107.9</th>
<th>Xi-112.7</th>
<th>Xi-116.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>(All values in kg/30m²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pine leaves</td>
<td>127.1</td>
<td>39.2**</td>
<td>37.1**</td>
<td>216**</td>
<td>19.2**</td>
<td>14.4**</td>
<td>10.5**</td>
</tr>
<tr>
<td>Rapeseed chaff</td>
<td>116.6</td>
<td>28.7**</td>
<td>26.6**</td>
<td>11.1**</td>
<td>8.7</td>
<td>3.9</td>
<td></td>
</tr>
<tr>
<td>Cut grass</td>
<td>112.7</td>
<td>24.8**</td>
<td>22.7**</td>
<td>7.2</td>
<td>4.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pig manure</td>
<td>107.9</td>
<td>20.0**</td>
<td>17.9</td>
<td>2.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bamboo leaves</td>
<td>105.6</td>
<td>17.6**</td>
<td>15.5”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice chaff</td>
<td>90.0</td>
<td>2.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>87.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Economic benefit analysis of mulches

Compared with the control, an average yield increase of 57.4% was observed when mulches were used. Pine leaves showed the highest yield of 116.8%. The average increase in shoot production value was 103.7%, and rice chaff gave the highest value of 270.3%. Average net profit increase
Table 6: Variance analysis of early emergence of shoots

<table>
<thead>
<tr>
<th>Item</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks</td>
<td>2</td>
<td>2.82</td>
<td>1.41</td>
<td></td>
</tr>
<tr>
<td>Treatment</td>
<td>6</td>
<td>5387.2</td>
<td>897.86</td>
<td>170.04**</td>
</tr>
<tr>
<td>Error</td>
<td>12</td>
<td>63.33</td>
<td>5.28</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7: LSD examination of early-emerged shoot yield

<table>
<thead>
<tr>
<th>Mulches</th>
<th>Yield</th>
<th>Xi-lo.1</th>
<th>Xi-21.9</th>
<th>Xi-26.4</th>
<th>Xi-28.7</th>
<th>Xi-29.8</th>
<th>Xi-44</th>
</tr>
</thead>
<tbody>
<tr>
<td>(All values in kg/30 m²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice chaff</td>
<td>64.0</td>
<td>53.9**</td>
<td>42.1*</td>
<td>37.6**</td>
<td>35.3**</td>
<td>34.2**</td>
<td>20.0**</td>
</tr>
<tr>
<td>Pine leaves</td>
<td>44.0</td>
<td>33.9**</td>
<td>22.1**</td>
<td>17.6**</td>
<td>15.3**</td>
<td>14.2**</td>
<td></td>
</tr>
<tr>
<td>Bamboo leaves</td>
<td>29.8</td>
<td>19.7**</td>
<td>7.9**</td>
<td>3.4</td>
<td>1.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pig manure</td>
<td>28.7</td>
<td>18.6**</td>
<td>6.8**</td>
<td>2.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cut grass</td>
<td>26.4</td>
<td>16.3**</td>
<td>4.5**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rapeseed chaff</td>
<td>21.9</td>
<td>11.8**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>10.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: LSD 0.05 = 4.088; LSD 0.01 = 5.731

was 67 140 yuan/km² and the mean increase rate was 90.44%. Rice chaff registered the highest net profit increase of 226 500 yuan/km² and the mean increase rate of 310.23% (Table 8). The best input-output ratio of 1:8 was also given by rice chaff. A comprehensive evaluation showed rice chaff to be the best among the eight mulches used (Table 9).

Conclusion
Mulching increased soil temperature, made the shoots emerge earliest and prolonged the shooting period, resulting in increased shoot yield, shoot
Table 8: Analysis of shoots production, value and economic benefits

<table>
<thead>
<tr>
<th>Mulches</th>
<th>Shoot yield</th>
<th>Shoot production</th>
<th>Input ('000 yuan/km²)</th>
<th>Net profit ('000 yuan/km²)</th>
<th>Input: output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amount</td>
<td>Increase (%)</td>
<td>Amount</td>
<td>Increase (%)</td>
<td>Material</td>
</tr>
<tr>
<td>Rice chaff</td>
<td>30 (000)</td>
<td>29.4</td>
<td>342.30</td>
<td>270.3</td>
<td>5.77</td>
</tr>
<tr>
<td>Pine leaves</td>
<td>50235</td>
<td>116.8</td>
<td>212.70</td>
<td>130.2</td>
<td>14.70</td>
</tr>
<tr>
<td>Bamboo leaves</td>
<td>43 500</td>
<td>87.7</td>
<td>200.10</td>
<td>116.5</td>
<td>24.23</td>
</tr>
<tr>
<td>Pig manure</td>
<td>41670</td>
<td>79.8</td>
<td>176.90</td>
<td>91.4</td>
<td>16.77</td>
</tr>
<tr>
<td>Rice stalks</td>
<td>272X5</td>
<td>17.7</td>
<td>172.68</td>
<td>16.3</td>
<td>7.77</td>
</tr>
<tr>
<td>Wood particles</td>
<td>21 210</td>
<td>-8.5</td>
<td>151.40</td>
<td>63.8</td>
<td>34.29</td>
</tr>
<tr>
<td>Rapeseed chaff</td>
<td>39.225</td>
<td>69.3</td>
<td>125.55</td>
<td>35.8</td>
<td>10.80</td>
</tr>
<tr>
<td>Chick grass</td>
<td>38700</td>
<td>67.0</td>
<td>124.30</td>
<td>34.5</td>
<td>8.00</td>
</tr>
<tr>
<td>Control</td>
<td>23175</td>
<td>92.43</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>57.4</td>
<td>106.7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
production value and net profit. A comprehensive evaluation of different mulches showed rice chaff covering to be the best. Mulching of stands with rice chaff, hence, is an essential measure for intensive cultivation of *Phyllostachys praecox*.

**Table 9: Comprehensive evaluation of mulches used**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Rice chaff</th>
<th>Pine leaves</th>
<th>Bamboo leaves</th>
<th>Pig manure</th>
<th>Rice stalks</th>
<th>Wood particles</th>
<th>Rape cut</th>
<th>Grass</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoot yield</td>
<td>4</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>3</td>
<td>1</td>
<td>6</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Shoot production value</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Net profit</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>5</td>
<td>6</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Input/output</td>
<td>9</td>
<td>6</td>
<td>3</td>
<td>4</td>
<td>7</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>40</td>
<td>31</td>
<td>25</td>
<td>22</td>
<td>21</td>
<td>8</td>
<td>14</td>
<td>16</td>
<td>12</td>
</tr>
</tbody>
</table>

Relative units

**Further reading**


Seasonal Change of Photosynthesis Rate and its Relation to the Growth of Phyllostachys bambusoides

Hiromichi Koyama and Etsuzo Uchimura
Osaka City University, Osaka, Japan.

Abstract

Phyllostachys bambusoides Sieb. et Zucc. (Madake), which grows in the temperate zone in Japan, has excellent mechanical properties and hence, is widely used for many purposes. Although the productivity of P. bambusoides appears related to the total photosynthesis rate, respiration rate, amount of chlorophyll present and the overall growth pattern, these relations have never been studied, mainly because of technical difficulties. Recently, however, technically advanced instruments have been developed for studying photosynthesis and respiration under natural conditions.

The results of this study indicate that photosynthesis rate increased with higher photosynthetic active radiation (PAR). Seasonal changes of net photosynthesis (Pn) and dark respiration (R) were related to the elongation of culm/rhizome. Saturation of PAR was at 1000 umol/m²/s, while Pn registered 12 umol/m²/s through the year. The study also revealed other significant aspects.

Introduction

More than 600 species of bamboos, including bamboo grass (called ‘Sasa’ in Japanese), are found in Japan. Phyllostachys bambusoides Sieb. et Zucc. (Madake), however, is the most useful bamboo species in terms of culm qualities, such as shear strength, compression strength, bending strength and tensile strength. Therefore, the culm of this bamboo is utilized for making many commonly used articles such as baskets, cages, furniture, musical instruments, agricultural and fishing implements, construction materials, etc.

While the ecological characteristics - environmental conditions
required, growth pattern, biomass produced and productivity - of *P. bambusoides* are well known, aspects related to growth and biomass production-dark respiration, light-photosynthesis-curve, seasonal changes of chlorophyll and photosynthetic active radiation - have not been studied earlier. The main reason for this is that the moisture content of leaves reduce as soon as they are removed from the plant, and that instruments for on-site measurements were not available until recently. A portable photosynthesis analyzer, which can be used to measure the photosynthesis of a leaf while it is still on the plant, has now been developed by Analytical Development Company Ltd. of Japan. This study has made use of this instrument to analyze seasonal changes in photosynthesis rate, dark respiration, chlorophyll content, etc. as related to the growth of *P. bambusoides*.

**Materials and Method**

The undamaged, disease-free leaves of a one-year-old culm of *P. bambusoides* from a clump growing on the river bank in the botanical gardens of Osaka City University, Osaka, were selected as the experiment material.

Photosynthesis rate (umol/m²/s) and dark respiration rate (umol/m²/s) of an individual leaf was measured using a Shimadzu Portable Photosynthesis Analyzer Model SPB-H3 and the chlorophyll content was measured using the chlorophyll meter SPAD-502.

The photosynthesis analyzer consists of three parts: analyzer cabin, specimen chamber with light receiver section, and air induction unit. The specimen chamber, into which the leaf is introduced while it is still on the plant, measures 5.7 cm² in area. The light receiver section is kept vertical against the incident sunlight, and gradually shielded with tracing paper, when the photosynthesis rate is to be measured. The air induction unit, which has a pipe three metres in length with an air induction device at the top end, is set up in the canopy of the bamboo.

**Results and Discussion**

The climatic conditions under which the study was carried out on-site are given in Figures la and lb. Although the annual rainfall in the area was 1 400 mm, the precipitation was much less during the study period (July-August 1994), particularly in July 1994 when the rainfall was just one-ninth of the usual rainfall (Figure la). There are four seasons in Japan - spring, summer, autumn and winter - but the duration of these are not clear-cut.
In effect, the spring is from late March to middle of May. *P. bumbusoides* shoots sprout in May, and they undergo elongation till the middle of June. About 70% of the old leaves fall by June and new leaves begin to take their place. Summer begins around early July and continues till the middle of September, with July-August being the hottest months of the year. Bamboo rhizomes elongate from August to October. Autumn lasts from the middle of October to the end of November. Winter starts from the middle of December and ends in early March, with January-February being the coldest months (Figure 1b).

**Seasonal changes in light-photosynthesis curve**

Light-photosynthesis curve was obtained by correlating photosynthetically active radiation (PAR) and photosynthesis. Seasonal changes in light-photosynthesis curve are shown in Figure 2. In general, photosynthesis rate increased when the value of PAR increased, and peaked when PAR reached its saturation level at almost 1,000 umol/m²/s. Rate of photosynthesis rate was lower in winter, but higher when the atmospheric
temperature increased and the rhizome was not elongating any more. Photosynthesis was higher from summer to early autumn, and its maximum value of 11.4 umol/m²/s was reached in early October. The minimum value of 5.5 umol/m²/s was in early April, before the bamboo shoots sprouted.

**Seasonal changes in net photosynthesis**

Seasonal changes in net photosynthesis (Pn) are shown in Figure 3. Higher Pn values during the year peaked from late August to the end of December, and fell in February and the middle of May. It may be noted that August-December is the period of rhizome growth, while leaves fall in May. Minimum Pn values, on the other hand, seemed to be almost the same throughout the year.

**Seasonal changes in dark respiration**

Seasonal changes in dark respiration (R) also showed the same trend as Pn (Figure 4). R decreased from December to February because of the cold weather, and again in the middle of May when new shoots broke the ground. Other months marked higher R values, particularly after May, when the fallen old leaves were replaced by new leaves which, in general, respire more than old leaves.
Fig. 2: Photosynthetic active radiation

Photosynthesis Active Radiation (1000 µmol/m²/s)
Seasonal changes in chlorophyll content

As said earlier, the amount of chlorophyll in leaf specimens was measured using the chlorophyll meter SPAD 502. Higher amounts of chlorophyll were observed only in winter, but the increase was not significant enough
to stand comparison with other seasons (Figure 5). Leaf specimens that grew inside and outside the crown gave different meter readings on the same day.

![Graph showing seasonal change of chlorophyll](image)

**Fig. 5**: Seasonal change of chlorophyll (based on SPAD)

**Relation between PAR and Pn on a given day**

Diurnal changes in PAR and Pn were measured towards the end of August, mainly because PAR was relatively high at this time than any other period during the year. Measurements were taken from 8:26 AM to 6:08 PM on 23 August 1994. Although the data showed some differences, the general tendency of PAR and Pn in a day was to run parallel (Figure 6). Both PAR and Pn showed higher values from morning to about 2:00 PM, and then gradually decreased towards the evening. It was ascertained that diurnal Pn increase was accompanied by an increase in PAR, and that PAR reached saturation at 700 umol/m²/s while Pn reached saturation at 8 pmol/m²/s.

Pn, recorded every ten minutes from 8:26 AM to 6:08 PM, accumulated 0.16 CO₂ mol/m²/s (Figure 7). This meant that the Pn of the plant doubled when the time increased two times.

**PAR-Pn relationship in a year**

The general tendency of PAR-Pn relationship in a year was to follow the trend of their diurnal relationship; PAR reached saturation at 1200 umol/m²/s, and Pn at 12 umol/m²/s (Figure 8).
**Fig. 6:** Relationship between PAR and Pn in a day

**Fig. 7:** Diurnal trend of integrated net photosynthesis

**Relationship between Pn and atmospheric temperature**

Knowledge about the relationship between Pn and atmospheric temperature is very important for studying the seasonal changes in photosynthesis because of its effect on the growth and the productivity of culm. As can be seen from Figure 9, Pn increases till the temperature reaches
Fig. 8: Relationship between PAR and \( P_n \)

\[27^\circ C, \text{ and thereafter rapidly decreases with the increase in temperature, because temperature rise beyond that level brings on increased respiration of leaf.}\]

Fig. 9: Relationship between \( P_n \) and temperature
Relationship between dark respiration and atmospheric temperature

The relationship between dark respiration (R) and atmospheric temperature is expressed in Figure 10. The higher the temperature, the higher was the value of R, which supported the conclusion drawn about the reason for the nature of Pn-temperature relationship.

![Fig. 10: Relationship between dark respiration and temperature](image)

![Fig. 11: Relationship between leaf temperature and temperature](image)
Relationship between atmospheric temperature and leaf temperature

Relationship between atmospheric temperature and leaf temperature can be expressed by the linear equation $Y = 0.876 + 3.38$ (Figure 11). Leaf temperature is higher than atmospheric temperature when the latter is on the lower side, but equal to or lower than atmospheric temperature when the latter is on the higher side. When the leaf respiration is factored in, leaf temperature is lower than atmospheric temperature (Figure 12), as expressed by the equation $Y = 0.907X + 0.559$. In such an approach, the aim would be to know more about active respiration than photosynthesis.

Fig. 12: Relationship between leaf temperature and temperature w.r.t. respiration

Conclusions

As the above results show, this study has revealed certain significant aspects about photosynthesis in *P. bambusdides*, such as:

- Seasonal changes in light-photosynthesis curve showed saturation at 1000 μmol/m$^2$/s for photosynthetic active radiation and 7-10 μmol/m$^2$/s for net photosynthesis (same results obtained for diurnal light-photosynthesis curve).
- Seasonal changes in net photosynthesis indicated a peak between early July and November, followed by end March and early April. The minimum net photosynthesis was in May, which coincided with the period
when leaves had fallen and the elongation of culm occurred, a period when much water was required for the growth of new shoots.

- Seasonal changes in darkiespiration also showed the same tendency as net photosynthesis.
- Respiration decreased between December and early February because of coldness, and towards the end of May when new leaves were replacing fallen old leaves.

The results showed much water supply during growth period and daytime in summer, and that net photosynthesis reduced when the atmospheric temperature rose above 27°C because the rate of respiration then overtook the rate of photosynthesis.

At present, similar data from other sympodial and monopodial bamboo species are being collected, and the relationship between their photosynthesis and other activities are becoming clearer. These will be presented at a future time.

Further reading


Anatomical Studies on the Rhizome of some Pachymorph Bamboos

Ding Yu-Long, Tang Geng-Guo and Chao Chison
Department of Forestry, Nanjing Forestry University, Nanjing, China.

Abstract
The anatomy of the rhizomes of 41 species of pachymorph bamboo was studied. The anatomical structure of the vascular bundles in pachymorph bamboo rhizomes are completely different from those in the leptomorph bamboo rhizomes or culm internodes. The xylem normally consists of only one metaxylem vessel. Protoxylem is absent or only faintly developed. Contrary to the pachymorph culms and similar to the leptomorph culm necks, there is no isolated fibre strand above or beneath the vascular bundles. Hence, the culm neck -which includes culm stalk and culm base-is used here to describe the subterranean part of pachymorph bamboo axes. Based on the main anatomical features, two basic types and four sub-types can be identified. The two basic types are more valuable than the four sub-types in taxonomic terms.

Introduction
The rhizome, as an important component of bamboo and a useful tool for the vegetative propagation of the plant, plays a crucial role in the regeneration of bamboo forests and establishment of plantations. In recent years, the physiological development and the anatomical structure of rhizomes have received some attention (Hsuing et al. 1982; Zhao et al. 1985; Xiao and Liu 1986; Jiang and Li 1987; Ding et al. 1993; Song and Wang 1994). However, there has been no systematic research on the structure of pachymorph bamboo rhizomes. Its origin and development, as well as its anatomical structure are still not fully understood. A sound knowledge of the culm habit of a bamboo is a prerequisite for understanding its subterranean part. This paper deals with the anatomical structure of some pachymorph bamboo rhizomes.
Materials and Methods

Rhizomes were collected from the species grown at the herbarium of Nanjing Forestry University, Sichuan Forestry School and the Botanical Garden of South China in Guangzhou (Table 1). Samples of about 1 cm length were taken from the middle part of matured rhizome segments. In order to ascertain whether there were any difference between the individuals of the same species, two samples each were taken from the different collections of *Sinarundinaria nitida*, *S. brevipaniculata*, *Thamnocalamus spatbaceus* and *Melocanna baccifera*. Three samples were taken from the culm neck of a leptomorph bamboo species growing in the bamboo garden of Nanjing Forestry University so that the anatomical structures between the pachymorph bamboo rhizomes and the leptomorph bamboo culm neck could be compared. All materials were cooked for two hours in an autoclave, and then infiltrated and embedded in polyethylene glycol (PEG) 2000. Transversal and longitudinal sections of about 25 um thickness were double-stained with safranin and astrablue, and mounted in Canada balsam.

Results and Discussion

Results

The transversal sections showed that most rhizomes are solid or have only a very small pith cavity, except *Yushania yadongensis* and *Y. qiaojiaensis*, both of which have a large pith cavity. Under the epidermis, three or four layers of sclereid cells build up the hypodermis. The cortex consists of uniform parenchyma cells or, as in the case of some species belonging to the genera *Fagesia* and *Yusbania* which usually grow in high altitudes, an endodermis with thickened cell walls. In such cases, there is nonnally a thick, complete fibre ring beneath the endodermis. The species that grow at lower altitudes – such as *Bambusa*, *Dendrocalamus* and *Schizostachyum* – do not possess such

Fig. 1: *Melocanna baccifera*, Type I
an endodermal ring (Figure 1), and the vascular bundles beneath the cortex are separated from each other. In some species which grow in higher altitudes, well-developed air canals exist in the cortex (Table 1). In the cortex, small vascular bundles are sometimes observed. It is assumed that these are branches which pass from rhizome to rhizome sheath, because they are similar in structure to those in the sheath.

Table 1: The species studied and some of their anatomical features

<table>
<thead>
<tr>
<th>Inflorescence type &amp; rhizome type</th>
<th>Species</th>
<th>Air canal</th>
<th>Endodermis</th>
<th>Fibre ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflorescence iteractant;</td>
<td><em>Fargesia alba-cerea</em></td>
<td>Y</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Pachymorph rhizome with long neck</td>
<td><em>F. contracta</em></td>
<td>N</td>
<td>Y</td>
<td>Y*</td>
</tr>
<tr>
<td></td>
<td><em>F. dura</em></td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td><em>F. frigidis</em></td>
<td>N</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td><em>F. gongshanensis</em></td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td><em>F. gyritosangensis</em></td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td><em>F. hygrophiila</em></td>
<td>Y</td>
<td>N</td>
<td>Y*</td>
</tr>
<tr>
<td></td>
<td><em>F. lingcangensis</em></td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td><em>F. scabrida</em></td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td><em>F. solida</em></td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td><em>F. subflexuosa</em></td>
<td>Y</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td><em>F. tenuillignea</em></td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Sinarundinaria nitida</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>S. brevipaniculata</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Tamnocalamus cuspidatus</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>T. spathaceus</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Yushania elevata</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Y. baishanzhuensis</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Y. glaqtdulosa</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Y. laevigata</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Y. longiuscula</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Y. polytricha</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Y. qiaojiaensis</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Y. vigens</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Y. violascens</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Y. xizangensis</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Y. yadongensis</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>
### Bamboo, People and the Environment

<table>
<thead>
<tr>
<th>Inflorescence &amp; rhizome type</th>
<th>Species</th>
<th>Anatomical feature</th>
<th>Air canal</th>
<th>Endodermis</th>
<th>Fibre ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflorescence iterant;</td>
<td><em>Bambusa chungii</em></td>
<td></td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Pachymorph rhizome with short neck</td>
<td><em>B. breviflora</em></td>
<td></td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td><em>B. emeiensis</em></td>
<td></td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td><em>B. prevariabilis</em></td>
<td></td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Inflorescence iterant;</td>
<td><em>B. textilis</em></td>
<td></td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Pachymorph rhizome with short neck</td>
<td><em>B. textilis var. gracilis</em></td>
<td></td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td><em>Dendrocalamus minor</em></td>
<td></td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td><em>D. strictus</em></td>
<td></td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td><em>Melocanna baccifera</em></td>
<td></td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td><em>Pachystachyum polymorpha</em></td>
<td></td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Leptomorph rhizome</td>
<td><em>Schizostachyum funghomii</em></td>
<td></td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Inflorescence iterant;</td>
<td><em>Arundinaria amara</em></td>
<td></td>
<td>N</td>
<td>N</td>
<td>Y*</td>
</tr>
<tr>
<td>Leptomorph rhizome</td>
<td><em>Phyllostachys aurea</em></td>
<td></td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td><em>P. vivax</em></td>
<td></td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>

Note: N = absent; Y = present; Y* = fibre ring interrupted occasionally by parenchyma cells.

The structure of the vascular bundles in pachymorph bamboo rhizomes is quite different from those in the rhizomes of leptomorph bamboos or in the culm internodes of any bamboo. The xylem normally consists of only one metaxylem vessel, although occasionally two can be found. The vascular bundle lies in or beneath the fibre ring. Protoxylem is either absent or weakly developed. The faintly developed fibre cap surrounds the vascular bundle or exists only on the phloem side. There is no isolated fibre strand above or beneath the vascular bundles as is the case with pachymorph bamboo culms. On the contrary, this character of vascular bundles closely resembles that of the culm neck of leptomorph bamboos such as *Phyllostachys* and *Arundinaria* (Figure 2).

Based on the above observations on the anatomical structure of rhizomes, pachymorph bamboos may be classified into two basic types and four sub-
types (Table 2). The species belonging to Type I grow in lower altitudes, and possess itemunctant inflorescence. The species belonging to Type II grow in higher altitudes, and have semelauctant inflorescence (Figures 3-6).

**Fig. 2:** *Anmdinativamaru* the vascular bundle in the culm neck of this monopodial bamboo has the same structure as the subterranean parts of pachymorph bamboos.
**Fig. 3:** *Yushania yadorgensis*, Type II, Sub-type 1

**Discussion**

**Terminology**

The basic structure of the bamboo plant is that of a ramifying system of segmented vegetative axes. There is no main axis, and each segmented axis is a branch of another segmented axis. Rhizomes build up the subterranean system.

There are different terms to describe the growth habit of bamboo rhizomes. The common terms used are pachymorph and leptomorph, or sympodial and monopodial, respectively (Figures 7a and 7c) (McClure 1966). The pachymorph rhizome could be divided into two sub-forms: short-necked and long-necked (Figure 7b). The short-necked pachymorph rhizome is relatively short and thick. Its diameter is larger than the length
of the internode, and the culms above the ground are caespitose. The long-necked rhizome is more or less elongated. Its diameter is smaller than that of the internode, and the culms above the ground appear diffused in space.

From Figure 7, it is difficult to understand the differences between the rhizome neck and culm neck ontogenetically, and between pachymorph and leptomorph rhizomes phylogenetically. The anatomical structure of pachymorph rhizome, however, is so different from that of the leptomorph rhizome that it raises the question whether these two are phylogenetically similar. In contrast, as mentioned earlier, the

**Table 2: Two basic types and four sub-types of pachymorph bamboos**

<table>
<thead>
<tr>
<th>Types</th>
<th>Characteristics</th>
<th>Some typical genera</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I</td>
<td>There is no fibre ring beneath the cortex. Air canal and endodermis are absent from the cortex. (Figure 1)</td>
<td><em>Bambusa, Dendrocalamus, Melocanna, Pseudostachyum, Scb izostachyum</em>, <em>Thyrsostachys</em></td>
</tr>
<tr>
<td>Type II</td>
<td>Fibre ring or fibre bend is always present beneath the cortex</td>
<td><em>Fargesia, Sinarundinaria, Thamnocalamus, Yushania</em></td>
</tr>
<tr>
<td>Sub-type 1</td>
<td>Air canals and endodermis present in the cortex (Figure 3).</td>
<td></td>
</tr>
<tr>
<td>Sub-type 2</td>
<td>Air canals are present but endodermis is absent in the cortex (Figure 4).</td>
<td></td>
</tr>
<tr>
<td>Sub-type 3</td>
<td>Endodermis is present but air canals are absent in the cortex (Figure 5).</td>
<td></td>
</tr>
<tr>
<td>Sub-type 4</td>
<td>Air canals and endodermis are absent in the cortex (Figure 6).</td>
<td></td>
</tr>
</tbody>
</table>
pachymorph rhizome has an anatomical structure similar to that of the culm neck of leptomorph bamboos. The implication is that the so-called pachymorph rhizome is rather an elongated culm neck than a rhizome. Ontogenetically, this is reasonable because the orientation of terminal bud in leptomorph bamboos is consistently diageotropic under most circumstances. The culms are normally derived from the lateral buds of the rhizomes, and only under certain conditions the terminal buds turn upwards to form culms. In the case of pachymorph bamboos, the culms are derived from the terminal buds, though they have a longer culm neck. Taking this into account, it can be said that only leptomorph bamboos have a real rhizome. This is the reason why the subterranean parts of pachymorph bamboos are called “pseudorhizome”.

The culm neck can be divided into two parts: culm stalk and culm base. The stalk is usually smaller than the culm base in diameter. On the nodes of the stalks there are neither buds nor roots and root primordia. The roots and buds emerge only on the node of the culm base. The revised terminology, based on the above discussion, is shown in Figure 8.
Anatomical features and their taxonomic significance

The main anatomical features of pachymorph bamboo culm neck are the presence or absence of air canals in the cortex, endodermis with thickened cell walls, fibre ring beneath the cortex and vascular bundle's characteristics. Based on these, bamboos may be divided into two basic types and four sub-types, as mentioned in Table 2. Type I bamboos grow in lower altitudes, have iteraeautant inflorescence and do not show elongation of culm neck. Type II bamboos grow in higher altitudes, have semelauctant inflorescence and feature a fibre ring, complete or occasionally interrupted by parenchyma cells, in the cortex. The peripheral vascular bundles are linked or embedded in the fibre ring. The presence or absence of air canal varies greatly in Type II bamboos: some genera have it while others do not. According to McClure (1963), even within the same species, some plants may have the air canals and others may not. This implies that the two basic types are valuable for the taxonomy of pachymorph bamboos, but the four sub-types are of less value.
Fig. 8: Revised terminology to describe the subterranean parts of bamboo
a) Pachymorph bamboo with short culm neck
b) Pachymorph bamboo with long culm neck
c) Leptomorph bamboo with uniform rhizome system
d) Leptomorph bamboo rhizome system with pachymorph character

The genus Fargesia, named by Frenchet (1893), differs from Thamnocalamus Munro (1868) based on the second indeterminate inflorescence. Keng (1957) differentiated Yushania from Sinarundinaria Nakai (1935) based on the elongation of the rhizome. Now, Thamnocalamus, Fargesia, Sinarundinaria and Yushania are four genera, something which is the most disputed aspect of Chinese bamboo taxonomy. Some accommodate the four under the two genera Thamnocalamus and Sinarundinaria (Chao, et al. 1980; Wang and Ye 1980; Clayton and Renvoize 1986; Soderstrom and Ellis 1987), and some under Fargesia and Yushania (Keng 1982; Song and Wang 1994). The latter group is not even sure whether there is any species of Thamnocalamus in China. It also believes that the genus Sinarundinaria should be reduced as a synonym of the genus Fargesia. Based on the anatomical results, Song and Wang (1994) considered the air
canal and the endodermis as very important criteria to differentiate *Fargesia* from *Yushania*. The results obtained by this study do not conform to their opinion as there are no clear-cut differences between the anatomical features of these two, or four, genera. The four sub-types also do not show any systematic evolutionary aspects.

With respect to the vascular bundles, the components of xylem in the culm neck of pachymorph bamboos are completely different from those in the leptomorph rhizomes and from those in the culm internodes of any bamboo. In most situations, the xylem consists of only one metaxylem vessel. This may be apparent in the diaphragm of culm nodes (Liese and Ding 1994). Weiner and Liese (1990) studied 13 genera of Palmaceae, the climbing palms, in which 10 genera were shown to have only one vessel in metaxylem. So the metaxylem vascular bundle consisting of only one vessel can be considered a primitive character. In this sense, the leptomorph bamboos are, from the systematic point of view, more evolved.

**Acknowledgements**

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**References**


Ageing of Bamboo culms: a Review

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Abstract

Properties and utilization of bamboos are influenced by structural changes brought about by ageing. During the few months of growth of a culm, only minor anatomical changes result from the meristematic tissue within one internode and along the culm length. Culms originating from a seedling or rhizome cutting show an age-related development in subsequent years, until their full size is attained. The life cycle of an individual culm is of special interest. Investigations of Phyllostachys *uiridiglaucescens* culms up to the age of 12 years have shown definite anatomical changes during the maturation period, and also in later years. They appear as cell wall thickening of fibres. Tyloses and depositions in vessels and sieve tubes develop with increasing age of the culm.

Introduction

The ageing of bamboo culms is still a matter of curiosity. Since ageing influences certain properties and consequently the processing and utilization, numerous investigations have dealt with possible structural, chemical and physical-mechanical modifications. Age-related changes have to be considered under different aspects: first, during the differentiation and growth of an individual culm; second, along with age of consecutive culms originating from seedling bamboo; third and most important, during the life cycle of an individual culm from its immature stage towards maturation and death.

Since the term “ageing” is sometimes used for different phases, the following attempt gives information about the various stages in the life cycle of a bamboo plant, with emphasis on the ageing of a fully elongated culm.
Growth Phase

The elongation of a culm results from the expansion of its individual internodes, already present in the bud. In the beginning, the whole internode consists of an intercalary meristem. Differentiation starts at its upper part by elongation of the different cell types, and moves down to the base of the internode. The differentiation of one internode is completed in only a few days (Xiong et al. 1980). Longitudinally, there is no difference in the composition and structure of the tissue within an internode, except for the length of the fibres. They perform a most significant elongation during the differentiation from only few um to about 2-3 mm, that is about 100 times. Along an internode, fibres near the upper and lower nodal ends are always much shorter than in the middle portion (Liese and Grosser 1972; Espiloy and Sasondoncillo 1978), thus resulting in easier breakage, especially in young shoots.

A bamboo culm grows up to its full height of 3-30 m within a period of few months. In contrast to a palm or a tree, where axial cell differentiation occurs by the apical meristem, in bamboo the meristematic tissue of the internodes moves with the growing parts telescopic-like, upwards.

Only minor anatomical changes exist along the culm length. The narrowing of the culm wall, because of the reduction of its inner portion containing more parenchyma and lesser vascular bundles, is obvious; and so is the decrease in the size of the vascular bundles. Thus their shape changes into oval or rounded. This also influences the appearance of the basic vascular bundles types II, III, IV present in the sympodial bamboos which can become modified along the culm height (Grosser and Liese 1971). The upper part with more vascular bundles has a higher specific gravity. Therefore, bending and compression strengths increase with height, influenced by the wall thickness of the species. Only the fibre length indicates a slight decrease from the base to the top (Liese and Grosser 1972; Grosser and Liese 1974; Espiloy and Sasondoncillo 1978; Abd. Latif et al. 1994).

During the development of an internode a central pith cavity is formed (Mohiuddin and Alam 1992). The cells at the inner periphery often consist of layers of parenchyma and also of thick walled cells, called ‘sclereids’. This “terminal layer” (Grosser and Liese 1971) can be composed of rectangular parenchyma with thicker cell walls than the adjacent ground parenchyma. A very thin membrane (Figure 1) may be attached to the inner wall or lie loosely even in a one-year-old culm (Figure 2). Whereas in
some species (Phylostachys *viridiglaucens*, *P. aurea*) it occurs in the first year itself, in *P. heterocycla* it appears only after three years of growth, and in some others not at all (Nomura 1993). The varied nature of the lining cavity is indicated by the presence of sclereids, fibrous tissue or a sclerenchymatous zone. This supports a diagnostic value, whereas the observations on its differing formation are of lesser significance as age-related modifications (Pattanath and Rao 1969; Sekar 1992; Wu and Hsieh 1994). Our TEM analyses with *P. aurea* have revealed a suberization of this inner, thin-walled cells.

**Fig. 1:** “Terminal layer” of a 12-year-old culm of *Phyllostachys viridiglaucens*

**Fig. 2:** Inner culm wall with “terminal layer” of *Phyllostachys viridiglaucens*

### Ageing of Seedling Bamboo

Observations on ageing of bamboo culms distinguish between the differences of the culms from consecutive years, like in a plantation established by seedlings or rhizomes, and those of a single culm with the passing
years. Precise information on age-related changes of seedling bamboos is important for determining yield, management needs and harvesting of a new plantation. It is generally known that with the years, height and diameter of the annual culms increase. As for Guadua angustifolia culms, an increase was registered even up to 10 years [2nd year (y): diameter (d) 1 cm, height (h) 1-1.5 m; 4y: d 7.5 cm, h 5-10 m; 7y: d 8.5 cm, h 10-15 m; 10y: d 9.5 cm, h 15-18 m] (Londono 1992).

Besides the dimensional changes, structural modifications are also evident. In seedling culms of P. heterocycla the average diameter of the vascular fibre sheath, metaxylem vessels and fibre length increase at about 6.7, 4.4 and 1.9 times, respectively, from the age of 1 to 5 years. Older culms developed a somewhat more stretched variation of the vascular bundle type (Nomura 1993).

Life Cycle of an individual Culm

General properties

Age-related changes within an individual culm are of special interest. Their significance is indicated by the terms “immature” and “mature”. Definite modifications occur within a grown-up culm during its life time. The influence of ageing on maturation, especially on strength properties, is well proven. Many attempts have therefore been made to identify some characters, which may indicate a certain age class of a culm. During the younger stage, changes of external characteristics are obvious, related to the culm sheaths, bud break, branching pattern, number of leaf scars and colour of the stem from fresh green often to yellow-grey. Banik (1993) could differentiate the ages from one to four years for five major species of Bangladeshi bamboos using such morphological characters.

During the maturation phase of up to three years, the moisture content decreases distinctly (Abd. Latif and Mohd. Zin 1992; Espiloy 1994; Sattar et al. 1994); but also later, even up to 10 years (Liese and Grover 1961). More significant are the chemical and structural parameters, which are reflected in the physical-mechanical properties. With regard to the chemical composition, the percentage of holocellulose and cl-cellulose tend to decrease in bamboo culms older than one year, while the lignin content remains unchanged or increases slightly (Chen et al. 1987). In relation to strength properties, the ageing effect on lignification is of interest. Studies by Itoh (1990) on 2 to 16 year-old culms of P. heterocycla have shown that
full lignification is completed within the first growing season, with no further effects with increasing age of the culm. Chen et al. (1987) indicated in their studies on 1 to 7-year-old *P. pubescens* that a remarkable change occurs in the ash composition, with decrease in copper, zinc, phosphorous, iron and potassium, and increase in calcium, magnesium and manganese.

Ageing involves the question of vitality, which is related to the storage and mobilization of carbohydrates. Therefore, the presence of starch as energy source has been investigated in 1 month to 12-year-old culms of *P. viridiglaucens* (Carr.) A.C. Riv. A young culm does not allow any starch to be stored during the growing phase, since all nutrients are to be utilized immediately for metabolic processes (Figure 3). But in all the older culms starch was present, even in ones aged 12 years (Figure 4). The starch granules were located in the vertically elongated cells of the ground parenchyma, in the contact parenchyma cells and in the parenchyma cells of the diaphragms (Figure 5). This also shows that the parenchyma cells are still alive in culms of such age.

**Fig. 3:** Ground parenchyma cells without starch of a one-year-old *Phyllostachys viridiglaucens* culm (longitudinal section)

**Fig. 4:** Ground parenchyma cells full with starch of a 12-year-old *Phyllostachys viridiglaucens* culm (longitudinal section)
No reports exist about residues which may result from cell metabolism, although the sieve tubes as well as the parenchyma cells maintain their function for often longer than 10-15 years. Since no known formation of toxic substances occurs with ageing, the natural resistance of bamboo against organisms is generally low. Nevertheless, certain hard-to-explain differences between species are known from experience, as well as field and laboratory tests. The amount of starch present might have something to do with this.

In certain species, especially in pachymorph species from the tropical regions, an amorphous siliceous material is found inside the pith cavity of older culms (Figure 6). It is called “tabashir” and is used for pharmaceutical purposes (Jones et al. 1966). Its origin and its formation as an age-related process is not known.

The activities of parenchyma and companion cells along the sieve tubes may lead to changes in the gas composition inside the culm over the years. The intercellular spaces between the short parenchyma cells could be a pathway (Figure 7). Since the epidermis indicates an impermeable nature,
the pith cavity might be some kind of a buffer reservoir for the gas. However, for the inner terminal layer no stomata-like openings have been observed so far. An analysis of the gas composition in culms of consecutive years could reveal interesting information.

With regard to the physical-mechanical properties, only few results can be determined from the many contributions (e.g. Zhou 1981; Espiloy 1987, 1994; Widjaja et al. 1987; Abd. Latif et al. 1990; Sattar et al. 1994). Although a few contradictory observations were reported, the general consensus is that a bamboo culm matures at about two to three years, and has by then reached its maximum strength. Also, by investigating culms of Bambusa balcooa and Melocanna baccifera of one to five years of age, a decrease in static bending strength and compression strength was noted in the oldest ones (Sattar et al. 1994). In flowered bamboo culms, however, a significant reduction of specific gravity and strength properties has been noted (Kitamura 1975) which could explain the breakage of culms following flowering.

Fibre characteristics

Changes in the physical-mechanical properties of bamboo tissue must be related to the modifications of the cell structures. Particularly important in this respect are the fibres, which are arranged in fibre sheaths and the respective additional fibre bundles, depending on the genus. Therefore, the cell structures of culms of P. viridiglaucescens from growing shoots up to 12 years were analyzed for the possibility of tracing structural modifications. Samples from the basal 4th and the 20th internodes were taken in May 1994 from freshly cut culms, immediately fixed in 4% formaldehyde, subsequently cut into smaller samples (5 mm width x 10 mm length x wall thickness/complete cross section) and processed for scanning electron
microscopy (Hitachi S520). To obtain a smooth surface, the fresh yet extremely hard samples were cut with a razor blade (angle 45°), air dried and sputter-coated with gold. Transverse sections of 15 um thickness were then cut on a sliding-microtome, double-stained with acridin red/chrysoidin and astra blue, alternatively also with phloroglucin. All sections were embedded in glycerin and analyzed by light microscopy (Olympus BH2).

The exact location and characterization of the specific fibres are required for a comparison of the fibre structures of different culms. Each vascular bundle is surrounded by four fibre sheaths in a trefoil manner, embracing the phloem field, the two metaxylem vessels and the one protoxylem tracheid. Several fibre types are present in the fibre sheaths:

- Fibres in direct contact with the surrounding ground parenchyma show a distinct polylamellation with numerous, thin lamellae, more than the other fibres of the same sheath.
- Fibres in the centre are bigger in size than the outer ones.
- Fibres in contact with the phloem field and the protoxylem tracheid are the smallest.

Special large cells within the fibre sheath near the protoxylem tracheid may represent groups of parenchyma cells (Figures 8a and 8b), as observed also by Murphy and Alvin (1992). Besides these differences within one

![Fig. 8: Parenchyma cells (arrows) inside a fibre sheath of a 8-year-old Phyllostacby viridiglaucescens culm (transverse section)](image-url)
fibre sheath and the fibre sheaths around vascular bundle, further modifications exist along the cross section of the culm wall. Fibres near the epidermis as well as near the inner part, the pith cavity, are thinner and often possess one or more lamellae less than those in the middle part.

These general findings relate to samples from the base (4th internode) as well as from the top region (20th internode). However, in spite of this similarity, certain differences between base and top portions exist. In the base portion, the fibres are generally thicker than those at the top. This pattern becomes obvious both in a young culm and in older ones (Figures 9a and 9b). In the one-year-old culm of *P. viridiglaucescens*, the fibre wall thickness between the base and the top portion differs by about 1 um, but in a culm of 12 years the range is 1.5-2.0 um. For the same species, Alvin and Murphy (1988) found a difference of 0.16 um between the 6th and 20th internode in a young culm and of 0.3 um in an older one. For *Gigantochloa scortechinii*, a difference of 2 um between base and top (1 year) and 3.2 um (2 years) was observed (Abd. Latif et al. 1994).

The recognition of such a pattern of differences in the fibre structure within a culm is a prerequisite for any investigation of possible changes brought about by ageing. Results are conclusive only when fibres are compared at the exact position. Based on the findings mentioned above, detailed light microscopic measurements have been undertaken to elucidate any possible changes in the fibre wall architecture. Although spectacular results could not be expected from the time-consuming exercise, some findings merit the efforts.

In the first month of the growing period, all fibres of the culm are still un lignified. Within the 20th internode the fibres have a combined, very thin wall of altogether 1.5-1.7 um. In a fully elongated culm of the same year, the wall thickness at this internode was 2.3 um and thinner than those at the lower 4th internode (2.6 um). The fibre wall consists of three lignified lamellae (Figure 10). After one year, it contains four to five lamellae and its thickness increases to over 5 um at the top and around 6 um at the base. Within the top portion of the two-year-old culms it was observed to be 5.5 um, while being about 6.8 um at the 4th internode. Observations by Fujii (1985) on the cell walls of *Pleioblastus chino* showed a continued thickening late into the second year. Alvin and Murphy (1988) investigated three culms of *Sinobumbusa tootsik* with an estimated age of less than one, one to two and more than two years, and revealed a similar significant increase in the average cell wall thickness.
Fig. 9a: Fibre cell wall thickness over the cross section at the 4th internode from 3 month (1994), 1-year (1993), 6-year (1987) and 11-year (1983) old culms of *Phyllostachys viridiglaucescens*.

Fig. 9b: Fibre cell wall thickness over the cross section at the 20th internode from 3 month (1994), 1 year (1993), 6-year (1987) and 11-year (1983) old culms of *Phyllostachys viridiglaucescens*.
Results for older culms are not known so far. The measurements of the culms between the third and ninth year showed no further deposition of lamellae. The wall thickness remains nearly the same. However, older culms of 9 to 12 years, revealed an additional increase of wall thickness. The fibres contain 5-6 lamellae with a wall thickness of about 8 µm and 6 µm at the respective basal and top portions (Figure 11). In Tables 1 and 2 the measurements of the fibre wall thickness at different ages and over the culm wall are summarised.

The formation of new lamellae was distinct in several samples by their un lignified status, as seen after staining. A lignified layer was earlier recognized in older culms of Thyrsostachys olivieri Gamble by Liese and Grosser (1971). A detailed analysis of the culms however revealed their rather localized occurrence, so that this “gelatinous” layer is seen as an incomplete cell wall differentiation and not as a stage of further ageing.

These results indicate that within the investigated material two development phases for the fibres occurred. The main one happened during the first two years that led to the development of fibres with lignified cell walls, while still containing their cytoplasm. A second followed several years
Table 1: Mean fibre wall thickness of vascular bundles at the 4th internode from *Phyllostachys viridiglaucenscens* (um)

<table>
<thead>
<tr>
<th>Culm age (month, year)</th>
<th>Average value (um)</th>
<th>Epidermis</th>
<th>Near pith cavity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1 2 3 4 5 6 7 8 9 10 11</td>
<td></td>
</tr>
<tr>
<td>3m</td>
<td>2.6 2.9 3.0 2.8 2.9 2.9 2.5 2.3 2.3 2.3 2.3 2.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1Y</td>
<td>6.2 6.9 7.3 7.9 6.9 6.6 6.2 5.5 4.7 4.3 - -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2Y</td>
<td>6.8 7.2 6.9 7.2 7.5 7.6 6.7 7.1 6.6 5.7 5.4 -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3Y</td>
<td>5.2 6.1 6.3 5.9 5.4 4.6 4.3 4.0 - - - -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4Y</td>
<td>6.8 6.1 7.0 7.4 7.3 7.1 6.5 6.3 - - - -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5Y</td>
<td>5.0 5.6 6.0 5.9 5.3 4.6 3.9 3.6 - - - -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6Y</td>
<td>3.6 5.2 4.0 3.4 3.4 3.1 2.6 2.8 2.6 2.5 - -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7Y</td>
<td>6.1 5.6 7.0 7.1 7.1 7.1 6.3 5.3 4.6 4.7 - -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8Y</td>
<td>7.2 5.6 6.2 7.1 7.3 7.8 8.1 7.5 7.4 6.3 5.6 -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9Y</td>
<td>4.8 4.9 6.8 6.8 5.4 4.0 3.1 3.2 2.7 - - - -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10Y</td>
<td>6.6 5.7 5.7 5.7 5.8 6.3 5.8 5.5 4.7 - - - -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11Y</td>
<td>8.0 7.0 7.6 8.3 8.5 8.3 8.4 6.6 8.3 8.4 7.4 -</td>
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<td></td>
</tr>
<tr>
<td>12Y</td>
<td>7.7 5.5 6.6 7.8 8.1 8.2 8.7 9.2 8.3 7.9 6.4 -</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Later by the additional formation of few lamellae by the cytoplasm. These are to be recognized first as un lignified lamellae upon the now-lignified wall.

The number of lamellae reported above were measured with the light-microscope and appear lesser than the polylamellate fibre structure observed from electron-microscopic measurements (Parameswaran and Liese 1976). This difference could be associated to the fact that the narrow lamellae became visible only after delignification and at high magnification; they may also be restricted to the outer vascular bundles with a distinct polylamellation.

The existence of living fibres and also parenchyma in older culms is confusing with observations on the widespread occurrence of a wart structure in these cells (Parameswaran and Liese 1977). Warts are considered as a final stage of cytoplasmic activity before a cell dies. The material investigated in those earlier studies has not been considered for its age and location within the culm. It was air-dried, so that during the death of the fibres and
**Table 2:** Mean fibre wall thickness of vascular bundles at the 20th internode from *Phyllostachys viridiglaucescens* (um)

<table>
<thead>
<tr>
<th>Culm age (month, year)</th>
<th>Average value (um)</th>
<th>Fibre sheaths in radial orientation over the calm wall</th>
<th>Near pith cavity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Eoidermis</td>
<td>1 2 3 4 5 6 7 8 9 10 11</td>
<td></td>
</tr>
<tr>
<td>3m</td>
<td>2.3 2.3 2.6 2.4 2.1 2.2 2.3 2.2 2.1 2.1</td>
<td>- - - - - - - - - - - -</td>
<td>- - -</td>
</tr>
<tr>
<td>1Y</td>
<td>5.2 4.8 6.4 6.2 5.4 5.2 4.6 4.1 - - -</td>
<td>- - - - - - - - - - - -</td>
<td>- - -</td>
</tr>
<tr>
<td>2Y</td>
<td>5.5 4.7 5.8 5.8 5.7 5.9 5.6 4.9 - - -</td>
<td>- - - - - - - - - - - -</td>
<td>- - -</td>
</tr>
<tr>
<td>3Y</td>
<td>5.2 5.5 5.5 5.1 5.3 5.1 4.6 - - - -</td>
<td>- - - - - - - - - - - -</td>
<td>- - -</td>
</tr>
<tr>
<td>4Y</td>
<td>6.7 6.3 6.6 7.1 6.9 7.5 5.6 - - - -</td>
<td>- - - - - - - - - - - -</td>
<td>- - -</td>
</tr>
<tr>
<td>5Y</td>
<td>4.6 5.2 5.3 4.8 4.5 4.2 3.5 - - - -</td>
<td>- - - - - - - - - - - -</td>
<td>- - -</td>
</tr>
<tr>
<td>6Y</td>
<td>3.6 3.8 3.7 3.7 3.3 - - - - - -</td>
<td>- - - - - - - - - - - -</td>
<td>- - -</td>
</tr>
<tr>
<td>7Y</td>
<td>5.8 6.6 6.7 6.6 5.6 4.8 4.3 - - - -</td>
<td>- - - - - - - - - - - -</td>
<td>- - -</td>
</tr>
<tr>
<td>8Y</td>
<td>7.2 6.5 7.2 7.7 7.0 7.4 7.3 - - - -</td>
<td>- - - - - - - - - - - -</td>
<td>- - -</td>
</tr>
<tr>
<td>9Y</td>
<td>5.8 5.1 5.9 5.9 6.1 6.0 5.5 - - - -</td>
<td>- - - - - - - - - - - -</td>
<td>- - -</td>
</tr>
<tr>
<td>10Y</td>
<td>6.6 5.3 6.4 7.3 7.4 6.8 6.2 6.6 - -</td>
<td>- - - - - - - - - - - -</td>
<td>- - -</td>
</tr>
<tr>
<td>11Y</td>
<td>7.2 6.7 7.1 7.7 7.6 7.3 7.3 6.6 - -</td>
<td>- - - - - - - - - - - -</td>
<td>- - -</td>
</tr>
<tr>
<td>12Y</td>
<td>6.0 4.9 6 6.5 6.4 6.2 6.0 5.8 - -</td>
<td>- - - - - - - - - - - -</td>
<td>- - -</td>
</tr>
</tbody>
</table>

parenchyma the wart structure might have developed. Studies on the formation of the wart structure in relation to ageing and dying of fibres and parenchyma in bamboo seem to be of interest.

Corresponding observations on developmental changes of fibre structures from ageing were also made on the palms *Rhapis excelsa* (Thunb.) Henry and *Calamus axillaris* Becc. (Weiner et al. 1995). Unlike bamboo, palms possess an apical meristem, and hence the occurrence of age-related changes could be examined along the stem in the investigated 5-year-old plant. The results have shown within this period a similar formation of additional lamellae with an increase in fibre wall thickness. A chemical analysis of *Rhapis excelsa* has indicated an additional lignification in the lower, older part of the stem.

**Further Symptoms of Ageing**

Senescence also leads to symptoms which are associated with the functional efficiency of the living culm. Most important, but also most endangered, is the conductivity of water which is transported in the metaxylem vessels and that of assimilates in the sieve tubes. It is remarkable that
these crucial pathways are formed within a few days of differentiation, and have to function in bamboo culms for numerous years and even much longer in palms. However, with increasing age certain symptoms can be observed in the conductive tissue. They are more of a general nature and not related to a distinct age. Some of these effects should be briefly mentioned.

Tylosis in bamboo leads to a blockage of the metaxylem vessels (Figure 12). The balloon-like protuberances originate from the surrounding parenchyma cells. Tylosis develops within the protoxylem tracheid in earlier stages, and may therefore have lesser importance with regard to water transport. Older culms show tylosis in the metaxylem vessels, which seals off the water conduction. Furthermore, slime substances may fill their lumen which also leads to a blockage. In both cases, an air embolism must proceed, through which the vascular parenchyma cells are stimulated to form tyloses and slime. The sieve tubes of older culms can show a blockage by callus. The accumulation of such age-related changes finally leads to a breakdown of the transport system, thussesulting in the death of the culm.

These modifications from senescence also occur as a consequence of mechanical wounding. An injured tissue has to develop defense reactions to protect its surrounding cells against the invasion of air and microorganisms. Damage of the culm could also be caused by insects, which penetrate the wall and use the pith cavity as their biotope (Kovac and Azarae 1995).

Following wounding, an additional thickening of parenchyma cell walls has been observed as a further reaction. The cell walls of the ground parenchyma exhibit the formation of new lamellae along the wounded tissue. Thus, the endangered tissue is like-wise sealed off against the damaged area (Weiner and Liese 1996). A similar phenomenon occurs in branches, which are cut off or die (Figure 13), wherein a thickening of parenchyma

Fig. 12: Tylosis in a metaxylem vessel of a vascular bundle, Pbyllostaechys viridiglaucescem
walls takes place above a node. Thus a barrier zone is formed to separate the living tissue from the dying one. Since branches also die from age, this parenchymatic response can also be seen as an age-related reaction.

A treatise on the ageing of bamboo culms may include considerations on the long-time behaviour of culms in use, as related questions have indicated. It should be stated therefore that bamboo used for buildings or for music instruments or sculptures, has not indicated any change of properties. Some impressive examples over the last 100 years include building constructions in Manizales, Colombia, the bamboo organ in Las Pinas, the Philippines, and the art objects in Chinese museums.

Acknowledgements

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References


Malaysian Bamboo: Research Priority Areas

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Abstract

This paper presents a summary of the current research on bamboo in Malaysia, incorporating the growing, production (propagation) and utilization aspects of bamboo research in Peninsular Malaysia. The future thrusts are briefly described.

Introduction

Bamboo, a giant arborescent grass previously considered as a minor forest produce, is an important forest resource in Peninsular Malaysia. It is next only to rattan in terms of economic importance, and has become increasingly important to both the industry and the rural people. Although there are 63 bamboo species in 11 genera found in this country, only 13 are being used commercially. They are mostly found in quantities in areas that are disturbed, such as logged-over forests, wastelands or in marginal localities fringing the forest (Aminuddin and Abd. Latif 1991). There has never been a complete inventory of bamboo resources in Malaysia. The ones conducted in the National Forest Inventories concentrated mainly on few commercial species. Abd. Razak and Abd. Latif (1988) estimated the total area under bamboo in Peninsular Malaysia to be about 320,000 ha.

The use of bamboo is wide and varied (Abd. Latif 1989). Bamboo is used to make a variety of products ranging from small articles of everyday use such as chopsticks and mats, to structural items like bridges, houses and scaffoldings. Bamboo-based industries have been growing rapidly, and currently there are about 1,000 such industrial units of various sizes in Peninsular Malaysia alone (Abd. Latif 1989). Out of this, only 104 mills have mechanized production of items such as skewers, chopsticks and toothpicks (32 mills), furniture (2 mills) and craft articles (70 mills). The remaining mills are classified as cottage and small-scale enterprises.
Knowledge on the biology of all commercial bamboos in Peninsular Malaysia is still rudimentary. At the Forest Research Institute Malaysia (FRIM), bamboo research began in the mid-1980s. The main emphasis of research then had been on seed germination, taxonomy and growth trials. Research works on the cultivation and utilization aspects of bamboo have created a growing awareness about the economic importance of bamboo.

In recent years, FRIM researchers have been involved in propagation, planting and looking at ways of managing bamboo stands. This paper discusses the present status of bamboo research in the country and also highlights the future thrust areas of the bamboo industry.

Prospects of Bamboo Industry in Peninsular Malaysia

It is time that the image of bamboo being a “poor man’s timber” changed in Malaysia to realize its full potential. In 1991, the world trade in bamboo and bamboo products was around US$4.5 million, although Malaysia managed to export only about 314,000 ringit (approx. US$125,000) worth of chopsticks and handicrafts. Ironically, Malaysia is still a nett importer of bamboo, to the tune of about 1.6 million ringits (approx. US$800,000) (1991 data). The industry needs about 400,000 tonnes (about three million culms) per annum, but such an amount of supply cannot be sustained since the current bamboo-growing areas can produce only about 250,000 tonnes (about two million culms) per year. These areas can meet the demand of the industry if steps are taken to manage them systematically.

The local market for bamboo products is around 3 million ringits. The cottage and small-scale enterprises should be encouraged to increase their production and export their products. The handicraft industries are mostly located in the west coast – Negeri Sembilan, Pahang, Perak, Kedah and Kelantan – where the transport network is good, whereas the industries making poultry cages and vegetable baskets are around Tapah and Cameron Highlands in Perak (Wong 1989). There are several problems that should be solved in order to encourage the industry. One of this is to ensure that there is a continuous supply of bamboo culms and, at the same time, explore the possibility of growing bamboo shoots commercially. The local market, though small at the moment, can create strong competition and this will force the industry to look for export markets where there is a lot of competition. The bamboo furniture industry can be competitive in both local and export markets if the production techniques are modified and production and other costs are kept to a minimum.
Current Research and Development Activities on Bamboo

FRIM started research on bamboo in the mid 1980s mainly looking at the techniques of propagation, growing and silviculture trial plantings. To enhance the benefits of bamboo resources to the rural economy and to improve bamboo production and utilization, an intensive research and development program should be developed and expanded. Some of the areas of current research focus that required to be expanded are described below.

Inventory

The recent National Forest Inventory III included some species of bamboo, but the results have not yet been analyzed. Therefore, it will be premature to attempt to quantify the bamboo resources of the country. The only serious attempt to quantify bamboo was done for the state of Kedah, where there are about 179,000 to 185,000 tonnes of air-dried bamboo of *Gigantochloa* species being produced per year.

The research in the area so far was concentrated on the development of a suitable bamboo inventory technique. Techniques using photo imagery and ground verification are being compared in Nami in Kedah and Segamat in Johore.

Silviculture and Management

Research on the propagation techniques of some of the commercial species were the focus of some investigations. Bamboo propagation by rhizome-offsets and culm cuttings was studied (Abd. Razak 1989). Propagation by branch cuttings was successfully tested by Hashim (1989) and Abd. Razak and Hashim (1993). However, little is known on the pests and diseases that afflict Malaysian bamboos, except for leaf spot and short hole.

On the silviculture side, the main attempts were to investigate the growth and yield of some of the commercial species growing on tin-tailing and problematic soil areas, and the responses of new culms and regeneration activities to harvesting intensities and fertilizer application. Among the species studied, *Bambusa vulgaris* survived better on tin-tailing areas, when compared with *Dendrocalamus asper* and *Gigantochloa levis* (Abd. Razak pers. comm.).

FRIM is currently carrying out a study on the management of the natural bamboo stand at H.S. Hebar in Kedah. The main aim is to transform the bamboo forest into a plantation so that the supply is continuous. This
is being tried by ensuring that some 15 culms per clump are retained at any one time. The study is being monitored.

Properties

Comparative vascular anatomy of one to three-year-old culms of three bamboo species was conducted at FRIM. The purpose was to classify the bamboos based on shape, size and arrangement of the vascular bundle. Further work on the physical and mechanical properties need to be continued since the selection of bamboo for industrial uses, construction and housing is closely related to the properties. Some of the studies have indicated that the compression and tensile strengths of bamboo are equivalent to wood or steel (Abang Abdullah 1983). Abd. Latif et al. (1990) observed that the strength properties of some wild bamboos increase with age. Siti Norralakmam and Abd. Latif (1994) have shown that nearly all the physical properties of Bambusa blumeana and B. vulgaris were negatively correlated with age and height, except for the density.

The machining properties of some bamboos suitable for conversion into satay sticks, toothpicks, blinds and skewers have been studied. Low-quality end-products were obtained if the bamboo culms were immature, resulting in low recovery rate and very fibrous material. It was also noticed that with young bamboo culms, which have a high moisture content, processing can cause the cutting tools to rust.

The chemical properties of some bamboos have been studied by Abd. Latif et al. (1990,1991). They found that the amount of total sugar was strongly affected by culm maturity and height. Owing to the high sugar content in green bamboos, the species studied were observed to be less suitable for the manufacture of urea and cement-bonded particle board. Bamboo soaked in water for seven days was found to be suitable to be used for particle boards (Chew et al. 1992).

Waste generated during processing of bamboo was used in the making of flooring material, and it was observed to be suitable for medium and heavy traffic conditions. FRIM has developed a parquet machine for this purpose.

Future Research Thrusts on Bamboo

With ample bamboo resources scattered all over the country, Malaysia should have no problem in ensuring a continuous supply of raw material to the bamboo industry. This must come with proper management techniques.
Although it has been said that the situation in the near future would be different because of the increased usage of bamboo culms by the cottage industries (Norini et al. 1994), the fact remains that the domestic demand so far has always been greater than supply. A systematic approach to bamboo growing and harvesting is required to meet the demand for continuous supply of bamboo culms. Development of practical methods to identify species and age of bamboo suitable for harvest for industrial purposes will benefit the industry.

Of the 63 species found in the country, only 13 species are commercially harvested. There are 50 other species growing in different states of abundance that can be explored as alternative species. This can only be achieved through an integrated approach starting from bamboo cultivation through to utilization.

The propagation techniques need to be improved. Although propagation through tissue culturing has been achieved by several researchers, the cost of production is still high. Other suitable methods from other bamboo-producing countries should be looked into for possible adoption. Efforts should be geared towards site-suitability studies, irrigation, spacing trials, culling and harvesting techniques (for culm and shoot) of the bamboos.

References


Vth International Bamboo Workshop &
IVth International Bamboo Congress
Ubud, Bali, Indonesia, 19-22 June 1995

RECOMMENDATIONS

1. In view of the deficits between demand and supply, the cultivation of
bamboo must be vigorously promoted. However, a number of constraints
to production need to be addressed, particularly in relation to the materi-
als used. Many of the subsequent recommendations are not new but have
been recognized for some time; the attention of national institutions is drawn
to them so that action may be taken in cooperation with international pro-
grams and projects.

2. In view of the wide distribution of many priority species, it is urgent to
match these with agro-climatic zones in order to characterize segments of
the diversity and identify the best materials for particular growing condi-
tions.

3. There is a need to identify the superior genotypes used by different
programs and institutions, and to fully document sources and characteri-
astics in relation to utilization.

4. Selection and development of elite materials should be promoted by
INBAR. In this respect, attempts should be made to identify characters in
seedlings - which can be observed in early stages of growth - that are
indicative of future growth, productivity or sustainability to an end use.

5. It is noted that an INBAR manual on propagation is in final stages of
preparation*. An updated guide to micropropagation should also be pre-
pared itemizing the most appropriate technologies, and the possibilities
for use in large-scale plantings.

6. More information is required on sources of material for a number of
more marginal environments - such as dry, water logged and degraded
lands - and evaluation of materials for a range of sites should be carried
out and results widely disseminated.

* A Manual for Vegetative Propagation of Bamboos has since been published.
7. It is recognized that large-scale plantings are the responsibility of government departments, private enterprises, NGOs and others, and INBAR is asked to help develop innovative partnerships and to promote the availability of relevant information.

8. It is recognized that the interests in plant materials range far beyond national needs for production, and that seed exchanges would be facilitated by the setting up of a central information registry of seed availability, documented in a standard format and data made available through Internet, e-mail or the INBAR Newsletter.

9. To facilitate seed exchange between researchers at all levels, institutions/individuals are urged to set up micro seed banks of research materials containing disease free seeds. It would be helpful if INBAR/IPGRI were to collate existing regulations pertaining to exchange and availability so that requesters can follow recognized procedures.

10. It is recognized that many technologies for the management of natural stands exist but are not always widely adopted. Transfer of technology in this area is urgent, particularly through NGOs and similar organizations.

11. The realization of a reasonable profit by farmers is a pre-condition to enhancing production, especially in establishing new plantations; and also farmers’ management skills need to be improved through extension training.

12. As a result of mass propagation, plantations might be potentially vulnerable. Experimentation on polycultures is urgent to minimize dangers and maintain a broad genetic base.