CONSTRAINTS TO PRODUCTION OF BAMBOO AND RATTAN

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INBAR is a research network promoting better production and use of bamboo and rattan. It is currently co-sponsored by the International Development Research Centre (IDRC) of Canada and the UN International Fund for Agricultural Development (IFAD), with inputs from the Government of Japan. The major areas of research on the two commodities include Socio-economics, Production, Biodiverstiy and Genetic Conservation, Post-Harvest Technology, and Information, Training and Technology Transfer. INBAR is managed by IDRC and hosted by the IDRC Regional Office in New Delhi.

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International Network for Bamboo and Rattan
International Development Research Centre
17 Jor Bagh, New Delhi 110 003, INDIA.

CONSTRAINTS TO PRODUCTION OF BAMBOO AND RATTAN

With special reference to planting materials and management of natural stands

Report of a Consultation held 9-13 May 1994
Bangalore, India

Co-sponsored by

International Network for Bamboo and Rattan (INBAR) and
Khoday Biotek, Bangalore

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FOREWORD

The publication of these proceedings marks an important step in INBAR's evolution, since it sets forward a number of proposals for priority research in two important areas.

INBAR is a network that relies heavily on the inputs from the members of its working groups, which are composed of senior scientists from premier research institutions across Asia. Most have already had years of experience with IDRC-supported bamboo and rattan research projects over the past fourteen years. The creation of INBAR in 1993 aimed to take research on bamboo and rattan to a higher plane - one involving research collaboration across the region, between scientists from different institutions in different countries, linked by common interests.

INBAR's Production Working Group met in Bangalore, India in order to address two major issues: *delivery systems for planting materials* and *sustainable management of natural stands*. These topics had been identified by INBAR's secretariat in response to various activities conducted during INBAR's first six months. The papers included in this volume have been rigorously edited so that this will be a significant and lasting contribution to the literature on bamboo and rattan.

INBAR wishes to acknowledge the contributions of Khoday Biotek, co-sponsor of the Bangalore consultation. In particular, Dr. I.V. Ramanuja Rao assisted in a significant way with local arrangements. We are also grateful to two members of IDRC's Board of Governors, Dr. Vulimiri Ramalingaswami and Mr. Brian Felesky, for joining us for the first morning's deliberations. In addition, Mr. Shantanu Mathur from the International Fund for Agricultural Development (IFAD) in Rome not only confirmed IFAD's support for this network activity, but willingly chaired one of the scientific sessions. Finally, we thank the participants for their active involvement and contributions to a successful consultation - one that may serve as a model for future INBAR meetings.

The real challenge still lies ahead of us - to pursue action programmes on each of the priorities identified.

Paul Stinson
Manager, INBAR

December 1994

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INTRODUCTION

1. The Research Advisory Group of INBAR, meeting in December 1993, noted that two areas relating to production of bamboo and rattan needed in-depth assessment. These were propagation and supply of planting materials and the sustainable management of natural stands. As a result, the INBAR Production Working Group and the Secretariat organised a research consultation in Bangalore, India, 9-13 May 1994. The agenda and list of participants is shown in Appendices 1 and 2.

2. Local arrangements for the consultation were made by Khoday Biotek, a private company in Bangalore, which kindly co-sponsored the week's activities.

3. Participants included experts from national programmes in Asia, resource persons, and representatives of international organisations and programmes: Food and Agricultural Organization of the United Nations, FORSPA and FORTIP; Consultative Group on International Agricultural Research, CIFOR and IPGRI (IBPGR); and the UN International Fund for Agricultural Development (IFAD).

4. The consultation was opened by Dr. Cherla B. Sastry of the International Development Research Centre (IDRC), the New Delhi office of which houses the INBAR Secretariat. IDRC is one of the major donors to INBAR and two Governors of IDRC welcomed participants and expressed their interest in the objectives and action of the network.

5. Prof. J.T. Williams, Science Adviser to INBAR, provided a background to the meeting and expected outputs (Appendix 3). He stressed that ecosystem conversion for bamboo and rattan harvesting and production has resulted in short-term economic gains but at the risk of long-lasting environmental damage. Both topics of this consultation are relevant to a wide range of land utilisation patterns.

6. For bamboo planting materials, the major constraint to raising more plantations is the limited availability of seed. A range of propagation techniques is currently in use, including for some species mass propagation through tissue culture. The consultation was asked to focus on the opportunities to quickly establish reliable delivery systems of planting materials. For rattans, seeds are usually available, and in recent years nursery techniques for a limited number of species have been standardised. However, much more research is needed in relation to seed handling and prolonging viability. Although some research has been carried out on tissue culture of rattans, cost-benefits seem to favour continued use of seeds despite tissue culture being a step forward in reducing unwanted heterogeneity in plantings and permitting more rapid genetic enhancement.

7. On sustainable management of the anthropogenic stands of bamboo and rattan, the lack of ecological research was highlighted. Strategic research is relevant to degradation and depletion of forest resources, restoration of specific ecosystems, standardisation of extractive economies and conservation of genetic resources.

8. Most management practices are traditional and have been applied locally. Very little enrichment planting has been attempted even when more exotic materials might be much more productive. For both bamboo and rattan almost nothing is known about population structures or how spatial heterogeneity affects population persistence. Closer linkages between research in this area and population genetic theory will help much-needed genetic enhancement.

REPORT

PROPAGATION AND SUPPLY OF PLANTING MATERIALS

9. Presentations concentrated on methods of propagation of bamboo rather than rattan since priority species of the latter are at present adequately propagated through seed. However,

discussions on integrating methods and considerations of better delivery systems included rattans. Specific Working Groups were established to consider recommendations for further strategic research as well as recommendations on other actions which would enhance production.

10. Mrs. A. Zamora (Philippines) provided an overview of micropropagation. This overview included literature reviews and summaries of recent developments (Appendix 4A).

11. For micropropagation, species and methods were summarised. So far, 20 genera and 73 species of bamboos have been researched under *in vitro*. Almost all the genera listed as INBAR priorities were mentioned. Tissue culture methods are still influenced by different responses of clonal tissues, different responses using juvenile or mature plants, or by collection at different seasons. Rooting responses are poor in certain species. It is clear that researchers in this area should concentrate their efforts to bring the existing protocols to the technology level. Recent research has also opened the possibility of creating artificial seeds in an important commercial species, *Dendrocalamus strictus*.

12. Tissue culture derived plantlets tend to be more convenient to transport than traditionally multiplied materials. In bamboo, there is also a tendency for plantlets from tissue culture to show early rhizome development in the nursery, an added advantage; and establishment and growth in the field is faster. In a limited number of species, tissue culture technology is being used for mass propagation. Dr. Dhawan (India) outlined technology currently used for *Bambusa tulda*, and *Dendrocalamus longispathus*. *Bambusa vulgaris* is also under study because although the two other species are available for mass propagation, this species can only be provided on a laboratory scale. She also highlighted the advantages and disadvantages of micropropagation of seed/seedling explants versus adult tissue explants. (Appendix 4B)

13. Miss Ramanakaye (Sri Lanka) outlined tissue culture

research in her country aimed at propagating *Bambusa vulgaris* and *Dendrocalamus giganteus*, the two major species, as also the potential for *Dendrocalamus asper* in view of demand for bamboo shoots by the tourist industry. She vividly pointed out that research in Sri Lanka, and elsewhere, should also be linked to:

- Introduction of good quality exotic species, and
- Rapid multiplication of superior genotypes.

14. Dr. R.L. Banik (Bangladesh) reviewed conventional propagation research in bamboo (Appendix 5). Six vegetative methods:

- Clump divisions
- Whole culm cuttings
- Layering
- Culm-segment cuttings
- Branch cuttings
- Macroproliferation

have been studied in different countries of Asia to develop propagation suitable for important local species. Additionally, propagation through seeds is widely used but there is often unpredictable availability of seeds; as a result, research on optimal methods of seed collecting and seed handling have been neglected.

15. No one conventional method of propagation is universal and effective for all species of bamboo. Each carries its own inherent risks, e.g. sexual propagation could result in death of stands by flowering before products are marketable and vegetative propagules result in a lesser productive period. Hence the development of appropriate strategies must be linked to a number of other considerations:

- Wider availability of materials. Germplasm collections and their representativeness are inadequate.
- More attention should be paid to flowering periodicities, since there is a degree of genetic control.

- Regional genepools need to be developed using a clear set of criteria.

These considerations are important to the development of the INBAR network.

16. With the current state of knowledge, it is possible to summarise research on various methods of vegetative propagation by informing scientists of the most appropriate method for each species. These should be linked to given conditions because they have to be cost-effective and reliable since rural farmers do not divorce technical matters from socio-economic implications.

17. The urgency for effective delivery of planting materials was highlighted by Dr. V.V. Srinivason (India) who stressed that the majority of natural stands of bamboo are overexploited and may show problems of re-establishment after flowering since fires and grazing prevent regeneration. In India, current demand for bamboo stocks are 90-120 million seedlings per annum but this is expected to increase to up to 300 million per annum. The key to success will be cost-effective, simple plant propagation techniques. These considerations are applicable to other countries. (Bamboo makes up 12.8% of India's forest areas).

18. Dr. I.V. Ramanuja Rao (India) focused his presentation on the need for a variety of delivery systems taking into account availability of suitable planting materials and the logistics of producing propagules in a centre and transporting them to planting sites (Appendix 6). Propagation has to produce large numbers in a short time, make these available on site and they must be of field plantable age. The three benchmarks for a successful method are cost-effectiveness, reliability and quality of materials, and delivery on time. Two types of propagation can be considered: mass propagation combining conventional and *in vitro* methods. Mass propagation tends to be slow although relatively inexpensive; rapid propagation is faster but more expensive. Decision-making options, therefore, have to weigh financial, social and environmental considerations as well as the time frame.

19. Although protocols for a limited number of high priority bamboos are at the stage where *in vitro* technology can be commercialised, this will not happen until an organisation like INBAR provides clear information. Past problems of unwillingness of scientists to share details of laboratory methods, lack of ready information on technical experts and almost total lack of research on social and environmental benefits and profits hamper the uptake of rapid propagation technologies by production agencies. Participants were asked to discuss how best INBAR could address these constraints - might be through a small expert group.

20. Dr. Rao also summarised the state of the art on tissue culture of rattan. This is not currently a viable alternative to propagation by seed when it is 100 per cent certain that seed can be obtained, and seed set is often very high. The constraint for rattan is seed storage. However, there is need for continued tissue culture research since it is often difficult to obtain viable research material, unless located near locally seeding material, and also tissue culture is a useful transfer system. For rattans, multiple shoots can be produced from the collar region of the seedling and somatic embryos can be produced; however the sub-culturing process cannot be continued for long and it is necessary to keep going back to seeds. Tissue culture of rattans will become more important as a tool in genetic enhancement.

21. Discussions on delivery systems identified the following as important:

i. Source of materials; quality and quantity of propagules.

ii. Systems should be linked to genetic enhancement, wherever possible.

iii. Systems and products have to have wide acceptability.

iv. Economic options need to be studied.

v. Systems and resultant wider planting have to be linked to conservation.

22. The following emerged during discussion as constraints:

- *Source of materials*
  - Seed collecting methods need upgrading since they lead to loss of viability.
  - Current lack of shared information by national programmes leads to poor knowledge of who holds what meterials.
  - Current lack of shared information on identification of quality planting meterial.
  - Current lack of predictability on availability of materials due to poor storage techniques.
  - Knowledge of appropriate propagation is scattered in the literature.
  - Information on mass/rapid propagation is not readily understood.
- *Links to genetic enhancement*
  - Genetic enhancement and ultimate cultivar development is not widespread.

- *Acceptability of materials*
  - There is some suspicion by foresters of tissue culture derived plantlets.
  - There is a lack of educational tools referring to the availability of appropriate technology information and gaps between scientific work and social/community involvement.
- *Economics*
  - Real costs of planting materials are not available. Forest institutes do not cost realistically (from collection to multiplication, mass propagation and delivery).
  - Employment potentials have not been considered as a result of delivery systems. No modelling on alternative delivery systems has been carried out.

- *Conservation*
  - Outside reserve areas, the involvement of communities in maintaining the resource base is limited.
  - Delivery systems can be geared to increasing and maintaining diversity but this is not currently widespread.

23. The Working Groups were asked to consider these wider aspects related to appropriate propagation and delivery; to identify action which includes strategic research and strategic action appropriate to the region and make such other recommendations as necessary. The following recommendations were adopted after discussion and modification by the whole consultation.

24. Recommendations on Bamboo Planting Materials

With reference to seed propagation

i. In view of the fact that most methods of collecting seeds are sub-optimal for maintenance of viability, it is recommended that a manual is produced on practicable and scientifically optimal methods and also on methods of storing seeds. The latter should be linked to distribution methods to ensure maximum viability, genetic integrity and representation of original population structure.

ii. Quarantine procedures should be made known more widely. (It was noted that INBAR is currently producing up-to-date reviews of pathogens and that IPGRI has offered to develop safe methods for movement of germplasm after the INBAR data are available).

iii. To aid the ready availability of materials, national collections/orchards should be promoted. These should fill a strategic role in storage and distribution.

iv. Seed testing methods for the individual species need to be refined and information gathered together in an INBAR manual. In the first instance, these should be concentrated on priority species.

v. Seed production areas, incidence of flowering and institutes from where seed can be obtained should be fully documented by national programmes, and data should form part of the INBAR Integrated Information System based in the two Information Centres in China and India.

With reference to conventional propagation

Various methods apply to different species. For priority species of INBAR, these should be summarised in a manual, possibly supplemented by audio-visual training kits, and wider training.

With reference to in vitro research

i. Although protocols are not available for all species, they exist for many of the priority species. Rather than continued support to basic research, INBAR is asked to act as a focus, making known the protocols and which institutes have expertise, especially when there are interests in commercialisation.

ii. INBAR should facilitate exchange of information by establishing a small group of experts to focus, in particular, on commercialisation, exchange of materials and for better awareness by the tissue culture community on applied needs for development.

iii. Some strategic research is needed on *in vitro* rooting of minor nodes of bamboos and on the methods of transference to soil.

With reference to all types of propagation

i. It is strongly recommended that a study of cost-benefits be carried out on the alternative methods of propagation (including comparisons across various agencies and localities).

ii. Since supply and demand data for planting materials are not widely available, it is recommended that such data are estimated and analysed (taking into account different user groups) in each country of the region.

With reference to genetic enhancement

i. Methods of selection and criteria for selection as well as identification of superior planting materials require focus. INBAR and IPGRI are asked to study how this can be done.

ii. Cataloguing superior (or plus) genotypes and "biotypes" should be vigorously pursued throughout the INBAR network.

iii. Collecting germplasm of diverse flowering genotypes of some species and pooling them in collections requires INBAR action so that material is readily available for selection, and also to provide continuous seed production stands in the proposed national seed collections.

iv. *In vitro* flowering offers possibilities for genetic improvement. INBAR should explore how strategic research could be implemented in this area.

25. Recommendations on Rattan Planting Materials

1. Planting materials for rattan must be increased due to an increasing demand for cane and to cause change from reliance on continued seed supplies collected from the forest. In this respect:

i. It is recommended that seed orchards are developed at the national level. In addition, a number of subregional orchards should be established to cover production areas and biodiversity in South, Southeast, East Asia and the Pacific.

ii. The preferred planting material should remain the seed, until selection has enhanced genotypes to the level that cloning is necessary.

iii. Seed orchards should be planned to have principle focus on locally available species but exotic material, as identified in the INBAR priority list, should be included.

iv. Exchange of materials should be in the form of seed, either treated or pregerminated in cotton. Further development of tissue culture methods for exchange should not be ruled out but, at present, appear not to be cost-effective.

v. Exchange of planting materials should be on a mutual basis, expecially for research purposes. INBAR is asked to identify institutes willing to provide exchange materials.

vi. It is recommended that strategic research is carried out on the germination process of the INBAR priority species. Knowledge on nursery techniques should be collated for priority species other than the main 3-6 commercial ones.

2. In the case of some priority species, more information is needed on vegetative mulitplication methods.

With reference to variation

i. Little information is available on patterns of genetic variation. More research is required to increase quality and quantity of production and also for application in genetic enhancement.

ii. This type of research should be carried out across genepools rather than on local segments. Both qualitative and quantitative markers are required and a database should be established in the INBAR Information System, including identification of superior genotypes.

TOWARDS SUSTAINABLE MANAGEMENT OF NATURAL STANDS

26. Presentations provided data, information and practices for a range of management interventions for stands of bamboo and rattan. These stands are collectively called "natural stands", representing spontaneous regeneration in a range of sites, including degraded forest areas. Maybe 95% of bamboo is produced in such areas and maybe 98% of rattan. Management for sustained yield of such ecosystems has been normal practice, and, despite research, has remained largely traditional.

27. Mr. A.K. Lakshmana (India) outlined normal management practices for clumping bamboos, including harvesting methods such as horse-shoe and inverted V cutting of clumps and a range of felling periods in relation to the age of the culms

(Appendix 7). Over-cutting and also irregular cutting tend to make the bamboo non-workable, and non-working causes additional congestion, one of the most serious problems in clump management. Irrigation and fertilisation both increase yield but the former showed increased mortality and the latter may not be cost-effective. Protection of regeneration after flowering includes protection from fire and grazing but major efforts are needed to strengthen cooperation with communities and NGOs to provide information, because in some areas protection from grazing is needed for a number of years.

28. Better production would result from the identification of silvi-ecological zones based on rainfall, temperature, soils and other parameters and the selection of the 5 best genotypes for each zone.

29. There is a need to transfer many stands into agroforestry and to adapt methods of social forestry much more for the management of natural stands.

30. Since too much clearing and thinning will motivate fires and poor utilisation results in sub-optimal management, there is a great need to understand the economics of management. This should provide a range of management interventions adapted to natural stand maintenance and also ecosystems conversion methods.

31. More attention needs to be given to management in fragile hill areas. Experience shows the use of fertilisers in such areas has often led to soil erosion. Also, clump management is difficult in many such areas because it is difficult to demarcate clumps.

32. Due to the high percentage of the production coming from natural stands, there is an overriding need to expand production from plantations where fertilisers and other practices can be applied more easily. Planning of land use, clear government agreements and mobilisation of funding are all needed. Failing these, natural stands can be managed better, but they alone cannot meet the supply/demand for bamboo. Much more attention is needed to the use of a wider array of germplasm, both native and exotic.

33. Prof. Fu Maoyi (China) outlined the silvicultural practices generally used on stands of non-clumping bamboo such as soil-loosening, harvesting culms in the appropriate seasons, clump cleansing machinery, and weeding and removal of dying-back culms (Appendix 8). A balance is sought between number of culms and quality of individual culms in terms of circumference, length and wall thickness. Fertiliser applications are beneficial. Many of the natural stands of bamboo in China are no longer truly natural regenerates since management has caused ecosystem conversion towards plantations. For *Phyllostachys*, areas in Japan are more akin to natural stands since they are maintained more as conservation ecosystems than for intensive use.

34. Dr. M. Watanabe (Japan) summarised ecological research on bamboos led by a number of Japanese scientists: Drs. Koichiro Ueda, Makoto Numata, Takashige Aoki and himself (Appendix 9). These include fundamental studies on dispersion structure within stands because understanding the patterns are essential for management. Plants may be dispersed in a random, aggregated or uniform distribution. Selective cutting should be related to stand density and average diameter of the stand. Current research in Japan is focused on industrial applications and some basic ecology and physiology are still researched; however, the interest in application to management of stands has decreased, and at the same time non-managed stands are not producing the quality material needed for industry.

35. Dr. Wan Razali (Malaysia) outlined a series of appropriate methodologies used on natural stand management of bamboos (Appendix 10). He suggested that due to demand exceeding supply, systematic management should be considered before resource depletion becomes critical. Inventory of areas is essential and traditional ground survey, taking into account species, quality and density classes, major forest types, clump characteristics and regeneration can usefully be combined with remote-sensing techniques and the use of aerial photographs. In combining the methods, sampling has to be modified to cover diverse land topographies.

36. For optimal management for harvesting, experimental work is needed using a split plot design and/or factorial experiments to take into account :

- Use of fertilisers
- Clump clearing to facilitate growth of new culms
- Regular thinning to sustain vigour
- Pre-planned felling schedules
- Mulching of clumps and mounding to promote culm production

37. Felling schedules are the most widely implemented aspect of management of bamboo stands. These are usually in cycles of (2-) 3-4 years depending on the conditions of the individual area and the species. However, supervision and strict accordance of felling rules are required.

38. Dr. Wan Razali further provided details of a successful ecosystem conversion in Malaysia where an uneven and relatively unstructured natural stand was managed to produce shoots and culms continuously throughout its productive growth period. This conversion utilised *Gigantochloa scortechini* (Figure 1). The degree of ecosystem conversion possible depends on natural stand structure as summarised by Dr. Watanabe and the degree to which conservation of natural stands is required. Such systems are also affected by methods to cope with pests and diseases. Early detection is important and practices vary. In Bangladesh and Malaysia, for instance, infected bamboos are removed and burned; in China there are control measures. The designation of preservation plots in natural stands of bamboo alone is insufficient for longer-term maintenance of biodiversity; however, this was a subject outside the objectives of this consultation.

39. Nonetheless, in terms of enhanced production in the Indo-Malayan area of Asia it is possible, according to Dr. Banik, to conceptualise three gross geographical growing zones (Figure 2). To add an element of conservation to sustain production,

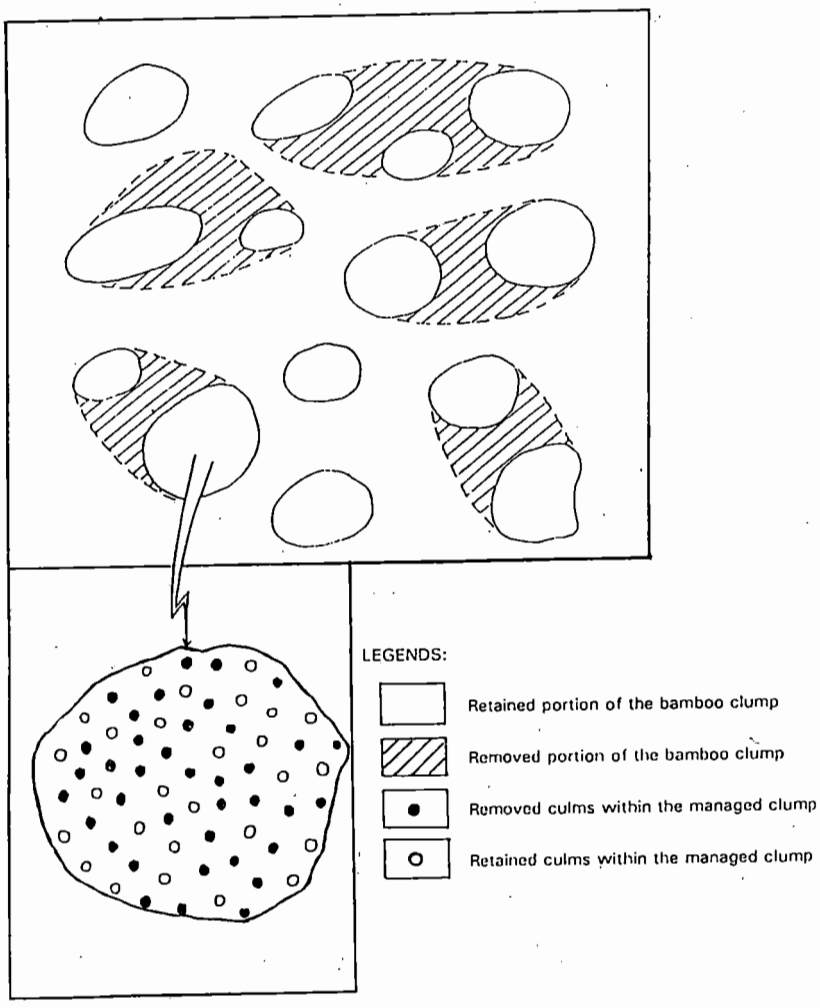

FIGURE 1. Methodology in the transformation of clumps of natural bamboo stands into managed bamboo stands.

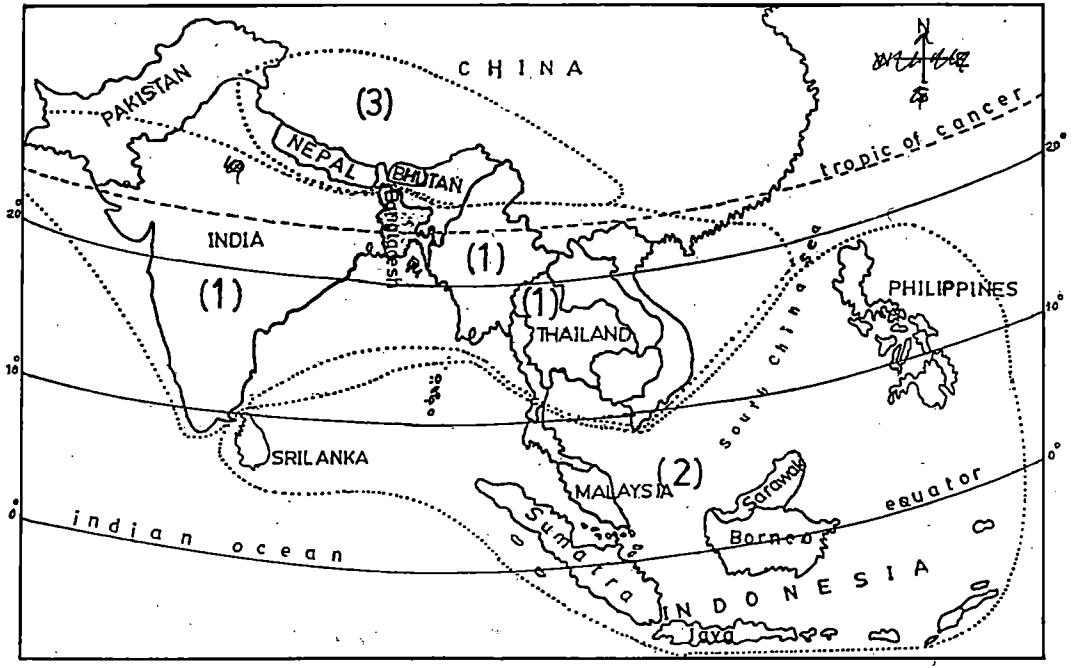

FIGURE 2. Bamboo growing zones in the Indo-Malayan region : (1) mainland (2) peninsular regions & islands, and (3) mountains.

sub-regional research and conservation centres can be proposed and these need detailed study.

40. For rattan, where there is a crisis in relation to world supply, research attention is focused on promotion of rattan cultivation. Since this is only a small percentage of the total production, promotion of the more sustainable management of natural stands is expected to assume a major role.

41. Ms. M. Stockdale (UK) pointed to the advantages of natural stands (Appendix 11).

i. they need relatively little initial investment,

ii. they are less vulnerable to attacks by pests and diseases,

iii. when combined with the managememt of other forest products they provide a flexible means of income generation,

iv. they may be more adapted to local social and cultural conditions, and

v. they provide substantial environmental benefits and can be used to protect a degree of biodiversity.

42. Research for sustainable management of natural stands of rattans includes :

i. inventory methods,

ii. modelling of sustainable yield,

iii. specific management practices,

iv. integration with other forest management practices, and

v. understanding the needs and capacities of local people.

43. *Inventory* : Rattan distribution may be in pockets, within which palms are random, or they may be more widely dispersed. Inventory provides information for management decisions but choosing the size, shape and number of sampling units depends on balancing three things: the effectiveness of the unit in representing the variance in the population, the ease of boundary definition, and the cost involved. There are a few examples of

stratification in rattan inventory, and stratification may variously be for altitude, forest type, level of protection and accessibility to people. Remote sensing is of very limited value and local enquiry followed by field visits is essential.

44. Sampling is still under study and a limited number of sizes and areas have been tested. Accuracy of results is constrained by identification problems, especially data on morphologies of immature plants.

45. *Modelling yield.* Estimates of sustainable yield have been made in Malaysia, Indonesia and the Philippines and methods suffer from the weakness that information is not yet available to determine whether the harvests calculated are sustainable in the long-term. This is a problem for all species at many ages and/or indeterminate ages. Growth modelling requires recurrent inventory using permanent sample plots. Some useful data are emerging from studies in Ghana, Thailand and Indonesia. Not only the lack of permanent study plots represents a constraint but it is confounded by a general lack of information on rattan demography, life history and ecology.

46. *Management practices.* Varied and sophisticated traditional practices have been recorded but they have not been tested in experimental conditions. The social and economic feasibility of the practices is important but little relevant study has been carried out in this area. Apart from specific harvesting and silvicultural methods, enrichment planting requires more study.

47. *Integration with other forest management.* More data are required on rattan abundance following shifting cultivation and selective logging although some data have been forthcoming in recent years.

48. *Involvement of local people.* The broad socio-economic background of rattan management has to be related to land tenure cycles, community social structure, processing, prices and tracking, and people have to be involved in developing appropriate management.

49. Discussion on sustainable management of natural stands of both bamboo and rattan focused on the principles for more sustainability in developing better practices. It was noted that foresters tend to be conservative in their work and tend to stress continued and enhanced production of target species, although, there is concern for protection of the genetic base. Notwithstanding this, the consultation placed great emphasis on the need for enhanced socio-economic research to be an integral part of the development of appropriate production systems. It was stressed that:

i management practices must be economically feasible, and

ii local people must be a prime focus in terms of products and benefits.

With regard to the latter, participants urged the broadening of the bamboo and rattan community to include suitable NGOs as an essential INBAR network development.

50. The presentations and subsequent discussions showed that sustainable management comprises a series of inter-related topics: inventory; ecology; management methods requiring research related to sustainable yield modelling and improvement of management; and integration of management with wider forest management and socio-economics. Working groups were established to discuss strategic research, and specific actions needed for bamboo and rattan and a summary of proposals is provided below.

51. Recommendations on Management of Bamboo Stands

In relation to resources

i. It was noted that baseline ecological studies in natural forests and managed stands are inadequate. In particular, research on nutrient cycling, adaptive tolerances and water relations need continued research. To promote such research, it was recommended that a study be carried out of the eco-silvicultural ranges and potentials

of priority species categorised by altitude, rainfall, temperature and soil and that known production be correlated.

ii. INBAR is asked to request national programmes to establish permanent sample plots in representative natural stands.

iii. There is a need to standardise inventory techniques.

iv. Since bamboo resources of many countries are in decline, it is important that bamboo research and development is duly recognised in national policies.

In relation to management

i. A detailed survey of traditional management systems should be carried out and, futhermore, analysis of the impact of diverse systems should be conducted.

ii. New management practices for optimisation of productivity should be developed.

iii. Enrichment planting should be promoted as a rapid way to increase productivity but insufficient data exist.

iv. Regeneration after gregarious flowering requires further study.

v. Cost-benefits of various management systems need to be determined in relation to the delivery of planting materials and the role of bamboo in rural economies.

In relation to information

The INBAR integrated information systems, to be based in the Information Centres in China and India, should pay due attention to making available databases related to the above areas of research.

52. Recommendations on Management of Rattan Stands

To support strategic research

i. It is recommended that national programmes identify

and promote long-term, secure study plots. These should be planned to cover different ecozones, distribution of INBAR priority species and regionally important species.

ii. To sustain a range of management systems, it is recommended that "hot spots" of species and genetic diversity be identified and conserved.

Strategic research is needed as follows

i. Ecological niches of priority species (relevant to each country in relation to ecological and anthropogenic factors) should be identified and characterised.

ii. Inventory techniques vary and researchers in this area work in isolation. It is recommended that,

   a. A workshop of specialists be held to share ideas and reach consensus on new techniques after evaluating current ones; and,

   b. Current taxonomic research should be applied, where possible, to generate appropriate field guides which would focus on seedlings, juvenile plants and easily accessible parts of mature plants. Vernacular names should not be used as a base. This recommendation does not negate the need for continued taxonomic work.

iii. Modelling of management practices and their testing should be pursued. Baseline socio-economic studies of existing traditional systems of management are prerequisites.

iv. Enrichment planting, where appropriate, should be implemented, and this should include indigenous and exotic germplasm. INBAR is asked to promote pilot studies to understand the ecological and socio-economic implications.

v. The past 5 years have seen major changes in the supply/

demand patterns for rattan in Southeast Asia. It is recommended that an updated analysis is made available as soon as possible as baseline information for researchers involved in enhanced production and sustainability issues.

In relation to sustainability and conservation

The concept of extractive reserves has been quoted as applicable to rattan conservation and sustainable management. It is recommended that an expert group develop social, cultural, biological and genetic parameters to be used in formulating guidelines to reserve establishment and longer term perpetuation.

OTHER TOPICS

53. Although not a primary topic of the consultation, genetic enhancement needs were stressed by Prof. Gunasena (Sri Lanka), Dr. Banik (Bangladesh), Dr. Subramanian (India) and Dr. Gurumurthi (India). For bamboo, the identification and documentation of plus types has to be vigorously pursued as have selection procedures. Great interest was expressed in evolving strategy for clonal development, including research and commercialisation.

54. Mr. Lakshmana (India), Prof. Gunasena (Sri Lanka) and Dr. Vongkaluang (Thailand) pointed to the need for more research on the nutritional and quality attributes of bamboo shoots as parameters for selection.

55. Dr. Banik (Bangladesh) and Dr. Subramanian (India) reiterated the need for orchards, including diverse genetic stocks of the same species of bamboo, to provide a constant supply of flowering forms for use in genetic enhancement.

56. The consultation was sensitive to the urgent needs for genetic conservation of genepools and looks forward to the proposed INBAR-IPGRI Working Group report. The representa-

tive for IPGRI, Prof. A.N. Rao, stressed the need for all national programmes to collaborate as action is developed.

57. The consultation noted that the mandate of INBAR includes poverty alleviation, networking synergies, small industries, capacity building and sustainable utilisation of resources. It was suggested that as the INBAR network expands, research will also need to focus more on applied research, social acceptability and economic feasibility.

58. The participants noted the value of including local people and indigenous knowledge in the planning of research and the potential benefits of suitable NGO linkages in this area.

APPENDIX 1

PARTICIPANTS

BANGLADESH

Dr. Ratan Lal Banik
Divisional Officer
Silvicultural Genetics Division
Forest Research Institute
P O Box 273, Chittagong.
Tel: 088-31-212102
Fax: 088-31-210901

CHINA

Prof. Fu Maoyi
Subtropical Forest Research Institute
Chinese Academy of Forestry
Fuyang, Zhejiang.
Tel: 86-5813-26804-3009
Fax: 86-5813-322719/324508

CIFOR

Dr. T. Boyle
Center For International Forestry Research (CIFOR)
Jalan Gunung Batu 5, Bogor 16001
Indonesia.
Tel: 62-251-343652
Fax: 62-251-326433

FORSPA/FAO

Mr. Anders Jensen
FAO Regional Office for Asia and the Pacific
Maliwan Mansion, 39 Phra Atit Road
Bangkok 10200 Thailand.
Tel: 662-2817844
Fax: 662-2804565

FORTIP/FAO

Dr. K. Vivekanandan
Chief Technical Advisor
Forest Tree Improvement Project
(FORTIP)
Ecosystems Research & Development Bureau
P.O. Box 157
College, Laguna 4031
Philippines.
Tel: 63-94-2809, 3628, 3481
Fax: 63-94-2809, 3628

IDRC

Dr. C.B. Sastry
Principal Program Officer
International Development Research Centre (IDRC)
17 Jor Bagh, New Delhi 110 003
India.
Tel: 91-11-4619411
Fax: 91-11-4622707

Mr. Paul Eastman
Consultant to IDRC
209 Chu-An Drive
Salt Spring Island
B.C., V8K 1H9, Canada.
Tel: 1-604-537-4301
Fax: 613-5632476 C/o T. Smutylo

IFAD

Mr. S. Mathur
Economist, Technical Advisory Division
International Fund for Agricultural Development (IFAD)
107 Via del Serafico
00142 Rome, Italy.
Tel: 39-6-54591
Fax: 39-6-5191702

INBAR

Mr. Paul Stinson
Manager, INBAR
International Development Research Centre (IDRC)
17 Jor Bagh, New Delhi 110 003
India.
Tel: 91-11-4619411
Fax: 91-11-4622707

Mr. Brian Belcher
Principal Economist, INBAR
International Development Research Centre (IDRC)
17 Jor Bagh, New Delhi 110 003
India.
Tel: 91-11-4619411
Fax: 91-11-4622707

Prof. J.T. Williams
Science Adviser, INBAR
1 Scott Circle NW #102
Washington, D.C. 20036, U.S.A.
Tel: 1-202-387-1573
Fax: 1-202-462-5419 for #102

INDIA

Dr. V. Dhawan
Tata Energy Research Institute
9 Jor Bagh, New Delhi 110 003. India.
Tel: 91-11-4617025 or 4621738
Fax: 91-11-4621770

Dr P M Ganapathy
Director
Indian Plywood Industries Research &
Training Institute (IPIRTI)
P.O. Box 2273, Tumkur Road
Bangalore 560 022., India.
Tel: 91-80-8394341/8384231
Fax: 91-80-8396361

Mr. A.C. Lakshmana
Special Secretary to Government
Department of Forests, Ecology and Environment
7th Floor, M.S. Building
Bangalore-560 001
India.
Tel. : 91-80-2264434

Mr. A.N. Moosvi
Principal Chief Conservator of Forests
Aranya Bhavan
Saifabad, Hyderabad 500 004.
India.
Tel: 91-40-235488
Fax: 91-40-237889

Dr. I.V. Ramanuja Rao
340, 8th Main
Mico Layout
BTM II Stage
Bangalore 560 076
India.
Tel: 91-80-846135
Fax: 91-80-646098

Dr. V.V. Srinivasan
Director
Institute of Wood Science & Technology
P.O. Malleswaram, Bangalore 560 003
India.
Tel: 91-80-3341731 or 3348611
Fax: 91-89-3340529

Dr K.N. Subramanian
Director
Institute of Forest Genetics & Tree Breeding
P.B. No. 1061, Coimbatore 641 002
India.
Tel: 91-422-41540, 42541
Fax: 91-422-40549

Dr. K. Gurumurti
Head, Division of Plant Biotechnology and Cytogenetics
Institute of Forest Genetics and Tree Breeding
Coimbatore 641 002
India.
Tel: 91-422-41540, 42541
Fax: 91-411-40549

Dr. D.N. Tewari
Director General
Indian Council of Forestry Research & Education
P O New Forest
Dehra Dun 248 006
India.
Tel: 91-135-27552; 27021-8
Fax: 91-135-23258

IPGRI

Prof. A.N. Rao
Consultant, International Plant Genetic
Resources Institute (IPGRI/IBPGR)
National University of Singapore
Lower Kent Ridge Road
Singapore.
Tel: 65-7722712/5
Fax: 65-7795671

JAPAN

Dr. Masatoshi Watanabe
97-2, Ichihara-cho Shizuichi
Sakyo-Ku, Kyoto 601-11
Tel: 81-75-741-2695
Fax: 81-75-741-1106

MALAYSIA

Dr. Wan Razali Wan Mohd.
Forest Research Institute Malaysia (FRIM)
Kepong, 52109 Kuala Lumpur
Tel: 6-03-6352534
Fax: 6-03-6367753

PHILIPPINES

Mrs. A.B. Zamora
Institute of Plant Breeding
College of Agriculture
University of Philippines at Los Banos
College, Laguna.
Fax: 63-94-3438

SRI LANKA

Prof. H.P.M. Gunasena
Dean, Faculty of Agriculture
University of Peradeniya
Peradeniya.
Tel: 94-8-88041/88239/88354
Fax: 94-8-32572/88041

Miss S.M.S.D. Ramanakaye
Institute of Fundamental Studies
Hantana Road, Kandy.
Tel: 94-8-32001/320020
Fax: 94-8-32131

THAILAND

Dr. Isara Vongkaluang
Faculty of Forestry
Kasetsart University
Bangkok 10903
Tel: 66-2-5614674
Fax: 66-2-5614761

UNITED KINGDOM

Mr. Peter G. Bezkorowajnyj
Centre for Arid Zone Studies
Thoday Building
University College of North Wales
Bangor, Gwynedd LL57 2 UW.
Tel: 44-248-382346
Fax: 44-248-364717

Ms. Mary Stockdale
Oxford Forestry Institute
Department of Plant Sciences
University of Oxford
South Parks Road
Oxford OX1 3RB.
Tel: 44-865-275113
Fax: 44-865-273113

APPENDIX 2

INBAR PRODUCTION RESEARCH CONSULTATION

9-13 May 1994, Bangalore, India

AGENDA

Monday 9 May

SESSION 1 : Opening Introductions 09:00 - 10:00

1. Welcome & Introduction of Guests
2. Addresses by Chief Guests
3. INBAR Networking - Paul Stinson
4. Reasons for this meeting and expected outputs - Dr. T. Williams

Tea 10:00 - 10:30

SESSION 2 : Propagation and Supply/ Demand of Planting Material

1. Review of micropropagation research - Mrs A. Zamora 10:30 - 11:15
2. Review of conventional propagation research - Dr. R.L. Banik 11:15 - 12:00
3. Supply & demand of planting materials - Dr. V.V. Srinivasan 12:00 - 12:45
4. Discussion 12:45 - 13:15

Lunch 13:15 - 14:30

5. Delivery systems : requirements and approaches 14:30 - 15:45 - Dr. I.V. Ramanuja Rao

Tea 15:45 - 16:00

6. Discussion 16:00 - 17:00

Tuesday 10 May

SESSION 2 - *Continued*

7. Discussion Group Meetings 09:00 - 10:30
8. Plenary Report of Discussion Groups 11:00 - 13:00

Lunch 13:00 - 14:00

SESSION 3 : Sustainable Management of Natural Stands

1. Review of past and current research on tropical bamboo stands - Mr. A.C. Lakshmana 14:00 - 14:45
2. Review of past and current research on temperate bamboo stands 14:45 - 15:00 - Prof. Fu Maoyi

Tea 15:00 - 15:15

SESSION 3 : Sustainable Management of Natural Stands

3. Appropriate methodologies in research on natural stands of bamboo 15:15 - 16:00 - Dr. Wan Razali
4. Discussion 16:00 - 17:30

Wednesday 11 May

Morning and early afternoon - field visits.

Other Invited Papers 16:00 - 18:30
Dr. Watanabe, Dr. Vongkaluang
Prof. Gunasena, Dr. Nasendi

Thursday 12 May

SESSION 3 : Sustainable Management of Natural Stands *(continued)*

5. Review of past and current research on rattan stands - Dr. Wan Razali 09:00 - 09:45

	6. Appropriate methodologies in research on rattan stands - Miss Mary Stockdale	09:45 - 10:30
	Tea	10 : 30 - 11:00
	7. Discussion	11:00 - 12:30
	Lunch	12:30 - 13:30
	8. Discussion Group Meetings	13:30 - 15:00
	9. Plenary Report of Discussion Groups	15:30 - 17:30
Friday 13 May	**SESSION 4 : Synergies with Other Organisations**	
	Presentations by observers IFAD, IPGRI, CIFOR, FORTIP, FORSPA and Dept. of Wastelands Development	09:00 - 10:30
	SESSION 5 : Strategic Research	
	1. Identifying and prioritizing research needs	11:00 - 13:00
	2. How to implement the strategic research	11:00 - 13:00
	Lunch	13:00 - 14:00
	SESSION 6 : Final Wrap-up	14:00 - 15:00

APPENDIX 3

SCIENTIFIC CONSIDERATIONS RELATING TO PLANTING MATERIALS AND MANAGEMENT OF STANDS

J.T. Williams

INTRODUCTION

This consultation will be reviewing a number of topics relevant to enhanced production of bamboo and rattan. These topics will also be relevant to ecologically sustainable development because critical aspects of research - and its applications - involve renewable natural resources; germplasm resources; forestry and silviculture; land, soil and water and even linkages to agriculture. All these critical aspects have to be taken into account in reviewing existing research and in shaping a new research agenda for the short-to-medium-term future and this does not make my task an easy one.

Although ecosystems modification or ecosystem conversion has over time resulted in short-term economic gains, these gains have often been obtained at the risk of long-lasting environmental damage. Even gains at the local level in terms of standards of living and income generation are poorly understood in terms of the exploitation of bamboo and rattan.

Since nations with limited capital are the ones which can least afford to underutilise the products and services stemming from natural ecosystems, strategies for sustained use of bamboo and rattan resources and enhanced production in plantations or on degraded lands or in secondary forests are clearly important. This being the case, it is essential that we are able to synthesise the results of appropriate research across a range of patterns of land utilisation. For resources such as bamboo and rattan, these range from extraction of forest products through regions of shifting

cultivation and subsistence agriculture to commercial plantations.

In assessing the research base it has become evident that two topics require attention and possibly re-focus, and these are the topics of this consultation, namely, 1.) enhancing the availability of planting materials and 2.) developing new protocols to sustainably manage natural stands. Either topic, or both, will be relevant to each pattern of land utilisation for the production of bamboo and/or rattan.

Having said the above, the whole question of the development of appropriate strategies is also complicated by the biologies of the two resources. Bamboo is a grass with almost unique periodicities of flowering (which might be an evolutionary strategy for predator-escape, Jantzen 1976) but there is some evidence that flowering can be controlled in part (Dajun and Shao-Jin 1987, Sharma 1994). Rattan is a palm with a morphology which is hardly user-friendly. How much easier it would be to discuss the topics of this consultation if we were referring to nearly all other plantation species or forest species where we can select for synchronised flowering cultivars, plant morphotypes amenable to intensive management through intensive mechanisation and cultivation and have prototype seed industries in place relatively quickly.

PLANTING MATERIALS

In the case of bamboo, the major constraint for raising fairly large-scale plantations is the limited availability of seeds as most of the bamboos produce seeds after long intervals. Research has followed three routes to remove this constraint.

1. Development of methods to store large quantities of seeds available during gregarious flowering. It has been shown that it is possible to prolong the seed viability to 27 to more than 40 months by manipulating seed moisture and storage temperature.

2. Development of vegetative propagation through rhizome offsets, culm cuttings and others such as rhizome cuttings or propagation by layers.

3. Development of tissue culture methods for mass propagation. For sympodial bamboos, propagation through macroproliferation of seedlings can yield high numbers of propagules (Adarsh Kumar, 1991, Adarsh Kumar, *et al.*, 1994). Also, some species are now being mass propagated through tissue culture (Rao *et al.*, 1990).

The questions which have to be posed now are: why has a widespread system not emerged for mass production of planting materials - by whatever methods; are there opportunities for wider commercialisation; and what constraints need to be addressed in an R & D context to quickly establish reliable delivery systems. Several points are pertinent:

1. For genetic enhancement of bamboo, we are hardly beyond simple selection procedures and not into breeding.
2. Due to the flowering behaviour, seeds when available are used but there is rarely targeting to populations of known patterns of adaptation and to clear production goals.
3. Systems now available can run into problems in that the last multiplication may start flowering due to a physiological maturity (Banik, 1987).
4. In satisfying the goal for productive plantations, little or no thought has been given to the problems inherent in using only one population source. Monocultures pose all sorts of problems and research must, as soon as possible, follow a population biology approach. Until adequate research is available polycultures might be advisable.

These research areas will also have practical application in how local people will view the development of bamboo plantations. We are all aware of the reputation a woody species can gain as being "antisocial", witness the controversies between local people, NGOs and forest departments in the 1980s regarding

Eucalyptus (Shiva *et al*, 1985). It would perhaps be wise during our discussions to leave the door open for collaboration with NGOs so that the complex constraints to narrowing the gap between demand and supply of bamboo are well understood since some trial and error is to be expected.

In the case of rattan, the constraints affecting supply of planting materials differ from those for bamboo. Rattans are usually propagated from seeds and recent commercial plantations have been established from seed. Shortages of seed, normally gathered from wild stands, were reported in the 1980s and there were a number of inter-related reasons (seasonal fluctuations, increasing scarcity of mature rattans in forest stands and logistics). (Yusoff, 1992). However, plantations have become seed orchards. Naturally, there may be constraints at specific local levels but as commercial plantations are planned and implemented, seed sources should not be a major constraint. It may be a constraint in many areas where rattans are not grown in plantations. Rattans, unlike bamboos, are not very amenable to vegetative propagation, but the seed scarcity in the 1980s did precipitate research on micropropagation through tissue culture and the methodology of the research laboratory could, with little effort, be applied to the field, but only for 4 species.

I believe that first, for rattans, a cost-benefit analysis would need to be done. Recently standardised nursery techniques for raising rattan seedlings and subsequent planting need to be fully costed and compared with a micropropagation delivery system in several areas.

Second, rattan seed sources are heterozygous and rarely, when gathered from the field, is the planting population the same. This results in a wide range of genotypes in the plantation. Advances in production will almost certainly come in major increments as selection proceeds and micropropagation of clones will be needed.

Third, rattan seeds cannot be kept as long as bamboo seeds. There are all kinds of problems associated with desiccation

sensitivity, poor germination, loss of viability during necessary quarantining and we are at a very primitive scientific stage of selecting seed sources and in handling the seed.

I have given a broad overview of the supply methods for propagules and outlined some of the problems. There are many apparent areas for refinement and for the development of strategic research. These may range from fairly low-key research towards developing prototype "seed" industries, to combining the research with, on the one hand, the socio-economic implications and, on the other, with the much needed genetic enhancement of planting stocks. The latter, for instance, for bamboo includes *in vitro* flowering; population studies in relation to structure and periodicity of flowering; and actual breeding. However, this is the topic for another consultation.

SUSTAINABLE MANAGEMENT OF NATURAL STANDS

From a biological point of view management of natural stands of bamboo and rattan is extremely interesting because it covers such a wide range of ecosystems. Whereas rattans are usually associated with primary forests and are deliberately planted in degraded forests or plantations of woody perennials, bamboos are more associated with anthropogenic forest vegetation. Of course, there are rattan species of less regional importance which are limited to somewhat narrow ecologies, e.g. some *Korthalsia* rattans in peat swamp forest (Dransfield 1992), but in general the rattans, at least, are found in the evergreen, semievergreen or moist deciduous forests. Several ecological aspects need further study:

1. The niches occupied by rattans within the forest. For instance, some are limited to deep ravines along water courses (Balagopalan and Sankar 1993). Others are associated with patch dynamics. We know nothing of population structure nor how spatial heterogeneity affects population persistence and stability. Any complex demography of substructured plant populations in patchy environments must be accompanied by a dy-

namic and spatially complex gentic structure (Levins 1968), and from the point of view of enhancing the resource, we must be able to link population ecology to population genetic theory (Rice and Jain 1985).

2. Probably a more critical area requiring investigation is the edaphic tolerances and relations over time of species of bamboo and rattan and the relationship between soil and ecosystem structure (Rao, 1994). Although bamboos tend to be tolerant of a wide range of soils, in natural stands the nutrient balances between component species, and their competition, has not been well researched. We have more information on fertiliser responses of both bamboo and rattan in artificial environments. Also, nutrient relations must be correlated with water availability and cycling and the natural distribution of bamboo and rattan species does relate to specific rainfall patterns. There is also some data on nutrient cycling by bamboos in colonising situations (Rao and Ramakrishnan, 1990).

3. Bamboos tend to show an aggressive weedy tendency in common with many other cultivated plants of the ecotones and disturbed areas such as oil palm, guava, papaya and cashew, to mention only a few (Smith *et al*, 1992). As such, many groves can represent unstable successional stages. Do we need information on how to manage successional stages or should many such old groves with constraints to their management be abandoned for the sake of artificially grown plantations?

4. In order to understand the natural resources, research is needed into the structure and predictability of natural mixed species plant communities. However, this should go hand in hand with targeted exploration and introduction maybe with new approaches to plantation design and reduction in maintenance costs and risk without detriment to production (Ashton and Bawa 1990).

Let us look at research another way. Management of natural stands for specific commodities must be strategic and involve four interrelated issues:

- Degradation and depletion of forest resources
- Restoration of specific ecosystems
- Stabilisation of extractive economies
- Conservation of genetic resources

Currently, most rattan is collected from the wild and there is clearly over-exploitation of the natural supply, since supply and demand are out of equilibrium; for bamboos, resources are similarly harvested in a non-sustainable manner. Total stoppage of collection and use for the sake of conservation would deprive rural artisans and craftsmen of income. A number of forest departments have introduced cutting rules for trees so that resources remain healthy and productive. There are a number of policy decisions with regard to overall management of the resource, at the for instance, State level in India and practical management at the forest division level. However, bamboo and rattan are, in practice, in Asia, rarely fully inventoried so parameters for management vary tremendously (see for instance, Nandakumar and Menon 1993, Kumar, 1990) and there have been recommendations for such management (see for instance, de Zoysa *et al.* 1990 for Sri Lanka, Tesora and Espiloy 1990 for the Philippines, Prasad 1990 for the Himalayas).

Policies and practices tend to apply to what resource already exists in the ecosystem rather than addressing what should be more optimal; what is effective population size; and how can phenotypically diverse assemblages be maintained in the population as a safeguard against negative genetic drift.

No strategies have been developed for alternative income generation if extraction is replaced by plantation cultivation. What management practices do exist relate to extraction of resources so that some remain available rather than for overall ecological management.

Nor do data exist on the economic implications of sustainable management of stocks of specific resources. Most of the interest and development efforts have focused on large-scale industrial

forestry until shifts in policy by international organisations in the mid-1970s led to inclusion of rural development. The past 15 years have seen government forest policies including incrementally recreation, nature conservation, landscape conservation and changing relationships between agencies and divisions - so that increasingly complex policy becomes less of a clear blueprint than vague references to multiuse without clarity through guidelines (Mather 1990). Although our discussions here are not geared to policy development, any consensus on management guidelines will be of great value to national authorities in this respect.

I would not wish to pre-empt any of the discussions; however, there are two final points I would raise:

1. In looking at management of stands which have been overexploited, almost certainly the population of the target resource will have gone through a genetic bottleneck and planting enrichment might well be better from a range of populations rather than the immediate local one.

2. For rattans at least, the design, management and operation of extractive resources has been prepared. A clear recommendation was made on this in 1991 (IFAR 1991) in the review of research on bamboo and rattan. Siebert (1993) supports this and points out that in some countries there is little reason to be optimistic about sustainable harvesting of rattan whether in extractive reserves or elsewhere. Other authors have criticised the whole concept of extractive reserves (Browder 1992). In my opinion, we do lack considered expert consensus on the framework of key ecological, socio-economic and political parameters for extractive reserve design. If we had, these, rattan would be an obvious candidate. For several years, I have tried to include an additional key category for consideration: genetic perpetuity over time of the resources in the reserve. Classical population genetics show that disruptive selection in spatially variable environments can maintain genetic variation (Via and Lande 1987). Current reserve design for a genetic resource usually opts

for fairly homogenous ecosystems and environments but we need to reconsider this urgently. Maybe this consultation will lead to better focus in this area.

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APPENDIX 4A

REVIEW OF MICROPROPAGATION RESEARCH ON BAMBOOS

Alfinetta B. Samora

INTRODUCTION

Supply of planting material remains critical in establishing bamboo plantations and groves from which culms may be taken to support bamboo-based industries. Bamboo forests have been generated from seed with subsequent asexual multiplication by rhizome. Asexual methods of multiplication have permitted planting of elite bamboos. Various asexual techniques of propagation, e.g. culm cuttings, prerooted branch cuttings and divisions have recently been augmented by the development of tissue culture propagation for some species. The development of this method of asexual propagation was a recommendation of a workshop on bamboo held in Singapore in 1980 (Varmah and Bahadur, 1980: Bumarlong and Tamolang, 1980). Aside from propagation, tissue cultures were anticipated to facilitate exchange of germplasm and subsequent establishment of collections.

Tissue culture has several advantages over traditional methods of propagation. These include greater numbers of propagants from a limited stock source *in vitro* and the compact size of propagules. Furthermore, tissue culture also permits the use of different plant parts which are not traditionally utilised.

TISSUE CULTURE TECHNIQUES

Tissue culture is a generic term encompassing several *in vitro* aseptic culture techniques that enable parts of a plant to be cultivated artificially on nutrient medium. The media are formu-

lated to permit diverse growth patterns including cell multiplication, organ formation and plant regeneration.

For bamboo, the first tissue culture study was conducted by Alexander and Rao (1968) who germinated embryos *in vitro*. Research (and successes) increased in the 1980s after the work of Mehta *et al.* (1982) on the production of plantlets of *Bambusa arundinacea* (*B. bambos*) through somatic embryogenesis. Subsequently, more studies became available for some species (Tables 1 & 2).

Seeds and seedling tissues as well as tissues from mature bamboo clumps were used as explants. In many research papers, the difficulty of obtaining seed is emphasised but despite this problem, many reports dealt with procedures based on seeds and seedling tissues. Perhaps this was due to the relative ease of culturability of juvenile material. Also, seeds are hardier in the stressful initial step to culture introduction, i.e. disinfection.

Procedures based on seeds and seedling tissues have the advantage of greater numbers of genotypes in culture from which propagation may proceed, thus ensuring greater diversity for the species while procedures based on tissues from mature clumps make possible the propagation of good-performing bamboo lines. The capacity for shoot multiplication among seeds of *Dendrocalamus strictus* (Mascarenhas *et al.* 1988) and growth rates for seed-derived *B. tulda* (Saxena, 1990) were considerably variable.

Plantlets were obtained either through *in vitro* germination, somatic embryogenesis, adventitive shoot formation through callus culture systems, micropropagation, germination of precociously induced rhizomes and artificial seeds. Of these routes to plant formation, the micropropagation technique using nodal explants appear to have worked in more species. However, somatic embryogenesis has been demonstrated to be highly efficient for generating plants.

Routes to plant regeneration using seed and seedling tissues

In vitro germination

In vitro germination offers some advantages over seedling germination *in situ* and can be coupled to other micropropagation techniques (Figure 1). Vasana *et al.* (1985) noted that germination was higher *in vitro* compared to the conventional method in four bamboo species.

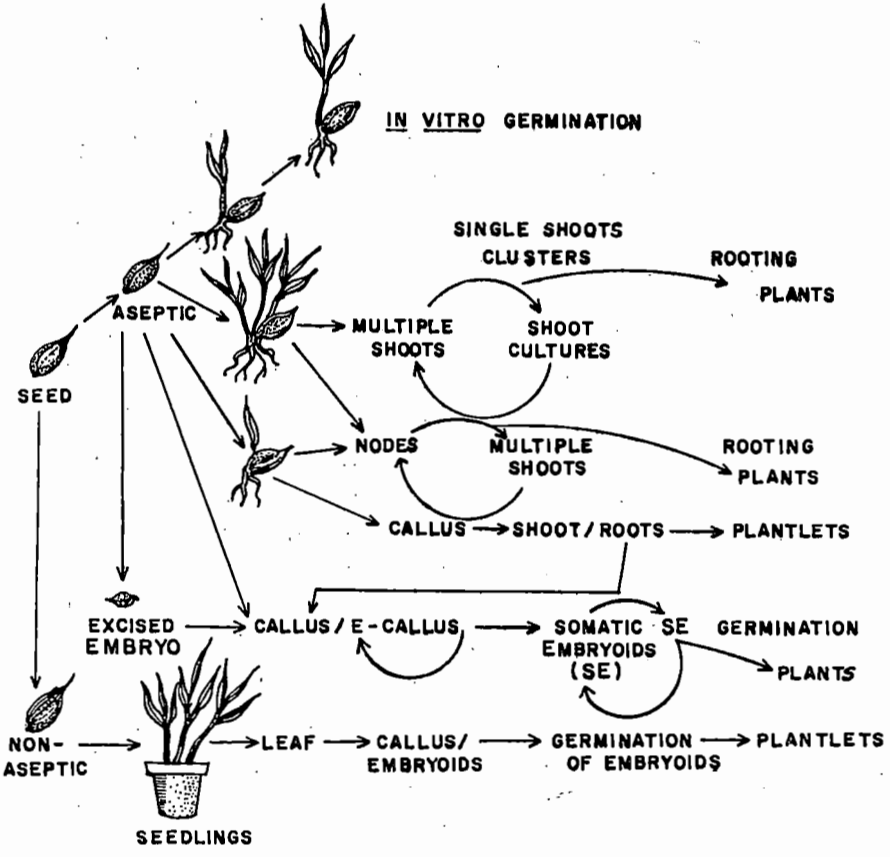

Figure 1. Routes to plant regeneration using seed and seedling tissues for tissue culture propagation.

Furthermore, the *in vitro* germinated seedlings provided aseptic explants for other propagation systems such as micropropagation, adventitive shoot formation and somatic embryogenesis for *B. arundinacea* (Mehta *et al.* 1982; Vasana, 1985; Vasana *et al.* 1985; Jerath, 1986), *B. tulda* (Saxena, 1990), *D. brandisii* (Vongvijitra, 1988), *D. membranaceus* (Vongvijitra, 1988), *D. hamiltonii* (Chambers *et al.* 1991), *D. strictus* (Mascarenthas *et al.* 1988) and *Otatea acuminata* (Woods *et al.* 1992).

Micropropagation

Micropropagation refers to techniques that make use of parts of a plant with pre-existing buds as explants. These pre-existing buds are induced to proliferate; subsequent propagation is by separation and proliferation. Resulting shoots are rooted to obtain plantlets for potting out.

In several species, explants were taken from aseptic seedling cultures or from young plants *in situ* (Nadgir *et al.* 1984; Vasana *et al.* 1985; Mascarenhas *et al.* 1988; Vongvijitra, 1988; Dekkers and Rao, 1989; Rao *et al.* 1992). The former is advantageous because the explants need not undergo disinfection.

Seeds were germinated aseptically on a medium supplemented with growth hormones to induce multiple shoots from the zygotic embryo. Such a strategy of germinating seeds on culture medium for multiple shooting increased propagation at the first stage of culture. Further multiplication was carried out by node culture (Vongvijitra, 1988) or by separation of single shoots (Nadgir *et al.* 1984) or shoot clusters (Mascarenhas *et al.* 1988).

Multiple shoot formation in seed and seedling tissues was induced with cytokinin (Vongvijitra, 1988) or with a combination of cytokinin and auxin (Vasana *et al.* 1985). Species may differ in their tissue culture requirements for multiple shoot formation and sustained shoot growth; *D. membranaceus* required 2×10^{-5} M BAP while *D. brandisii* required lower concentrations of the cytokinin for both stages (Vongvijitra, 1988).

Similarly, the culture media with respect to growth regulators for rooting also appear to be species-specific. Vongvijitra (1988) found that *D. brandisii* shoots could be rooted on plain culture medium or in the presence of low concentrations of BAP while *D. membranaceus* required NAA. BAP was inhibitory to rooting in *D. membranaceus*. Liquid culture was better than solid culture for *D. strictus* (Mascarenhas *et al.* 1988).

At times even for the same species, recommendations from laboratories differ. Vasana *et al.* (1985) reported that *B. arundinacea* required both auxin and cytokinin (i.e. NAA and 6-BAP) for multiple shooting in germinating seeds while Jerath (1986) obtained multiple shoots in 58.7% of the seed cultures of *B. arundinacea* on a medium with cytokinin only. These differences may be due to seed stocks used, i.e. physiological state of embryos. Procedural differences were also noted. Mascarenhas *et al.* (1988) recommended separation of shoot clusters while Nadgir *et al.* (1984) were able to use single shoots for subculture for *D. strictus*.

Micropropagation through multiple shoot formation has been investigated in several species of bamboo and proliferation rates vary with species and laboratories. For *D. strictus*, Nadgir and co-workers (1984) estimated that 10,000 plants could be obtained from a seedling in one year. Based on their results, 6-7 shoots were induced from single shoots that were cultured in shaken liquid medium. Subculture was done at intervals of 6-7 weeks apart for 15 subcultures within a year. In *D. membranaceus*, the germinated seed yielded 3-5 multiple shoots within three weeks and by subsequent node culture from the multiple shoots, produced about 25-30 shoots in 3-4 months (Vongvijitra, 1988).

Somatic embryogenesis

Somatic embryogenesis refers to the initiation and development of embryoids from somatic cells. In terms of structures, the somatic embryoids are similiar to the zygotic embryoids, both bear shoot and root axes and can be germinated to yield plants.

Rao and Rao (1988) emphasised several advantages with somatic embryogenesis. First, the embryoids have both preformed shoot and root poles and thus do not require a rooting stage as with multiple shoots. Second, multiplication is very rapid and over a hundred embryos may be observed per culture compared to only a few shoots from nodes and shoot cultures. Third, maintenance is less labour intensive than shoot cultures. Handling of somatic embryoids is easier than handling of shoot cultures during subcultures. Fourth, it is anticipated that the life span of plants derived by somatic embryogenesis would be similar to those derived from seeds. Furthermore, Rao and Rao noted that the bulk of propagules from somatic embryogenesis did not arise from callus; the callus phase was confined at the initial stages of culture and subsequent multiplications of embryoids were by secondary embryogenesis, i.e. embryoids developed from the scutellar region of primary embryoids.

Using seed and seedling tissues, somatic embryogenesis has been obtained in several bamboos including *D. strictus* (Rao *et al.* 1985, 1987, 1989, 1990; Dekkers and Rao, 1989; Samora and Gruezo, 1990); *Phyllostachys viridis* (El Hassan and Debergh, 1987); *Schizostachyum lumampao* (Samora and Gruezo, 1991) and also *Sinocalamus latiflora* (Yeh and Chang, 1987).

Somatic embryoids were obtained from compact or embryogenic calli that arose from vascular bundles in aseptically germinated seeds (Rao *et al.* 1988), from excised mature embryos (Mascarenhas *et al.* 1988; Rao *et al.* 1988; Samora and Gruezo, 1990), from callus obtained from *in vitro* derived root tissues (Yeh and Chang, 1986) and from leaf tissues of *in situ* grown seedlings (El Hassan and Debergh, 1987). El Hassan and Debergh (1987) noted that season did not affect the establishment of embryogenic calli from leaf tissues of greenhouse-grown *P. viridis* seedlings.

The primary embryoids were further propagated by secondary somatic embryogenesis arising for the scutellar tissues of the primary embryoids. El Hassan and Debergh (1987) approximated that there were about 10,000 somatic embryos per gram

leaf-derived callus of *P. viridis* and that increase was seven-fold for each culture. With subcultures every 4-5 week intervals, cultures remained embryogenic even for more than a year. Callus of *Otatea acuminata* remained embryogenic even for two years (Woods *et al.* 1992).

About 14,000 plants were propagated by these techniques from explanted embryos on a B5 medium supplemented with 2,4-D (Rao *et al.* 1988). About 60% of callus cultures from mature embryos exhibited E-callus which yielded somatic embryoids; a 30-day-old culture had 14.6 embryoids. The somatic embryoids were germinated in media with low 2,4-D or in plain media. Other procedures also yield well; subcultures were made every fortnight (Samora and Gruezo, 1990).

Adventive plant formation

Callus was induced from seedling tissues: shoots and roots arose adventitively from the callus of *B. arundinacea* (Vasana *et al.* 1985), *B. oldhamii* and *Thyrsostachys siamensis* (Huang *et al.* 1989).

Routes to plant regeneration using explants from mature plants

Protocols for cultures initiated from mature plants are also available in the literature. The routes to plant regeneration were by micropropagation using nodes and culm buds, adventitive plant formation from shoot apices of lateral shoots, internode tissues and inflorescences (Figure 2), somatic embryogenesis was recorded for only one study but anther tissue were used; plantlets were haploid (Tsay *et al.* 1990).

Micropropagation

Rao and Rao (1988) noted the large numbers of dormant axillary buds on culms which could be utilised for micropropagation. Recently, Prutpongse and Gavinlertvatana (1992) demonstrated that it is possible to use a single formulation for multiple shoot formation and rooting for nodal explants of

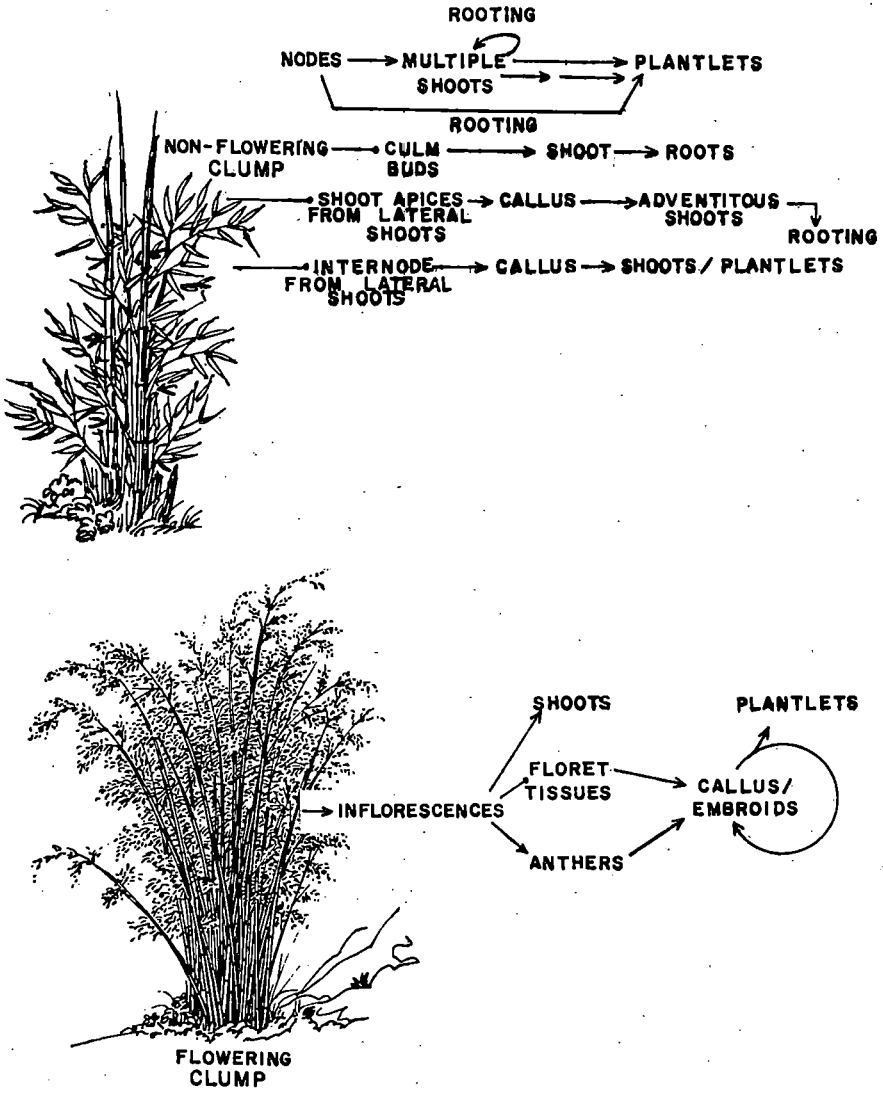

Figure 2. Routes to plant regeneration using tissues from mature flowering and non-flowering clumps of bamboo for tissue culture propagation

non-flowering bamboos belonging to 54 species of 16 genera. The procedure is encouraging, species-specific responses may also be anticipated. Thirteen species were not micropropagated with the procedures workable for the 54 species. Based on evaluation of genera with at least three (3) representative species, culturability was not associated with particular genera.

Aside from the work of Prutpongse and Gavinlertvatana (1992), bud breaking and sprouting of axillary buds have been amply demonstrated in many bamboo species, but rooting was the main constraint. For *B. vulgaris* and *D. strictus*, only about 4-10% of the nodal shoots were rooted (Roohi, 1989 in Rao *et al.* 1992). Growth regulators and activated charcoal were found necessary by Nadgir *et al.* (1984) for nodes from mature plants. Chaturvedi and co-workers (1993) reported that rooting was influenced by polarity; only the nodes which were inoculated in an inverted position rooted.

Aside from the influence of genera/species, the age of the node influences micropropagation. Mascarenhas *et al.* (1988) concluded in their work on *D. strictus* that the medium effective for node culture in seedlings is ineffective for node culture in mature plants. Multiple shoots were more easily induced in seedlings than mature plants (Chaturvedi *et al.* 1993); shoots of seedlings were more easily rooted than shoots from older plants (Rao and Rao, 1988).

The season when nodes were taken from the culms influenced rooting. Chaturvedi and co-workers noted that explants taken in July-August showed better rooting response with about 30% of shoots induced to root than in September-October when less than 5% rooting was obtained. They theorised that differences in the metabolic status of donor plants have a carry-over effect in the excised explant cultured *in vitro*. The more favourable months coincided with vigorous growth *in situ*, i.e. period of bud break in culms of the donor.

Adventitive shoot formation

Adventitive shoot formation refers to regeneration of plantlets from callus cultures induced from tissues without pre-

existing buds. In bamboo, callus cultures have been initiated from somatic tissues such as leaves, inflorescences, internodes and shoot apices. Adventitive shoot formation was obtained in *B. oldhamii, B. multiplex, Phyllostachys aurea* and *Sasa pygmaea* from callus cultures that arose from shoot apices (Huang *et al.* 1989) and in *D. latiflorus* (Samora *et al.* 1989).

Although studies have been reported for several other bamboo species (Prutpongse and Gavinlertvatana, 1992, Dekkers and Rao, 1989), only calli were obtained. Browning of calli was one of the major problems during establishment and multiplication.

Callus cultures which did not regenerate shoots were established on medium supplemented with 2,4-D only (Huang and Murashige, 1983; Dekkers and Rao, 1987, Prutpongse and Gavinlertvatana, 1992; Aala, 1992) with the exception of callus of *B. flexuosa* derived from leaf explants and of *D. asper* derived from inflorescence explants (Prutpongse and Gavinlertvatana, 1992). In 1989, Huang and co-workers reported that calli of *B. oldhamii, P. aurea, S. pygmaea* and *B. multiplex,* which were established on 2,4-D, proved to be non-organogenic while when produced in BA and NAA-supplemented medium, calli were capable of organogenesis. Our work on *D. latiflorus* demonstrated that shoots could be formed from callus induced on medium with 2,4-D and BA, albeit infrequently (Samora *et al.* 1988). Huang found that shoot formation was obtained only if the culture explants had the epidermis. Similarly, we have also found regenerative callus induced from explants with epidermis taken from the lateral branches and ground corms of *D. latiflorus* (unpub. data).

OTHER ADVANCES IN TISSUE CULTURE RELATED TO PROPAGATION

Artificial seeds

Seeds are advantageous over potted plants in terms of transport for outplanting. However, because of relative infrequency

of flowering and seeding in bamboos, this approach to plant establishment is limited. Artificial seed may overcome problems of quantity and availability. Given that somatic embryogenesis may be developed for bamboo species, this approach could be promising.

Tissue culture techniques for somatic embryogenesis in *D. strictus* were applied to create artificial seeds (Mukunthakumar and Mathur, 1992). The somatic embryoids were encapsulated in a matrix containing 6% sodium alginate, 100mM $CaCl_2$ $2H_20$, 1 mg/l NAA and 0.5 mg/l kinetin and were demonstrated to germinate in plain agar (95%) and in soil (56%).

In vitro flowering

In vitro flowers were induced from multiple shoot cultures in *D. hamiltonnii* (Chambers *et al.* 1991), *B. arundinacea* and *D. brandisi* (Nadgauda *et al.* 1990) on culture media with cytokinins and coconut water. Aside from possible use in intergeneric or interspecific hybridisation, *in vitro* flowering is useful to recover seeds of bamboo which in turn may be used for propagation.

POTTING OUT AND FIELD OUTPLANTING

The success of any tissue culture-based propagation technique hinges on its effectiveness to generate plantlets at a rate suitable to meet the demand for planting material and the survival of potted out plantlets after transfer from the culture vessels to soil.

For *D. strictus*, survival of plantlets derived from somatic embryogenesis from culture to pot in the greenhouse was 78% while survival in a growth chamber was 90-95% (Rao *et al.* 1988). When precocious rhizome is present on the plantlets, transplant survival was 100%. Survival and growth in the nursery was influenced by root system of the plantlets and the potting mix (Samora *et al.* 1992). Potting mixes with soil:compost favoured earlier development of the rhizome.

Tissue culture-derived plantlets are more convenient to transport than traditionally multiplied bamboo. Also, plantlets may be field planted earlier due to early rhizome development in the nursery (Samora *et al.* 1992). Survival of four-month-old plantlets was 100%. In the forest or degraded mountain slopes, outplanting of older plants (i.e. bigger plants) would ensure an advantage over possible competing grasses.

Plants from tissue culture established faster than seed-derived plants, an advantage for reforestation and plantations. Sixteen months after field planting, there were 4 stems for tissue culture-derived plants compared to 1 stem for seed-derived plants (Rao and Rao, 1988).

ASSESSMENT OF TISSUE CULTURE TECHNIQUES FOR APPLICATION TO PROPAGATION

Technical feasibility

Somatic embryogenesis is sufficiently developed in *D. strictus* to warrant application to propagation. However, widespread application is limited by amount of information on various bamboo species and availability of seeds or explant source to initiate culture systems.

Species

For species such as *D. strictus*, propagation techniques have been confirmed by repeated application of the procedures for many seed batches. Somatic embryogenesis permits a turnover of tens of thousands of plants from one selected embryogenic callus line within a year of operation. Furthermore, these somatic embryoids in *D. strictus* were used to demonstrate that artificial seeds of bamboo could be made (Mukunthakumar and Mathur, 1992).

For other species where propagation has been reported, the application of such techniques will be dependent on developing

procedures to a state of routineness for application. The work of Prutpongse and Gavinlertvatana (1992) points to the possibility of a single procotol that is workable for a wide range of species and genera of bamboo. However, reports of a system which was found workable for one species may not be workable for another species and work on the same species in one laboratory may not be workable in another laboratory. This may be due to the influence of the explant donor on the successful initiation of culture, (Chaturvedi *et al.* 1993). Clones of *D. asper* exhibited culturabilities (Prutpongse and Gavinlertvatana, 1992).

Seed availability and storage

Bamboo seeds may be collected for field planting but this is limited by the flowering habits of different bamboo species. Seeds may be plentiful when gregarious flowering occurs. Seed-based propagation has an advantage in developing new bamboo forests.

Seeds, whenever available, can be extended by the use of various tissue culture techniques to increase the number of plants which can be obtained from one seed. However, knowledge on systems of seed storage is necessary to permit the timely introduction of new genotypes. Proper storage permits longer availability of seeds for culture: *Thyrsostachys siamensis* loses viability within 21 months when stored at 25-30°C but retains high viability (>90%) even after storage for 27 months when stored at 2-4 or -5°C (Ramyarangsi, 1988). Other species lose viability faster than *Thyrsostachys* (Saxena, 1990). For *B. tulda*, seeds remain viable up to 30-35 days at room temperature but seeds stored at 0°C for four months showed 50-60% germination.

Factors affecting propagation

Somaclonal variation

El Hassan and Debergh (1987) did not observe any aberrant plants among more than a thousand plants potted out in the greenhouse and field. Furthermore, Nadgir *et al.* (1984) also did

not observe any abnormalities at 15 months. However, somaclonal variation is likely to occur when propagation is carried out by tissue culture techniques.

A plagiotropic mutant of *Bambusa arundinacea* was obtained by Rao and Rao (1988). In our laboratory, we observed variegation and albinism in embryogenic callus and plantlets when cultures were older than a year. It is possible that variations (non-visual) could have been generated within the first year of propagation on the 2,4-D supplemented culture medium.

It will be important to know when variation occurs or when its incidence increases. Tests and parameters to detect such variations have hardly been studied.

In vitro flowering

In vitro flowering is detrimental to a propagation system generating plantlets of multiple shoots. Plantlets of *D. strictus* which flowered *in vitro* did not survive upon potting out unlike non-flowering plantlets (unpub. data). This phenomenon leads to a reduction of suitable explants for further shoot multiplication.

Anticipated issues *vis-a-vis* tissue culture propagation

Forest renewal is basically a problem of discipline among users. Bamboo forests as well as other natural resources have become depleted because of lack of proper management. The problem of rapid bamboo reforestation could technically be addressed by augmenting other procedures of multiplication with tissue culture. However, the application of any technology on a large scale should be carefully evaluated. For tissue culture application, the major issue is its effect on biodiversity.

Loss or lack of biodiversity in bamboo plantations and forests is likely to occur because of the intrinsic nature of the methodologies available for rapid asexual multiplication. Differences in the rates of *in vitro* multiplication (Prutpongse and Gavinlertvatana, 1992; Mascarenhas *et al.* 1988; Saxena, 1990) could lead to greater multiplication of the clones which are more responsive.

Multiple shoot formation from germinated seeds or from nodes of nonflowering bamboo clumps are obviously asexual propagants of particular genotypes. Somatic embryogenesis from any material, whether seed, inflorescence, immature embryo, mature embryo, seedling leaf sheath or seedling root, that lead to production of plants by germination of embryoids are asexual propagants of that particular genotype.

The scale of multiplication possible for either technique and the problems encountered by a technician in introducing fresh material *in vitro* are additional pressures to limit propagation to very few genotypes within the species. Problems at the laboratory including collection of fresh material, losses due to contamination and lower multiplication rates of multiple shoot micropropagation at the initial phases which all affect profitability.

The problem of possible homogeneity in the field may be reduced by management strategies such as monitoring of plant stocks with respect to seed source and intentionally spreading plantlets from different seed sources during distribution. Another issue is the need for support technology on virus indexing to avoid propagating from infected sources.

SUMMARY

A review of the literature on bamboo shows that tissue culture work has been carried out on 20 genera, 73 species and four cultivars. However, the majority of the species need further research to develop routine protocols of propagation. For a few species, e.g. *D. strictus*, tissue culture protocols have been sufficiently developed for commercial application, reflecting the amount of research undertaken. Large-scale application of the technologies should be implemented with specific strategies to safeguard biodiversity of the bamboo in the forest.

Research on seed storage as well as induced flowering *in situ* and *in vitro* could improve the technological know-how.

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Table 1. *Tissue culture requirements for species of bamboo*

General/ Species	Stage Explant	Results Media	Culture Requirements Environment		Authors, Year
Arundinarea					
A. auriculata	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
A. auriculata	1 leaf	callusing	MS + 13.5 - 27.0 uM 2, 4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
A. pusila	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
A. pusila	1 leaf	callusing	MS + 13.5 - 27.0 uM, 2, 4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
A. superecta	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
A. superecta	1 leaf	callusing	MS + 13.5 - 27.0 uM 2, 4-D	25°C, 16 hr photoperiod, umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992

Table 1. *Continued...*

Atatea					
At. aztecorum	1 leaf	callusing	MS + 13.5 - 27.0 uM 2, 4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
Bambusa					
B. arundinacea	1 embyro 2 callus	callus embryoids + 1 mg/1 BAP	N6 + 7 mg/1 2, 4-D N6 + 7 mg/1 2, 4-D		Mehta et al, 1982
B. arundinacea	1 node from mature tree (10-15 yrs old)	multiple shoots	MS + 0.5 mg/1 BAP + 0.2 mg/1 Ki + 10% CW		Nadgir et al, 1984
B. arundinacea	1 seeds	multiple shoots (6 seedlings)	medium + 1 mg/1NAA + + 4 mg/1 6-BAP		Vasana et al, 1985
B. arundinacea	1 seed 2 seedling 3 callus	seedling callus plantlet 0.5 mg/1 NAA	WP/MS - WP/MS + 1 & 3 mg/1 2, 4-D WP + 2 mg/1 BAP +		Vasana, 1985
B. arundinacea	1 node from non-flowering clump 2 shoot	multiple shoots rooting	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar MS + 5.4 uM NAA	25°C, 16 hr photoperiod 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
B. arundinacea	1 leaf	callusing uM 2, 4-D	MS + 13.5 - 27.0 photoperiod, 250 umol $m^{-2}s^{-1}$	25°C, 16 hr	Prutpongse and Gavinlertvatana, 1992
B. arundinacea	1 seeds (58.7%)	multiple shoots	medium + cytokinin		Jerath, 1986

B. beecheyana	1 floret tissues	callus/ embryoids/	MS + 3 mg/1 2, 4-D + 2 mg/1 Ki + 100 mg/1 myo-inositol + 0.5 mg/1 nicotinic acid + 0.5 mg/1 pryi-doxine + 0.1 mg/1 thiamine + 2.0 mg/1 glycine + 1 g/1 casein hydrolysate + 60 g/1 sucrose + 7 g/1 agar, pH 5.7	15-40 uEsec^{-1} 16 hrs photoperiod 26^{0}C+1	Yeh & Chang, 1986
	2 embryoids	embryoids	fresh medium		
	3 embryoids plantlets	germination/ hormose-free	on same medium or on medium		
B. beecheyana	1 adventive root from cultures	callus/ plantlets/	MS + 3 mg/1 2, 4-D + 2 mg/1 Ki	15-40 uEsec^{-1} 16 hrs photoperiod 26^{0}C + 1	Yeh & Chang, 1986
	2 callus structures/ somatic embryoids	nodular	fresh medium		
	3 nodular structures	somatic embryoids	fresh medium/ transfer to hormone-free medium		
	4 somatic embryoids	plantlets on same medium	transfer to hormose-free medium or		
B. beecheyana var. pubescens	1 leaf	callusing	MS +13.5 - 27.0 uM 2, 4-D	25^{0}C, 16 hr photoperiod, 250 umol m^{-2} s^{-1}	Prutpongse and Gavinlertvatana, 1992

Table 1. *Continued...*

B. brandisii	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
B. bandisii	1 leaf	callusing	MS + 13.5 - 27.0 uM 2, 4-D 250 umol $m^{-2}s^{-1}$	25°C, 16 hr photoperiod,	Prutpongse and Gavinlertvatana, 1992
B. burmannica	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
B. burmannica	1 leaf	callusing	MS + 13.5 - 27.0 uM 2, 4-D 250 umol $m^{-2}s^{-1}$	25°C, 16 hr photoperiod,	Prutpongse and Gavinlertvatana, 1992
B. flexuosa Munro	1 young leaf	callus	(WP or MS) + 3&6 mg/1 2, 4-D		Vasana, 1985
B. flexuosa	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
B. flexuosa	1 leaf	callusing	MS + 13.5 - 27.0 uM 2, 4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 callus	shoots	MS + 2.2 - 8.8 uM BA + 1.4 - 5.5 uM NAA		

B. glaucescens	1 culm bud	shoots	MS + 1 mg/1 BAP + 3 g/1 AC	14 hr photoperiod 28°C	Banik, 1987
	2 shoots	rooting	MS 1 mg/1 BAP + 3 g/1 AC + 1 mg/1 NAA		
B. glaucescens	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
B. glaucescens	1 leaf	callusing	MS + 13.5 - 27.0 uM 2, 4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
B. gracilis	1 leaf	callusing	MS + 13.5 - 27.0 uM 2, 4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
B. humilis	1 leaf	callusing	MS + 13.5 - 27.0 uM 2, 4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
B. longispiculata	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
B. longispiculata	1 leaf	callusing	MS + 13.5 - 27.0 uM 2, 4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992

Table 1. *Continued...*

B. multiplex	1 shoot tip cell suspension	callus/	MS + 3 mg/1, 2, 4-D		Huang, 1988
B. multiplex	1 shoot tip shoots/roots	callus/	MS + NAA + BAP		Huang, 1988
B. multiplex	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2}5^{-1}$	Prutpongse and Gavinlertvatana, 1992
B. multiplex	1 lateral shoots from young culms	callus	MS + 3 mg/1 2, 4-D + 30 g/1 sucrose + 100 mg/1 inositol + 1 mg/1 thiamine + 0.5 mg/1 nicotinic acid + 0.5 mg/l pyridoxine HCl + 2 mg/l glycine, 8 g/ITC agar, pH 5.7	27°C, darkness	Huang and Murashige, 1983
B. multiplex	1 lateral shoots from young culms	nodular callus	MS + 1 mg/1NAA + 1 mg/1 BA + 30 g/I sucrose + 1 mg/l thiamine + 0.5 mg/l nicotinic acid + -.5 mg/l pyridoxine HCl + 2 mg/l glycine, 2 g/l gelrite, pH 5.7	27°C, 16 hr photoperiod	Huang et al, 1989

	2 nodular callus	nodular callus/ adventitious shoots	same medium as above except BA at 0.3-3.0 mg/l		
	2 adventitious shoots	roots	MS + 1 mg/l NAA + other components except BA		
B. multiplex (variegata)	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/l agar	25°C, 16 hr photoperiod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
B. multiplex (variegata)	1 leaf	callusing	MS + 13.5 - 27.0 uM 2, 4-D 250 umol $m^{-2} s^{-1}$	25°C, 16 hr photoperiod, 1992	Prutpongse and Gavinlertvatana,
B. nana	1 nodes from young branches, 3.5 mm dia	bud sprouting	medium + NAA + 2, 4-D + BAP		Vongvijitra, 1988
B. nigra	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/l agar	25°C, 16 hr photoperiod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
B. nigra	1 leaf	callusing	MS + 13.5 - 27.0 uM 2, 4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
B. oldhamii	1 shoot tip	callus	MS + 3 mg/l 2, 4-D		Huang, 1988
B. oldhamii	1 shoot tip	callus/	MS + NAA + BAP		Huang, 1988

Table 1. *Continued...*

	shoots/roots				
B. oldhamii	1 inflorescence	callus/embryoid	MS + 3 mg/1 2, 4-D + 2 mg/1 Ki		Yeh and Chang, 1988
	2 embryoid	germination	MS + 2 mg/1 Ki		
B. oldhamii	1 root ivc	pltlet albino	MS + 3 mg/1 2, 4-D + 2 mg/1 Ki		Yeh and Chang, 1988
B. oldhamii	1 lateral shoots from young culms	nodular callus	MS + 1 mg/1 NAA + 1-3 g/1 BA + 30 g/1 sucrose + 1 mg/1 thiamine + 0.5 mg/1 nicotnic acid + 0.5 mg/1 pyridoxine HCl + 2 mg/1 glycine, 2 g/1 gelrite, pH 5.7	27°C, 16 hr photoperiod 4.5 nEcm^{-2} sec^{-1}; fluorescent light	Huang et al, 1989
	2 nodular callus adventitious shots	nodular callus/	same medium as above		
	2 adventitious shoots	roots except BA	MS + 1 mg/1 NAA other components		
B. oldhamii	1 node from non-flowering clump	mutiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod 250 umol m^{-2} s^{-1}	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
B. oldhamii	1 leaf	callusing	MS + 13.5 - 27.0	25°C, 16 hr	Prutpongse and

			uM 2,4-D	photoperiod, 250 umol m^{-2} s^{-1}	Gavinlertvatana, 1992
B. oldhamii	1 inflorescence 2 callus	callus shoots	MS + 13.5 - 27.0 uM 2,4-D		Prutpongse and Gavinlertvatana, 1992
B. oldhamii	1 inflorescence	shoots	MS + 22uM BA	Prutpongse and	Gavinlertvatana, 1992
B. polymorpha	1 mode from non-flowering clump	multiple shoots	MS + 22uM BA + 88uM sucrose + 6 g/1 agar + 5.4 uM NAA	25°C, 16hr photoperiod, 250 umol m^{-2} s^{-1}	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
B. polymorpha	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16hr photoperiod 250 umol m^{-2} s^{-1}	Prutpongse and Gvinlertvalana, 1992
B. tulda	1 seed	germination w/ multiple shoots	MS(liquid)+ +3-6 X 10-6 M BAP 2% sucrose fluorescent light	26 ± 2°C 12 hr photoperiod 6,000 lux, white	Saxena, 1990
	2 shoot clusters (3)	shoot cluster	MS + 8 x 10^{-6} M BAP		
	3 shoot clusters	rooting	MS + 10^{-5} m IAA		

Table 1. *Continued...*

B. ventricosa	1 node	shoots	MS + 3-40 mg/1 BAP		Dekkers, 1989
B. ventricosa	1 node	shoots	MS + 5 mg/1 BAP + 0.1 - 10 mg/1 NAA + 0.31%AC		Dekkers, 1989
B. ventricosa	1 culm sheath base	callus	MS + 0.5- 25 mg/1 2, 4-D		Dekkers, 1989
B. ventricosa	1 culm sheath base	callus	MS + 3-10 mg/1 NAA		Dekkers, 1989
B. ventricosa	1 culm sheath base	callus	MS + 10 mg/1 IBA		Dekkers, 1989
B. ventricosa	1 culm sheath base	callus	MS + 5 mg/1 IBA + 5mg/1 NAA		Dekkers, 1989
B. ventricosa	1 internode	callus	MS + mg/1 2,4-D		Dekkers, 1989
B. ventricosa	1 node from non-flowering clump	multiple shoots	MS + 22uM BA + 88uM sucrose + 6 g/1 agar + 5.4 uM NAA	25°C, 16 hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
B. ventricosa	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
B. ventricosa (variegata)	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992

	2 shoot	rooting	MS + 5.4 uM NAA		
B. ventricosa (variegata)	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16 hr photoperiod 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
B. vulgaris	1 node	multiple shoots	MS + 0.5 mg/1 BAP + 0.2 mg/1 Ki + 10% CW		Nadgir et al, 1984
B. vulgaris	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
B. vulgaris	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
B. cv. Dam Khan	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
B. cv. Dam Khan	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
B. cv. Bong Ban	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992

Table 1. *Continued...*

B.cv. Bong Ban	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/l agar	25°C, 16 hr photoperiod 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
B. cv. Bong Naew	1 leaf	callusing	MS + 13.5 - 27.0 uM, 2, 4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
B. cv. Bong Naew	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
Cephalostachyum					
C. pergracile	1 node from non-flowering clump	multiple shoots	MS + 22 um BA + 88um sucrose + 6 g/1 agar	25°C, 16 hr photoperiod 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
C. pergracile	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
C. viratum	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
Dendrocatamus					
D. asper	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88um sucrose + 6 g/1 agar	25°C, 16 hr photoperiod 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992

	2 shoot	rooting	MS + 5.4 uM NAA		
D. asper	1 inflorescence 2 callus	callus shoots	MS + 13.5 - 27.0 uM 2,4-D		Prutpongse and Gavinlertvatana, 1992
D. asper	1 inflorescence	shoots	MS + 22uM BA		Prutpongse and Gavinlertvatana, 1992
D. asper	1 nodes from young branches, 3.5 mm dia	bud sprouting	medium + NAA + 2,4-D + BAP		Vongvijitra, 1988
D. asper	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
D. brandisii	1 seed	seedling with multiple shoots	MS 2 x 10^{-5} M BAP		Vongvijitra, 1988
	2 multiple shoot	sustained growth	MS 2 x 10^{-5} BAP		
	3 multiple shoot	rooting	MS plain MS or lower BAP		
D. giganteus	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
D. giganteus	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
D. hamiltonii	1 leaf	callusing	MS 13.5 - 27.0 uM 2,4-D		Prutpongse and

Table 1. *Continued...*

					Gavinlertvatana, 1992
D. hamiltonii	1 seed	aseptic germination	MS + MS vitamins + 3% sucrose + 0.7% agar, pH 5.6	darkness, 25°C	Chambers et al, 1991
	2 seedling epicotyl nodal sections	multiple shoots/ in vitro flowering	MS + 4.4 uM BA + MS vitamins + 3% sucrose + 0.7% agar, pH 5.6	16 hr photoperiod 140 umol $m^{-2}5^{-1}$ 30°C	
D. cv. Bong Kaiy	1 node from non-flowering clump	multiple shoots	MS + 22uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16hr photoperiod 250 umol $m^{-2}5^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
D. cv. Bong Kaiy	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2}5^{-1}$	Prutpongse and Gavinlertvatana 1992
D. latiflorus	1 internode	callus	MS + 1-25 mg/1 2,4-D + 20 g/1 sucrose		Zamora et al, 1989
	2 Callus	shoot/ plantlet	MS + 1 mg/1 BAP + 1 mg/1 2,4-D + 20 g/1 sucrose		
D. latiflorus	1 shoot tip roots	callus/shoots/	MS + NAA + BAP		Huang, 1988
D. latiflorus	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°c, 16hr photoperiod 250 umol $m^{-2}5^{-1}$	Prutpongse and Gavinlertvatana, 1992

	2 shoot	rooting	Ms + 5.4 uM NAA		
D. latiflorus	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16hr photoperod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
D. latiflorus	1 inflorescence 2 callus	callus shoots	MS + 13.5 - 27.0 uM 2,4-D		Prutpongse and Gavinlertvatana, 1992
D .membranaceus	1 node from non- flowering clump	multiple shoots	Ms + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS _ 5.4 uM NAA		
D. membranaceus	1 leaf	callusing	MS + 13.5 - 27.0 uM 2, 4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
D. membranaceus	1 seed multiple shoots	seedling with	MS + 0.5-2 x 10^{-5}M BAP		Vongvijitra,
	2 nodes	Callus/E-Callus	MS + 1-1.5 x 10^{-5}M 2,4-D + 0.2 x 10^{-5} M BAP		
D. membranaceus	1 seed multiple shoots	seedingh	MS		Vongvijitra, 1988
	2 multiple shoot	sustained growth	MS + 2 x 10^{-5}M BAP		
	3 multiple shoot	rooting	plain MS or lower BAP		
D. merrillianus	1 leaf	callus	MS + 3 & 5 mg/1 2,4-D + ascorbic acid + citric acid		Aala, 1992

Table 1. *Continued...*

D. merrillianus	1 node	bud sprouting	MS + BA		Aala, 1992
D. nutans	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16hr Photoperiod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
D. nutans	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16 hr photoperiod 250 umol $m^{-2} s^{-1}$	Prutponges and Gavinlertvatana, 1992
D. sericeus	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-d	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
D. strictur	1 node	multiple shoots	MS + .05 mg/1 BAP + 0.2 mg/1 Ki + 10% CW		Nadgir et al, 1984
	2 shoot (4 days)	root induction	MS + 1 mg/1 1BA		
	3 shoot	Rooting	mS (0.5 x) + 0.25% AC		
D. strictus	1 seeds	seedling	Whites + 2% sucrese		Nadgir et al, 1984
	2 seedling	multiple shoots + 5% CW	MS + .02 mg/1 BAP liquid shaken, 120 rpm, 1000 1ux 25°C		
	3 shoot	root induction (2 days)	MS + 0.1 mg/1 IBA		
	4 shoot	rooting	MS (0.5x) + 0.25% AC		
D. Strictus	1 seed + embryoids +	callus from embryo	85 + 10^{-5}/27°C 3 x 10^{-5} M 2,4-D	2,5000 lux continuous light	Rao et al, 1985

	plantlets		+ 2% sucrose + 0.8 agar, pH 5.8		
	2 embroyed	germination	B5 + 5 x 10-7 M IBA + 10-7 M NAA + 2% sucrose, (liqued)		
	3 plantlets	further growth	85 (0.5 x) + 1 % sucrose + 5 x 10^{-7} M IBA + $^{-7}$ M NAA		
D. strictus	1 seed	callus from embry0	85 salts + vitamins + 30 uM 2,4-D + 2 % sucrose + 0.8% agar-agar, pH 5.8		Rao et al, 1987
	2 embryogenic callus	somatic embryos	same medium		
	3 scutellar region of embryos	secondary embryoids	same or fresh medium		
	4 embryoids	plantlets/ rhizome development	85 basal medium		
D. strictus	1 node	shoot growth and rooting	MS + 1 mg/1 NAA + 1 mg/1 IBA + 0.5 mg/1 2,4-D		Chaturvedi and Sharma, 1988
D. strictus	1 excised embryo	callus	MS + 10 uM 2,4-D	27°C, 8 hr photoperiod	Zomora and Gruezo, 1990
	2 embryogenic callus	plantlets	MS (micronutrients at half normal concentration +		

Table 1. *Continued...*

			150 m1/1 CW + 0.1 g/1 Myo-inositol		
D. strictus	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 887M sucrose + 6 g/1 agar	25°C, 16 hr photoperiod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
D. strictus	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-B	25°C, 16hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
D. strictus	1 seeds	seedlings	White's + 20 g/1	darkness	Mascarenhas et al, 1988
	2 seedings	multiple shoots shaken, 120 rpm	MS-liqued		
	3 shoot clusters	rooting	MS + 0.1 ppm IBA + 20 g/1 sucrose		
D. strictus	1 embryos	callus with somatic embryogenesis (60-70% of callus with SE)	MS + 3.5 mg/1 2,4-D 40 mg/1 thiamine HCI 1000 mg/1 inositol		Mascarenhas et al, 1988
	2 embryoids	plantlets	MS no 2,4-D 40 mg/1 thiamine HCI 1000 mg/1 inositol		
D. striclus	1 nodes from mature tree	bud sprouting (80%)	MS + 0.5 Ki + 1 BAP + 0.8% agar + 5% CW + 2% sucrose		Mascarenhas et al, 1988
	2 nodes with sprouted buds	elongation and multiplication + 200 mg/1 CH	MS + 0. 5 Ki + 1 BAP + 2% sucrose + 5% CW		

D. strictus	1 seed embryoids	callus from embroyo 2,4-D + 10% CW	MS + 1 and 10 mg/1	Dekkers, 1989
D. strictus	1 seeds	callus/embryoids + 0:5 mg/1 Ki	MS + 3 mg/1 2,4-D	Mukunthakumar and Mathur, 1992
	2 embryoids	artificial seed	encapsulation matrix (6% sodium alginate + 100 mM $CaCl_2$ $2H_20$) + 1 mg/1NAA + 0.5 mg/1 Ki	
	3 artificial seed	germination	plain agar or soil	
D. strictus	1 node (field-grown, 10 yr old)	culture	MS + 1500 mg/1 NH_4NO_3 + 1500 mg/1 KNO3 + 15 mg/1 AdS + 0.2 mg/1 Thiamine HCI + 0.5 mg/1 IAA + 20 g/1 sucrose + 7 g/1 agar, pH 5.8	2 Klux fluorescent 14 hr photoperiod 27 ± 1^0C Chaturvedi et at, 1993
	2 shoot	multiple shoots	MS (mod) + 1 mg/1 IBA+ + 1 mg/1 NAA + 20 g/1 sucrose + 7 g/1 agar, ph 5.8	
	3 shoot	root induction	MS (mod) + 1 mg/1 IBA + 1 mg/1 NAA + 0.5 mg/1 AdS + 0.1 mg/1 biotin + 10 mg/1 arginine HCI + 1 mg/1 phloroglucinol	

Table 1. *Continued...*

			+ 20 g/1 sucrose + 7.5 g/1 agar, pH 5.2		
	4 shoot w/just formed roots	root growth	MS mod + 0.5 mg/1 IAA + 15 mg/1 AdS + 20 g/l sucrose + 7.5 g/1 agar, pH 5.2		
Dinochloa					
D. scandens	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA+ 88uM sucreses + 6 g/1 agar	25°C, 16hr photoperiod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
D. scandens	1 leaf	callusing	MS + 13.5-27.0 uM 2,4-D	25°C, 16hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
Gigantochloa					
G. albociliata	1 node from non-flowering clump	multiple shoots	MS + 22uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
G. albociliata	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
G. apus	1 mode from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + b g/1 agar	25°C, 16 hr photoperiod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		

G. apus	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D 250 umol $m^{-2}s^{-1}$	25°C, 16 hr photoperiod, 1992	Prutpongse and Gavinlertvatana,
G. auricurata	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/l agar	25°C, 16 hr photoperiod 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
G. auriculata	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,40D	25°C, 16 hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertavatana, 1992
G. compressa	1 node from non-flowering clump	multiple shoots	MS + 22 um BA + 88uM sucrose + 6 g/l agar	25°C, 16 hr photoperiod 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
G. compressa	1 leaf	callusing	MS + 13.5 -24.0 uM 2,4-D	25°c 16 hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
G. densa	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°m, 16 hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
G. hasskarliana	1 seeds	seedings	WP + Whites vitamins		Vasana, 1985
G. hasskarliana	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88 uM sucrose + 6 g/l agar	25°C, 16 hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		

Table 1. *Continued...*

G. hasskarliana	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
G. hosseusii	1 node from non-flowering clump	multiple shoots	MS + 22uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
G. hossuesii	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	250C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
G. levis	1 embryo	E-callus/plant	MS + 2 mg/1 2,4-D		Zamora and Gruezo,1991
Hibanobambusa					
H. trianguillans	1 mode from non-flowering clump	multiple shoots	MS + 22uM BA + 88uM sucrose + 6 g/l agar	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
H. trainguellans	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
Helocatamus					
M. compactiflorus	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
Otatea					
O. acuminata	1 seed/excised	callus/E callus	MS or B5 + 3 mg/1	23 hr photoperiod,	Woods et al, 1992

	embryes		2,4-D + 2% sucrose + 0.2% gelrite, pH 5.8	25°C, white cool fluorescent lights	
	2 E-callus/ somatic embryoids	somatic embryoids	MS + 3 mg/1 2,4-D + 2% sucrose + 0.5 mg/1 BA	dark incubation 25°C	
	3 E-callus	plantlets	B5 plain medium		
Oxytenanthera					
O.albociliata	1 node fron non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM surose + 6 g/1 agar	25°C, 16 hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
O.albociliata	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
Phyllostachys					
P. aurea	1 shoot tip	callus/ cell suspension	MS + 3 mg/1 2, 4-D		Huang, 1988
P. aurea	1 node from non-flowering clump	multiple shoots	MS+ 22 uM BA+ 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod 250 umol $m^{-2}5^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
P. aurea	1 leaf	callusing	MS + 13.5 -27.0 uM 2, 4-D	25°C, 16 hr photoperiod 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
P. aurea	1 lateral shoots	nodular callus	MS +1 mg/1 NAA	27°C,	Huang et al, 1989

Table 1. *Continued...*

	from young culms		+10 mg/1 BA + 30 g/1 sucrose + 1 mg/1 thiamine + 0.5mg/1 nicotinic acid + 0.5 mg/1 pyridoxine HCI + 2 mg/1glycine, 2 g/1 gelrite, pH 5.7	16 hr photoperiod	
	2 nodular callus adventitious shoots	nodular callus/	same medium as above		
	2 adventitious shoots	roots except BA	MS + 1 mg/1 NAA + other components		
P. bambusoides	1 node from non-flowering clump	multiple shoots	MS +22 uM BA + 88uM sucrose + 6 g/l agar	25°C, 16 hr photoperiod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
P. bambusoides	1 leaf	callusing	MS + 13.5 -27.0 Um 2, 4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
P. gramineus	1 node from non-flowering Clump	multiple shoots	MS + 22 uM BA+ 88 uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
P. gramineus	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992

P. humilis	1 leaf	callusing	MS + 13.5 - 27.0 uM 2, 4-D	25°C, 16 hr photoperiod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
P. nana	1 leaf	callusing	MS + 13.5 -27.0 uM 2,4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
P. nigra	1 leaf	callusing	MS + 13.5 -27.0 uM 2,4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
P. nigra f. megurochiku	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA+ 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
P. nigra f. megurochiku	1 leaf	callusing	MS + 13.5 -27.0 uM 2,4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
P. pubescens	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6g/1 agar	25°C, 16 hr photoperiod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
P. pubescens	1 leaf	callusing	MS + 13.5 -27.0 Um 2,4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
P. sulphurea	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992

Table 1. *Continued...*

	2 shoot	rooting	MS + 5.4 uM NAA		
P. sulphurea	1 leaf	callusing	MS + 13.5 -27.0 uM 2,4-D	25^{0}C, 16 hr photoperiod, 250 umol m $^{-2}$ s $^{-1}$	Prutpongse and Gavinlertvatana, 1992
P. viridis	1 leaf from young plants H/1 mm dia stems	callus/ embryoids	MS macrosalts + + Nitsch micro and organic + 5.6. x 10-4 M myo-inositol +1.2 x 10-6 M thiamine HCI + 9.5 x 10-5 M Na Fe EDTA + 2 mg/1 2,4-D + 2% sucrose + 0.6% agar, pH 5.8	23+2^0 C contimuous light	Hassan & Debergh, 1987
	2 embryoid	germination	MS macrosalts + Nitsch micro and organic + 5.6 x 10-4 M myo-inositol + 1.2 x 10-6 M thiamine HCI + 9.5 x 10-5 M NafeDTA + 2% surose + 0.6% agar,pH 5.8		

Fleroblastus					
Pl. fortunee	1 node from non-flowering clump	multiple-shoots	MS + 22 uM BA+ 88um sucrose + 6 g/1 agar	25°C, 16 hr photoperiod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
Pl. forunee	1 leaf callusing	MS + 13.5 -27.0 uM 2,4-D	25°C, 16 hr	Prutpongse and photoperiod, 250 umol $m^{-2} s^{-1}$	Gavinlertvatana, 1992
Psuedosasa					
P. iaponica	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88 uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
P.iaponica	1 leaf	callusing	MS + 13.5 -27.0 uM 2,4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
Sasa					
S. pygmaea	1 shoot tip	callus/cell supension	MS + 3 mg/1 2. 4-D		Huang, 1988
S. pygmaea	1 shoot tip	callus/shoots roots	MS + NAA + BAP		Huang, 1988
S. pygmaea	1 lateral shoots from young culms	nodular callus	MS + 1 mg/1 NAA + 1 -3 mg/1 BA + 30 g/1 sucrose + 1 mg/1 thiamine + 0.5 mg/1 nicolinic acid + 0.5 mg/1 pyridoxine HCI +	27°C, 16 hr photoperiod	Huang et al, 1989

Table 1. *Continued...*

			2 mg/1 glycine, 2 g/1 gelrite, pH 5.7		
	2 nodular callus adventitious shoots	nodular callus/	same medium as above		
	2 adventitious shoots	roots	MS + 1 mg/1 NAA + other components except BA		
S. fortunei	1 node from non flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
S. fortunei	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16 hr photoperiod, 250 uMol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
Sasaella					
S. sumekoana	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar + 5.4 uM NAA	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 um NAA		
S. sumekoana	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
Schizostachyum					
Sch. aciculare	1 node from non-flowering clump	multiple shoots,	MS + 22uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		

Sch. aciculare	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
Sch.brachycladum	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod, 250 umol $m^{-2}s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
Sch.brachycladum	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
brachycladum	1 culm sheath base	callus	MS + 1,5 & 10 mg/1 2,4-D		Dekkers, 1989
Sch. brachycladum	1 culm sheath base	callus	MS + 3 & 5 mg/1 NAA		Dekkers, 1989
Sch. brachycladum	1 internode	callus	MS + 10 mg/1 2,4-D		Dekkers, 1989
Sch. brachycladum	1 root (IYC)	callus	MS + mg/1 2,4-D		Dekkers, 1989
Sch. lumampao	1 embryo	E-callus/plant	MS + 2 ppm 2,4-D		Zamora and Gruezo, 1991
Sch. zollingeri	1 leaf	callusing	mS + 13.5 - 27.0 uM 2,4-d	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
Semiarundinaria					
S. fastuosa	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992

Table 1. *Continued...*

	2 shoot	rooting	MS + 5.4 uM NAA		
S. fastuosa	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
Sinocalamus					
Sn. latiflora	1 embryo	callus/embryoids	MS + 6 mg/1 2,4-D + 3 mg/1 Ki		Yeh & Chang, 1987
	2 embryoids	plantlets	MS + 3 mg/1 2,4-D + 2 mg/1 Ki		
Sn. latiflora	1 anthers loose callus	E-compart callus/	MS or N6 + 1 mg/1 2,4-D + 1 mg/1 BA + 9% sucrose + 0.2 % charcoal + 0.8% agar, pH 5.8	darkness, 25°C	Tasy et al, 1990
	2 compact callus	embryoids	plain medium		
	3. embryoeds (weak, later died)	plantlets	plain medium	16 hr photoperiod, 135 uE/$m^{-2} s^{-1}$	
Thyrsostachys					
T. oliveri	1 node from non-flowering clump	multiple shoots	MS + 22 uM BA + 88uM sucrose + 6 g/1 agar	25°C, 16 hr photoperiod 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992
	2 shoot	rooting	MS + 5.4 uM NAA		
T. oliveri	1 leaf	callusing	MS + 13.5 - 27.0 uM 2,4-D	25°C, 16 hr photoperiod, 250 umol $m^{-2} s^{-1}$	Prutpongse and Gavinlertvatana, 1992

T. oliveri	1 nodes from young bravches, 3.5 mm dia	bud sprouting	MS + NAA + 2,4-D + BAP	Vongvijitra, 1988
T. siamensis	1 seed	multiple shoots (30 seedlings/ seedling stock)	MS + 1 mg/1 NAA + 2 mg/1 6-BAP	Vasana et al, 1985
T. siamensis	1 Seed	multiple shoots (30 seedlings/ seedling stock)	MS + 2 mg/1 NAA + 4 mg / 1 6 - BAP	Vasana et al, 1985
T. siamensis	1 seed 2 seedling 3 callus	seedling callus plantlet 0.5 mg/1 NAA	WP/MS WP/MS + 1 & 3 mg/1 2,4-D Wp + 2 mg/1 BAP +	Vasana, 1985

Table 2 : *Summary of methods of in vitro propagation for different bamboo genera*[1]

Bamboo genera (Number of species/ cultivars)	Number of species/cultivars reported for different methods of *in vitro* propagation							
	In vitro germination	Somatic embryogenesis		Micropropagation		Adventitive plant formation		
		S/ Sgs	F	S/ Sgs	N-F	S/ Sgs	N-F	F[2]
Arundinaria (3)	-	-	-	-	3	-	(3)	-
Atatea (1)	-	-	-	-	-	-	(1)	-
Bambusa (19/3)	2	2	2	2	16	2(1)	4(17)	1
Cephalostachyum (2)	-	-	-	-	2	-	(2)	-
Dendrocalamus (10/1)	4	1	-	4	7(1)	(1)	1(9)	2
Dinochloa (2)	1	-	-	-	1	(1)	(1)	-
Gigantochloa (8)	2	1	-	-	6	-	(6)	-
Hibanobambusa (1)	-	-	-	-	1	-	(1)	-
Melocalamus (1)	-	-	-	-	-	-	(1)	-
Otatea (1)	1	1	-	-	-	-	-	-
Oxytenanthera (1)	-	-	-	-	1	-	(1)	-
Phyllostachys (10)	-	1	-	-	6	-	1(8)	-
Pleioblastus (1)	-	-	-	-	1	-	(1)	-
Psuedosasa (1)	-	-	-	-	1	-	(1)	-
Sasa (2)	-	-	-	-	1	-	1(1)	-
Sasaella (1)	-	-	-	-	1	-	(1)	-
Schizostachyum (5)	-	1	-	-	2(1)	(1)	(4)	-
Semiarundinaria (1)	-	-	-	-	1	-	(1)	-
Sinocalamus (1)	-	1	-	-	-	-	-	1[3]
Thyrsostachys (2)	1	-	-	1	2	1	(4)	-

[1] Listing covers number of species with reports wherein whole plantlets were obtained from cultures=1...x; and where a part of propagation protocol available=(1...x).

[2] Abbreviations for explant for culture initiation; S/Sgs=Seed/Seedlings; N-F Explants from a non-flowering clump; F=Inforescence explants.

[3] Anther culture leading to plantlets.

Table 3 : *Methods of in vitro propagation for different bamboo species*[1].

Bamboo Species	Methods of *in vitro* propagation							
	In vitro germination	Somatic embryogenesis		Micropropagation		Adventitive plant formation		
		S/ Sgs	F	S/ Sgs	N-F	S/ Sgs	N-F	F[2]
Arundiraria								
A. auriculata	-	-	-	-	X	-	P	-
A. pusila	-	-	-	-	X	-	P	-
A. superecta	-	-	-	-	X	-	P	-
Atatea								
A. aztecorum	-	-	-	-	-	-	P	-
Bambusa								
B. bambos	XXX	X	-	XX	XX	X	P	-
B. beecheyana	-	X	X	-	-	-	P	-
B. brandisii	-	-	-	-	X	-	P	-
B. burmannica	-	-	-	-	X	-	P	-
B. flexuosa	-	-	-	-	X	P	X	-
B. glaucescens	-	-	-	-	XX	-	P	-
B. gracilis	-	-	-	-	-	-	P	-
B. humilis	-	-	-	-	-	-	P	-
B. longispiculata	-	-	-	-	X	-P	-	
B. multiplex	-	-	-	-	-	-	XXPPP	
B. multiplex (variegata)	-	-	-	-	X	-	P	-
B. nana	-	-	-	-	P	-	P	-
B. nigra	-	-	-	-	X	-X	-	
B. oldhamii	-	-	X	-	X	Xx	XXXPP	XX
B. polymorpha	-	-	-	-	X	P	-	
B. tulda	X	-	-	X	-	-	-	-
B. ventricosa	-	-	-	-	XP	-	PPP	-
B. ventricosa (variegata)	-	-	-	-	X	-	P	-
B. vulgaris	-	-	-	-	XP	-	P	-
B. cv. Dam Khan	-	-	-	-	X	-	P	-

Table 3. *continued...*

B. cv. Bong Ban	-	-	-	-	X	-	P	-
B. cv. Bong Naew	-	-	-	-	X	-	P	-
Oephalostachyum								
C. pergracile	-	-	-	-	X	-	P	-
C. viratum	-	-	-	-	X	-	P	-
Dendrocalamus								
D. asper	-	-	-	-	XP	-	P	X
D. brandisii	X	-	-	X	-	-	-	-
D. giganteus	-	-	-	-	X	-	P	-
D. hamiltonii	X	-	-	X	-	-	P	-
D. cv. Bong Kaiy	-	-	-	-	X	-	P	-
D. latriflorus	-	-	-	-	X	-	XXP	X
D. membranaceus	X	-	-	X	X	P	P	-
D. merrillianus	-	-	-	-	-P	-	P	-
D. nutans	-	-	-	-	X	-	P	-
D. serieus	-	-	-	-	-	-	P	-
D. strictus	XX	XXXXXX		-	XX	XXXXP	-	P
Dinochloa								
D. scandens	-	-	-	-	X	-	P	-
D. sp.	X	-	-	-	-	P	-	-
Gigantochloa								
G. albociliata	-	-	-	-	X	-	P	-
G. apus	-	-	-	-	X	-	P	-
G. auricurata	-	-	-	-	X	-P	-	
G. compressa	-	-	-	-	X	-	P	-
G. densa	-	-	-	-	-	-	P	-
G. hasskarliana	X	-	-	-	X	-	P	-
G. hosseusii	-	-	-	-	X	-	P	-
G. levis	X	X	-	-	-	-	-	-
Hibanobambusa								
H. trianguillans	-	-	-	-	X	-	P	-
Melocalamus								
M. compactiflons	-	-	-	-	-	-	P	-
Otatea								
O. acuminata	X	X	-	-	-	-	-	-

Table 3 *continued...*

Oxytenenthera								
O. albociliata	-	-	-	-	X	-	P	-
Phyllostachys								
P. aurea	-	-	-	-	X	-	XPP	-
P. bambusoides	-	-	-	-	X	-	P	
P. gramineus	-	-	-	-	X	-	P	-
P. humilis	-	-	-	-	-	-	P	-
P. nana	-	-	-	-	-	-	P	-
P. nigra	-	-	-	-	-	-	P	-
P. nigra f. megurochiku	-	-	-	-	X	-	P	-
P. pubescens	-	-	-	-	X	-	P	-
P. sulphurea	-	-	-	-	X	-	P	-
P. viridis	-	X	-	-	-	-	-	-
Pleioblastus								
Pl. fortunee	-	-	-	-	X	-	P	-
Psuedosasa								
Ps. japonica	-	-	-	-	X	-	P	-
Sasa								
S. fortunei	-	-	-	-	X	-	P	-
S. pygmaea	-	-	-	-	-	-	XXP	-
Sasaella								
Sa. suwekoans	-	-	-	-	X	-	P	-
Schizostachyum								
Sch. aciculare	-	-	-	-	X	-	P	-
Sch. brachycladdum	-	-	-	-	X	-	PPP	-
Sch. lima	-	-	-	-	-	P	-	
Sch. lumampao	-	X	-	-	P	-	P	-
Semianundinaria								
Se. fastuosa	-	-	-	-	X	-	P	-
Sinocalamus								
Si. latiflora	-	X	-	-	-	-	-	-X[3]
Thyrsostachys								
T. oliveri	-	-	-	-	XP	-	P	-
T. siamensis	XXX	-	-	X	X	X	PPP	-

[1] Listing covers reports, X=wherein whole plantlets were obtained from cultures and P=part of propagation protocol available.

[2] Abbreviations for explant for culture initiation; S/Sgs=Seed/Seedlings; N-F Explants from a non-flowering clump; F=Inflorescence explants.

[3] Anther culture leading to plantlets.

Table 4 : *Summary of methods of in vitro propagation for INBAR priority species for bamboos*[1]

Bamboo Species	Methods of *in vitro* propagation							
	In vitro germination	Somatic embryogenesis		Micropropagation		Adventitive plant formation		
		S/Sgs	F	S/Sgs	N-F	S/Sgs	N-F	F[2]
Bambusa bambos	3	1	0	2	2	1	(1)	0
B. blumeana	0	0	0	0	0	0	0	0
B. polymorpha	0	0	0	0	1	0	(1)	0
B. textiles	0	0	0	0	0	0	0	0
B. tulda	1	0	0	1	0	0	0	0
B. vulgaris	0	0	0	0	1(1)	0	(1)	0
Oephalostachyum pergracile	0	0	0	0	1	0	(1)	0
Dendrocalamus asper	0	0	0	0	1(1)	0	(1)	0
D. giganteus	0	0	0	0	1	0	(1)	0
D. latiflorus	0	0	0	0	1	0	2(1)	0
D. strictus	2	6	0	2	4(1)	0	(1)	1
Gigantochloa apus	0	0	0	0	1	0	(1)	0
G. levis	1	1	0	0	0	0	0	0
G. psuedoarundinaria	0	0	0	0	0	0	0	0
Guadua angustifolia	0	0	0	0	0	0	0	0
Melocanna baccifera	0	0	0	0	0	0	0	0
Ochlandra	0	0	0	0	0	0	0	0
Phyllostachys pubescens	0	0	0	0	1	0	(1)	0
Thyrsostachys siamensis	3	0	0	1	1	1	(4)	0

[1] Listing covers number of reports wherein whole plantlets were obtained from culture=1...x; and where a part of propagation protocol is available=(1.....x).

[2] Abbreviations for explant for culture initiation; S/Sgs=Seed/Seedlings; N-F Explants from a non-flowering clump; F=Inforescence explants.

[3] Anther culture leading to plantlets.

MICROPROPAGATION RESEARCH IN SOUTH ASIA

Sanjay Saxena and Vibha Dhawan

INTRODUCTION

At one time, the supply of bamboo was thought to be perpetual. However, this impression has turned out to be a mirage. The mounting pressure of rapidly rising human and livestock populations and over-exploitation by paper and pulp industry has resulted in a significant decline in bamboo cover. Currently, there is a wide gap between the demand and supply of bamboo and if immediate and appropriate measures to restore denuded bamboo areas are not taken, the existing situation will deteriorate further.

Regeneration of bamboo takes place sexually as well as vegetatively. However, both the methods of propagation are beset with many problems that restrict their large-scale use. In view of the constant increase in demand, the scarcity of planting material and the problems associated with conventional methods of propagation, development of effective *in vitro* methods of clonal propagation for different bamboo species is highly desirable.

CURRENT STATUS OF TISSUE CULTURE

Although the pioneering report describing regeneration of bamboo plantlets through embryo culture appeared way back in the late 1960s (Alexander and Rao, 1968), extensive *in vitro* studies on bamboos started only about a decade ago. A complete protocol for micropropagation of *Bambusa bambos* (*Bambusa arundinacea*) was published for the first time by a group of Indian

workers (Mehta *et al.* 1982). Micropropagation methods for many bamboo species have since been successfully worked out (see Table 1, Saxena, 1993).

Micropropagation in bamboos has been attempted both from seed/seedling and mature explants. Whereas with seed/seedling explants one can merely bulk up the planting material (quantitative gains), multiplication of superior bamboo clumps possessing desirable traits (qualitative gains) is possible only with the use of adult tissues. Unfortunately, in comparison to embryonic tissue, very limited success has been achieved with adult tissues. As far as the development of a micropropagation protocol is concerned, both materials have their own merits and demerits. These are compared in Table 2 (after Paranjothy *et al.*, 1990).

All three modes of *in vitro* propagation, forced axillary branching, somatic embryogenesis and organogenesis have been exploited for the micropropagation of bamboos.

Forced Axillary Branching

For transmittance of parental traits to progenies, the *in vitro* raised plants must be true to the parent type; otherwise, the whole purpose of micropropagation is defeated. From this point of view, forced axillary branching method of shoot multiplication is considered to be the most suitable. Nadgir *et al.* (1984) successfully employed this technique to multiply the shoots derived from seedlings of *Dendrocalamus strictus* and proposed a protocol by which nearly 10,000 plants could be produced annually from a single embryo. Working with the same species at National University of Singapore, Dekkers and Rao (1989) obtained multiple shoots, but only a few of them could be rooted. Saxena (1990) adopted a similar methodology to produce plants of *Bambusa tulda* on a large-scale. Other reports also describe regeneration of plantlets by this method (Table 1) but as they lack procedural and technical details, they are not discussed here.

In relation to the micropropagation of adult plants of bamboo, the success has been rather restricted. Nadgir *et al.* (1984) made

Table 1 : *Current status of tissue culture of bamboos*

Species	Adult/ Juvenile	Explant	Mode	Results	References
Bambusa (bambos)	J	Seed	SE	Plantlets	Mehta *et al.*, 1982
	A	Nodal Segment	Axil.	Shoot	Nadgir *et al.*, 1984
B. beecheyana	A	Young inflorescence	SE	Plantlets	Yeh & Chang, 1986
B. glaucescens	A	Dormant culm bud	Axill.	Plantlets	Banik, 1987
B. multiplex	A	Shoot-tip	Adv.	Plantlets	Huang *et al.*, 1989
B. oldhamii	A	Shoot-tip	Adv.	Shoots	Huang *et al.*, 1989
		Young inflorescence	SE	Plantlets	Yeh & Chang, 1986
B. tulda	J	Seedling	Axill.	Plantlets	Saxena, 1990
B. ventricosa	A	Nodal segment	Axill.	Bud-break	Dekkers & Rao, 1989
	A	Culm sheath base		Callus	Dekkers & Rao, 1989
B. vulgaris	A	Nodal segment	Axill.	Shoots	Nadgir *et al.*, 1984
Dendrocalamus brandisii	J	Seedling	Axill.	Plantlets	Vongvijitra, 1990
D. latiflorus	A	Internode	Adv.	Plantlets	Zamora *et al.*, 1989
D. membranaceus	J	Seed	Axill.	Plantlets	Vongvijitra, 1990
D. strictus	J	Seedling	Axill.	Plantlets	Nadgir *et al.*, 1984
	J	Seed	SE	Plantlets	Rao *et al.*, 1985
	J	Seed	Axill.	Plantlets	Dekkers & Rao 1989
	J	Seedling	Axill.	Plantlets	Preetha *et al.*, 1992
	A	Nodal segment	Axill.	Plantlets	Nadgir *et al.*, 1992
	A	Nodal segment	Axill.	Plantlets	Chaturvedi & Sharma, 1993
Otatea acuminata aztecorum	J	Seed	SE	Plantlets	Woods *et al.*, 1992

Table 1. *Continued ...*

Species	Adult/ Juvenile	Explant	Mode	Results	References
Phyllostachys aurea	A	Shoot-tip	Adv.	Plantlets	Huang *et al.*, 1989
Sasa pygmaea	J	Shoot	Adv.	Shoots	Huang *et al.*, 1989
Sinocalamus latiflora	J	Seed	SE	Plantlets	Yeh & Chang, 1987
	A	Anther	SE	Haploids	Tsay *et al.*, 1990
Schizostachyum brachycladum	A	Culm sheath base		Callus	Dekkers & and Rao, 1987
Thyrsostachys sianensis	A	Culm sheath base		Callus	Dekkers & Rao, 1987

Table 2 : *Merits and demerits of micropropagation of bamboos from seed/ seedling and adult explants*

No.	Character	Explant	
		Seed / Seedling	Adult
1.	Availability of explant	Restricted	Substantial
2.	Time for initiating fresh cultures	Round year	Generally restricted to rainy season
3.	Microbial contamination	Negligible	Often serious
4.	Multiplication of shoots	Relatively easy	Difficult
5.	Rooting ability of shoots	High	Low
6.	Browning of medium	Rare	Common
7.	Clonal uniformity between the mother and the regenerated plants	Unlikely	Almost certain
8.	Propagation of elites	Not possible	Possible
9.	Precocious flowering of regenerated plants	Improbable	High probability

a breakthrough in multiplying shoots derived from nodal explants of adult *Bambusa bambos, B. vulgaris* and *Dendrocalamus strictus*. However, rooting occurred only in *D. strictus* and that too, at a very low frequency (maximum of 20%). Chaturvedi *et al.* (1993) failed to multiply *D. strictus* shoots but succeeded in inducing 30% rooting along with regeneration of axillary shoots when nodal segments were cultured upside down on a complex medium containing 2,4-D and phloroglucinol. In *B. glaucescens*, the excised axillary buds produced multiple shoots on a medium supplemented with 5 mg/l BAP, 1 mg/l NAA and 3 g/l activated charcoal (Banik, 1987), but further multiplication of these shoots did not occur. In *B. tulda*, more than 95% branch cuttings formed shoots *in vitro*; however, such shoots failed to multiply beyond four passages (Saxena and Bhojwani, unpublished). Recently, Saxena and Bhojwani (1993) have reported a complete protocol for multiplication of 4-year-old plants of *Dendrocalamus longispathus* growing in the field. For the first time in a micropropagation protocol involving adult bamboo plants, a rooting frequency of more than 70% and transplantation success of over 85% have been achieved. The protocol was successfully applied to produce more than 200 tissue cultured plants. According to the authors, the protocol should be workable on a still larger-scale.

Paranjothy *et al.* (1990) have highlighted some of the probable factors responsible for poor success with adult explants. These include microbial contamination, browning of the medium, and inconsistency in shoot multiplication process. However, low rooting frequency has been regarded as the most serious bottleneck in developing a complete micropropagation protocol.

Somatic Embryogenesis

Somatic embryogenesis is a useful technique for producing plants on a commercial scale. In comparison to the forced axillary branching method, this approach is less cumbersome and relatively cheaper. Various explants, such as mature embryos, seedling-shoots, shoot-tips, culm sheath bases, young inflorescences,

anthers and adventitious roots, have been used to initiate embryogenic cultures in bamboos. While callus formation was observed in almost all cases, complete plantlets via somatic embryogenesis could be regenerated only in *B. arundinacea* (Rao *et al.*, 1985). *B. beecheyana* (Yeh and Chang, 1986b), *B. oldhami* (Yeh and Chang, 1986a), *D. strictus* (Rao *et al.*, 1985; Niraula and Raj Bhandary, 1987) and *Sinocalamus latiflora* (Yeh and Chang, 1987; Tsay *et al.*, 1990).

Organogenesis

Generally, the organogenic pathway of producing tissue cultured plants is avoided as this approach is highly susceptible to producing variants. Regeneration of bamboo plants through organogenesis has been reported only in *Bambusa multiplex* and *Phyllostachys aurea* (Huang *et al.*, 1989) and *Dendrocalamus latiflorus* (Samora *et al.*, 1989).

Most reports dealing with bamboo tissue culture have come from Asia, particularly India, China and Thailand (Table 1). This is possibly due to the fact that nearly 3/4th of the total bamboo reserves in the world are located in this region. As far as India is concerned, there are many laboratories that are engaged in research on bamboo tissue culture. Some of the major research centres are the National Chemical Laboratory (Pune); the University of Delhi; and the Tata Energy Research Institute (TERI), New Delhi. Reports dealing with micropropagation of bamboo have also come from the National Botanical Research Institute (Lucknow); the University of Gorakpur, the Institute of Forest Genetics and Tree Breeding (Coimbatore); and the CSIR complex, Palampur. Besides mostly government-aided laboratories, private commercial companies, such as Indo-American Hybrid Seeds, are also working on micropropagation.

Over the last six years, TERI has been actively involved in developing micropropagation protocols for various bamboo species. However, the efforts were mainly focused only on three species : *Bambusa tulda, Dendrocalamus longispathus* and *Bambusa vulgaris*. While success was achieved in developing complete

protocols for mass propagation of *B. tulda* and *D. longispathus*, plants of *B. vulgarts* could be produced only at a laboratory scale.

Bambusa tulda

Bambusa tulda, is widespread in North-east India. It is also planted in the plains and foothills of North India. It generally grows 6-21 m in height and 2.8-8.0 cm in diameter. *B. tulda* flowers gregariously once in 30-60 years. Sporadic flowering has also been reported. The culms which are harvested after 4-5 years are strong and hold good market value. Besides being a major source of raw material for the paper and pulp industry, this bamboo is routinely used in house construction and for many other purposes.

Seeds of *B. tulda* obtained from the Forest Research Institute, Dehra Dun, were surface sterilised with 0.05% mercuric chloride and germinated on filter paper bridges dipped in liquid MS (Murashige and Skoog, 1962) medium supplemented with 2% sucrose. The shoots from 3-week-old seedlings multiplied best on liquid MS + BAP ($8x10^{-6}$M) + Kn ($4x10^{-6}$M) with a multiplication rate of about 4-5 fold every four weeks. Under *in vitro* conditions, 92% of the shoots rooted within 4 weeks on a modified MS medium (NH_4HO_3 reduced to half strength) supplemented with $1x10^{-5}$M IBA and $6.8x10^{-5}$M coumarin.

The rooted shoots were hardened *in vitro* for 7 days in bottles containing soilrite and irrigated with inorganic salts of MS medium (major salts reduced to half strength). Subsequently, the plants were transferred to polythene bags containing equal quantities of soil, soilrite and farmyard manure and reared in a glasshouse (RH 75%-80%) for 3 months. Thereafter, the plants were kept in the nursery for 6 to 8 months and then planted in the field. The detailed methodology and other experimental observations have been discussed elsewhere (Saxena, 1990). Following this procedure, nearly 2,000 plants were produced. These plants were planted in various states (Haryana, U.P., M.P. and Bihar) through respective Forest Departments during 1991-92.

Since the ultimate objective of *in vitro* propagation is to multiply superior clones, the studies performed with seedling explant were later extended to the adult plants of *B. tulda*. Cultures were initiated with experimental material brought from the State Forest Research Centre, Jabalpur. Multiple shoot formation (5-8) was achieved within 10-12 days on MS medium containing BAP ($1.5x10^{-5}$M) and Kn ($4x10^{-6}$M). These shoots could be multiplied for two passages at a rate of 4 fold every 3 weeks. Thereafter, the multiplication rate declined drastically and by the end of the 5th passage, all the shoots became dormant. These shoots failed to rejuvenate and finally died. The study suggests a strong maternal influence, which could not be overcome by manipulation of phytohormones and other growth nutrients present in the culture medium or change in physical conditions (Saxena, 1993).

Although, it is premature to derive any conclusions on the basis of early performance of the plants in the field, so far the survival and overall growth of these plants has been satisfactory. In fact, some of the plants planted at Mohan (U.P.) in 1991 had reached 5.5 m in height in about 2 years after field transfer.

Dendrocalamus longispathus

D. longispathus grows widely in parts of West Bengal, Assam and other areas of Eastern India, usually along streams. It can grow up to an elevation of 4,000 m. The culms generally attain a height of 10-18 m. ft and a diameter of 6-10 cm. It is one of the 15 economically important bamboo species of India that are recommended in the manufacture of paper, particularly craft paper. It also has many other uses.

Four-year-old clumps growing at Gual Pahari, Haryana, served as the source material for micropropagation work. Single node segments excised from actively growing branches were surface sterilised with 0.1% mercuric chloride for 10 minutes. After three washings with sterile distilled water, the explants were inoculated on MS and B_5 (Gamborg *et al.*, 1968) medium containing

cytokinins (BAP, Kn and 2-ip) and auxins (IAA and NAA), either individually or in various combinations. 75% explants showed bud-break within 2 weeks on MS medium supplemented with $1.2x10^{-5}$M BAP and $3x10^{-6}$M Kn. For shoot multiplication, the entire clusters of axillary shoots produced by 2-week-old primary cultures of nodal segments were transferred to liquid MS medium supplemented with various phytohormones. On the optimal medium for shoot multiplication [MS + BAP ($1.5x10^{-5}$M) + IBA ($1x10^{-6}$M) + coconut water (10%)], the shoots were multiplied for over 15 passages at a rate of 3.2 fold every 4 weeks.

Rooting was attempted both *in vivo* and *in vitro*. No rooting was achieved when shoots were directly transferred to the soil under *in vivo* conditions. Therefore, rooting was attempted *in vitro* for which MS was used as the basal medium. For root induction, a variety of auxins such as IAA, IBA and NAA were tested at different concentrations. Whereas 11% shoots rooted on ($1x10^{-5}$M) IBA, no rooting was achieved with IAA or NAA. 36% shoots rooted when coumarin ($6.8x10^{-5}$M) was used in conjunction with IBA ($1x10^{-5}$M). However, rooting frequency increased sharply to 73% when the shoots were rooted on a modified MS medium (salts reduced to half strength) containing $1x10^{-5}$M IAA, $1x10^{-5}$M IBA and $6.8x10^{-5}$M coumarin. After *in vitro* hardening, more than 85% micropropagated plants were successfully transferred to soil. The surviving plants produced new culms within 5 to 6 weeks. More than 200 tissue culture raised plants have been successfully transferred to soil.

Bambusa vulgaris

B. vulgaris, grows wild in the warmer parts of the country up to an altitude of 1,500 m, thriving best near river banks. This widely cultivated species grows 6-18 m in height and 5-10 cm in diameter. The most commonly grown variety 'Striata' bears characteristic green streaks on a yellow background. This bamboo grows very fast and can attain a height of 9 m within 3 months. It is a highly versatile bamboo and is extensively used. The culms are relatively soft and possess long fibers, making

them a valuable source of paper pulp. The variety 'Striata' is a popular ornamental. *B. vulgaris* has perpetually remained vegetative with no flowering reported. In some isolated and not well documented cases, it is reported to have flowered sporadically without producing any viable seeds. Consequently, vegetative propagation through cuttings and rhizomes is the only method of raising new plantations.

Young lateral branches were collected from Gual Pahari (Haryana) and the State Forest Research Centre, Kanpur, U.P. Single node segments derived from the middle of branches served as explants. The primary cultures were often infested with bacterial and fungal contamination. The explants were thoroughly washed with "Cetavlon" under running tap water and surface sterilised with 0.1% mercuric chloride for 10 minutes. The nodal segments were then cultured on medium containing streptomycin and chloramphenicol. For the induction of bud-break and shoot multiplication, B_5 and MS basal medium were tried. The media were routinely supplemented with various cytokinins (BAP, Kn and 2-ip) and auxins (IAA, IBA and NAA), either individually or in various combinations. On optimal medium (MS + $1.2X10^{-5}$M BAP + $4x10^{-6}$ M Kn), 72% of the explants showed bud-break. Of the various multiplication media that were tried, the best results were obtained on MS medium supplemented with BAP ($2.5x10^{-5}$M) + Kn ($5x10^{-6}$M). On this medium, the shoots multiplied at a rate of 2.4 fold every 6 weeks (Saxena, 1993). Occasionally, there was a decline in this multiplication rate but the shoots recovered on their own in subsequent passages. The cause for this peculiar phenomenon, also observed in some forest tree species, could not be ascertained.

Although, a variety of auxins (IAA, IBA and NAA) and other growth regulators such as phloroglucinol, coumarin, activated charcoal and boric acid were tested to induce rooting, only a maximum of 10% rooting was achieved when shoots were cultured on MS supplemented with IAA, IBA and coumarin (100 mg/l each) for 2 days and then transferred to a hormone-free MS

medium. Attempts to improve rooting frequency by altering physical environment also proved futile. According to Saxena (1993), low rooting frequency will be the major bottleneck in the establishment of a commercially viable protocol of *B. vulgaris*. A few tissue cultured plantlets were successfully transferred to soil in pots.

Future Trends

With the passage of time the demand for bamboo will increase while its availability will decline. The existing gap between consumption and supply of bamboo is likely to widen further. To bridge this, bamboo production should be stepped up from its current level. This can be achieved either by bringing more land under bamboo or by increasing yields from existing bamboo areas. Due to population pressure and other developmental constraints, it may be rather difficult to bring additional land under bamboo cover. However, a genuine effort must be made to raise new bamboo plantations under various social forestry and agro-forestry programmes.

Micropropagation of bamboos would be useful even with seed/seedling tissue as it would augment the supply of planting material. However, it would be ideal to perform micropropagation with adult tissues as it would help in multiplying superior bamboo clumps on a large-scale. Recent success with *D. longispathus* (Saxena and Bhojwani, 1993) is a step forward in this direction.

Besides exploiting the existing superiority of certain bamboo clumps, efforts should be launched to develop improved varieties through hybridisation. Conventional breeding in bamboos is extremely difficult on account of long and often erratic flowering cycles. Tissue culture can be of immense help in solving this problem. Success has already been achieved in inducing *in vitro* flowering in various bamboo species such as *Bambusa bambos* and *Dendrocalamus brandisii* (Nadgauda *et al.*, 1990), *D. strictus* and *B. arundinacea* (Rao and Rao, 1990), *D. hamiltonii* (Chambers *et al.*,

1991). Recently, Prutpongse and Gavinlertvatana (1992) reported sporadic *in vitro* flowering in 8 bamboo species. However, research on *in vitro* flowering in bamboos is still in its infancy and more effort is required before this technique is applied to develop new bamboo varieties.

It may be concluded that the potential of bamboo tissue culture has not yet been fully realised. Both extensive and intensive research is required in this direction. Besides various State Forest Departments, voluntary agencies and NGOs and INBAR can play a vital role in meeting this goal.

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APPENDIX 5

REVIEW OF CONVENTIONAL PROPAGATION RESEARCH IN BAMBOOS AND FUTURE STRATEGY

R.L. Banik

INTRODUCTION

Bamboo is a wonderful gift of nature. The people of Asia, Africa and South America are dependent it for their housing and agricultural implements. It is extensively used for making pulp and paper, domestic commodities and in cottage industries. Bamboo shoots are eaten as vegetables, expecially in Southeast and East Asia. The plant is also known as "green gold" for its fast growth rate. In addition, it conserves soil, regreens eroded slopes and provides short-term income and employment in small cottage industries. Many cultural traditions in the rural areas of Asia are intimately connected with bamboo. With a conservative estimate, Liese (1992) pointed out that 2.5 billion people depend on or use bamboo materials at a value of 7 billion US $ per annum.

There are as many as 75 genera and 1250 species of bamboo distributed in tropical, sub-tropical and temperate zones of different parts of the globe (Sharma 1980). Tropical Asia is the major centre of bamboo diversity, with as many as 45 genera and 750 species (Biswas 1988).

Bamboos have been cultivated regularly in the villages compared to forest bamboos which occur naturally. The rural poor are the principal users of bamboo, using many times more material than the pulp and paper industries. The world's annual production of bamboo has been estimated at more than 20 million tonnes (Sharma 1980). Annual production of bamboo

sometimes fluctuates within a wide margin, mainly because of large-scale death of bamboo clumps due to gregarious flowering. The yield of bamboos varies considerably, depending upon the intensity of stocking and biotic interference. It varies between 0.2 to 4.0 t/ha and in most cases is not very encouraging.

In the past, bamboo was a perpetual resource because of its vigorous vegetative regeneration. But at present, over-exploitation associated with growing human populations, destruction of tropical forests, and new demands for industrial uses (especially by the pulp and paper industry) have resulted in wide-scale reduction of bamboo stocks.

There is an urgent need to develop the bamboo resource base through massive programmes for plantations with genetically improved planting stocks. As bamboo is a fast growing and quick harvested crop, the output of plantations will be apparent 2 to 3 years after afforestation and reforestation activities.

The main beneficiaries will be the rural poor because, as the resource base increases, there will be socio-economic benefits, and employment, both in harvesting and cottage industries, will increase.

CONVENTIONAL METHODS OF BAMBOO PROPAGATION

Vegetative Propagation

The bamboo plant consists of three morphological parts - the aerial part (the culm) and two underground parts (the rhizome and root). A bamboo propagule must develop all three structures. Failure in development of any of these structures leads to failure of a propagule (Banik 1980). Due to the scarcity of seeds, bamboo is generally propagated by vegetative methods. These include:

- Clump division - offsets, rhizome,
- Whole culm cutting,
- Layering,
- Culm-segment cutting,

- Branch cutting and
- Macroproliferation.

These methods have been studied in different countries and each country has methods suitable for their own species. (Table 1).

Clump divisions

This is the traditional, and perhaps the most generally prevalent method of vegetative propagation (McClure 1966). Clump divisions are generally done in two ways - offset planting, and rhizome planting.

Offset planting

The term "offset " was designated by Deogun (1937) for bamboo propagules, each composed of the lower part of a single culm with the rhizome axis basal to it. According to Deogun, 1- or 2-year old offsets of *Dendrocalamus strictus* gave best results, while propagules consisting of material 3 years or more in age gave progressively poorer results. Over a century ago, Peal (1882) reported that propagation of bamboos by offset planting was common in the villages of Assam and Bengal. It is evident from Table 1 that offset planting is common in most bamboo growing countries.

Both age of the offsets and their collection time have significant effect on their survival and growth in plantations (Banik 1991). Offsets of *Bambusa balcooa, B. longispiculata, B. tulda, B. vulgaris, D. longispathus, M. baccifera, Neohouzeaua dullooa* and *O. nigrociliata* were planted both in April and June. Success was higher (44-76%) when collected and planted in April than in June (3-38%). The younger (1 year old) offsets showed higher percentage of survival than older ones (2-3 year old). Thin walled species like *M. baccifera, N. dullooa* and *O. nigrociliata* showed poor success in offset planting. In these species, success was obtained (30-40%) by planting rhizome assemblies (part-clumps) with 2-3 offsets at a time.

Rhizome planting

Reports on the propagation of bamboos by rhizome planting are meagre (McClure 1966). Dabral (1950) described it as "the best method", but he did not mention the species or details of the method. The use of rhizomes for propagating bamboo has been limited to non-clump forming species (Uchimura 1977).

Oh and Aoh (1965) mentioned that planting of rhizome cuttings, 40-50cm long, 10cm deep, gave good results in Korea. In propagating *Shizostachyum lumampao*, an endemic species of Philippines, Uchimura (1977) obtained success only by planting of rhizomes or offsets. This was usually done with 1-year old culms that were excavated along with their root systems. The culms were cut to about 1-m high and planted during the rainy season.

McClure (1966) opined that planting of rhizomes might have advantage over offsets, being lighter and less bulky. However, he also mentioned that offsets could be physiologically more suitable for plantations as they have some foliage.

Use of these propagules are practicable only in cultivating a few clumps, particularly within a small accessible area.

Whole culm cutting

Kurz (1876) described this method as "by taking whole halms (culms) with their roots and burying them length-wise in the ground". Pathak (1899) tried propagation of *Dendrocalamus strictus* using 3-5 year old culm cuttings. Although sprouting was good in the initial stages, the cuttings failed to establish during summer. McClure and Kennard (1955) did some experiments with *D. strictus* and *B. tulda* and reported that 2-year old culms produced more propagules than 1-year old culms. The success was reasonable, but the procedure was cumbersome.

Layering

The layered stem when rooted is detached to become a new plant. Three layering procedures for bamboos have been described (McClure 1966). These are:

Ground or Simple layering: Either a whole culm or only the branch bearing part of it is bent down to the ground and into a shallow trench, fastened in place by means of hooked or crossed stakes, and covering it with suitable propagating medium.

Stump layering: The 1-2 node stumps of severed culms are covered with a suitable propagating medium.

Air-layering or marcotting: A culm is kept erect, and the base of each branch complement in the mid-culm range is surrounded with a suitable propagating medium, held in place by a suitable receptacle.

McClure (1966) found that 1-year old culms of *B. textilis* and *Guadua angustifolia,* when bent down and covered with earth while still attached to the mother clump, satisfactorily produced little plants. According to him, this method was too cumbersome except in dwarf cultivars of *B. mutiplex* var. *riviereorum.* Cabandy (1957) obtained a survival of 28% for *B. blumeana* by ground-layering 1-year old culms pruned off branches.

While studying the stump layering methods in *B. longispiculata,* McClure (1966) obtained only 25% rooted branches, but it increased up to 54% when the stumps were treated with 200 ppm IBA. He also tried the same method with 4 other species: *B. textilis, B. tulda, B. tuldoides* and *D. strictus,* and reported that either the plants died or did not produce any rooted propagules.

In exploratory studies, McClure (1986) tried air layering of matured branch components of 1-year old culms of *B. tuldoides* and current year (developing) branch complements of *Semiarundinaria fastuosa* without achieving any success with either species. Cabandy (1957) obtained success (70%) in marcotting only with *B. blumeana.*

Culm-or Stem-cutting

Propagation of bamboos through culm or stem segments is known as the culm-cutting or stem-cutting technique (McClure 1966, Troup 1921). Generally, culm segments of bamboos of 1, or usually 2-3 nodes bearing healthy buds or branches, have been

used for propagation (McClure 1966). The branches on each culm segments are generally pruned to a length of less than 25cm and no foliage is retained. Such cuttings are usually set upright or at an angle, with at least one node well covered.

As early as in 1899, Pathak used 2-node culm cuttings for propagating *D. strictus* in Orissa, India. The success was about 95% after one year, and finally all died after 2 years. Later, Dabral (1950) reported limited success in this species at Dehra Dun. Sharma and Kaushal (1985) obtained best rooting and survival in 1-node culm cutting taken from 1-10 basal nodes of 6-8 month old culm in the month of March (Spring). Good success and survival were also obtained in *B. nutans*, *B. tulda*, and *D. hookerii* by culm cutting methods (Bohidar 1989, Stapleton 1987). Surendran and Seethalakshmi (1985) reported that rooting and sprouting responses were significantly enhanced by the application of growth regulators. The success rate was 80% in *B. arundinacea*, 70% in *D. strictus*, 50% *D. scriptoria* while treated with hormone in contrast to the control 40%, 50% and 10%, respectively. In *B. balcooa*, they obtained 40% success in branch cuttings, and 60% in culm-cuttings. Effective hormones were IBA and NAA.

In Nepal, a good success rate (60-80%) from single node culm cuttings have been achieved in *B. balcooa*, *B. nutans*, *D. hamiltonii*, *D. hookerii*, and *D. nigrociliata* (Das 1988).

Propagation studies in Sri Lanka showed that 2-node culm-cuttings of some major bamboo species are more satisfactory than split culm-cuttings, and the technology is being gradually transferred to the planters (Vivekanandan 1987).

In the Philippines, Chinte (1965) reported a 60% survival for *B. vulgaris* and 28% for *Gigantochloa asper*, whereas *B. blumeana* and *G. levis* failed to grow. Three node cuttings survived better than 2-node planting stocks, and the basal sections were superior to the middle and top sections. Another study on *B. blumeana* showed a greater percentage of survival (60%, 8%) in culm cuttings planted unsplit (Cabandy 1957). For *G. levis*, unsplit culm cuttings also gave better results, and the middle and top

portions of the culm were the best material for propagation (Bumalong and Tamolang 1980). Mabayag (1937) found that the basal portions of culm cuttings of *B. blumeana* were better than the middle and top portion of the culm. In a separate study, 2-node split and unsplit (about 1-2 year old) culm-cuttings of 4 different bamboo species planted directly in the field showed better result (94%) after 3 months and poor results (11.7%) after 15 months of trial (Bumalong and Tamolang 1980). Suzuki and Ordinario (1977) obtained 45% survival of *B. blumeana* treated with IBA and 32% for controls; 80% for treated *B. vulgaris* and 75% for controls; 60% for treated *D. merrillianus* and 53.5% for controls. However, Uchimura (1977) found that, of the three growth regulators (IAA, IBA and NAA), cuttings treated with 100 ppm of IBA for 24 hours gave better rooting percentage and formation of longer roots in *B. vulgaris*. In a similiar study with *B. blumeana* using different concentrations of IAA, IBA and NAA, Bumalong and Tamolang (1980) observed that rooting was maximum with 600 ppm NAA. Palijon (1983) reported that cuttings treated with rooting hormones were higher in shoot production and the shoots were taller and wider in diameter than those of untreated cuttings, but there was no difference in survival rate at field level between them. Scientists also believed that the starch content and the levels of various nutrients in the cuttings might have influenced the rooting. Joseph (1958) found high amount of starch content in culm cutting of *B. arundinacea* during February and March. Banik (1987) emphasised that preparation of culm segments in the month of April-May from the mid-zone of a young culm was critical for obtaining successful results in *B. vulgaris*, *B. balcooa*, *B. tulda*, *Dendrocalamus giganteus*, *D. longispathus* and *Melocanna baccifera*.

Recently, Gonzales *et al.* (1991) from the Philippines reported that split-culm cuttings can reduce the weight of the planting stock in comparison to those produced as whole culm cuttings. They obtained 100 percent survival with cuttings of *Bambusa blumeana*, *B. blumeana* var. *luzonensis*, *B. philippinensis*, *B. vulgaris*, *B. vulgaris* var. *striata* and *G. asper*.

Branch cutting

White (1947) reported that it was possible to propagate *Gigantochloa verticillata* and *Sinocalamus oldhami* by branch cuttings. Delgado (1949) and McClure and Durand (1951) also propagated bamboos by using branch cuttings, but with poor rooting percentages.

Studies showed that in most bamboo species of Bangladesh, normal branch cuttings rooted well under mist tents, but the majority of them did not produce any new culm, owing to the failure of rhizome development (Hasan 1977). Such cuttings might survive up to 4-5 years only with the help of roots but without any further shoot production and clump formation (Banik 1980).

Banik (1980) successfully induced *in situ* rooting and rhizome at the branch bases of some thick-walled bamboo species of Bangladesh. Artificial induction was possible by chopping the culm tops and removal of newly emerging culm. He termed these "pre-rooted and pre-rhizomed branch cuttings". Such cuttings performed better than normal branch cuttings (Banik 1984, 1987a). These cuttings have to be collected through excising the branch base from the nodes of the standing culms during April to June. For activating the aerial roots and rhizome, branch cuttings are to be inserted to a depth of 7 cm in sand and maintained under overhead misting for one month. A propagation bed is a 3-layered sand, each layer being 7-10 cm deep and made up as follows :

- gravel and large size sand at the bottom
- medium size sand in the middle
- fine sand at the top

In each layer clean, sand is placed so that the bed remains well-drained. A propagation bed is 1.2m wide and 12m long, situated on level ground in the nursery. Within 30 days each of the prerooted and prerhizomed branch, cuttings produce pro-

fuse active roots in the propagation bed. Once profusely rooted, the cuttings are transferred to polythene bags and kept in the nursery. The average rooting and rhizome formation ability of these type of branch cuttings are 67% in *B. balcooa*, 70% in *B. nutans*, 93% in *B. polymorpha*, 90% in *B. vulgaris* and 63% in *D. giganteus* (Banik 1984, 1991). Like seedlings, cuttings also need aftercare in the nursery at least up to the next monsoon. Survival of these cuttings in the field is as high as high 85-97%.

Macroproliferation of bamboo seedlings

Several methods of vegetative propagation are common in many grasses, e.g. use of tillers, culms, rhizomes or stolons (Langer and Ryle 1958). Like many other grasses, bamboo has the inherent proliferating capacity to reproduce itself probably due to its long interseeding period. By utilising this habit, an interesting technique has been developed by Banik (1987a) for multiplication of a seedling through the rhizome separation method. He termed the technique macroproliferation of seedlings. He reported that 5-9 month old seedlings of *B. tulda* can be multiplied 3-5 times in number through this technique. Every year the seedling can be multiplied at the same rate and a big portion of them may be planted while keeping a stock for future macroproliferation. The survival rate of these multiplied seedlings is 90-100%. It has also been observed that seedlings of *B. arundinacea*, *B. tulda*, and *D. strictus* raised in big-sized polythene bags (15x23cm) produced a higher number of shoots (6-8 number) within one year than in small sized bags (10x15cm). Therefore, seedlings raised in big polythene bags produced a higher number of multiplied seedlings (5-7 times), whereas seedlings in a small-sized bag could produce only 2-3 number of multiplied seedlings. Later, Adaresh Kumar *et al.* (1988) also used this method successfully for multiplication of the seedlings of *B. arundinacea*, *D. strictus*, and *D. hamiltonii*. Recently, in India a detailed plan has been developed by Adaresh Kumar (1991, 1992) for continuous production of field plantable saplings in

massive numbers viz., *B. arundinacea*-49000; *B. tulda*-25000; *D. hamiltonii*-16000; and *D. strictus*-36000 (or in multiples) every year for any desired number of years.

Advantages of this method are that once seedlings of a bamboo are available, the process can be continued at least for a number of years. Proliferated seedlings remain small in size due to continuous rhizome separation, thereby making it easy to handle and transport them (Banik 1987, Tewari 1992). However, Banik (1987a) suggested that seedling multiplication in this way should not be continued for a very long time since the time gap between the last multiplication and subsequent flowering gets shorter. As a result, the last multiplied seedlings might start flowering due to their physiological maturity before attaining the commercial culm size.

Propagation through Seeds

Seed characters and measurements

As bamboos produce seeds after long time intervals, the knowledge on different aspects of seed propagation is very limited. Bamboo produces one-seeded fruits with thin pericarp adnate to the seed coat, known as a *caryopsis* and covered with a number of persistent glumes (Gamble 1896). Kurz (1876) described the fruit of *Melocalamus compactiflorus* as "a small wood-apple", and the fruit of *Melocanna baccifera* as "berry-like". Seeds of bamboos are very different both in size and weight depending on the species. Seeds are generally small, grain-like and wheat-coloured; but those of *M. baccifera* are onion-shaped, big and green coloured. Generally large-sized bamboos produce smaller seeds than small-sized bamboos (Anantachote 1988).

Seed production per clump varies from 30-80g in *B. arundinacea* var. *spinosa*, 15-17g in *B. glaucescens*, and 40-90g in *Dendrocalamus longispathus*. One full grown clump of *Melocanna baccifera* produces 5-7 kg seeds. In general, the number of seeds per kg varies from 13,000-15,000, depending on the species (Banik 1987b, Liese 1985). According to Anantachote (1987), the weight of 10 seeds

of *T. siamensis*, *B. nutans*, and *Gigantochloa hasskarliana* is 0.62g, 0.30g, and 0-38g, respectively.

Seed collection and processing

In bamboo species, mature seeds drop on the ground and become exposed to predators, such as birds, especially chickens and pigeons in the homestead, and to rats, porcupines and wild boar in the natural forests. Birds and squirrels also eat seeds while on the plant. Only careful collection can overcome the predation problem. Seeds can be collected both from the clumps and from the ground. Generally, seeds produced in the early part (mid-February to May) of the season are healthy and more viable.

Except for *M. baccifera*, glumed seeds of all other species can be separated from debris and empty seeds by floating in water. As the seeds of *M. baccifera* are big and not covered with glumes, they can be separated easily from debris and unwanted materials.

Seed germination, longevity and storage

Seeds of different bamboo species possess embryos at their swollen stalk-ends and, therefore, care should be taken to bury this portion in the soil during sowing to protect germinating radicles from being desiccated. Seeds should be sown in polythene bags just after collection. Bamboo seeds germinate at higher percentage under shade than in direct sunlight. Thus, bamboo seeds can be considered as negatively photoblastic (Banik 1991). The germination media (soil and cowdung 3:1) should be wet, but not waterlogged. Seeds start germinating within 3-7 days of sowing and continue up to 15-25 days (Banik 1987b).

Banik (1991) reported that for *M. baccifera*, the seed weight has a significant effect on seedling survival. Seedlings survive up to 70-75% when raised from seeds heavier than 50 g, while it drops to 50% when raised from light weight seeds (7-17 g). Different types of abnormalities, such as rootless plumules, stunted radicles

and radicles growing upward, were observed in seedlings of *M. baccifera* produced from light weight seeds.

It was found that the fresh seeds of *B. arundinacea* var. *spinosa*, *B. tulda* and *D. longispathus* germinated better than stored ones (Banik 1987b). The seeds have a germinative power which lasts only 1-2 months. It was possible to preserve the seed viability of a bamboo species (*Phyllostachys* sp.) by storing the seed over calcium chloride at room temperature. Sur *et al.* (1988) observed that for maintaining the vigour and viability of seeds of *D. strictus*, soaking-drying treatment with low concentration of disodium hydrogen phosphate (10^{-4}M) proved to be better than water. However, the seeds of *D. strictus* could be stored over silica gel or anhydrous calcium chloride in a desiccator, or at 3-5°C ambient temperature after reduction of its moisture content to 8% (Varmah and Bahadur 1980). Seed lots with 67% germination capacitiy were stored under these three conditions and exhibited 51,54 and 59% germination, respectively, after 34 months. Similarly, Banik (1987b) reported that it was possible to increase the seed longevity period of *B. tulda* up to 18 months by storing over silica gel in a desiccator. The fleshy seeds of *M. baccifera*, when stored in a air-conditioned room, retained viability up to 45 days, while it was only 35 days in normal room conditions, and prolonged further up to 60 days when stored with dry sand in jute bags. The seeds of *M. baccifera* can be carried with dry sand in jute bags during long distance transportation to minimise damage and to retain viability (Banik 1991).

Seedling nursing and management

Initially, seedlings do best in partial shade compared to direct sunlight. Complete shading over seedlings should be discouraged. The emergence of shoots is successive. The new shoots are bigger and taller than older ones. The germinating plumules are very thin (1-2 mm diameter) in *B. tulda* and thick (4-6 mm) in *M. baccifera*. Within 1-4 weeks, plumules elongate rapidly into stems bearing single leaves arising alternately. The stems of *B. tulda*, *D. longispathus*, and *B. polymorpha* are more or less woody in nature, but *M. baccifera* has a soft and succulent stem with

vigorous growth. *M. baccifera* seedlings become most elongated (175 cm) and thick (0.8 cm, dia.) at 3 months of age (Banik 1991).

A rhizome system starts to develop in the seedling 1-2 months after germination, and at a young stage, the rhizome movement is strongly geotropic. Therefore, roots and rhizomes of a seedling penetrate the neighbouring polythene bags of other seedlings in a nursery. This creates a mass of twisted and intertwined roots and rhizomes of seedlings. As a result, the roots and rhizomes are damaged at the time of transportation. Frequent shifting of seedlings from one bed to another helps in minimising the root rhizome intermingling. Seedlings need regular weeding and daily watering in the nursery.

Wild seedlings

Wild seedlings of bamboo look like rice or wheat seedlings and are often seen on the ground just below the flowering mother clumps. The numbers of seedlings can be very profuse and they often form a thick mat on the ground. These dense seedlings compete strongly for survival. Such seedlings should be thinned out to minimise the competition (Banik 1987a, 1989, 1991). Wild seedlings so collected should be brought to the nursery and transplanted to polythene bags containing soil mixed with cowdung (3:1) At the beginning, seedlings have to be kept under shade for 3-5 days for hardening, then placed them under partial shade. Two-to four-leaved stage of wild seedlings of *B. tulda* and *D. longispathus* are best for collection, while in *M. baccifera* germinating seedlings are best. For better survival (about 80-90%) in the field, less than one-year old seedlings should not be transplanted. The rainy season is the best time for planting of seedlings in the field.

WEAKNESSES AND GAPS IN CONVENTIONAL PROPAGATION METHODS

The traditional rhizome/offset methods are applicable only in cultivating few clumps, particularly within a small accessible area. The limitations of traditional methods are:

i. The method is expensive due to high cost of the propagules and labour for excavation and transportation.

ii. Offsets and rhizomes are bulky and heavy (4-30 kg per propagule) and as a result, difficult to handle and transport.

iii. In most species, the survival success is 5-50%.

iv. Availability of propagules per clump is limited, as only young (1-2 year old) culms can be used as propagules. Not more than 30-50% young culms should be collected from a clump; otherwise, it would lose regeneration capability.

McClure (1966) mentioned some problems in propagating clump forming bamboo through rhizomes. These were: i) meagre development of roots, ii) decay of rhizomes, and iii) slowness of rhizome buds to break dormancy.

Other methods such as whole culm cutting are also not always applicable to all bamboo species. Both whole culm cutting and ground layering methods need sufficient space near the clump, which may not always be available. Depending on the species, a culm 10-35m long has to be buried lengthwise. After the striking of roots and shoots on the nodes, propagules have to be excavated for transplanting. The success is also limited (10-40%). The procedure is expensive and labour intensive. The marcotting (air-layering) method is comparatively easier; propagules are smaller in size and success is also reasonable, but the applicability of the method is species specific.

The culm or stem-cutting method is comparatively well studied. This method is also expensive and the propagules are difficult to transport. The disadvantages of the method are:

i) Such cuttings are generally of 1-to 2-node culm segments and, therefore, the length of the segment may vary from 0.1 to 1.5m, and obviously need big-sized pots for planting in the nursery.

ii) Handling, carrying and transportation of these big-sized pots are difficult and expensive due to their heavy weight. Split-culm cuttings can be used to overcome such problem, but applicable only to a few species.

iii) There is the limitation of using 1-2-year-old culms, which can otherwise be put to other uses.

Abeels (1962) mentioned that "there are indications that the stem layering in bamboos may be successful if it is carried out *in situ* and the layered stem is not transported". However, while studying the air-layering in bamboos, Abeels (1962) also mentioned that "cutting out of rooted parts is not easy and on planting time in the nursery, their survival is not definite".

Prerooted and prerhizomed branch cuttings are comparatively more dependable as propagules than are normal branch cuttings. This method has been found suitable mostly for thick-walled and stout branching bamboo species.

As far as is known, most of the thick-walled bamboo species are amenable to vegetative propagation techniques. Thin-walled species like *Melocanna baccifera*, *Oxytenanthera nigrociliata*, and *Neohouzeaua dullooa* are difficult to propagate by any of the known conventional vegetative propagation methods. However, in general no one method of vegetative propagation of bamboos is universal and effective for all the species. From the published literature and practical experience, it is evident that there is *an optimum age for rooting in each type of propagating material* (rhizome, offset, culm segment, branch cuttings, etc.).

In addition, there is also serious risk in vegetative propagation methods in propagating bamboos. Most of the species, in general, maintain a definite period of vegetative state before flowering and synchronised death. The period may vary from 15-120 years. Suppose a species *M. baccifera* flowers after a 30 year interval. If propagules are collected from a 15-year-old clump and planted in the field, they will flower within the next 15 years and die. Thus, the productive life of that vegetative propagule is always less than a naturally grown propagule (seedling). Although some techniques have been developed for determining the age of a culm present in a clump, it is completely impossible to determine the clump age (Banik 1993). Moreover, it is not yet possible to recognise a bamboo clump that is going to

flower within the next 1-2 years. Therefore, any propagule collected from a ripe "to flower" clump will flower within a few years of planting, incurring heavy loss to the planter. During 1979, in Bangladesh, a 10 ha experimental plantation of *B. tulda* was raised through planting of rhizomes collected from Sylhet (Adampur). All the planted propagules flowered and died in 1980 synchronous with their mother clumps at Adampur. The species with gregarious flowering nature would impose risk in raising plantations through vegetative propagules compared to those of sporadic flowering species. However, species like *B. vulgaris* and *B. balcooa*, so far as is known, flower rarely and after long intervals (Banik 1979, Banik and Alam 1987) and, therefore, have less risk from vegetative propagation.

The main limitation of sexual propagation in bamboos is the unpredictable availability of seeds and seedlings. As flowering is not common, the knowledge on seed productivity, seed biology, including germination, viability and storage, is inadequate and also not known for many species. Excepting for a few species, seedling raising and nursery management are also not yet practiced. Few studies have been made on the growth performance of each of the propagule types and time required for attaining commercial size. So in many cases, planters cannot make financial predictions.

Farmers and field foresters often ask how to produce different types of vegetative propagules and seedlings; which method is superior for which species; and how far earlier marketable harvest can be made. With the present state of knowledge, answers to some of the queries can be given, but in most cases they cannot.

EFFECTIVE APPLICATION OF THE CONVENTIONAL METHODS AND OUTLINE FOR FUTURE RESEARCH

Vegetative Propagation

True-to-type progeny with genetic qualities identical to the mother plant are obtained through vegetative propagation. Propa-

gation methods developed in different countries are presented in Table 1. Experience and knowledge in one country can be utilised and adapted in another country for immediate application in producing large-scale planting stocks.

The new technologies, like prerooted and prerhizomed branch cuttings and split culm-cuttings, have substantially cut costs of bamboo plantations in comparison to those raised from conventional planting stocks of rhizomes and offsets. Banik (1992) made a financial analysis of a plantation of *Bambusa vulgaris* raised through prerooted and prerhizomed branch cuttings which yield a financial rate of return of 37%. So, in financial terms, the income from clonal plantations of bamboo are profitable and attractive.

Bambusa balcooa and *B. vulgaris* are the most commonly cultivated bamboo species in the villages of Bangladesh and NE India and they do not produce seeds after flowering (Banik 1979, Banik and Alam 1987). Therefore, these species need to be cultivated only through vegetative propagation.

Further research is necessary to develop easy and cheap mass-scale propagation techniques for bamboos. In this context, possibilities of producing rooted branch node-cuttings, 1-5 cm long, are worth investigating.

Sexual Diversity, "Seed Stand" and Seed Propagation Research

In the past, almost all the multiplication studies in bamboos have been made using different techniques, of vegetative propagation. Due to limitations of these techniques it is necessary to change the research strategy. Seed must be used as a tool of propagation research, and all seedlings must be optimally utilised. In fact, seed propagation ensures a wide genetic base. It is important to study the seeding behaviour of different species.

Variation in flowering periodicity have been observed and documented among the clumps under the same bamboo species (Hasan 1980, Menon 1918, Brandis 1899, Janzen 1976). In addi-

Table 1 : *Conventional propagation techniques developed for bamboo species in different countries of Asia*

Species	Propagation techniques					
	Seed/ Sdl	McPrl	Culm Ct Split ClCt	Marcot/ Grdly	PrBrct/ BrCt	Offset/ Rhizome
B. bambos	Bd, In, Th, Ph	Bd, In	In, Pk	-	-	Bd, In
B. balcooa	-	In, Np, Bd	-	-	Bd, In	Bd, In
B. blumeana	-	-	Ph	Ph	Ph	Th, Ph
B. glaucescens	Bd	Bd	-	-	-	Bd, In
B. longispiculata	-	-	-	-	-	Bd, In
B. nutans	-	Bd	Np, Bd, In	-	Bd	Bd. In
B. pervariabilis	Ch	-	Ch	Ch	Ch	Ch
B. polymorpha	Bd	-	In	-	Bd	Bd, In
B. textilis	Ch	-	Ch	-	Ch	Ch
B. tulda	Bd	Bd, In	In	-	-	Bd, In
B. vulgaris	-	-	Th, In, Ph, Sl, Ind, Ch	Ph, Bd	Bd, Ph	In, Bd Th, Ph
D. asper	-	-	Ind	-	-	Th, Ph
D. brandisii	Th, In	-	Ind	-	-	Th, In
D. giganteus	-	-	In	Bd	Bd	In, Bd, Th
D. merrillianus	-	-	Ph	-	Ph	Ph
D. hamiltonii	In	In	Np	-	-	Np, In, Bd
D. longispathus	Bd	In	Bd	-	-	Bd, In
D. strictus	In, Th, Bd, Sl	Bd, In	In, Pk	-	Bd, In	Np, Bd, In
D. latiflorus	-	-	-	-	Ph	Ph, Th
G. aspera	-	-	Ph, Ms	-	-	Th, Ph, Ms
G. levis	-	-	Ph, Ms	-	-	Th,Ms,Ind
L. chungii	-	-	Ch	-	Ch	Ch
M. baccifera	Bd, In	-	-	-	Bd, In	Bd
N. dullaooa	Bd	-	Bd	-	Bd, In	-
Phyllostachys sp.	Ch, Jp	-	Ch,Jp	Ch, Jp	Ch, Jp	Ch, Jp
S. lumampao	Ph	Ph	-	Ph	Ph	Ph
T. siamensis	Th	Bd	-	-		Th, In, Bd

N.B.: *Propagation techniques*

Sdi=Seedling, Mcprl=Macroproliferation, Culm Ct/SplitClcT=Culm-cutting/split culm cuttin, Marcot/Grdly=Marcotting/Groundlayering, PrBrct/BrCt=Prerooted and prerhizomed branch cutting/branch cutting.

Countries:

Bd= Bangladesh, In= India, Th=Thailand, Ph=Philippines, Ind= Indonesia, Ms= Malaysia, Sl= Sri Lanka, Np= Nepal, Bh- Bhutan, Pk= Pakistan, Ch= China, Jp=Japan,

tion to the gregarious habit of flowering *Bambusa arundinacea, B. longispiculata, B. nutans, B. tulda, Dendrocalamus hamiltonii, D. longispathus,* and *D. strictus* have also showed sporadic flowering in isolated clumps, or in small groups of clumps (Table 2). Records show that *Bambusa tulda,* in addition to its 20-30 years gregarious flowering, also exhibits frequent sporadic flowering. In lower Bengal, *B. tulda* flowered four to five occasions within 16-18 years of time during the period of 1866 to 1884 (Brandis 1899). Similarly, the species also flowered sporadically on 9 occasions in Chittagong within 12 years (1978-1990) (Banik 1991). So, *bambusa tulda* also has a number of "flowering genotypes" occurring in nature. A number of flowering cycles have also been reported for *D. strictus* (Table 2). In S. India, it is 24-28 years (Kadambi 1949); in N, E, and C. India 40-44 years (Kadambi 1949, Gupta 1952); and W. India 65 years (Mathauda 1952). In Bangladesh, the species was introduced from the Angul District of Orissa and flowered synchronously after 45 years (Banik 1981), showing the same periodicity of *D. strictus* originally from C. India. In *D. longispathus,* three flowering genotypes have been observed, having different duration of flowering period (Banik 1986). Kawamura (1927) and Janzen (1976) inferred that such variation in flowering is due to different clones within the same species of bamboo that are slightly "out-of-phase" in flowering with each other. According to Hasan (1980), Watanabe and Hamada (1981), such out-of-phase flowering clumps are the expression of different pedigree and may have evolved through mutation. Such "flowering genotypes" should be identified in nature and centralised in one place. In the next flowering time, these genotypes are likely to flower one by one and also in between the normal gregarious flowering period. The following steps should be taken to collect these "flowering genotypes".

- Regular collection of information on the incidences and locality of flowering,
- Explore and visit both natural and planted populations to locate and identify the flowering clump(s) of indigenous and introduced species, respectively.

Table 2 : *Flowering nature and estimated cycle of some bamboos of Indo-Malayan region*

Species	Flowering nature	Estimated cycle	References
Bambusa arundinacea (= *B bambos*)	Gregarious, sporadic and irregular	30 (Coast. India) 45 (N India)	Banik (1980)
B. atra	Annual	-	Gaur (1987)
B. balcooa	Rarely in fowering state, no seed Production	40±5	Banik and Alam (1987)
B. glaucescens	Part flowering	not known	Banik (1986)
B. longispiculata	Sporadic, rarely gregarious	20±5	Banik (1987a)
B. nutans	Part flowering sporadic	not known not known	Anantachote (1988) Banik (1987a)
B. polymorpha	Gregarious,spradic	50±5	Banik (1991)
B. tulda	Frequently sporadic and irregular,occasionally gregarious	20±5 or less or more	Banik (1991) Hasan (1973) Hasan (1980)
B. vulgaris	Rarely in flowering state,no seed production	80±8	Banik (1979)
Dendrocalamus asper	Gregarious	not known	Anantachote (1987)
D. hamiltonii	Sporadic Gregarious	every year 30	Rogers (1900) Cavendish (1905)
D. longispathus	Often sporadic occasionally gregarious	30±2	Banik (1991)
D. strictus	Gregarious and sporadic	25 (S.India) 40-45 (N,E,C,Indian) 45+5 Bangladesh 65 (W.India)	Kadambi(1949) Gupta (1952) Banik (1981) Mathauda (1952)
Gigantochloa albociliala	Gregarious	not known	Anantachote (1987)
G. hasskar liana	Gregarious	not known	Anantachote (1987)
Melocanna baccifera	Mainly gregarious, Rarely sporadic	30±5 45±5	Brandis (1906) Troup (1921)
Neohouzeaua dullooa	Sporadic and occasionally gregarious	45±2 15±2	Banik (1991) Janzen (1976)
Ochlandra rheedii	Annual	-	Gaur (1987)
Ochlandra travancorcia	Gregarious, sporadic	7 (?)	Varmah and Bahadur (1980)
Oxytenanthera nigrociliata	Sporadic and, occesionally gregarious	47±3	Banik (1991)
Phyllostachys sp.	Gregarious	60	Ueda (1960)
Schizostachym brachycladum	Continuous	-	Anatachote (1987)
Thamnocalamus falconeri	Gregarious, sporadic	28±2	Varmah and Bahadur (1980)
T. spathiflorus	Gregarious	16±2	Varmah and Bahadur (1980)
Thyrosostachys oliveri	Gregarious	48+2	Bor (1941)

- Diagnose the nature of flowering (sporadic, part flowering clump, complete flowering clump, gregarious, etc.). For a given species, different clumps may exhibit these in different or the same localities in different or the same years.
- Each of the flowering clumps may be designated "flowering genotypes" and documented. For instance, *Bambusa tulda* flowered in four different years in different localities of Bangladesh and they have been labelled as follows: - *Bambusa tulda*/Shishak/1977, *Bambusa tulda*/Kaptai/1980, *Bambusa tulda*/Sylhet/1984, *Bambusa tulda*/Keochia/1989.
- Collect seeds/seedlings/other propagules from identified flowering clump(s).
- Raise seedlings and collect wild seedlings and other propagules. Mark each according to the label of the mother flowering clump and maintain separately in the nursery. Group these planting stocks according to the species.
- After one year of maintenance in the nursery plant, mark the flowering genotypes species wise in a suitable site.
- Plant the seedlings/other propagules in lines according to the seeding year under each species.
- Accordingly, a number of "flowering genotypes" within different species will be identified and centralised in one common place.

Such centralised plots may be termed "seed stands". Some species growing in different countries may flower at different times. It is worthwhile to collect "flowering genotypes" of a species and plant them in plots and thus, seed yield will be more frequent.

It is reported that a number of bamboo species growing in the Malayan zone flower sporadically from time to time or, in some cases, flower almost continuously (Holttum 1958). Anantachote

(1987) reported that the following bamboo species flower almost every year in Thailand. The species are *Arundinaria pusilla, B. arundinacea, B. blumeana, Cephalostachyum pergracile, C. virgatum, Gigantochloa albociliata, G. hasskarliana, G. apus, Thyrsostachys oliveri* and *T. siamensis*. In general, all these species die after flowering. However, *Schizostachyum brachycladum* flowers continuously and does not die after flowering (Anantachote 1988). If all the species are grown in one place, the availability of bamboo seeds will be much more frequent.

For this purpose, regional cooperation for exchange of seeds, other planting materials and information on "flowering genotypes" are necessary.

In addition, emphasis has to be given to studies of seed germination, dormancy, and seed storage of different species.

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DELIVERY SYSTEMS FOR PLANTING MATERIALS : REQUIREMENTS AND APPROACHES

I.V. Ramanuja Rao

INTRODUCTION

The objectives of the INBAR Production Research Consultation are evidence that serious constraints exist in the supply of bamboo and rattan. This is true in most countries where bamboo and/or rattan have been traditionally utilised. Since production is largely from natural forests, demand has outstripped the annual incremental production capacity of the forests. This is largely due to rapidly increasing populations in most countries where bamboo and/or rattan are traditionally utilised. At the same time, there are other countries which see a role for bamboo and rattan in their rural or national economies but do not have suitable resources.

A distinction has to be made between the needs of countries that have traditionally utilised bamboo and rattan, and those where utilisation is in a nascent stage of development. In the former, the need for greater quantities is paramount whereas in the latter the requirement is more qualitative since demand is yet to cross the lag phase of growth. This is a critical distinction, since it can have great effects on the identification of bottlenecks, the methodology used (especially the number of steps), and consequently the time taken for putting into place an effective delivery system.

Another important point that needs to be taken due cognisance of is the needs of large industries such as paper and rayon. The story of how bamboo, widely regarded as a "weed" in the 1930's by Indian foresters, became a "commercial" crop due to the entry

of big industry and its effects on the poor, has more socio-economic lessons than are commonly realised. Because of the effects of the unequal competition for a common plant resource, a distinction must be made between the needs and effects of (a) "mass" (poor people) and (b) "rapid" (big industry utilisation. If INBAR is ever to realise its stated objectives, industrial needs must be given due importance and attention in order to, paradoxically, protect the interests of the poorest of the poor since supply and demand are interlinked.

This paper is mostly focused on the bamboos because of the enormous gap in the availability of planting materials. In the case of rattans, except for occasional 'off' years, seed production is abundant and seeding occurs more than once a year. The problems related to rattans, especially in tissue culture, are relevant more to overcoming difficulties caused by short viability of the seed and in getting material across from one region to the other. Other needs are, for example, improvement of the material or getting a multiple stemmed manan, than straightforward propagation.

FOCUS ON PRIORITY SPECIES

Much of the past research on production has tended to be rather diffused, in major part due to the large number of species. Production research, including that on delivery systems, will need to focus more on the limited number of high priority species already identified by INBAR, if significant benefits are to be realised in the short-term.

Choice of Delivery Systems

While there can be several, the choice in a given situation will depend on (i) availability of suitable planting material, and (ii) logistics involved in getting the material form the production centre to the planting site. Essentially, there are four steps:

ensuring availability of the desired species

- production of large numbers of propagules of bamboo and rattan in the shortest time frame using a method suitable to the species
- raising of plants to field-plantable age, and
- delivering to users/clients.

The benchmarks that constitute a successful or desirable method are:

- reliability of the method and quality of the plant
- cost-effectiveness
- delivery on time.

Importance of Time-frames : Mass vs Rapid Propagation Methods

A distinction needs to be made between "mass-propagation" and "rapid-propagation" methods. This is a significant conceptual distinction with polity implications, since it not only takes into account production (mass) but also the time frame in which this is accomplished (rapid). Mass-propagation is simply the production of a large number of propagules. The time-frame is not defined and can include the long-term. In comparison, rapid propagation methods are mass-propagation methods which can be accomplished in a compressed or a short time period.

The suitability of either the mass-propagation or the rapid propagation approach, within the context of forestry and more specifically as applied to bamboo and rattan, depends on the kind of return envisaged and the time-frame in which the desired impact is sought to be achieved. This could be social, financial or environmental, or a combination of two or even all three of them, since forests provide multi-fold and extended benefits. While rapid propagation methods are often costlier, the returns can be much greater in the longer-term in the context outlined above.

A wide repertoire of propagation methods are available. For successful establishment and growth, a bamboo propagule must possess three structures: a well-developed root system, a rhi-

zome and a shoot. Conventionally, bamboos have been propagated (depending on the species) using seeds, divisions, macroproliferation, rhizomes, offsets, layering, and culm and branch cuttings (Rao *et al.* 1992a). More recently, tissue culture methods have been developed which utilise micropropagation or somatic embryogenesis (Rao *et al.* 1992b). Both conventional and tissue culture-based methods have advantages and disadvantages, and depending on the starting material, can provide clonal or segregating material.

CONVENTIONAL PROPAGATION

Seeds

Bamboo seeds are very convenient for propagation and, due to their small size, easily transportable. Bamboo seeds are light in weight: one kilogram of *Bambusa bambos* seed contains about 90,000 seeds; *tulda*: 26,000; *Dendrocalamus longispatus*: 150,00; *strictus*: 40,000; and the pea-like seeds of *Melocanna bamboosoide*: only 70. Liese (1985) reported that the average seed production in a gregariously-flowered area in Shahdol district of Madhya Pradesh (India) varied from 0.9 to 1.5 ton per ha.

Although gregarious flowering results in the production of a large number of seeds, propagation by seeds is not always practical because of the unusually prolonged flowering cycles of monocarpic bamboos. This is commonly the major limitation. Although sporadic flowering, or off-cycle flowering occurs almost every year, it usually does not result in seed formation, or at best in only a few viable seeds from a large mass of empty florets. However, due to the relatively large number of flowering cohorts, some seeds are always available although the quantities may largely vary from year to year. Such a situation is largely the case for *D. strictus*, and less so for *B. bambos*. Thus, seeds are generally not available or are in short supply for most bamboos. This is indirectly supported by the fact that over the years, vegetative propagation methods have been developed in vari-

ous communities in several countries. In comparison, seed-based propagation is either unknown or nearly non-existent.

The difficulty in using bamboo seeds lies in their low viability, poor storage characteristics and microbial infestations. In addition, the dependence on sporadic off-cycle flowering makes their availability irregular. The principal problem with the use of bamboo seeds is their poor viability (Bahadur, 1979; Varmah and Bahadur, 1980). Generally, bamboo seeds lose viability about 2-3 months after harvest. Another problem is the presence of seed-borne fungi and other microbes in some bamboo species. The embryos in such infected seeds do not germinate.

Because of abundant seed production in gregarious flowering, sufficient regeneration usually occurs in the flowered areas except where the soil is too hard. In most places, seedlings appear in large numbers. However, grazing and fire are most detrimental to the survival of seedlings. In order to overcome this problem, the entire flowering area should be closed but this is not always possible because of socio-political problems. In an experiment in the Shahdol region (Madhya Pradesh), seedlings generally existed only in places where some physical and mechanical barriers had been provided (Dwivedi, 1990).

A critical reassessment of the basic cost of bamboo seeds needs to be carried out in terms of potential financial, social and environmental benefits. In more ways than one, seeds are the most ideal propagule. A proper cost-assessment of seed-value will promote measures such as incentives to villagers for immediate collection on gregarious flowering and attract much needed investment for storage facilities. This is crucial since seed maturation takes place in the hot summers while optimal storage is below zero degrees centigrade and at low humidity.

Vegetative Propagation

Vegetatively bamboos are propagated through divisions, macro-proliferation, rhizomes, offsets, layering, marcotting, culm and branch cuttings. In general, it has been observed that there

is increasing difficulty in producing bamboo propagules as one goes from the rhizome to the culm and to the branch. At the same time, the number of 'cuttings' or potential propagules increases. McClure clearly foresaw this and called for the development of new methodologies which would utilise this enormous potential for the benefit of the mankind. In 1966, he wrote: "No published account of the successful use of artificial means to break the dormancy of buds has come to my attention. A satisfactory degree of success in the vegetation propagation of bamboos can be achieved only when routines effectively solving this problem have been established". To this day, propagation of bamboo from the nodes of the minor branches taken from adult plants remains a very difficult, if not an impossible task.

It is also necessary to be aware of the debilitating effects of continued vegetative propagation on the longevity of the bamboo stands. Although vegetative propagation is commonly practised in bamboo cultivation, it should be kept in mind that the actual age is the same in every part of the bamboo. This means that plants developed through vegetative propagation will all be as old as their stock and will tend to flower and die simultaneously. In Thailand, *Dendrocalamus asper* from which bamboo shoots are produced for export, is largely propagated by clump and branch cuttings. In recent years, there have been increasing complaints of flowering and death of the clumps. In several instances, plants in the nurseries also died. To combat this and since seeds are not readily available, somatic embryogenesis in tissue culture is being attempted since plants originating from somatic embryos can be expected to last the full life-time of the bamboo, similar to zygotic embryos in seeds.

IN VITRO PROPAGATION

McClure (1966) wrote: "Reduction in the mass of the individual propagule makes for economy of the propagating material, simplifies the labour of preparing it, and reduces the requirements of space and other facilities. As the bud is deprived more

and more completely of the maternal tissue that supports it, the control is perfected, the number of unassessed and uncontrolled variables is reduced, and the prospects of establishing pertinent basic principles and determining the optimal conditions of vegetative propagation for each kind of bamboo improve".

Prophetically, he realised that "the development, or adaptation, or the appropriate refinements of these procedures will require experience in the routines of sterile culture, tissue culture, the breaking of dormancy in buds, the use of hormones for stimulating root initiation and so forth". It has now become possible to routinely produce large numbers of bamboo plants through tissue culture, principally through the methods of somatic embryogenesis and micropropagation.

Plant tissue culture offers the unique opportunity not only for realising the totipotency of cells into whole plants but also provides conditions under which physiological manipulations can be carried out with the objective of overcoming endogenous controls inherent in the intact plant. *In vitro* methods offer an attractive alternative to offsets, cuttings and seeds for the propagation of bamboos. Although development of tissue culture technology, its field-testing and refinement of procedures may be a slow and time-consuming process, when established, it enables mass-production of plantlets on a large scale and in a short span of time.

Several other tissue culture methods, such as precocious rhizome induction are also possible. Treatment of bamboo seeds with various hormones, in addition to increasing germination, induces rhizome formation. Other methods such as detopping used *in vitro*, also lead to precocious rhizome induction. This is very useful as it facilitates the easy transfer of plantlets to soil.

Availability of explants all the year round is not a problem. Moreover, diverse explants can be utilised. The multiplication rate in tissue culture is also high and is several times that obtained by conventional methods. Propagation by conventional vegetative methods does not make efficient use of the

resource since only a limited number of explants/clumps can be obtained for conventional propagation. The explants are also available after long periods of re-growth, whereas in the case of *in vitro* methods, explants are available as and when required, all the year round.

Most importantly, tissue culture methods are entirely independent of the external environment and can be carried out all the year round, whereas conventional vegetative methods are limited by the growth cycle of the plant as well as environmental conditions. Dormancy requirements or rest periods must be satisfied for each crop to allow successful propagation and growth. The tissue culture laboratory usually does not have these constraints during multiplication. It is only when the propagule is placed in the glasshouse or the field, that the plant becomes subject to seasonal factors such as day length and temperature, which control subsequent growth and development.

Between conventional and *in vitro* methods, the appropriate choice lies somewhere in between and is related to the scale of demand and the time frame. The industrial appetite for bamboo raw material, which has not been met using conventional propagation methods - and which has come into conflict with the more pressing social needs of the people, needs to be addressed using newer methods that lend themselves to the industrial scale. At the same time, time-tested conventional techniques will have to be used in smaller-scale operations. However, with more improvements in tissue culture techniques, e.g. development of the technology of suspension cultures and secondary somatic embryogenesis, the future may belong to tissue culture, especially due to the in-built industrial approach. Embryogenic suspension cultures offer the prospect of large-scale cloning of plants through proper staging and control of development, the imposition of artificial dormancy and the creation of artificial seeds and/or the use of mechanised planting systems.

Inter-Country Transfer of Germplasm

Plant tissue cultures offer two major advantages in this regard. In the first place, disease-free material can be obtained and

easily taken across national boundaries. Secondly, since commercial tissue culture companies observe quarantine regulations on a daily basis, it will be very easy for them to ship planting material to the country of choice. Such inter-regional/inter-country transfer of planting material has already proved to be of major benefit to countries such as Kenya.

Conservation

The use of plant tissue cultures has been well-established as a viable means of conservation, although more research is needed on slow-growth protocols. Since bamboos have been shown to be amenable to tissue culture, this is a promising area for future action, especially for targeted conservation of superior seeds (although seed conservation for the long-term is likely to be developed, the sheer scale of regenerating seed stocks of heterogeneous materials poses operational considerations).

CONSTRAINTS

The constraints in the delivery system are manifold but can broadly be classified into two main types: (a) scientific constraints and (b) practical constraints.

Scientific Constraints

The scientific constraints fall into two areas; related to development of technologies and the implementation of technologies.

Development of technologies

Research priorities: In India, for example, the government has been the prime mover of research and its direction through control of funding. Much of the research has been what the government and scientists consider is needed by the country and the people, and not what is priority for the industry. What is generally missed in such research strategies is whether the research is marketable. The fact that with a couple of exceptions,

companies have primarily gone into the ornamental field and not into cereals, legumes, forest trees, etc., is testimony to this. Profit being the prime motive of industry, social considerations can only be secondary after survival in the market-place is ensured. In other words, the uptake of technology from research laboratories will be dependent on the potential price realisation possible.

Research Institutions: Government research institutions consist of national laboratories and universities, While the former have a clear mandate to develop technologies, a lot of talent is available in the universities, where the volume of output being higher the cost of research is often much lower. These also have a more creative environment. However, universities do not have a mandate for undertaking long-term research. Besides, the research being largely Ph.D-oriented, there is the resultant problem of discontinuity of emphasis at the conclusion of a doctorate. Clearly, these relationships will need to be further clarified if meaningful outputs are to be obtained.

Incentives: The incentives for scientists are primarily through publishing of research papers since these are an important measure of an individual's ability and serve to get him recognition, and a better salary through promotion or selection to a higher position. He, therefore, has little incentive in branching out to applied research where little can be published, especially if funded by industry. Methods, therefore, need to be devised by which the progress of an individual can be measured in such situations.

One solution could be to provide enlarged benefits to the best researchers. This can be through higher pay, additional research support, consultancy fees, etc. Free enterprise among scientists should be encouraged wherein teachers/scientists could commercially exploit their achievements while retaining their positions. In other words, a new 'cadre' of 'academic entrepreneurs' needs to be developed and encouraged. Scientists who develop commercial techniques and technologies should be monetarily

rewarded in proportion to the pricing of the technology. They should also be eligible to receive an appropriate proportion of the royalties.

Interaction with the Industry: Research parks should be established in the universities (on the lines of science parks) with facilities that could be utilised by industry. Collaborative tie-ups should be entered into between industry and R&D institutions. Participation by industry in research projects should be made mandatory. This will make the work more goal-oriented and will benefit both parties. What is required is strategic, well-coordinated research. As industry sees more benefit flowing from such research, funds from industry to research could only increase. Training of students in commercial laboratories would become possible through such a cooperation.

Protocol Development in Tissue Culture: Bench-marks need to be clearly defined in order that a researcher can assess whether a research methodology is still a technique, at what level it becomes a technology, and with what additional work does it become a packaged, industrially-usable technology.

Factors relating to continued subculturability and predictability need to be worked out and defined, since the cost of initiating cultures is very high. The number of subcultures possible is also important. At the earliest possible opportunity, one must scale up and graduate to a larger container. A separate rooting step *in vitro* should be avoided since it adds to the cost of the plant. Protocols should be designed such that rooting is either simultaneous or possible *in vivo*.

Problems of Secrecy as against Sharing

One unfortunate fallout of the commercialisation of plant research has been the drying up of communication-lines among researchers. This has resulted in duplication of work in several institutions. Even where bottlenecks are encountered by research groups, there is little exchange of information on problems encountered. There are rarely published accounts of nega-

tive results. A forum is required for bamboo and rattan, which could bring together those working on a common theme so that barriers are broken and communication encouraged.

Implementation of Technologies

Market research is needed to determine the size and requirements of the market, and to identify clients/buyers. In some countries, changes in land utilisation policy are needed to enable the private sector to achieve the benefit of scale.

Agencies such as forest departments, which currently produce and plant nearly all forest trees, have several responsibilities, including social and environmental. There is a large element of "indirect subsidy" through the non-accounting of many of the costs of maintaining the organisation, since this is justified by the "social profits" and the "environmental profits" or benefits that are visualised. Consequently, the planting material is priced at very low levels, much below the real cost of production. The under-calculation of cost by government agencies such as forest departments (eg. Rs.0.60 per bamboo plant) is a barrier for the entry of the private sector into the scene. In fact, some of you will be surprised to know that bamboo plantlets produced through tissue culture were imported at a cost of Rs.6.00 by an Indian firm from a Dutch tissue culture company. This shows that (i) adequate numbers of plants are not available locally and (ii) the cost of production is actually much higher.

Production by non-governmental agencies will be feasible only when the financial equivalence of the "subsidisation" is extended to them. In a similar way, the successful implementation of the largest plantation programme in the world using bamboo plantlets produced through tissue culture was made possible by the Thai Army actually doing the propagation, rearing, transportation and planting work. Actually, the "subsidization" costs were taken from the Thai Army through utilisation of their manpower, facilities, etc.

In more ways than one, the success of a mass and/or rapid propagation programme depends on an accurate and correct

costing of the propagule and determining the extent of the "indirect subsidy" element in the cost. There is a need to view the forest department as a "company" and calculate costs thereon, similar to that if a private agency would have produced the plants. INBAR may wish to investigate this.

Practical Constraints

The practical constraints in delivery systems are related to the choice of the bamboo propagule, their unique problems of packaging, maintenance and/or rearing, and the logistics involved, such as transportation. These would differ among individual countries depending on their infrastructure.

Five propagule types can be visualised:

- seeds
- unhardened, ex-agar plants
- two-month-old hardened tissue culture plants/seedlings
- one-year-old tissue culture plants
- conventionally-produced one-year-old plants.

For example, the handling of the conventional explants poses a problem due to the heavy weight of the explants, thus making the process very tedious and difficult. The weight of rhizome offsets being as much as 20-40 kg, these are difficult to handle and expensive to transport.

CONCLUSIONS AND RECOMMENDATIONS

The need for planting material is urgent and lack of current it is adversely affecting the poor, INBAR's stated target group. The current over-emphasis on first understanding the socio-economics before embarking on the remedial programme can, therefore, be viewed by the target countries and societal groups therein with some cynicism and alarm, because of (i) indigenous knowledge and the long history of bamboo and rattan utilisation, and (ii) the anticipated delays because of the time needed such studies. While this may not immediately be appar

because of Asian politeness, what might perhaps be more appropriate are parallel, cross-influencing programmes rather than linear-programmes, since both client and donor concerns need to be simultaneously addressed. Care should also be taken that socio-economics does not become an end in itself, with the poor being offered reams of reports rather than much needed plant material.

Socio-economics is an umbrella-science and can be remarkably illuminating if used for general guidance, provided it is not unconsciously allowed to become a strait-jacket to INBAR's programmes. Perhaps, one of the most important aspects is research on policy and land tenure since the best of programmes (in bamboo and rattan) can be stymied if these are not adequately addressed. In fact, for many of INBAR's programmes to succeed, the responsible government departments/agencies need to be given the status of "alternate client" to the people, and addressed suitably.

1. All methods of mass and rapid propagation are an important part of bamboo propagation programmes. A specialist advisory group should be established on conventional propagation and micropropagation in order to provide a forum for interaction and information exchange.

2. A more responsive and scientifically-supported programmes should be put into place for the collection, conservation and distribution of bamboo seeds. This should lead to the development of seed-testing kits, the setting up of model seed-collection, and storage programmes. Internationally-mandated seed-collection and distribution centres should be set up with national sub-centres for both bamboo and rattan. At the very least, this will enable researchers to get tested, certified seed for research.

A species-wise map, catalogue and calendar of flowering, seed production areas and seed storage centres need to be developed and maintained (see also Appendix by R. Banik in this volume). I propose that the mandate of the Information Centres be expanded to include the above.

3. Cooperative programmes need to be put into place between forestry organisations and commercial organisations to promote "twinning". The latter can be given the responsibility for developing and coordinating an international bamboo and rattan tissue culture program with national nodes. These should address aspects of micropropagation, germplasm exchange and conservation. Only countries agreeing to free-sharing of information and methodology among themselves should be given membership to these centres.

4. More basic research is needed into the problem of rooting and rhizome formation from the minor nodes of mature bamboo. Further research also needs to be undertaken on somatic embryogenesis and production of artificial seeds.

5. A study of the economics of plant production by various agencies needs to be urgently undertaken.

In this age of "glasnost" and "free-market", we perhaps need a second "social" revolution in some of the target countries, which will see the "brahmin" governmental organisations joining hands with the "pariah" semi-commercial/commercial organisations. Let us work together and contribute towards providing some of the basic essentials and enhance the living standards of the rural poor.

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APPENDIX 7

PRIORITIES FOR RESEARCH ON MANAGING NATURAL STANDS OF TROPICAL BAMBOO

A.C. Lakshmana

INTRODUCTION

This is not an historical review or reminiscence. The work carried out on bamboo over the past half a century is voluminous; hence I shall restrict this discussion to priority areas for further research.

The identification of priorities is important because forest destruction is reported to be going on at a rate of 1 ha per minute, or 15 million ha per annum. At the same time, annual afforestation is only 1 million ha. The consequences of this annual gap are obvious. Afforestation is usually carried out by giving priority to a limited number of species, resulting sometimes in monocultures, which are necessarily environmentally sound.

In forest areas, there is puacity of natural regeneration, often as high as 75% in many places. This is alarming and means that the remaining natural forests will not be in a position to continue their natural cycle, resulting in continued shrinkage of forest areas after felling or death of existing vegetation. This is likely to have a serious impact on the environment; and against this background, I wish to discuss the many virtues of bamboo.

Bamboo is a fast-growing plant, capable of growing up to half-a-metre per day during the peak growing season. It is quick-spreading and in open places, increases 20 to 25% in areas every year. Once established, most bamboo species continue to perennial production until they produce seeds and then die, sometimes in 40 to 60 year cycles. Bamboo is a very good soil binder and conserves moisture. In India, the annual loss due to

soil erosion is estimated to be around Rs. 1,200 crores. Soil erosion affects many aspects of agriculture and forestry, and even reduces the life of irrigation and power projects. Bamboo is useful to reduce soil erosion because of its fibrous roots. Bamboo leaflets (estimated to be 20 lakh for a clump of 20 culms) protect the soil from heavy rains and culms (ranging from 3000 to 5000 per ha) reduce soil run-off and erosion. Its deciduous nature adds organic matter to the soil from 4 to 6 tonnes per ha in ideal areas. Moreover, the leaves and young shoots are eaten by wild life, such as elephants, sambar, deer, monkeys as well as by domestic animals.

A Case Example : Bamboo in Karnataka

In Karnataka, bamboos are extensively used in agriculture, building construction and in the agarbatti, silk, paper, rayon and

Table 1 : *Bamboo statistics for the State of Karnataka.*

Division	Forest area ha	Bamboo area ha	Percen -tage of bamboo	Annual yield in tonnes area	Annual production tonnes/ha
Hunsur	65139	13630	21	48813	3.65
Kollegal	191670	13350	7	48813	3.65
Shimoga Dist.	439500	193574	44	89533	0
Hassan & Chick-magalur Dist.	291500	33836	13	33981	1.0
Mundagod of Yellapur	9408	-	-	2500	2.25
Manchikere of Yellapur	41660	28600	-	N.A.	
Bangalore		15400	-	N.A	
Bamboo area			21		
Anticipated annual yield per ha.					1.67

N.A. Not available. The wide variation in yields suggests caution in using these data for generalisations about yield.

cottage industries. The estimated demand for bamboo for selected uses in Karnataka is approximately 6,46,000 tonnes. The area under natural bamboo in Karnataka by a rough estimate is abut 4.00 lakhs ha. Based on available statistics (from working plan reports and Forest Survey of India), an estimate of the area under bamboo is shown in Table 1.

Based on Table 1, the average annual yield is expected to be 1.67 tonnes per ha from the bamboo-rich forests of Karnataka. However, there is a big gap between the annual anticipated yield and actual extraction. (Table 2)

Table 2 : *Demand and supply of bamboo in Karnataka.*

	Estimated yearly demand	Yearly supply	Imports from other states
Medars	2,26,000	29,000	N.A.
Paper Mills	2,84,000	72,000	51,000
Silk Rearing	1,10,000	N.A.	
Grape Basket	22,500	N.A.	
Agarbatti	4,000	2,000	
	6,46,500	1,01,000	51,000

Since most of the bamboo is from natural stands, all efforts should be made to increase the productivity of bamboos to meet existing demand and to improve employment generation.

Priorities for Research

In spite of its many virtues, bamboo carries a stigma because it is highly perishable and deteriorates quickly. Treatments can be applied to extend durability, but chemical treatments can be costly, and poor people are not aware of appropriate treatments.

Also in India, bamboo is used widely as fuel. It is quick-burning and somewhat explosive; hence treatments are needed.

These are general needs for research and development but sustainable management for natural stands has also received

little research attention, owing to a wide range of constraints. These include the following topics :

- There appear to be low-vitality and high-vitality periods. This requires in-depth study.
- Some clumps appear to produce more culms than others. Further studies to analyse genotypic and environmental factors determining higher productivity are essential.
- Marking of plus bamboo clumps has to be carried out. The qualities to be considered are linger nodes, bigger firth, fewer thorns, higher culm production and resistances to pests and diseases.
- Mortality of young rhizomes requires careful study, as nearly 35 % mortality is observed.
- In the international network, priority should be given to the best five species in each silvi-ecological zone. A compendium of such species should be prepared for international reference and silvicultural and other important characters should be highlighted.
- In terms of longevity of clumps, *Dendrocalamus strictus and Bambusa arundinacea* die after 9 years of age. Studies on other species need to be carried out.
- Studies on some species have revealed that they take about 3 years to attain maturity. Maturity studies need to be extended to other species and the optimum period for exploitation for each species documented.
- There appears to be a correlation between rainfall (moisture), temperature and production of rhizomes. New rhizomes are produced at different periods of the year; in some species before rains, in some after the commencement of rains. This requires further study. (In the case of *Dendrocalamus strictus*, usual heavy rains in November - December produced new rhizomes in Karnataka.)
- Irrigation : I have carried out some studies on providing irrigation of natural stands of bamboo. Different quanti-

ties of water were tried. Irrigation gave increased production, but the mortality of young rhizomes was also high. This is a very important aspect of bamboo production and requires major attention.

- Moisture content varies widely. For *Dendrocalamus strictus and Bambusa bambos*, it varies from 36 to almost 50%. Moisture content affects estimates of the number of pieces per tonne (see Table 3).

Table 3 : *Numbers per tonne (based on old reports).*

Author	*D.strictus*	*B.bambos*
Narasimhaiah	300	75
Eagles	250	75
Venkatarao and Lakshmana	300	100

However, B.bambos in the natural forest at Balehonnur in Chickmagalur and Muthodi forest with very high rainfall gives only 40-65 pieces to a tonne.

Thus standards are required for different species for numbers per tonne based on weighing, and also on volume measurements and correlated to silvi-ecological zones.

Silvi-ecological Zones

On the basis of agroecology, it would be valuable to divide the bamboo growing areas into silvi-ecological zones according to rainfall, temperature, soil, and other factors. Data should be added for productivity and yield per hectare. Depending upon annual rainfall, there are three broad groupings, viz:

Below 1500 mm	***1500 to3000 mm***	***Above 3000 mm***
Dendrocalamus strictus	*Bambusa bambos*	*Ochlandra travancoricus*

D. membranacea *Bambusa blumeana*

Oxytenantheara thwaitesii *Oxytenanthera* *Bambusa sp.*

monostigma

Bambusa burnanica

O. nigraciliata

They can be subdivided according to:

i. Altitude - Below 750 m, 750 to 1500 m, above 1500 m.

ii. Temperature - below 20ºC, 20-30ºC, above 30ºC.

iii. Soil Clay, loam, sand, etc.

Yield per ha

Yield per ha in natural stands should be quantifiable. Yield data are fragmentary, except it is known that fertilisers and water can increase yields substantially.

ASPECTS OF MANAGEMENT OF NATURAL STANDS

Thinning

Heavy thinning of up to 75% and clear-felling of the whole clump have both proved to have a harmful effect; however, thinning to 50% has little ill effect. Similarly, ill effects are observed when thinning is up to 25% and 33%. Different authors have recommended retaining a minimum of 6 or 10 culms in a clump. Some have suggested two times the number of clums produced during the previous year while others have recommended retaining three or four times the number of culms produced during the previous year. These recommendations require further investigation and clarification.

The thinning of bamboos with thorns poses a major problem for foresters. To overcome this, pruning the thorn-producing branches in the younger stages can be carried out. This is possible under cultivated conditions and also in areas free from biotic interference of browsing by domestic and wild animals. In

other places, I have carried out thinnings in the form of inverted 'V' cuts. This has helped in removing congestion and allows extraction of overmatured and dead bamboos. But this is very difficult to implement in the field. In order to overcome this, I have tried to remove one-third from one side in the first year and another one-third from the other side. If this is carried out, it becomes easier to do the balance, one-third in the centre, in the third year.

Felling

Different authors have suggested felling cycles of two, three, four and five years. Some have gone up to seven years. This requires further study as longer felling cycles will leave too many bamboos in the clumps unutilised.

Cutting above five nodes has given good results. But one has to consider the aspect of wastage. Felling at just above one node minimises wastage. This too requires further study.

Monitoring of Vegetation

Before the 1930's, bamboo was considered a menace in the forest and was thus not even recorded while preparing working plans. Later, bamboo clumps were enumerated in strip samplings carried out to find the stocking of vegetation in the forest. This is cumbersome and slow. To overcome this, remote sensing can be used. I have used this for Sandurr, Muthinakoppa and Gajanoor areas in Karnataka at two different periods. This has yielded valuable information and similar studies in other bamboo-growing areas will be of immense value.

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MANAGEMENT OF MONOPODIAL BAMBOO STANDS : PAST AND PRESENT RESEARCH AND FUTURE RESEARCH DIRECTIONS

Fu Maoyi

INTRODUCTION

Of the large number of bamboo species, roughly half are monopodial. They are considered to be evolutionarily advanced and they are widely distributed in warm, temperate zones, North and mid-subtropical zones of Asia-Pacific, the Americas and Africa. Production from these bamboos is centred on East Asia, particularly China and Japan where stands have been managed for more than a thousand years. In fact, the stands have become, over time, plantations, which have supplied products to the people. Bamboo has essential roots in both the agrarian society and also products are used industrially.

Over the past decade, research has been focused, thanks to the interest of international organisations and the local government. This research, which is ongoing, represents the current activities, and these may be contrasted with those from the past.

Development needs and the occurrence of forest damage over large areas, coupled with environmental degradation, means that future research needs an even sharper focus, and that it will need to be linked to new policies and strategies.

PAST RESEARCH

Bamboo Resources and Biological Properties

Bamboo resources and their biological properties have been the main areas of past research.

For bamboo distribution, the world can be divided into three major regions: Asia-Pacific, Americas and Africa. Within each major region, subregions can be recognised on the basis of climatic differences and bamboo types. Monopodial bamboos mainly grow in warm temperate and subtropical areas, the former with annual mean temperatures 10-15° and annual precipitation 800-1000 mm, while the latter have annual mean temperatures 15-20° and annual precipitation 1000-1500 mm.

The Asia-Pacific bamboo region covers Japan, Korea, the southern half of China, Southeast Asia, Australia, New Zealand and the Pacific Islands. Due to their relatively strong frost-resistance property, the monopodial bamboos are distributed in higher latitudes, such as Japan, Korea, the Yellow River Valley and the Yangtze Valley of China, where winters are severe. Ecologically, this subregion's bamboos centre on the genera: *phyllostachys, pleioblastus, sasa and indocalamus*. As a centre of diversity of bamboos and the largest area of bamboo stands, China has bamboos of 38 genera and more than 550 species, varieties and forms. Half are monopodial (Table 1), but they predominate in making up the natural stands.

In order to improve yields and develop technology for fast growth, the growth patterns and ecological properties of some

Table 1: *Monopodial bamboo species in China.*

Genus	No. of species	Genus	No. of species
Acidosasa	8	*Metasasa*	2
Arundinaria	25	*Phyllostachys*	49
Brachystachyum	1	*Pleioblastus*	18
Chimonobambusa	20	*Qiongzhea*	8
Ferrocalamus	2	*Sasa*	6
Gelidocalamus	5	*Shibataea*	8
Indocalamus	23	*Sinombambusa*	16
Indosasa	15	*Semiarundinaria*	1

species with high economic value have been studied. Species studied include *edulis (pubescens), P.praeocox, P.nuda, P.viridis, P.glauca, pseudosasa amabilis and bashania fargesii.*

Arundinaria is the only monopodial bamboo in the Americas bamboo region, while *A.gigantea* and its three subspecies are the only indigenous ones in the USA, where they occur scattered under mixed hardwood forest in the southeast. Many US Botanic Gardens have introduced other monopodial species from Asian countries, mainly from China and Japan. Introductions have also been made to the Meso-America region.

The African bamboo region is relatively small: the bamboo flora is represented by less than 10 species on the continent. However, about 40 species in 11 genera of indigenous and introduced bamboos occur in the Island of Madagascar. Its main species of monopodial bamboos are *Sinarundinaria,* which can form pure natural stands or understorys mixed with hardwoods. The significance of monopodial bamboos in Africa is much less than in other areas.

There were bamboos in ancient times in Europe, but they were destroyed during the fourth Ice Age. Due to the activities of the member countries of the Euuropean Bamboo Society as well as many bamboo lovers, many bamboo species, mainly *phyllostachys,* have been introduced into England, the Netherlands, France, Germany and Italy, where they are widely used for bonsai and garden decoration.

Reforestation and High-yield Technology

Both bamboo timer and edible shoots with good quality and high economic values come mainly from plantations. These plantations are based on monopodial species with different end uses, and are managed accordingly. Planting materials (offsets and seedlings), density, season, planting methods, general cultivation, etc., have been studied systematically by foresters and researchers of China, Japan and USA. Intensive management includes loosening soil, purifying stands, maintaining shoot and

new culm production, fertilising, covering and watering; and integrated technology has been created to obtain high and stable yields of products with good quality.

Disease and pest control

Diseases and pests may be serious in bamboo stands. Decades ago, a bamboo leaf pest, *ceracris kiangsu*, was recorded. Up to the 1960s, more than 30 papers on bamboo pests were published in China; meanwhile, research changed from emphasis on leaf pests to that on culm and shoot pests. Basic studies were carried out on pest morphology, life cycling and habits.

CURRENT RESEARCH

Whereas the past research was basic silviculture and descriptive science, recent years have seen a shift to a much more science-based approach. Management research is much more linked to ecology and physiology, improvement is linked to genetics and breeding, and control methods for pests and diseases are more biotechnological. However, the older descriptive work forms a solid base for a number of endeavours, such as agroforestry - an ancient practice for which new needs have arisen.

Taxonomy

In the last century, less than 200 species of bamboos were discovered and named in China; but work of taxonomists in the latest decade has resulted in an additional 200 species. Although it lets people know how rich their bamboo resources are, it has also caused a degree of confusion and errors may be expected in such research. The time has come to re-assess the situation and clarify the taxonomic base.

Ecology, Physiology, Genetic Breeding and Biotechnology

Ecological studies of large or mid-sized monopodial bamboos

have been related to biomass and carbon allocation to different organs, the dynamics of litter and its decomposition, through fall, stemp (culm) flow and run off, nutrient and water balances, soil and water conservation aspects of stands, also the effects of environmental factors on production.

Physiological studies have involved growth and development, flowering mechanisms, photosynthesis, on-year and off-year physiology, mineral nutrients, hormones, and enzymes on more than 10 species with high economic values.

Genetic research on population selection and clonal and sexual breeding have been done, but there is a long way to go before breeding is widely implemented.

Biotechnology, including tissue culture, gives a basis for mass propogation and genetic conservation. As with many of the studies mentioned, a start has been made but there is still a long way to go.

Disease and Pest Control

Current studies on bamboo diseases and pests have moved to an emphasis on natural enemies and control methods. To date, more than 150 papers or reports have been published on pests: classification, and those of shoots, leaves, branches and culms. Around 600 species in more than 280 genera have been listed, but only 200 species have been studied, and there is a need to consolidate this research.

Bamboo agroforestry

Major international attention has been focused on agroforestry since it considers optimal and integrated ways of using the natural resources, and models can be developed which are environmentally sound and provide the best socio-economic benefits. Whereas the practice has been in place for millenia, only from the 1970s has its scientific basis become the subject of intensive study.

Bamboo is one of the major woody components in agroforestry, but its studuy has lagged behind that of use of fast growing trees. Traiditional models where bamboo is incorporated into the system include bamboo + tea, and bamboo + fish ponds. In recent years, some new models have been designed to the needs of rural socieites. These are being tested to analyse ecological, and socio-economic benefits as well as undertstanding the interactions between components of the systems.

DIRECTIONS FOR FUTURE RESEARCH

Despite the progress of recent research, this has been inadequate to meet the needs of development. However, bamboo stands and their management are likely to asusme an even greater role than in the past, and this means that the basic research associated with the management of stands needs to be intensified. Essentially, there are three areas for focus: bamboo biodiversity and its protection; more intensive research on management of stands; and wider use of better agroforestry systems.

Bamboo Biodiversity

INBAR, in association with IPGRI, is currently looking at ways to conserve bamboo genetic diversity and to ensure resources for use in the future. With so many species, priorities are needed and the INBAR report is welcomed. However, this should not detract from continued taxonomic research, especially looking at materials from remote areas.

Silviculturises would welcome a review of the species and their actual or putative synonomies, and the attention of taxonomists is drawn to this.

In relation to conservation, due attention will need to be given to pests and diseases. For pests alone, there are still about 400 species not yet researched. Whereas stands of bamboo have existed for long periods in balance with pests and diseases, establishment of specific collections of vegetative materials can be vulnerable.

INBAR, at the planning workshop in mid-1993, accorded priority to analysis of information on pests and diseases, and this will be welcome.

Management of Stands

Whatever the results of past research, be it on fertilisers or basic studies on ecology and physiology, research has to be intensified within the context of sustainability. Production of higher quality products by local people surely necessitates much more attention to better selection of genetic forms, and ultimately more attention to genetic enhancement through various breeding methodologies. A strategy needs to be developed for this.

Not enough attention has been given to natural monopodial bamboo forests distributed in remote mountainous areas or mixed under deciduous and confierous trees. In China alone, there are 3.8 million ha of such bamboo forests, occupying more than 50% of the total bamboo stands. Such forest ecosystems are the habitat of some rare wildlife, such as the panda, the golden hair monkey and the elephant, and play a major role in soil and water conservation. Because of lack of knowledge, when the natural bamboo forest dies due to flowering, or damage, people do not know what to do.

Agroforestry

Whereas the development of agroforestry models using bamboo have followed the traditional technical route, i.e. diagnosis, design, re-diagnosis, redesign through to delivery through extension, more attention has to be given to the genetic materials used, and to the use of species in improving degraded areas. Again, the latter is a priority for INBAR decided at the 1993 workshop.

Steps to the Future

Future research will benefit from strategic planning. The following are essential to the overall framework:

i. Adoption of methods and concepts of "social forestry" to attract the fullest participation of all people in the work.

ii. To increase the linkages between governments, international organisations and NGOs in networked research.

iii. To strengthen international networking, through INBAR and others, so that the scientific standards of research are raised, with the net result that technologies promoted through extension are of higher value.

Inherent in the above steps is the continued need for socio-economic research applied directly to the specific research on stand management.

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ON THE MANAGEMENT OF BAMBOO STANDS, WITH SPECIAL REFERENCE TO JAPANESE RESEARCH

M. Watanabe

INTRODUCTION

This paper reviews the large body of research built up in Japan on the management of temperate bamboo stands. This enables the identification of gaps in research. Additionally, numerous Japanese scientists have carried out research on tropical bamboo stands, and this research is also summarised.

The interests in bamboo research in Japan are closely related to the needs of industry, and there are a number of current constraints, especially in the availability of quality materials. This being the case, research interests in Japan contrast with those of many of the countries participating in the INBAR research network. Nonetheless, this paper points out a number of areas where closer synergies between researchers will be to the advantage of all.

Modern research on propagation of bamboo, and on the management of bamboo stands, has developed from the pioneering efforts of three researchers : the late Dr. Koichito Ueda, Dr. Makoto Numata, and Dr. Takashige Aoki. Basic studies by Dr. Ueda led to the practical aspects of the physiology of growth, nutrition and propagation. This research was embodied in a large list of publications, too numerous to itemise here. However, his thesis, 'Studies on the Physiology of Bamboo' (Ueda, 1960), became recognised as a landmark publication with profound effect on the understanding of the physiology of bamboo, and on worldwide interest in applying the relevant science to better utilising bamboo resources in many parts of the world.

The publication was so significant that, when copies of the original were no longer available, the Resources Bureau of the Science and Technics Agency, in the Prime Minister's Office, reprinted the work.

The research of Dr. Ueda went far beyond the emphasis of plant physiology. Through the publication of many books, he promoted sound methodology for basic cultivation practices. For instance, his book 'Useful Bamboo and Edible Sprout', is still the most precious and practical manual for cultivators in Japan.

Dr. Numata is an eminent plant ecologist who made fundamental studies on the ecological characteristics of *Phyllostachys* stands in Japan. His work and that of his co-workers resulted in a series of twelve papers in the period 1955-64. These covered aspects of vegetation structure, growth forms, habitat factors, water economy and flowering. In 1979, he edited a book, entitled 'Ecology of Grasslands and Bamboolands in the World', and this was the first major recognition of bamboo communities.

The above research was paralleled by the study of forest management by Dr. Aoki. Basic research on bamboo forests was related to stand composition, age rotation, volume production and the yield for industrial organisations. In 1961, he published on stand structure, and in 1987, edited bamboo research of Japanese scientists in the book 'Studies for Native Main Bamboos in Japan'.

FUNDAMENTAL RESEARCH ON TYPIFICATION OF BAMBOO STANDS

In order to manage bamboo stands efficiently, it is necessary to understand the different types. Watanabe (1968) proposed that this typification needed to take into account life form, propagation form, growth form and culm size (Figure 1). By establishing a number of types of stands, it is possible to consider their management, irrespective of the species and genotypes, because each ecological type can be managed according to the ecology.

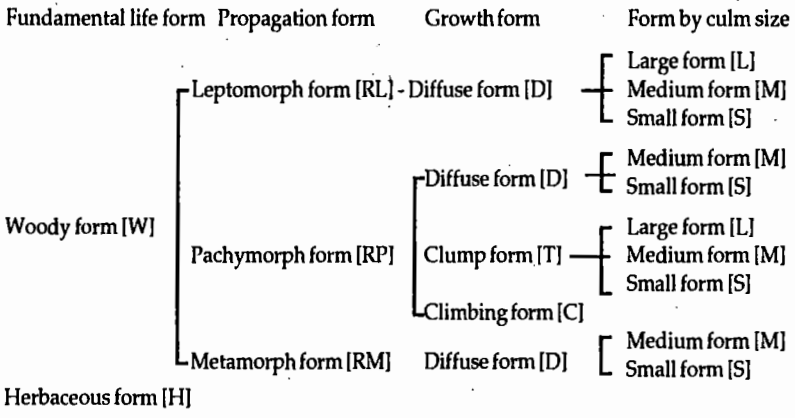

Fig. 1 : Typification of bamboo forests by Watanabe, 1986

STAND STRUCTURE

Following basic studies by Numata *et al.* on density and distribution of plants within stands and the application of theoretical considerations of dispersion of populations (Lloys, 1967, Iwao, 1968), the parameters mean crowding and mean density can be measured and plotted.

It is possible to determine the **m**-m relation, where **m** indicates "mean crowding" and m indicates "mean density", and the dispersion pattern of population can be discussed by the relationship between **m** and m. A number of patterns emerge, e.g **m**=m means a random distribution, but **m**>m means an aggregate distribution. Also, the **m**-m relation can be expressed by the equation of **m** = + m.

Application of this measured dispersion provides an objective, quantitative description of the stands and this assists greatly in deciding management options for selective cutting. This quantification has been applied to the ecological types (Watanabe 1986), especially to those natural stands which are not managed.

Figs. 2 and 3 show examples of stand, structure of standing bamboo, and its dispersion patterns using the **m**-m relation. In the case of a long term non-managed *Phyllostachys bambusoides* stand in Kyoto, as shown at Fig. 2, the dispersion pattern shows

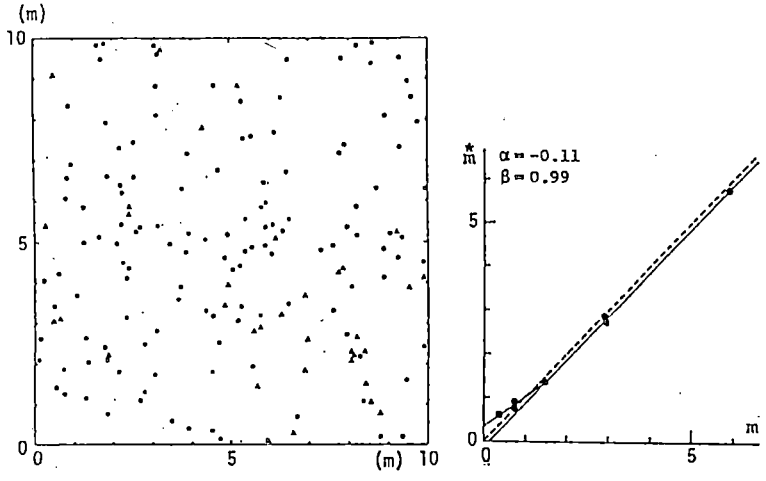

Fig. 2 : Distribution of standing bamboos (left) and m — m relation (right) in *Phyllostachys bambusoides* stand, Kyoto by Watanabe, 1987.

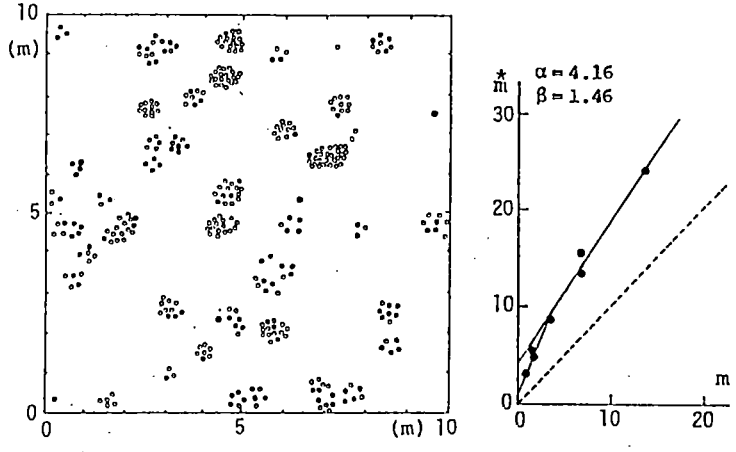

Fig. 3 : Distribution of standing bamboos and clumps (left) and m — m relation (right) in *Thyrsostachys siamensis* forest Kanchanaburi, Thailand by Watanabe, 1987.

almost poisson, or random distribution with small colonies existing.

Since temperate *Phyllostachys bambusoides* bamboo tends to form a diffuse - form stand, the pattern of random distribution with randomly distributed small colonies must be normal under natural or nearly natural conditions. Knowing the dispersion pattern of standing bamboo is important for control of stand density in actual management.

Fig. 3 shows the stand structure of standing bamboos and clumps in a tropical clump-form stand, and its dispersion pattern by **m**-m relation of *Thyrsostachys siamensis* in Kanchanaburi, Thailand. The stand is composed of scattered large and small sized colonies and can be subjectively seen. However, **m**-m relations shows the structure to comprise compact clumps in a somewhat aggregated distribution.

It could be thought that tropical clumping bamboo has a tendency to distribute clumps at random, which is the same character as shown in individual clums distributed at random in temperate bamboo. An aggregate distribution of compact clumps might be, however, not ideal when looked on dispersion pattern.

Wider application of the **m**-m relation to determine stand structure can be expected to have important applications on the sustainable management of stands.

PRODUCTIVITY

Ueda (1960, 1963) investigated the productivity of temperate

Table 1 : *Annual production of culms by selective cutting method in diffuse-form stands in Japan.*

Species	Site	Number (no/ha)	Fresh wt. (ton/ha)	Dry wt. (ton/ha)
Phyllostachys pubescens	Good	500	19.0	11.4
	Ordinary	800	13.0	7.8
	Poor	1,000	6.0	3.6
Phyllostachys bambusoides	Good	1,200	14.0	8.4
	Ordinary	1,700	9.0	5.4
	Poor	2,000	5.0	3.0

Note. Dry weight was estimated by fresh weight as 40% of water content.

Table 2 : *Above-ground biomass in diffuse-form stands.*

Species	DBH (cm.)	Density (no/ha)	Dry weight Culms (ton/ha)	Branches (ton/ha)	Leave (ton/ha)	Total (ton/ha)	References
	8.3	4,500	40.6	7.3	3.1	51.0	Suzuki,
P.pubescens	9.3	5,100	49.2	9.2	4.2	62.6	1976
	9.2	8,800	87.6	12.5	5.5	105.6	
P.pubescens	7.0	6,120	36.5	8.2	3.5	48.2	Kao,Y.-P.,
	9.4	5,120	63.5	11.0	4.8	79.3	1986
P.pubescens	9.6	3,700	43.2	8.3	3.9	55.4	Wang, T., 1981
P.bambusoides	2.6	18,300	12.6	3.5	3.3	19.4	Watanabe
	2.9	22,000	23.2	7.1	6.9	37.2	et al., 1978
P.bambusoides	5.4	7,250	25.5	4.4	1.9	31.8	
	5.5	10,750	41.3	7.0	3.1	51.4	Wantanabe,
	5.6	12,800	52.1	8.7	3.9	64.7	1983
	3.1	15,800	17.3	4.4	1.4	23.1	
	3.9	16,800	29.3	7.1	2.4	38.8	
	4.5	10,400	28.3	6.5	2.6	37.4	Watanabe &
P.bambusoides	4.5	6,700	15.7	3.8	1.6	21.1	Ueda,1976
	5.0	8,800	27.8	6.6	2.4	36.8	
	7.2	8,900	61.2	13.7	6.0	80.9	
	8.7	4,800	55.2	12.4	5.4	73.0	
	3.0	26,200	28.0	5.4	3.8	37.2	
P.nigra v.	3.6	18,000	28.0	5.8	3.4	37.2	Suzuki &
henonis	3.8	23,800	40.0	7.4	6.0	53.4	Uchimura,
	4.4	15,200	36.6	7.2	4.4	48.2	1980
	6.6	13,800	73.6	12.6	9.2	95.4	

stands under various degrees of cultivation and measured annual production. To the data of Ueda in Table 1 have been added dry weight production, estimated as 40% of water content in fresh weight.

Productivity studies are now more focused on the ecosystem and estimation of biomass. Uchimura (1972) looked at biomass in *P. bamusoides* stands which were recovering from flowering. Since that study, biomass estimations have become more routine.

The above-ground biomass in temperate *Phyllostachys* stands in Japan and Taiwan are summarised in Table 2. In dealing with production in the material cycling of ecosystems, the production is usually expressed by weight in a definite area and period. This production is called productivity.

Net production is the newly produced biomass in a certain period. Few studies have been reported to date, but these are summarised in Table 3. More research is required because productivity is greatly affected by species, genotype, G X E interactions and management.

Table3 : *Net production in diffuse-form stands.*

Species	DBH (cm)	Density (na/ha)	Net production (ton/ha. yr) Culms	Branches	Leaves	Sheaths	Total	References
	8.3	4,500	5.0	0.9	3.1	1.2	10.2	
P.pubescens	9.3	5,100	8.3	1.5	4.2	1.6	15.6	Suzuki,1976
	9.2	8,800	6.0	0.9	5.5	1.7	14.1	
P.pubescens	7.0	6,120	5.3	1.1	2.3	0.5	9.2	Kao, et al.
	9.4	5,120	10.8	2.1	2.2	0.5	15.6	1986
P.pubescens	9.6	3,700	9.1	1.8	3.0		13.9	Wang,1981
P.bambusoides	5.5	10,750	14.3	2.3	3.9	1.2	21.7	Watanabe,1983
	5.6	12,800	9.7	1.6	5.2	1.7	18.2	
	3.0	26,200	3.6	0.7	2.3	*	6.6	
P.nigra	3.6	18,000	3.6	0.7	2.0	*	6.3	Suzuki &
v. henonis	3.8	23,800	4.9	0.9	3.6	*	9.4	Uchimura,
	4.4	15,200	5.0	1.0	2.7	*	8.7	1980
	6.6	13,800	6.0	1.1	5.2	*	12.3	

Note : *Sheaths are included with leaves.

STAND DENSITY

An extremely important aspect of sustainable management is the control of density in stands. In order to maintain consistent high yields each year, density has to be controlled.

Ueda (1960) measured stand densities (Table 4) and Uchimura (1972) developed a plot of stand density and average diameter of stand, which permitted the theory of density control based on the adoption of a density index.

Table 4 : *Stand density of diffuse-form stands.*

Species	Site	Number (no/ha)	Fresh wt. (ton/ha)	Dry wt. (ton/ha)
Phyllostachys pubescens	Good	4,000	154	92
	Ordinary	6,000	96	58
	Poor	8,000	51	31
Phyllostachys bambusoides	Good	8,000	93	56
	Ordinary	12,000	53	32
	Poor	15,000	39	23

Note. Dry weight was estimated by fresh weight as 40% of water content

Table 5 : *Stand density and determination of crop per ha in stands of* Phyllostachys bambusoides.

Mean of D.B.H. (cm)	Stand density	Determination of crop
3	40,000±6,000	
4	22,000±2,500	Unproductive stand (Small diam. stand)
5	15,000±2,000	
6	10,000±1,500	Ordinary stand (Medium diam. stand)
7	7,500±1,200	
8	5,500±1,000	
9	4,500±500	Productive stand (Big diama. stand)
10	3,500±500	

Note: Original table showed stand density per 0.1ha.

Regarding stand density, Uchimura (1972) also showed standard determination of crop per definite area in *Phyllostachys bambosoides* (Table 5). These data, based on modern ecology, are valuable for sustainable management. Uchimura (1994) has recently published a Japanese book introducing the value of this type of research to the general public.

FLOWERING

During the 1960's and 1970's, stands of *Phyllostachys bambusoides* flowered simultaneously throughout Japan, causing a panic in bamboo industry. Hence, it is very important to have data which give information on the genetic trait of flowering in the sense that time intervals can be predicted. Watanabe *et al.* (1981) recorded time intervals, as in Table 6.

It is a very important problem how stands biologically and ecologically recover from the destruction by flowering. Figure 5 shows the recovery from a flowered stand, which had been well managed and had adequate density control and fertiliser application. Dry weight increment of culm during 5th to 12th years after flowering increased year by year, and reached a maximum at the 11th year. This confirms the old Japanese saying that flowering is like a "ten year withering disease."

Table 6 : *Exact records of flowering interval*

Species	Country	interval (years)
Bambusa arundinacea (bambos)	Brazil	31-32
Bambusa arundinacea (bambos)	India	45
Dendrocalamus strictus	Cuba	44
dendrocolamus strictus	Taiwan	47
Guadua trinii	Argentina	30
Phyllostachys dulcis	U.S.A.	43
Phyllostachys pubescens	Japan	67
Thyrsostachys oliveri	India	48

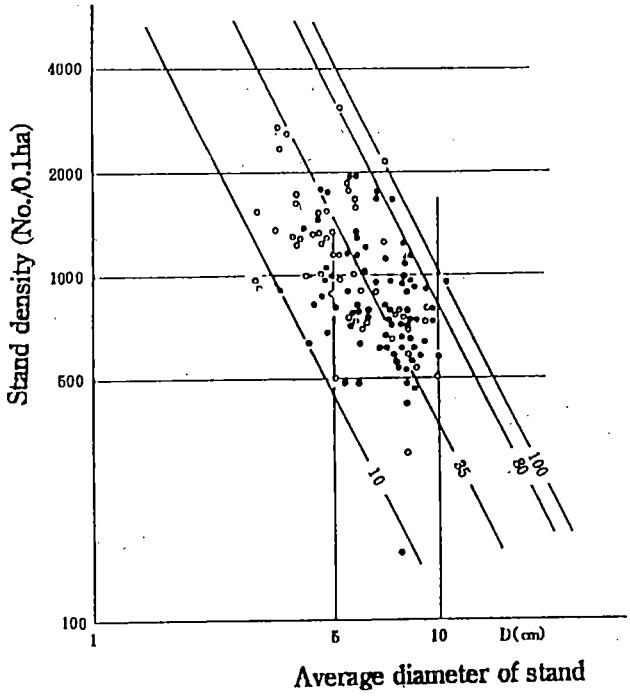

Fig. 4 : Full density curve and stand density index of *Phyllostachys reticulata*.

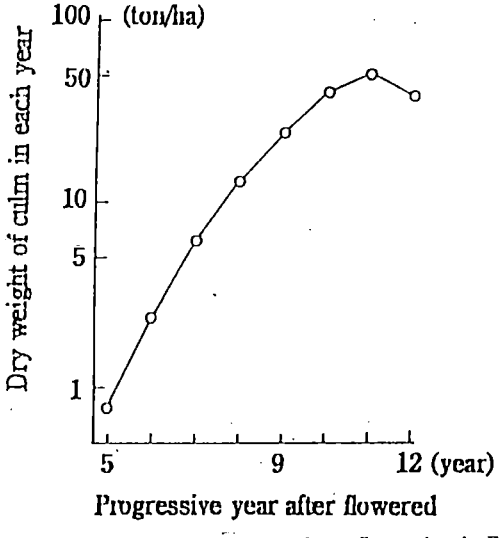

Fig. 5: Increment of standing crop in recovering from flowering in *Phyllostachys bambusoides* stands.

JAPANESE RESEARCH IN OTHER COUNTRIES

Much research by Japanese scientists has been reported on tropical bamboo forests. The pioneer was Ueda (1960, 1966) and he reported fundamental research in natural bamboo forests in southeastern Asia. His recommendation (1966) on bamboo resources for pulp and paper making in Thailand was a landmark at the time.

After that, many papers on tropical bamboo forests have been published from Japan. For example, Watanabe (1972) reported on afforestation using mixed bamboo seedings with leguminous tree seedings. Table 7 shows the result of a plantation of mixed *Thyrsostachys siamensis* seedling with *Cassia fistula* seedling in Kanchanaburi, Thailand. Even though the results were obtained after two growing seasons, the benefit of the nitrogen fixing is obvious. Wider use of such mixed plantings on poor soils in tropical areas will promote the growth of bamboo at lower cost.

Table 7 : *Growth aspect of Thyrsostachys siamensis and Cassia fistula seedings by mixed plantation after the second growing season*

	Thyrsostachys siamensis					Cassia fistula			
Plot	Survival rate (%)	Bamboo newly produced No/hole (No.)	Ave.D (mm)	Ave.H (cm)	Volume (m^3)	Survival rate (%)	Growth Ave.D (mm)	Ave.H (cm)	Volume (m^3)
A	95.8	1.2	3.9	49	11	-	-	-	-
B	-	-	-	-	-	91.7	9.2	49	54
C	83.3	3.5	6.6	84	243	-	-	-	-
D	-	-	-	-	-	100.0	17.9	98	378
E	87.5	1.9	4.2	54	23	95.8	5.8	37	19
F	72.9	3.4	7.9	110	374	95.8	9.9	66	129

Plot A= Planting of *T. siamensis* seedling
Plot B= Planting of *C.fistula* seedling
Plot C= Fertilising in addition to A
Plot D= Fertilising in addition to B
Plot E= Planting mixed *T. siamensis* with *C.fistula* seedling
Plot F= Fertilising in addition to E

Table 8 : *Growth of culms, branches and leaves of Bambusa vulgaris propagated by cutting.*

Characteristics		Stage of culm development						
		First year				Second year		
		1	2	3	4	5	6	7
Culms:								
No. of culm	(pc)	1	2	2	3	3	5	2
Length	(m)	1.20	2.43	4.26	5.43	6.28	8.44	8.85
Diameter*	(cm)	0.95	1.15	2.43	3.10	4.10	4.89	4.88
Green weight	(gm)	10.5	69.65	445.03	1522.20	2651.0	5650.1	5414.97
Moisture content	(%)	10.15	10.29	32.21	41.47	43.66	45.46	51.27
No. of node	(pc)	8	12	21	30	33	38	35
Branches**								
Maximum length	(m)	-	0.91	1.49	2.45	2.53	3.45	3.93
Green weight	(gm)	-	54.7	360.6	1300.5	1743.2	3923.6	3805.7
Moisture content	(%)	-	9.44	34.10	48.4	50.62	54.00	60.00
Leaves**								
No. of leaves	(pc)	-	-	306	2281	3566	6442	4753
Green weight	(gm)		-	29.5	354.6	693.9	2135.9	1623.1

*Diameter measured at 30 cm above the ground level.
**No data available at the initial stages of elongation in the first year of observation.

Various papers on ecological characteristics, productivity and propagation of Philippine bamboo have also been reported by Japanese scientists (Suzuki & Jacalne, 1986, Uchimura, 1978a & 1978c). Experiments on rhizome cuttings (offset) and culm cuttings of Philippine bamboo by Uchimura (1978a & 1978c) are reported in Table 8.

BAMBOO INDUSTRIES IN JAPAN

The Bamboo Culm Industry

A summary of statistics is provided in Table 9. This shows that the area of culm production decreased over the period, and that imports of culms gradually increased, except for a decrease 1981-87.

Table 9 : *Recent bamboo culm industry in Japan.*

Year	Area of stands (ha)	Import (ton) 1	Production (ton) 2	Export (ton) 3	Supply (ton) 1+2-3	Prod./Area per year (ton/ha)
1978	120,390	28,825	228,723	1,870	255,678	1.900
1979	121,355	31,352	215,600	1,344	245,608	1.777
1980	124,498	25,034	224,125	1,001	248,158	1.800
1981	120,934	21,230	210,700	1,128	230,802	1.742
1982	117,984	21,049	203,375	1,105	223,319	1.724
1983	117,386	17,395	193,500	680	210,215	1.648
1984	111,791	17,629	199,150	996	215,783	1.781
1985	104,777	17,763	186,975	490	204,248	1.785
1986	101,174	18,297	178,400	521	196,176	1.763
1987	94,362	17,479	177,775	749	194,505	1.884
1988	93,342	23,827	175,600	295	199,132	1.881
1989	88,190	22,514	171,550	112	193,952	1.945
1990	88,171	23,265	170,550	102	193,713	1.934
1991	84,440	27,104	164,200	83	191,221	1.945
1992	79,633	25,840	144,970	79	170,731	1.820

Note:
1) Areas & production are from the information of Forestry Agency.
2) Imports & exports are from statistics of Customs Office.

Data not included in Table 9 relate to the imports of bamboo products. In the past, export of products was important for currency earnings but this is not now the case.

During the past 15 years, production and supply of culms in Japan have been reduced by about one third. The reasons for this decrease are as follows:

First, the demand for construction materials has decreased. A large amount of culms used to be consumed for Japanese wooden houses in the past. For example, mesh formed bamboo piece supporters for constructing clay mud walls were required in the past. However, the Japanese living style is more westernised and typical Japanese housing is not as popular. In case of constructing traditional houses, high cost are required than for western style housing.

Second, the demand for bamboo products is decreasing. Various bamboo products for use in the daily life of the Japanese people are being replaced by petrochemical derivatives such as plastic substitutes. Many are imported from neighbouring countries. Many handicrafts made by Japanese are now valued, like high-level art not suited for daily use.

Third, due to decreased demand, farmers are less willing to cultivate bamboo, and younger people are not involved with such work.

Despite these changes, the production per unit area has remained fairly constant, even at low levels. Management of stands and cultivation techniques remain satisfactory.

Shoot Industry

The trends in the industry are shown in Table 10. Stand area has remained almost constant, but production has decreased. Imports have increased. Significantly, production per unit area is decreasing.

Table 10 : *Recent bamboo shoot industry in Japan.*

Year	Area (ha)	Production (ton)	Import (ton)	Demand (ton)	Prod./Area (ton/ha.yr.)
1981	50,179	156,674	29,874	186,548	3.122
1981	48,444	153,886	34,255	188,141	3.177
1981	47,422	167,275	36,165	203,440	3.527
1981	44,513	146,929	38,619	185,548	3.301
1981	51,103	161,123	42,191	203,314	3.153
1981	51,362	146,773	48,288	195,061	2.858
1981	35,660	137,216	81,022	218,238	3.848
1981	33,428	150,349	95,733	246,082	4.498
1981	53.181	138,276	70,294	208,570	2.590
1981	53,129	137,616	72,546	210,162	2.590
1981	54,324	112,460	90,129	202,589	2.070
1981	48,994	99,466	98,665	198,131	2.030

Note
1) Areas & production are from the information of forestry Agency
2) Imports are from the statistics of Customs Office

Shoot production in Japan has always been intensive, but there are indications for a decline.

Reasons for decrease in domestic productions are related to two factors. One is that the farmer's income from cultivating shoots is declining due to competition with low cost imported shoots. The second is due to lack of manpower for intensive cultivation and interest by younger people in this work.

Fortunately, shoots are in demand in some districts and fresh shoots can command high prices in markets as compared to canned shoots. There is anxiety about imports of fresh shoots.

RESEARCH TRENDS IN JAPAN

An analysis of published research over the past 5 years is provided in Table 11. It will be seen that management of stands and more applied topics are less than mere fundamental ones. Also, two other areas are highlighted : those related to industry and utilisation and those related to landscape, conservation and gardening. Whereas at one time Japanese research focused on

Table 11 : *Numbers of research papers reported during past five years in Japan.*

Fields	1988	1989	1990	1991	1992	Total	%
Taxonomy	1	5	0	2	3	11	3.8
Physiology	11	3	4	7	5	30	10.4
Ecology	12	18	14	7	18	69	24.0
Production of planting materials	1	3	2	1	2	9	
Management of bamboo stands	3	1	1	1	1	7	
Total	4	4	3	2	3	16	5.6
Bamboo culm indutry	4	8	5	3	3	23	8.0
Bamboo shoot	10	4	9	7	5	35	12.2
Technological Arts	3	7	6	1	1	18	6.3
Utilisation	10	6	8	6	16	46	16.0
Environment, Gardening, others	8	7	5	1	15	36	12.5
Insects & Fungi	1	0	1	1	3	6	2.1
Total	64	62	55	37	72	290	100

(by Bamboo journal No.s 7-11, 1989-93, Japan Bamboo Society published)

stands and their management, in this analysis only 14 out of 290 papers were on such topics.

Research on propagation was reported in 9 papers during five years, and only a few of them were valuable scientifically. For example, Uchimura (1990) reported on the growth of seedlings under different environmental conditions. Shibata (1989) reported on propagation, and Yachiguchi and Wakayama (1992) in tissue culture. Other authors include Utsunomiya (1988), Hamada *et al.* (1991), Watanabe (1988), Nishida (1988), Nishida *et al.* (1989, 1990).

GAPS IN RESEARCH

Most points which follow relate to the situation in Japan.

Planting Materials

As pointed out by Fu (1992), studies on bamboos for environmental protection are still in their infancy. Whereas, in Japan, supply of materials for afforestation is not a high priority at present, the supply for other purposes is.

Planting materials are currently supplied through conventional propagation. In many cases, there is a very narrow genetic base.

Much more attention need to be given to establishing better quality material supply through rapid methods.

Management of Stands

Research needs have to be viewed against the deterioration in non-managed stands and the need for new culm products, which would cause an increase in culm consumption.

Research is needed on production of higher quality culms and increased yield, but this requires the cooperation of industry.

Tropical Bamboos

There is a need to transfer Japanese research methodology more widely in topical regions.

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APPROPRIATE METHODOLOGIES IN RESEARCH ON NATURAL STANDS OF BAMBOO

Wan Razali Wan Mohd. and Azmy Hj. Mohamed

INTRODUCTION

Natural bamboo stands in the forest play a vital role in the socio-economics of rural populations. In India, the total forest area covered by bamboos is about 9.6 million hectares (Prasad, 1990). In Malaysia, natural bamboo stands were estimated to occupy about 1.5% of the total forested land, that is 300,000 ha, but they are widely scattered. In Indonesia, natural bamboo stands in Sumbawa Besar were estimated to occupy 3,442,250 ha (Sindoesoewarno, 1963). In the Philippines, as reported by Ramoran (1989), bamboo forest covered an area of about 7,924 ha. In Bangladesh, bamboo covered about 600,000 ha (Md. Haron, 1992), and in Vietnam, 1.5 million ha (Manh Hoat, 1992).

Due to the rapid utilisation of bamboos in Southeast Asia (Rao, 1992), it appears that, in the near future, the demand may exceed the supply if they are not cultivated, or enriched, or properly regulated. This may lead to impoverishment of natural stocking of bamboo in the forest and to loss of genetic material (Rao, 1992). Systematic management of natural stands should be considered, especially at the earlier stage before resource depletion becomes critical.

There are about 70 species of bamboo known in Malaysia: 50 in Peninsular Malaysia, 30 in Sabah and 20 in Sarawak (Wong 1989). The genera include *Bambusa, Dendrocalamus, Dinochloa, Recemobambos, Schizostachyum, Thyrsostachys, Chusquea, Yushania, Phyllostachys and Gigantochloa.* There is no complete inventory of bamboo resources in Malaysia; however, it is known that bamboo grows in many scattered areas.

This paper identifies some appropriate methodologies in research on natural stands in order to manage them for sustainable supply to meet local consumption and/or industrial requirements.

METHODOLOGIES

INVENTORY OF BAMBOO AREA

Remote Sensing and Aerial Photography

Bamboo inventory using a proper technique is important in order to take stock of its availability. With the inventory, first-hand information can be gathered on the distribution, condition, and location of natural stands of bamboo. In addition, the volume of the resources can be estimated based on the extent of the tracts covered.

Research has showed that the use of remote sensing and aerial photographs to locate and survey the extent of the bamboo areas is very promising (Khali Aziz 1993).

Aerial photographs give better results because of their high resolution, stereo image capability and detailed scale. Experience has shown that the photographic texture (smoothness or coarseness of images), tonal contrast and relative sizes of bamboo images with a scale of 1:10,000 can give satisfactory results in differentiating between bamboos and other vegetation in a disturbed natural forest. Experience in FRIM has shown that natural bamboo stands in the forest exhibit a bluish-green colour on imageries from Landsat TM (on Band 453).

Ground Inventory

Ground inventory is also an important activity in the management of natural bamboo stands. Research showed that for the ground survey, the sampling method to be adopted to inventory bamboo would depend on the different bamboo habitats. It was found that in India, line plot and strip sampling was very useful for bamboos growing on plains and gently undulating areas,

whereas for highly undulating and steep areas, two or three stage stratified sampling was used (Sharma, 1990).

In Malaysia, the ground inventory takes into consideration species, quality and density classes, major forest types, stocking, clump distribution, clump size and bamboo regeneration conditions. Bamboo inventory has been carried out simultaneously with forest resources inventory in the 3rd National Forest Inventory (1992-1993), and it has used the cluster sampling method.

Ground inventory results when combined with the aerial photograph information or remote sensing imageries would give better results than ground inventory alone.

FERTILISATION OF BAMBOO CLUMPS

Bamboo yields in the forest can be increased by applying organic and compound fertiliser to get maximum yield and to produce vigorous shoots. (Shi *et al*;1987; Qiou and Fu, 1987). For most of the times, the harvesting of bamboo culms within the same clumps can reduce the vigour of the rhizomes. By applying fertiliser, growth in the length and basal area of regenerated bamboos can be promoted (Kasahara, 1971). In addition, weeds which were removed, can be buried as green manure to promote shoot development (Zhong, 1988).

The most appropriate and most widely-used methodology to conduct fertiliser research is the use of Randomised Complete Block Design, Split Plot Design and Factorial **Experiments**. Some examples (in a summarised version) are shown in Annexes 1, 2 and 3.

According to Azmy (1992), the application of 2 kg of compound fertiliser of N, P, K (15:15:15) on, for example, every clump of *Gigantochloa scortechinii* natural stand can yield 30% more new shoots per clump every month, except during the dry season. An increase in the diameter growth of the culms, using a mixture of N,P,K and calcium silicate acid (Ueda *et al*, 1961), is possible. The increase in the number of culms and yield will help to sustain the bamboo forest for a longer period.

The fertilisers should be applied about a month in advance of sprouting period so that the effects of better sprouting and increased growth of rhizomes can be seen during sprouting rhizomes (Uchimura, 1980).

CLEANING OF BAMBOO CLUMP

Cleaning of bamboo clumps is essential to facilitate growth of new culms. The importance of cleaning has been stressed in the management of *Dendrocalamus strictus, Bambusa bambos, B. balcooa, B. tulda, B. vulgaris and Thyrsostachys oliveri* in India (Parkash and Khanna, 1979). In Bangladesh, such operations are acknowledged necessary for *Dendrocalamus longispathus, Meloccana bacifera, Neohouzeau dullooa and Oxytenanthera nigrociliata* (Hasan *et al.*, 1976), and in China cleaning is a must for all bamboos in general (Ye, 1988).

The objective of cleaning of the bamboo clump is to reduce competition, encourage new sproutings (of culms), and to reduce the infestation of pests and diseases. The activity is usually a routine maintenance of the bamboo stands and has been acknowledged as necessary. Therefore, it is not so important as a research problem.

THINNING OF BAMBOO CULM

Regular thinning of bamboo is a pre-requisite for sustaining the vigour of rhizomes. In *Dendrocalamus strictus* areas in India, where natural seedlings appear as a result of flowering or gap-planting, three weedings were done in the first year and two in the second year (Parkash and Khanna, 1979). It is important to thin the culms yearly, especially for *Dendrocalamus strictus*, because this helps to increase the number and quality of shoots. It also lessens fire and insect danger. In congested clumps, the rate of increment in bamboo is reduced due to the limited space available for the newly grown culms to survive. According to Kadambi (1949), after each cleaning and thinning, there was an

increase in culm production of *Dendrocalamus strictus* for the next two or more years. Congested clumps with dead, broken and malformed bamboos should be removed.

Clumps containing more than 60 culms at the time of working are not easy to work with and usually resulted in twisted and deformed culms. The best solution is to clearfell some of them, and then tend the clumps in such a way as to produce a uniform size of the culms. In China, according to Ye (1988), the thinning of *Phyllostachys pubescens* shoots caused the number of culms to double.

FELLING RULES AND FELLING CYCLE

A well organised, pre-planned felling schedule is generally one of the most recognised and implemented aspects of bamboo management. For *Dendrocalamus strictus*, felling (cutting) cycles of 2, 3 and 4 years are practiced according to the conditions of the individual bamboo area. A 4-year felling cycle was most widely used, but in the Philippines, a 2-year cycle is practiced (Tomboc and Virtucio, 1994). In Bangladesh and Indonesia, a 3-year cycle is used (Chaudhury, 1986; Sindoesoewarno, 1963). In Thailand, felling of *Thyrsostachys siamensis* is done alternate years (Kraitpraneet *et al.*, 1978). The difference in the duration of a felling cycle is reflected in the amount of the culms harvested. In the Philippines, all culms older than two years old are removed in each harvest (Tomboc and Virtucio, 1991).

In natural stands, harvesting of culms less than 3 year old is not recommended. According to Ye (1988) and Zhong (1988), a productive stand of *Phyllostachys pubescens* contains 3,000-3,800 culms per ha, the distribution of which includes 25% of 1 - 2 year old, 35% of 2 - 3 year old and 40% of greater than 3 years old. At least 50% of the culms retained are distributed along the clump periphery (Chaudhury, 1986). Culms are usually cut at not more than 30 cm above ground level (Mohan, 1931; Parkash and Khanna, 1979; Varmah and Bahadur, 1980). Felling operation should be constantly supervised and undertaken in strict accordance with the recommended felling rules.

In order to study the optimum harvesting intensity of natural stands, a recommended design is to use Split Plot Design and/or Factorial Experiments as in Annexes 2 and 3, respectively.

MOUNDING/MULCHING OF BAMBOO CLUMPS

Mounding/Mulching is also important in managing natural bamboo stands in the forest. In China and India, this operation is routinely employed to promote culm production. In the forest, the soil associated with individual bamboo clumps tends to be thinner and prone to erosion, especially on hilly ground. In forest areas in India, mounding the clumps with earth or mulching with humus was done to promote culm production (Chaturvedi, 1988). The process is to nourish the spreading rhizomes and promote peripheral development of the culms (Parkash and Khanna, 1979). For *Phyllostachys pubescens* in China, deep ploughing of the soil is used to increase the yield (Qin, 1986). In addition, loosening of the soil layer of the chosen site will improve drainage and promotes growth (Jiang, 1988; Tang and Ye, 1988).

Many methodologies are available to conduct research on mounding or mulching of natural clumps. For example, we are currently examining the effect of mounding of *G. scortechinii* clumps on the number of shoots and on the diameter growth of the culms. We used the Split Plot Design, which effectively detects the effect of the main treatments (mounding (A) and no mounding (B)) in combination with different levels of fertiliser application. We found that mounding with fertiliser application had induced the number of shoot growth significantly better than no mounding (with fertiliser).

PROPAGATION OF BAMBOO

Regeneration can occur naturally in the forest. After gregarious flowering the young rhizomes and the butt of young culms can be maintained to help build up production of *Phyllostachys*

bambusoides to reach a normal level within 10 years (Lu, 1981). According to Watanabe *et al.* (1980), the regenerative recovery of flowering bamboo stands could be enhanced by treatments, such as by suitable fertilisation and selective cutting.

However, in many instances, flowering of natural stands is unpredictable. Even if it is predictable, the accessibility in most cases is too difficult in order to collect seeds or even to clean or treat the areas so that natural regeneration can take place.

Alternatively, other means of producing planting material have to be researched. Generally, success of propagation through branch cuttings, culm cuttings and rhizome offsets, depends very much on the physiology of respective bamboo species.

In Malaysia, for example, *B. vulgaris, D. asper, G. levis and B. blumeana* can be successfully (greater than 80% survival) propagated via branch cuttings, coupled with the use of IBA hormone to enhance the rooting capability of the bamboo. *S. zollingeri, G. wrayi, B. vulgaris and G. scortechinii* were successfully propagated via culm cuttings, producing greater than 80% survival 30 months after field planting. Similarly, notable success was also achieved by using rhizome offsets for *S.zollingeri and G.wrayi*, but this technique is not recommended due to difficulties in extracting and transporting the rhizome offsets because of bulkiness.

In some cases, the success of producing bamboo planting material for commercial use, via biotechnology (tissue culture), has been encouraging, as in Thailand (*D. asper*) and India (*D. strictus, B. bambos and B. balcoa*). In the Philippines, *D. latiflorus* was also produced through tissue culture for commercial use.

PESTS AND DISEASES

The natural stand bamboo is susceptible to pests and diseases. Measures should be taken to control them or reduce the attacks. For Indian *D. strictus*, grazing inside the bamboo area was avoided because the new culms which appeared on the

periphery of the clumps after felling were damaged by cattle, although those appearing in the interior were spared (Gupta, 1964). In China, pests and diseases control procedure consists of surveys to detect such occurrences so that early control treatments could be done where a need is perceived. These measures are incorporated in the management of *Sinarundinaria fangiana, Chimonobambusa* sp., *Phyllostachys* sp.. and *Yushania* sp. (Zhang and Cheng, 1988).

Bamboo blight can attack perfectly healthy clumps of *B. balcooa, B. tulda and B. vulgaris* for many years with little or no signs of impending death (Boa and Rahman, 1987). A thorough understanding of how bamboo blight is caused and how it spreads is required before control measures can be devised. In Bangladesh, bamboo blight caused by *Sarocladium oryzae* attacks the new culms of natural bamboo stand. There is no real indication that chemical control could overcome bamboo blight. Those clumps showing signs of attack by bamboo blight should be removed from the site and burnt.

Young bamboo culms of *G. scortechinii* between shoots stage and less than 1-year old culms were easily attacked by *Estigmina chinensis* (Abd. Razak and Azmy, 1991). Once they settled down by boring in the internodes, they lay eggs and the nymphs will feed on the internode wall and cause damage to the culms. Removing the affected culms and burning them (away from the site) could easily control this insect attack. Similarly, disease such as brown wilt can be controlled by removing the affected culms and burning them.

MANAGEMENT OF NATURAL BAMBOO STANDS OF G. SCORTECHINII : A MALAYSIAN EXPERIENCE

Bamboo culms in the forest are used and extracted very often for traditional and industrial uses. There is a high demand for bamboo culms and shoots. The management of natural stands is necessary to sustain the resource for future supply. It is possible

to have systematic and good management of natural bamboo stand because it can offer profitable returns.

A natural bamboo stand is defined as a scattered and an uneven distribution of clumps consisting of culms on a unit area in the forest. The aim of managing the natural bamboo stands is to produce culms and/or shoots. As Malaysian bamboos are sympodial in nature (as opposed to monopodial for temperate bamboos), the management of natural stands is aimed at converting the original, uneven, and unstructured stand to look like a planted stand (See Figure 1 in the text of the main report), so that the management of the converted stand can be done systematically and with ease. It also helps to produce bamboo shoots and culms continuously throughout its productive growth period.

The following procedures, based on research results, are suggested to manage natural stands of *G. scortechinii* (Buluh Semantan) in Malaysia:

1. A natural stand of bamboo is managed by identifying the bamboo species and demarcating the clump that consists of individual culms.

2. With some experience, it is possible to identify the age of bamboo culms in each clump. One is able to do this by looking at, for examples, blotches or spots on the culms and colour of the culms. If most blotches or spots are evenly distributed on the culms (up to 8 m in height), this may indicate that the bamboo culms are 3 years or older. Darker green culms indicate that the bamboos are mature, i.e. 3 years or older.

3. Depending on the density of bamboo in one particular area, we suggest that the number of clumps be limited to between 150 to 200 clumps per ha. Each clump at any one time should consist of between 30 - 50 culms of various ages. We should harvest the mature culms as in step (4) and manage the stand to meet the requirements in steps (6) and (7).

4. First harvesting of the mature bamboo culms (greater than 3 years old) in the managed natural stands should be done on a 50% to 70% cutting intensity, i.e. 50% to 70% of the total mature culms per clump can be felled selectively. The mature culms are usually found in the middle of the clump.

5. On the average, about 4 new shoots will emerge per month. In order to manage the natural bamboo stands for both shoot and culm, we advise that two bamboo shoots (less than 30 cm in height) be harvested from each clump each month. Therefore, in any given year, about 24 new shoots will be allowed to grow into culms; however, only about 70% to 80% (16 - 20 culms) survive.

6. As the old culms have to be cut or harvested, the new shoots emerge. At the time of converting the natural bamboo stand into a "look like" plantation, we suggest that the proportional percentage of culms per clump be guided to maintain the following proportion:

Age Class	Suggested number of culms/clump	Avg. no. culms/ clump	%
(a) 3 years old and above;	10 - 20	15	40
(b) 2 to 3 years old;	07 - 15	10	30
(c) 1 to 2 year old;	05 - 10	08	20
(d) 1 year old and below.	03 - 05	04	10

7. Once the bamboo stand is cut, we should allow ample time for the existing culms to grow and regenerate. Subsequent harvest of mature culms should be done on a 40% cutting intensity based on a 2-year cutting cycle. We found that this combination (i.e. 40% cutting intensity and 2-year cutting cycle) is able to produce both shoots and culms continuously for 10 years before new planting needs to be done to enrich the growing stock of the stand.

8. Culms should be cut as low as possible, leaving only one internode above ground. If it is cut leaving more than one internode above ground, bushy and twisted culms will be

produced in the future stand, and this will affect the quality of the culms.

9. Harvesting of the bamboo culms should preferably be done in a 2-year cycle. This is to produce well distributed culms in the clump.

10. Undesired culms, such as those that are twisted and attacked by diseases, should also be cut.

11. Bamboo culms should not be clear felled under whatever circumstances. If clear felled, clumps generally degenerate into a bushy form and take a few years to produce normal culms again.

12. All cut debris will be kept at least one metre away from the clump or be removed outside the bamboo area. This is to keep the clump free from possible attack by pests and infestation by diseases.

13. Each clump needs to be fertilised once a year using 2 kg of NPK. This amount of fertiliser will help to increase about 30% of the total yield of shoots per clump, i.e. an increase of about 1-2 shoots per clump or on the average 210 shoots per ha.

14. Clumps, which showed sporadic flowering, should be cut, provided that they have shed the seeds before they die.

15. The above management technique, based on the existing experiment, produced the following results:

(i) an availability of about 150 clumps per ha.

(ii) each clump, on the average, produced about 10 mature culms at each harvest.

(iii) each clump produced 1 to 2 bamboo shoots per month.

(iv) the cost to establish a managed natural bamboo stand was about RM737.00 (US$270.00) per hectare.

(v) total income of about RM1125.00 (US$420.00) per hectare, i.e. 150 clumps x 10 culms/clump x RM 0.75/culm, could be obtained. This excludes the income that could be derived from selling bamboo shoots at the local market at

about RM1.00 to RM2.00 per shoot (about 1.0 kg to 1.5 kg in weight). Financial analysis calculated was between 10.5% and 12.0% IRR.

16. As a result of this research and the recommendations on the need to ensure the supply of bamboo on sustainable basis, the Forestry Department has agreed to manage about 2000 ha of natural bamboo stands — 250 ha in 1994, 250 ha in 1995, and the remainder from 1996 to 2000, depending on the success of this commercial and pilot-scale experimental management. Notwithstanding the above, there is a great need to carry out market potential for the large supply of bamboo shoots and culms.

Good management of natural bamboo stands is important. It helps to ensure the sustainable supply of bamboo culms in meeting industrial requirements and development. Bamboo industries cater not only for growing local demands, but also increase revenue through exports in the expanding world market.

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RESEARCH METHODOLOGY USED IN NATURAL BAMBOO STAND EXPERIMENTATION

I. RANDOMISED COMPLETE BLOCK DESIGN (RCBD)

Field Layout :

Block I

A	D
B	C

Block II

B	C
A	D

Block III

D	A
C	B

Block IV

C	B
D	A

- A, B, C, D are four (4) different bamboo species, planted using a single rhizome. They are assigned at random within each block.
- Blocks I, II, III, IV could be different compound fertiliser (NPK) levels (0, 2, 4, 6 kg).
- The hypothesis to be tested is that four different bamboo species do not differ in the number of culms produced (originally planted using a single rhizome) despite the differences in NPK level.

RESEARCH METHODOLOGY USED IN NATURAL BAMBOO STAND EXPERIEMENTATION

II. THE SPLIT PLOT DESIGN : When two or more types of treatment are applied in factorial combinations, one type can be applied on relatively small plots while the other type is best applied to larger plots.

	I			II			III		
A	a	d	e	a	e	b	c	a	f
	f	b	c	c	d	f	b	e	d
B	e	c	f	a	b	c	d	b	e
	d	a	b	e	f	d	c	f	a

- Each main plot (I, II, (III - denotes as Block) is split into 2 subplots : (A, B)).
- Treatment (a, b, c, d, e, f) are assigned at random to subplots within each main plot.
- a, b, c, d, e, f could be different levels of a compound (NPK) fertiliser.
- A, B could be two levels of the intensity of culm harvest or mounding and no mounding.
- Block I, II, III could denote site differences.
- The hypothesis to be tested is that a bamboo species does not differ in terms of the number of culms produced, despite of the differences in the intensity of culm harvested (or mounding/no mounding), different levels of fertiliser and differences in site condition.

RESEARCH METHODOLOGY USED IN NATURAL BAMBOO STAND EXPERIMENTATION

III. FACTORIAL EXPERIMENTS are aimed at evaluating known or suspected interactions. Each factor to be studied is tested at several levels and each level of a factor is tested at all possible combinations of the levels of the other factors. For example :

Field Layout or Nursery Layout :

BLOCK I

C_2	B_2	C_0
A_0	B_0	C_1
B_1	A_2	A_1

BLOCK II

B_2	B_1	A_0
A_1	C_0	B_0
C_2	A_2	C_1

- A, B, C denote three (3) different species of bamboo assigned randomly within each block.
- 0, 1, 2 denote three (3) level (kg) of Nitrogen fertiliser.
- Blocks I and II could be two (2) levels of intensity of culm harvest (in Field Layout) or 2 levels of moisture regime (in nursery condition).
- The nine possible treatment combinations (A_0, A_1, A_2, B_0, B_1, B_2; C_0, C_1, C_2,) were assigned at random to nine plots in each of the two blocks.
- The hypothesis to be tested is that there is no effect of fertiliser on the annual diameter growth of bamboo culm (over a 3-year period) of 3 different bamboo species and 3 different levels of compound fertiliser applied to 2 blocks of different intensity of culm harvest (in field layout), or 2 levels of moisture regime (in nursery condition).

APPROPRIATE METHODOLOGIES IN RESEARCH FOR SUSTAINABLE MANAGEMENT OF NATURAL STANDS OF RATTAN

Mary C. Stockdale

INTRODUCTION

The high social and economic importance of rattans, and the present crisis in the world rattan industry due to shortage of supply, are well known. The reasons for this shortage, accordingly to Peluso (1986) and de Beer and McDermott (1989), range from loss of forest habitat due to logging and agriculture, to overharvesting as a result of increased demand for rattans in the international market, increased commercialisation of rural communities, and the breakdown of traditional systems of management and trade.

One response to this shortage has been to develop and promote rattan cultivation. Research into cultivation has been very active; an excellent review of the literature is that provided by Wan Razali *et al.* (1992). A second response to the shortage of supply has been to promote the more sustainable management of natural stands. Wild populations remain the major sources of rattan and are likely to continue to play an important role (Dransfield, 1981).

The relationship between natural rattan stands and rattan plantations parallels, in many senses, that for timber production from natural and plantation forests, which has been extensively discussed elsewhere (eg. Kanowski *et al.*, 1992; Sargent and Bass, 1992). While plantations have an important role to play in maintaining and enhancing supply, the continued management

of natural stands has a number of advantages as, unlike plantations, natural stands:

1. are less likely to be vulnerable to attacks by pests and diseases (Speight and Wainhouse, 1989);
2. incur relatively little initial investment;
3. when combined with the management of other forest products, can provide a more diverse and flexible means of generating income than sole reliance upon one product;
4. may be more adapted to local social and cultural conditions, and;
5. provide substantial additional benefits in maintaining natural forest, such as protection of genetic and species diversity and the regulation of air, soil and water quality.

Smallholder cultivation of rattans is intermediate between plantations and natural stands. It combine the advantages of cultivation (such as increased production) with some advantages of natural stand management (such as requiring relatively low initial investment), being part of a flexible and diversified agricultural system and being more adapted to local social and cultural conditions (Weinstock, 1983; Godoy and Tan, 1989).

In comparison to research on cultivation, little attention has been focused on management of natural stands for production. It is for this reason that the International Network for Bamboo and Rattan (INBAR) Production Working Group convened a consultation to discuss appropriate methodologies in research for sustainable management of natural stands of rattan.

SOME PRINCIPLES FOR SUSTAINABLE MANAGEMENT

As with the forestry debate more generally, there are both narrow and broad perspectives of sustainable management (Poore, 1989). These may be characterised as:

1. *'Sustainable Forestry'*. This narrower view of sustainable management simply involves ensuring the continued production of desired species. This corresponds to the 'sustained yield' principle which foresters have long applied for wood production (Lee, 1982).

2. *'Sustainable Forestry'*. This broader view of sustainable management has a multi-sectoral agenda that seeks to balance use, including the production of non-timber as well as timber products; conserves forest ecosystems and the genetic and species diversity within them; and generates income, employment, consumption and investment benefits for local forest dwellers as well as national economies. This corresponds to the 'sustainable development' principle which 'new forestry' is seeking to apply (Aplet *et al.*, 1993; Behan, 1990; Brooks and Grant, 1992; Schreckenberg and Hadley, 1991).

As others have argued elsewhere (eg Aplet *et al.*, 1993), I suggest that sustainable production will not be successful on a large scale unless attempts are made simultaneously to achieve sustainable forestry. Rattan supply is threatened by loss of forest habitat as well as by overharvesting, and resolution of this dual threat requires a broad appreciation of land and resource use policy and their consequences (Peluso, 1986; de Beer and McDermott, 1989).

The general principles listed below are drawn from the literature, and identify the broader requirements for sustainable management of rattans. Research for improving management is best devised and developed within the context of these principles.

1. *Local people must be involved in planning as well as the actual management of rattans.* This is desirable, not only because it is ethical that the resources continue to benefit the people who have always relied upon them, but because otherwise both overharvesting and habitat loss are likely to continue. It is very difficult to 'police' the rattan resource because of its dispersed and unpredictable distribution; thus, local people are likely to continue to collect rattans regardless of externally-imposed

regulation (Jessup and Peluso, 1985). Also, if local people are no longer deriving economic benefits from the forest, they are likely to attempt to convert the forest habitat to agricultural uses (Oldfield, 1988). Community-based licences can make a strong contribution to sustainable management by giving local people the right to exclude others; however, if given to outsiders, they would have the opposite effect and exclude local people, as has happened in some cases in the Philippines (Torreta and Belen, 1990).

2. *Long term land tenure and control over resources is essential for sustainable management.* There is considerable recent literature (e.g. Arnold, 1992; Arnold and Stewart, 1991; Chambers and Leach, 1990; Cornista and Escueta, 1990: Fortmann and Nihra, 1992) discussing the complex topic of tenurial arrangements which enable or promote sustainable management. While the case for private versus common property rights varies with political idealogy, with social traditions and with the strength of indigenous management systems, it is universally acknowledged that open access and insecure land or product tenure - which may have resulted from the breakdown or displacement of traditional management arrangements - are likely to promote Hardin's (1968) " tragedy of the commons".

3. *Management regimes should develop from and complement traditional management practices.* There is a myth that local people must be taught how to manage rattans sustainably, when in fact they often have considerable knowledge and experience and have managed rattans sustainably for generations. Often sustainable management systems have broken down as a result of the influx of outsiders to local communities, social change or severe economic pressures, rather than as a result of ignorance (de Beer and McDermott, 1989).

4. *Management regimes should be economically feasible.* If costs outweigh profits, the management regimes simply won't be followed. In a study of timber management, Whitmore (1992) noted that post-harvesting silvicultural treatments for wood production in the tropics, to a large degree, have been abandoned due to expense.

IMPORTANT RESEARCH AREAS FOR SUSTAINABLE MANAGEMENT

Research important for the more sustainable management of natural stands of rattans comprises the following topics:

1. inventory methods;
2. modelling sustainable yield;
3. management practices;
4. integration with other forms of forest management;
5. ecological studies, and;
6. socio-economic studies.

In the following sections, each topic is reviewed, and the constraints to and gaps in knowledge of each are discussed:

INVENTORY METHODS

Inventories provide an essential source of information for management decisions. After determining the general purpose of an inventory, specific objectives should be defined. These include the geographical area to be surveyed, the data that are desired, the minimum tolerable level of precision, and the limits of resources such as money, time and skills (Philip, 1983). An important concept is cost efficiency, which implies minimising the cost of achieving a desired level of precision.

An appropriate sampling design will meet objectives in the most cost-efficient manner. Many of the issues which are considered when designing a sampling method for rattans are no different from those for tree inventories, and have been discussed by FAO (1973), Husch *et al.* (1972), Loetsch *et al.* (1973), and Philip (1983). Those of particular relevance to rattan inventory include decisions on sampling methods, categorisation of rattans and measurements of parameters, and are summarised below.

Sampling Decisions

Stratification of sampling area

A way of increasing cost efficiency, which is almost univer-

sally used in forest inventory, is to stratify the sampling area into homogeneous units or strata. Stratification aims to remove or reduce variance within strata and maximise variance between strata and is often based on geographical location, age classes in plantations, and vegetation or soil type (Philip, 1983).

There are a few examples of stratification in rattan inventory. The national forest inventory of Peninsular Malaysia, which included rattans amongst other forest products, stratified forests into the following categories: very good, good, medium, logged over, disturbed/spoilt, shifting cultivation, peat swamp, and poor/montane (Aminuddin, 1990).

In India, Nandakumar and Menon (1992) developed different forms of stratification for different scales of sampling area. At the State level, stratification was based on altitude ('800 m, 800m-1600m, '1600m), accessibility to people (accessible, inaccessible), and level of protection from biotic interference (low, medium, high). At the Division level, stratification was based on attributes of natural rattan 'pockets', areas of high rattan density which range in size from 3-150 ha. These attributes are the size of pockets ('25 ha, 25-100 ha, '100 ha), stocking density ('1000 shoots/ha, 1000-2000 shoots/ha, '2000 shoots/ha) and age class structure (mature: immature ratio '1:50, 1:50-1:10, '1:10), and were estimated for each pocket by a reconnaissance survey.

Remote sensing techniques using satellite imagery and aerial photography can play a role in stratification by identifying various forest types. However, at present their role in direct identification of rattan pockets is limited, as rattan crowns are mostly covered by the forest canopy. In India, remote sensing methods involving the use of satellite images were tested for their capacity to associate rattan populations with overstory vegetation, in order to eliminate areas without rattans from the survey (Menon, 1992). Although imagery could separate probable cane growing areas from caneless areas, they could not identify the pocket boundaries within the probable cane growing areas.

Testing sampling unit design

There is a common methodology for testing and comparing options in sampling design. This methodology involves a 100% enumeration of a study site, which has been divided into small sub-plots, typically 5 m X 5 m or 10 m X 10 m in size. For each subplot, the number of rattans and the time taken to enumerate them are recorded; this data can then be used to test various types of sampling unit design for the following criteria:

1. *accuracy*, the difference between the estimated mean and the true mean;
2. *precision*, the range of the confidence interval around the estimated mean; and
3. *cost efficiency*, the cost incurred for a given precision.

A number of options in sampling unit design are discussed in the following three sections.

Systematic versus random sampling

One decision to make when designing an inventory is whether to select sampling units systematically or randomly. The advantage of systematic sampling (in which the sampling units are selected by a systematic routine or spatial pattern), is that it is easier to plan the layout and locate the sampling units in the field; furthermore, all parts of the population are visited and represented in the sample. However, there is a greater chance of bias in systematic sampling than in random sampling, as the pattern of sampling may match or partially match some periodic pattern of variation in the population (Philip, 1983).

In the Philippines, Tentage (1984) found systematic methods (line plot sampling and continuous strip sampling) to be equally accurate, but more cost-efficient, than simple random sampling.

Within a natural rattan pocket in India, KFRI (1991) compared two-way systematic line plot sampling with simple random sampling without replacement, at the same sampling intensity, and found them to have equal precision. The precision of the

systematic method was calculated by assuming there was no pattern to the variability of the population in the rattan pocket. This assumption was confirmed by regressing the total number of rattan plants in 20 m X 4 m plots by the plots' positions from an arbitrary origin; the very low R^2 values indicated an almost random distribution.

Strip sampling versus line plot sampling versus others

Several studies have compared two sampling methods, viz, line plot sampling, in which lines are systematically or randomly chosen and along which plots are systematically sampled, and continuous strip sampling, in which long strips are systematically or randomly chosen and completely enumerated.

In the Philippines, Tandug (1984) compared the above methods at 5% and 10% sampling intensities for the line plot sampling method and 10%, 15% and 20% for the strip sampling method, using 10 m X 10 m plot size for line plot sampling and 10 m width for strip sampling. For all sampling intensities, both methods were comparable in accuracy; the strip sampling method at 10% sampling intensity was the most cost-efficient method overall.

In Indonesia, Siswanto and Soemarna (1988, 1990) and Siswanto (1991) have compared these two sampling methods at 10%, 20% and 25% sampling intensities, using 10 m X 10 m and 20 m X 20 m plot sizes for line plot sampling and 10 m and 20 m widths for strip sampling. Continuous strip sampling with a width of 10 m and a sampling intensity of 20-25% was said to be 'adequate' because the sampling errors (a measure of precision) for these methods (10-14%) were lowest; their cost efficiencies, however, were not compared.

A study in India by KFRI (1991) compared two line plot sampling methods using plots of sizes 20 m X 20 and 20 m x 4 m, and three strip sampling methods using 4 m wide strips, which were either undivided or divided into contiguous plots of two sizes, either 4 m x 20 m or 4 m x 100 m. All represented approximately 4% sampling intensity. The lowest sampling

error (greatest precision) was found in the 4m wide strip divided into contiguous plots of 4 m x 20 m. No comparison of cost was made, although it was stated that the 20 m x 20 m plots in particular had a plot layout time of at least 10 minutes, which the 4 m wide strips avoided, considerably lowering cost.

In Malaysia, these methods have been compared to a third method called cluster sampling. This case involved 100 m x 90 m clusters consisting of 6 subplots of 28 m x 10 m. All methods were at 10% sampling intensity. Strip sampling was found to be most accurate but line plot sampling, and point sampling (prism sweeps with 5 m radius fixed plots), involved the least time, and strip sampling the most (as reported by Nur Supardi, 1992). The accuracy and precision of these methods were not discussed in Nur Supardi's (1992) report.

Shape and size of sampling units

Choosing the shape and size of sampling units involves balancing three aspects (Philip, 1983):

1. the effectiveness of the unit in representing the variance in the population;
2. the ease of boundary definition; and,
3. the convenience and cost of using such a sampling unit.

The optimum sampling unit shape for the inventory of rattan was tested in the Philippines by Tandug (1978), who found a square plot to be most cost efficient. In contrast, in Brunei Darussalam, Stockdale and Wright (in press) found that rectangular plots, oriented parallel to the direction of the slope, were most cost efficient than square plots. One explanation for this difference may be that the rectangular plots were randomly oriented in Tandug's study. Another explanation is that the topography in her Philippines plot was less sharply dissected than in the Brunei site of Stockdale and Wright, causing the variance to be less influenced by the slope and hence the orientation of the plot; if so, this highlights the importance of testing sampling designs across different site types.

The optimum sampling unit size in Tandug's (1978) study was 0.01 ha; this was within the 0.0025 to 0.025 ha range found to be optimum by Stockdale and Wright (in press), within which range the specific size of a sampling unit was determined by the desired precision, the total area under inventory and the parameters to be estimated.

Categorisation Decisions

Species

Rather than deducing the scientific name of a rattan from the vernacular or local name, it is essential that the scientific identity is determined by using taxonomic guides, if available, by collecting voucher herbarium material, which can be used if there are any doubts over the identity of the species. The use of local names leads to confusion and to lack of comparability across studies, because different names for the same species may be used in different areas, or the local names may aggregate a number of separate species (Dransfield, 1992a). Serious confusions over taxonomy have occurred in national inventories in the Philippines and Malaysia (Wakker, 1991; Dransfield, 1992a).

Taxonomic guides for rattans, which have developed mature leaf forms, have been developed for Peninsular Malaysia (Dransfield, 1979), Sabah (Dransfield, 1984) and Sarawak (Dransfield, 1992b); one has also been completed recently for India (Basu, 1992); and that for Sri Lanka is nearly complete (de Zoysa, in press). The rattans of China, Thailand and the Philippines have been studied in some detail but taxonomic guides have not yet been written. Research has been conducted on the rattans of the islands of New Guinea and Indonesia but taxonomic inventories of these countries are not complete (Dransfield, 1992a).

Seedling and juvenile rosettes are notoriously difficult to identify as their leaves do not resemble those of the mature plants. No taxonomic guides for these stages have been written,

although Dransfield (1984) describes the general categories of first seedling leaf or eophyll and links them to genera.

Growth form categories

As rattan researchers use a variety of names for growth form categories, and as the same terms may have different meanings to different people, it is important that categories are clearly defined in any inventory report. Rattan plants can be 'seedlings' if they have a seedling leaf or eophyll, 'juvenile rosettes' if they have an older leaf morphology but no stem and are infertile, and 'mature rosettes' if they are fertile, as is the case with stemless species. Plants are 'solitary' if they have only one shoot; if they have more, they are 'clumps', 'clusters' or 'genets'.

An individual 'shoot' is also called a 'sucker' or 'ramet', and has its own growth form categories. Shoots can be 'juvenile' if they have not yet developed a stem, and 'stems' if their internodes have begun to elongate. Flowering and fruiting maturity is usually reached before commercial maturity; stems are usually classified as 'immature' or 'mature' according to the latter definition. The criteria for commercial maturity vary from country to country; Sharma and Bhatt (1982) in India consider a stem which is bare of leaf sheaths for more than 3.7 m (12 feet) of its length to be 'mature', whereas Siswanto and Soemarna (1988) in Indonesia consider a stem 'half-mature' if its bare length is 5-15 m and 'mature' if its bare length is greater than 15 m.

Measurement Decisions

All rattan inventories obtain counts of rattan plants, divided amongst species and growth form categories. The stems are often further quantified in the form of length/ha, volume/ha, green weight/ha or air dry weight/ha, as rattans can be sold by any of these units of measurement.

Of these measurements, stem length is the most important because, unlike trees, growth of rattans occurs as an increase in length alone, with diameter remaining constant. Volume esti-

mates give no additional information to length estimates as the diameter is fairly constant within a species. The usefulness of weight estimates as measures of quantity has been questioned by Sharma and Bhatt (1982), since, like timber, the weight depends upon moisture content, which decreases progressively after cutting.

Lee (1994) has developed models for estimating stem length, volume and weight from the number of internodes, and Nur Supardi and Abd. Latif Mohmod (1991) have used a similar method for estimating length. Four methods for estimating stem length, including visual estimates, internode counts, and triangulation using a ruler or a clinometer, have been tested by Stockdale and Power (1994). The method of triangulation using a ruler was found to be most accurate, as it was most robust when applied to the longer or more curved stems; furthermore, it was demonstrated that this method could be considerably improved by the use of calibration modelling.

Constraints and Gaps in Knowledge

Stratification of sites on which rattans grow can be improved by studies of rattan distributions and their relationships to site factors such as topography, soil type or vegetation type. Technologies such as GIS may provide a means of furthering this understanding. Remote sensing technologies, if further refined, may also assist stratification.

Tests of sampling designs such as systematic sampling versus random sampling, line plot sampling versus strip sampling, and comparisons of sampling unit shapes and sizes have been made in various countries. One constraint to drawing generalised conclusions from these tests is that often different criteria for comparison are used; in one study it may be accuracy, in another it may be cost efficiency. It also appears that different sampling designs may be optimum under different site conditions. Future tests would be considerably improved if the methods presently advocated by the different countries were compared directly in each study, the criteria for comparison standardised amongst

researchers and studies conducted across a range of site types.

The lack of taxonomic keys to mature rattans in some countries and to immature rattans in all countries is a serious constraint to inventories. Inventories would be rendered more interpretable if growth form terminology were standardised amongst researchers or at least more clearly defined in reports. Methods for estimating or measuring stem length need to be further refined and tested.

MODELLING SUSTAINABLE YIELD

Compared to the literature on estimating yields of cultivated rattans (reviewed by Tan and Woon, 1992; Aminuddin *et al.* 1992), there have been relatively few attempts to estimate the sustained yield of natural stands of rattans. All estimates have relied upon information from resource inventories, interviews with rattan gatherers and/or guesswork, since little experimental information is not yet available.

Estimating Sustained Yield in Indonesia

Siebert (in press) calculated the area of forest in the Sungai Tutung region of Sumatra, Indonesia, necessary to support the local *Calamus exilis* industry at current consumption levels. An annual sustained yield cut of 478 m/ha can be calculated from the average density of rattans (1910 m/ha), obtained from an inventory, and an estimated replacement rate of harvestable stems in each cluster of four years.

According to local informants, the replacement rate is three years. This was examined by Siebert (in press), who counted all new harvestable stems at a site where all harvestable stems had ben counted and cut 2.5 years previously, and found the average number of harvestable stems per plant had declined from 6.81 to 3.17 (some canes had been harvested during the 2.5 year period; if they had not, the average would have been a slightly higher 3.77). Although the difference was not significant, these results

indicate that the original levels had not yet been replaced; for this reason, Siebert (in press) increased the recommended harvesting cycle to 4 years.

This is the best that could be done with the information available. However, a number of problems remain. Firstly, the four year replacement rate of harvestable canes may not be sufficient as it was extrapolated and not directly determined. Secondly, although the number of canes may have been replaced after four years, the amount of lineal meters of cane produced may not have been; this needs to be measured directly. Thirdly, the study by Siebert (in press) also indicated that the replacement rate of stems may vary with the age or size of the cluster; this needs to be better understood. Fourthly, the replacement rate refers only to vegetative regeneration; lack of information on the effect of this level of cut on sexual regeneration brings its long-term sustainability into question.

Estimating Sustained Yield in the Philippines

The Philippines Department of the Environment and Natural Resources (DENR) has drafted an Administrative Order (No. 21; Torreta and Belen, 1990) which states that only stems 25 m or greater in length can be cut, and that the sustained yield cut that is granted annually for a rattan cutting license should be calculated from the following formula:

$$SYC = (((A \times D/r) f)$$

where:

SYC is the sustained yield cut in lineal metres;

A is the forested area in hectares;

D is the average density of rattans in lineal metres per hectare;

r is the rotation period of 15 years, and;

f is the 'recovery factor' of 85%.

The rotation period in the DENR formula was set at 15 years because this is supposedly the age at which rattans in natural

stands reach 25 m and are ready for harvesting (Ordinario, 1973). The recovery factor of 85% is the proportion of the total annual allowable cut which may be harvested, leaving 15% behind to ensure regeneration.

Members of a workshop on rattan production in the Philippines considered the minimum length of 25 m to be too high and 4 m to be more realistic (Torreta and Belen, 1990). Many people also questioned the 15 year cutting cycle, as this may be appropriate for a large diameter non-clustering species, but some small diameter species reach harvestable lengths in 7 years and those species which produce suckers can be reharvested every 3-4 years (Torreta and Belen, 1990). This example demonstrates how the lack of taxonomic understanding can lead to untenable and simplistic generalisations. Some scientists have advocated a recovery factor of 60% instead of the 85% in the formula, but there is no experimental basis for either figure (Wakker, 1991).

Further, the concept of rotation in the DENR formula is invalid, according to Revilla (1990), as it can only be applied to even-aged, monospecific stands; rotation periods in natural stands should be based on expected growth increment of various age classes for each species.

Constraints and Gaps in Knowledge

The problems associated with estimating the long-term sustainability of yield for many species of varying ages and/or indeterminate ages are common to natural stands of timber as well as rattans. Vanclay (in press) has recently reviewed the literature on growth modelling to determine sustainable timber yields in tropical moist forest.

A prerequisite for growth modelling is an adequate database drawn from permanent sample plots studying long term population dynamics or demography (Vanclay, in press). Demographic study is the study of regeneration, and age- or size-specific growth, survivorship, and flowering and fruiting phenology.

So far, only Chandrashekara (1992) in India has published a study of the long term demography of rattans, using data from 15 ha of plots established in 1987 specifically to examine *calamus hookerianus*. The only other published studies of rattan demography have been phenological (reviewed by Raja Barizan, 1992) and demographic studies conducted at one point in time and involving two or three crude age class groupings (Tandug, 1984; Abdillah and Phillips, 1989; Niangu, 1990; Nandakumar and Menon, 1992; Stockdale, in prep., a).

However, longer term demographic studies of rattans are in process or planned for Malaysia (50 ha, established in 1986; Wan Razali, pers. comm.), Thailand (Bøgh Petersen, pers. comm.), Ghana (Falconer, pers. comm.) and Indonesia, where Stockdale (in prep. a) is studying 3 ha, established in 1992, of *Calamus caesius* in Kalimantan, and Siebert (1991) is studying *Calamus exilis* and *Calamus zollingeri* in Sumatra and Sulawesi, respectively.

At present there are several methodological constraints to long term demographic study of rattans:

1. *Security of permanent sample plots.* It may prove difficult to protect permanent sample plots from entry and harvesting by local people; as advocated earlier in this paper, the best way to attempt to safeguard the plots would be to involve local people in their planning and management.

2. *Estimating growth.* Growth occurs as an increase in length alone and is not related to stem diameter. While the length of shorter stems can be measured directly, longer stems cannot be measured without dislodging them, which may affect the rate of growth (Putz, 1990). The only published studies of growth of longer rattans in natural stands have been made by Abdillah and Phillips (1989), who estimated growth from height 'guesstimates' made by trained personnel. Refinement of this length estimation method, or use of those developed by Stockdale and Power (1994), Lee (1994) or Nur Supardi and Abd. Latif Mohmod (1991), should improve growth estimation.

3. *Estimating age.* A third constraint is the estimation of plant or stem age, which at present is confined to very crude growth form categorisations. The analysis of the periodicity of internode lengths and inflorescence scar positions along the length of a stem in order to estimate stem age is being tested for accuracy by Stockdale (in pre., b). Although quite different in practice, this analysis is analogous to growth ring analysis in trees.

4. *Access to inflorescences.* Rattan inflorescences often occur in the canopy, rendering bother observation and study very difficult. As with tree species, advances in technology enabling researchers to climb up to the canopy will improve their capacity to study rattan phenology.

MANAGEMENT PRACTICES

Varied and sophisticated traditional management practices have been recorded for some countries, but their effects have not been tested in natural stands of rattan. Inspiration for management practices can come from a variety of sources, including existing traditional practices, studies of experimental treatments of cultivated rattans, or studies of the ecology and life history of wild rattans. Potential management practices, paralleling those which exist from timber management (Whitmore, 1992), could include harvesting, silviculture and/or enrichment planting, as discussed below.

Harvesting methods

Harvesting methods may influence the survival, growth and vegetative or sexual reproduction of other stems in the cluster, but so far very little experimental work has tested these effects. The age of first harvest and the optimum harvesting cycle, according to farmers who cultivate rattans, have been recorded by Dransfield and Suwanda (1974), Dransfield (1977) and Alrasjid (1980).

Depending upon species, small diameter rattans can be harvested at as early as six years after planting, according to cultivators in Indonesia (Dransfield, 1977). Clustering rattans can be harvested more than once, and the lowest recorded harvesting cycle is 1.5 years for *Calamus trachycoleus* (Dransfield and Suwanda, 1974). In India, Saharia and Sen (1990) tested the effect of 2,3,4 and 12 year harvesting cycles on the growth and yield of *Calamus tenuis* over a 12-year period, and found that the 2-year cycle obtained the maximum number as well as length of stems per plot. This was because the stems were at maximum growth in the first two years, slowing down considerably afterwards. Such work needs to be done for other species.

There are several examples of traditional laws regulating how may canes should be harvested on each occasion. In East Kalimantan, only 10-20% of the stems in a cluster are harvested at a time (Peluso, 1986). In the Philippines, a local leader in Kayasan has asked the gatherers not to cut the canes which cannot be easily pulled from the canopy, in order to prevent waste (Wakker, 1991). Both practices may ensure that at least some part of the plant is photosynthesising well and that three is a seed source for adequate regeneration; however, further study of this topic is needed.

Another traditional law in East Kalimantan requires a one metre stump to be retained, and its tip bent over and pushed into the earth; local people claim this prevents the absorption of rain water which is held to hinder the production of suckers (Senega, 1986), or cause the death of the rest of the clusters (Sirait, pers. comm.). Long stumps are also cut in the Philippines (Virtucio and Sy, 1988) and Ghana (Falconer, pers. comm.), perhaps for the above reasons; however, another explanation is that this part of the stem may also be thicker and less commercially valuable. No tests have specifically investigated this practice.

Seasonality of harvest is another subject that would benefit from research. According to Senega (1986), collectors in some parts of Indonesia do not work during the rainy season; the reasons for this are not given and may have nothing to do with

rattans per se. However, harvesting after the rainy season is the time of fruit maturation in many rattans and a rule of thumb in tropical timber management; for example, the Malaysia Uniform System; is that "harvesting must follow seeding" (Whitmore, 1992).

Silviculture

No traditional silvicultural practices have been observed in natural stands of rattans but silvicultural practices in traditional rattan gardens and larger commercial plantations include weeding, fertilising, training the young stem to climb the support tree, pruning off the first 'mother' stem to encourage vegetative reproduction, peeling dried leaf sheaths off the stem to eliminate breeding habitat for long horn beetles which reduce the quality of the stems, and opening up the forest canopy to increase light levels (Tan, 1992; Aminuddin and Nur Supardi, 1992).

Few of these practices have been tested scientifically, apart from the effects of fertilisers and opening the forest canopy, discussed below. While the effects of weeding have not been tested, Chandrashekara (1992) recommends it, noting that a weedy shrub, *Nilgirianthus ciliatus*, reduces the spread of rattans in gaps.

Studies in Malaysia and India found that rattan stem growth and rhizome production benefited from fertiliser treatments during the first three years but not after this time; however, fertiliser requirements are related to the particular soil characteristics of a site; so these treatments may not be appropriate in all cases (see review by Raja Barizan and Aminuddin, 1992; Parameswarappa and Lakshmana, 1992; Lakshmana and Singh, 1992). The importance of light for stem growth has been investigated in a number of studies (Manokaran, 1977, 1985; Aminuddin, 1985; Cadiz, 1987; Putz, 1990). However, a range of light conditions exist in the forest and different species seem to be suited to different conditions (Dransfield, 1979; Siebert, 1993b); thus, canopy opening may not be advisable for all species.

Enrichment Planting

Enrichment planting involves the establishment, by planting and cultivation, of rattans in natural forest. A Dayak farmer in East Kalminatan pointed out to me a *Calamus caesius*cluster in natural forest which was planted by his father; the abundance and genetic quality of commercial species in 'natural stands' may be more influenced by people than is presently believed, and ways of ensuring that this can continue must be sought.

Germination, nursery and planting methods used inrattan gardens and plantations are summarised by Wan Razali *et al.* (1992). If the species are not the same as those used in commercial plantations, their site requirements for successful seedling establishment not be known; in this case, observations or studies of microhabitat preferences, those by Dransfield (1979), Aminuddin (1990), Abdillah and Phillips (1989) and Siebert (1993b), are very useful.

Constraints and gaps in knowledge

The key to improving management practices is controlled experimentation, testing the responses of rattan species to manipulation by people. The use of split plots, in which one half of the plot receives the treatment and the other half is the control, is often an appropriate way of investigating management practices (e.g. Vanclay, in press). Constraints to such studies are the same as those for permanent sample plots, discussed above. The involvement of local people in the planning and execution of these trials not only is likely to improve the security of the experiments, but is a good way of demonstrating the effectiveness of alternative traditional and innovative methods to the people who will ultimately determine which will be implemented.

INTEGRATION WITH OTHER FORMS OF FOREST MANAGEMENT

Rattan management is not likely to operate in isolation; it will often be integrated with and affected by other forms of forest

management, such as conservation, shifting cultivation or selective logging, each of which are discussed below.

Conservation

Rattans are an ideal resource for forest management in which conservation of biodiversity is an objective, as their harvesting is non-mechanical and causes minimum damage to the forest habitat, and their reliance upon trees for structural support provides a strong economic incentive to maintain tree cover. For example, Siebert (1991, 1993b) believes that managed harvesting of the commercial species *Calamus exilis* and *Calamus zollingeri* in two Indonesian national parks is compatible with forest conservation objectives. The delineation of 'extractive reserves' or 'buffer zones' are two means by which rattan management can be integrated with conservation (Oldfield, 1989; Peluso, 992; Siebert, 1993a).

Shifting cultivation

Shifting cultivation is correctly perceived to have a largely negative impact on rattan abundance, but the situation is actually more complicated. If fallow periods of at least 7 years are feasible, smallholder farmers may intercrop rattans with rice, leaving the stems to grow up with the recovering secondary forest. This is a longstanding practice of the Luangan Dayaks in East and Central Kalimantan, Indonesia (Weinstock, 1983).

There has been very little research into natural rattan regeneration following shifting cultivation. Wild rattans are found with cultivated rattans in East Kalimantan smallholder rattan gardens (Fried, pers. comm.). In a 20 m x 5 m plot set up in a Philippine forest 8 to 10 years after shifting cultivation, nine species with harvestable stems were found, none of which had been planted (Wakker, 1993). Rattan gatherers estimated that of these species, there were 150 m of large diameter stems and 450 m of small diameter stems in this plot; the commercial quality of these species was not described.

The potential for natural regeneration would be expected to be highest when smaller patches are cleared, and when the surrounding forest is primary or older secondary forest and can supply the seeds, which are primarily animal-dispersed. Not all rattans may be seeded from the surrounding forest. Some species apparently "coppice"; in the Philippines, Wakker (1993) observed a burned "gatasan" (probably *Daemonorops mollis*) cluster with fresh shoots at its base.

Selective logging

A study of one hectare of ridge dipterocarp forest in Sabah prior to and one year after logging found a reduction in species richness from 15 to 8. There was a reduction in abundance of 70% of all rattan clumps, and 76% of commercial clumps, with the main cause of death being the felling and extraction of trees (Abdillah and Phillips, 1989).

The impact of selective logging on rattan diversity and abundance was studied in East Kalimantan, by Stockdale (in prep., c). Although species richness did not decrease, species evenness did, as a few species became more dominant in secondary forest one year after logging. Abundance of all rattan plants, from seedlings to mature clumps, decreased by 28%, and of commercial rattan plants by 49%. The decrease in commercial species may be due, in part, to the harvesting of rattans which occurs at the same time as timber extraction.

The effects of logging are not all adverse; some species, such as *Korthalsia hispida*, appear to benefit from the increased light levels (Stockdale, in pre., c), and logged-over forest has been found to be a good habitat for the cultivation of many of the commercial species (Tan, 1992; Aminuddin and Nur Supardi, 1992).

Constraints and gaps in knowledge

There is little information on the long-term effects of these forest management practices, thus emphasising the need for

permanent study plots testing different management regimes. Controlled experimentation into management practices such as shifting cultivation or logging will improve understanding of how to minimise adverse effects on rattans, and maximise rattan survival, regeneration, growth and within-species genetic diversity. Constraints to such studies are the same as those for permanent sample plots, discussed earlier.

ECOLOGICAL STUDIES

Ecological studies

Shorter term studies of the ecology and life history of rattans can play an important role both in refining growth models and providing inspiration for improving management practices. The ecology and life history of some wild populations of rattans has been discussed by Dransfield (1979, 1984, 1992a, 1992b); this information is based upon extensive field observations during the course of taxonomic collections, not upon statistically tested data.

The few existing studies of the latter variety can be separated into studies of species' ecological ranges (Aminuddin, 1990), microhabitat preferences in terms of light intensities (Cadiz, 1987; Putz, 1990; Balagopalan and Sankar, 1992; Siebert, 1993b), topography, soil type and water drainage (Phillips, 1990; Aminuddin, 1990; Balagopalan and Sankar, 1992; Siebert, 1993b), the behaviour of their insect pollinators (Lee *et al.*, 1993), and the three-way relationship between rattans, ants and scale insects (Rickson and Rickson, 1986).

Constraints and gaps in knowledge

There is a general lack of information about rattan ecology and life history. Shorter term, ecological studies which examine the relationship between site factors and productivity, ecological ranges, microhabitat preferences, pollination, breeding systems,

seed dispersal, sex ratios, the role of animals as herbivores, pollinators and seed dispersers and the symbiotic relationship with ants and scale insects would all be extremely useful for improving management. The conduct of such studies faces constraints as do permanent sample plots, of security, access, and measurement or estimation of growth and age.

SOCIOECONOMIC STUDIES

Socioeconomic studies

As discussed earlier, management plans which do not address the needs and capacities of local people, and which have not involved them in their inception and development, are most unlikely to be followed (see for example Wakker, 1991). Furthermore, as Cleary (1992) has observed, "ignorance of the socioeconomic dynamics of complex collection and trading systems could lead to projects that would restrict and potentially damage local livelihoods rather than enhance productivity of the forest".

Various researchers have described the role of rattan collection in household economies (Conelly, 1985; Siebert and Belsky, 1985; Peluso, 1983); and the impacts on rattan management of land tenure systems, of social structure of communities, of market prices and trade networks, and of the dynamic forces which are causing the above to change (Dunn, 1975; Vayda *et al.*, 1980; Peluso 1983, 1986; Nessup and Peluso, 1986).

Constraints and gaps in knowledge

Much remains to be learned of the socioeconomic aspects of rattan management; de Beer an McDermott (1989) identify as priorities the need to develop efficient methods for assessing socioeconomic value of rattans for local people, and quantifying trading patterns. Cost/benefit analyses of alternative management practices is another important area of study. In addition to learning about local people, much can be gained by learning from them about the taxonomy, uses, ecology and management

of rattans. The constraints of socioeconomic research relevant to sustainable forest management are discussed in detail by Schreckenbeg and Hadley (1991).

CONCLUSIONS

In summary, it appears that the most appropriate and necessary methodologies in research for the more sustainable management of natural stands include:

Inventory

1. Studying the relationship between site factors and patters in rattan distribution, using GIS, remote sensing techniques or field studies, would improve our ability to stratify sampling areas.
2. Sampling designs advocated by different researchers should be compared directly using data from 100% enumerations and time studies in large (>1 ha) study plots. Such studies would benefit from standardisation of the criteria for comparison amongst researchers, and comparisons across the full range of site types.
3. Developing taxonomic keys for mature rattans in some countries and for immature rattans in all countries, since lack of these is a serious constraint to inventories.
4. Further refinement of methods for estimating stem length would improve the accuracy and cost efficiency of inventories.

Growth modelling

5. Secure permanent study plots investigating the long term demographies of important rattan species are essential for accurate growth modelling for their more sustainable management.
6. Developing methods for estimating stem growth and age would overcome major constraints to demographic studies.

Rattan management practices and its integration with other forms of forest management

7. Experimental plots testing the responses of rattan species to management practices, and to indirect manipulation of their habitat as a result of shifting cultivation or logging, would indicate the effect of these practices on rattan survival, regeneration, growth and within-species genetic quality.

Ecological studies

8. Studies of rattan ecology and life history are important for improving growth models and management practices.

Socioeconomic studies

9. Socioeconomic studies are essential for improving our understanding of the management of natural stands and how it can be more sustainable.

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