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# Silvicultural management of bamboo in the Philippines and Australia for shoots and timber

**ACIAR PROCEEDINGS**

# 129

Research that works for developing countries and Australia

# **Silvicultural management of bamboo in the Philippines and Australia for shoots and timber**

**Proceedings of a workshop held in Los Baños,  
the Philippines, 22–23 November 2006**

*Editor:* David J. Midmore



**ACIAR**

Research that works for developing  
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Cover: ACIAR project participants measure soil moisture using tensiometers installed in the 3.5-year-old bamboo (*Dendrocalamus latiflorus*) trial at Coastal Plains Horticultural Research Farm near Darwin, Australia. Photographer: Dan White.

# Foreword

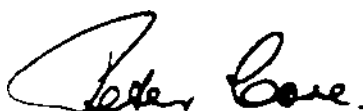
There is a push at the national and international levels to (re)introduce perennial species into cropping and ‘at-risk’ lands, capitalising upon their more notable ecosystem service properties of containing soil and water erosion, protecting soil carbon reserves and sequestering atmospheric carbon dioxide on a real-time basis.

Bamboo is one such species that provides these and other services, and more. It is a commodity of extensive social and economic importance in Asia, and it is gaining ground in Africa and Latin America. In Australia, it was introduced over the past 20 years as a potential plantation species, principally for bamboo shoots but also for timber, while in the Philippines, bamboo culms (poles) are a poor-person’s resource at the household level, and it is also commercially exploited.

The Australian Centre for International Agricultural Research (ACIAR) funded research on bamboo in Australia and the Philippines, to identify production practices that lead to sustainable harvesting of shoots and/or culms from newly established or old and degenerated stands of bamboo.

Co-sponsored by the Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD), a symposium was organised in November 2006 in Los Baños, Laguna, the Philippines, to provide an opportunity for researchers to present their findings to a wide range of interested parties, including personnel from the National Economic Development Authority (the Philippines), the Center for International Trade Expositions and Missions (the Philippines), the Philippine Bamboo Foundation and Oxfam Hong Kong, and people from Indonesia and Vietnam.

The peer-reviewed papers contained herein provide an opportunity to fully report on the research. They will act as a valuable resource for people interested in the sustainable production and use of bamboo.



Peter Core  
Chief Executive Officer  
ACIAR



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Many thanks go to the Rural Industries Research and Development Corporation for having the foresight to fund initial research on bamboo in Australia; to the Australian Centre for International Agricultural Research (ACIAR) for continuing the funding and extending the project activities to the Philippines; to the Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD) and its Executive Director Dr Patricio Faylon and staff, particularly Dr Nimfa Torreta, for their attention to detail in the local management of the project in the Philippines and that of the conference; to the Mariano Marcos State University, the Department of Environment and Natural Resources Regions VI and X, the Forest Products Research and Development Institute, the Ecosystems Research and Development Bureau, the Northern Territory Department of Primary Industries and Fisheries and Central Queensland University for allowing their staff time to develop and to work on the project; to Mary Webb for extensive editorial assistance; and of course to dedication of the many persons involved in the research but not mentioned individually as authors or otherwise acknowledged in the papers.

# Overview of the ACIAR bamboo project outcomes

David J. Midmore<sup>1</sup>

## Introduction

As a group of generally tall, woody grass species, bamboo in the West is an enigma in terms of its science and technology, and its history, habit and the opportunities it presents. In its major natural home in Asia, bamboo is already part of the mainstream environment and biomass movements. It contributes significantly to the economy of Asian countries, both directly as a commercialised commodity and indirectly as a resource, often of the ‘commons’—that is, it is used for housing and other structures, and as a woody resource replacing the use of timber.

Given its central role in the lives of so many in Asia—reports suggest that up to 2.5 billion people use it as a source of food and fibre—and its increasing importance in Africa and the Americas, it might be expected that significant amounts of research aimed at increasing productivity would have been undertaken by the scientific community, but the reality is otherwise.

In 2001, following negotiation between institutions in Australia and the Philippines, a 6-year project began, funded by the Australian Centre for International Agricultural Research (ACIAR), entitled *Improving and maintaining productivity of bamboo for quality timber and shoots in Australia and the Philippines* (ACIAR Project No. HORT/2000/127). The project addressed both some of the shortfall in the scientific basis for technical recommendations, and the vacuum in the availability of recommendations themselves that are currently available to those who use bamboo for their livelihood or as a readily available natural resource. The information presented

in these proceedings—a set of papers detailing the outcomes of the research in both countries—provides the basis for further development both of the resource of bamboo and of its utilisation in the Philippines and Australia. The information in these proceedings is presented on a subproject basis, dissected into both a disciplinary (silviculture, wood properties, socioeconomic and postharvest processing) and geographical (three locations in the Philippines and two in Australia) format.

This summary brings together the trends from across disciplines and geography, to draw out principles that we believe can be applied beyond the set of conditions upon which the data are based. The approach in this summary is to:

1. highlight and evaluate the effects of the natural and imposed (i.e. thinning, irrigation, fertiliser application and mulching) environments on the production of shoots and culms
2. investigate the effects of the same on the physical and chemical properties of those culms
3. explore the markets and profitability of bamboo in the Philippines
4. demonstrate how simple technology can provide quality-controlled, consistent products to allow for expansion of the use of bamboo in the housing market.

The papers on the current status of the global, Australian and Philippine bamboo sectors stand alone and are not summarised herein.

The approach in the field experiments conducted throughout this project was to impose—based upon outcomes from our earlier research (Midmore et al. 1998; Midmore and Kleinhenz 2000; Kleinhenz and Midmore 2001, 2002) and from the meagre other published information—the best set of management

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practices as a 'control' treatment, and then in other treatments to omit one or other practice (for example, omit fertiliser and/or irrigation, omit the thinning regime) and to quantify the impacts upon shoot and culm (pole) production.

## Shoot production

Starting in the 1990s, bamboo in Australia was originally planted with a view to producing bamboo shoots to offset the importation of canned produce (Midmore 1998), and later to expand into rewarding export markets identified in Asia (Collins and Keiler 2005). In contrast, in the Philippines, bamboo is harvested mainly as a timber substitute, with only localised cultivation and use of shoots as a vegetable—indeed, local ordinances often prohibit shoot harvests (Virtucio and Roxas 2003).

Management factors that influence shoot production (Kleinhenz and Midmore 2001) fall mainly under irrigation, fertiliser, mulch and thinning regimes. Species has an overriding effect on shoot size, number and timing of production and, although it was not studied as an experimental factor, some tentative conclusions are drawn from the experimental data published in this volume.

### Irrigation and rainfall

Supply of water to bamboo just before and during the shoot season has been recognised as an enhancing factor for the onset and continued production of shoots from running (monopodial, e.g. *Phyllostachys pubescens*) species of bamboo (Kleinhenz et al. 2003), and data from the currently reported experiments confirm this for clumping (sympodial) bamboo species.

In the Philippines, at the two sites where irrigation was an experimental factor (Ilocos Norte and Capiz), irrigation increased the number of emerged shoots, with the effect being greatest if combined with fertiliser application. In one of the Australian sites (Queensland), withholding irrigation was confounded by a complete absence of clump management, the combined effect of which was to significantly reduce the number and size of shoots that emerged. However, the major irrigation factor under investigation in Australia was that of testing the need for irrigation during the dry, winter season.

In Queensland, the water-use efficiency of shoot production was raised by 28% by omitting irrigation during winter, and in the Northern Territory (NT; the

other Australian project site) year-round irrigation was also shown not to be important for shoot production, provided it was supplied just before the anticipated shoot season—a 'date' characteristic to each species for reasons that remain a mystery. At one of the sites in the NT, the number of shoots was even greater in the treatment without winter irrigation than in the treatment supplied with irrigation throughout the year.

Although irrigation rates were planned to supply water equivalent to that used through pan evaporation, drought in Queensland and in Ilocos Norte, together with logistical difficulties at the latter site, reduced the quantities of water supplied. In the NT trial, irrigation was likewise supplied at a rate calculated to supply that equivalent to pan evaporation which, in hindsight, may have been less than optimal for bamboo. At one site, in Bukidnon, where rainfall normally exceeds 100 mm per month, no irrigation treatment was imposed. In 2 of the 5 years, monthly rainfall did drop below 100 mm, but the time of shoot emergence was not markedly affected. Shoots began to emerge annually in June in Bukidnon, at least 2 months after the driest months of the year.

### Fertiliser

Based on earlier research (Kleinhenz and Midmore 2002) and the response curves of percentage leaf nitrogen (% leaf N) to N application rate, fertiliser N was added to ensure that % leaf N was maintained at close to 3%.

Application of fertiliser at these and even higher rates invariably allowed clumps to achieve high shoot yields, consistently hastening not only the onset of shoot production in one of the sites in the NT, but also the rate of emergence and number of shoots. Even organic fertiliser showed a small, but consistently positive response.

In Queensland, withholding N fertiliser led to significantly lower % leaf N than in fertilised treatments, the latter receiving an average 700 kg N/year. Leaf N declined during the shoot season, perhaps due to a within-clump dilution effect with the rapid growth of new culms and leaves during that period. Withholding N fertiliser also led to smaller (and unmarketable) shoots in Queensland, but in the NT shoot size was not affected when N application was reduced to one-quarter of the calculated rate, but shoot number and yield decreased.

In the Philippines, without irrigation (in Bukidnon), withholding N fertiliser had a depressive effect on

shoot production, both number and size, but the magnitude varied between years. Without fertiliser, shoot numbers were reduced in Ilocos Norte, and in Capiz shoot emergence and yield were reduced by lack of N fertiliser, but mortality was significantly lower than in other treatments.

Quite clearly, the rates of N required to maintain % leaf N at c. 3% are uneconomic for shoot production; a lower leaf N concentration is called for, specific to species and grower expectation, although even so it is unlikely that in the Philippines copious amounts of fertiliser will be applied simply for shoot production.

### Culm thinning practice

In general in Australia, treatments at all sites that had high numbers of young culms (1 and 2 years old at the time of shoot emergence) led to high shoot numbers. Indeed, in the high rainfall site in the NT, shoots selected for culm production at the beginning of the shoot season themselves produced edible shoots near the end of the same shoot season. In the drier environment of Queensland, shoot production was greater when all early shoots were removed for sale, leaving only late-season shoots for culm production—possibly minimising the effect of apical dominance that may inhibit later shoot emergence. Weight per harvested shoot was not affected by thinning regime in the NT, or by the spatial arrangement of standing culms in Queensland (widely spaced versus narrow spacing within a clump).

In the Philippine sites of Capiz and Ilocos Norte, treatments with more young culms raised the productivity index (the number of shoots produced per standing culm) and, in the rainfed site of Bukidnon, the standing culm density (SCD) of 10-10 (ten 1-year-old and ten 2-year-old culms) gave more shoots than the 6-6 treatment.

Leaving all shoots to grow into culms caused congestion in the clumps, and constrained production of shoots in later years. For this reason, some minimal annual thinning of culms or shoots is necessary if clumps are to continue to produce shoots (and culms) on a sustained basis.

### Species

The agronomy/silvicultural trials were conducted on four bamboo species. These differed in their responses to the imposed treatments not only because of their genetic make-up but also because of their relative ages. The mature *Dendrocalamus asper*

(giant bamboo) of Bukidnon produced few shoots, on average c. 1 shoot per standing culm, but they were large if harvested for consumption (reaching 4.5 kg). In contrast, the young (3–7 years old during the trial) *Bambusa blumeana* (kawayan tinik) at the Capiz site produced very few shoots, although the poor soil or some other factor may have had an overriding effect, as average shoot number per clump did not increase during the 5-year course of the experiment. Even older clumps of the same species in Ilocos Norte produced few shoots per culm—only 8 of 65 treatment × year combinations produced more than 7 culms per clump.

The commonly recognised, smaller-shoot-producing species *Bambusa oldhamii*, with clumps close to 10 years of age, produced on average over 20 shoots per clump in the optimal treatments in Queensland. This was unlike *Dendrocalamus latiflorus* in the NT, aged 3.5 and 4 years at commencement of the experiments, which produced many shoots early on but fewer as the clumps aged (on average c. 40 shoots per clump in the first year, c. 30 in the second and c. 10 in the third year). However, the proportion of marketable shoots increased over time.

## Culm production

Culms, or poles as they are commonly known as in the Philippines, are the major commercial and subsistence bamboo product in that country. In contrast, with minor exceptions, in Australia the culms present a logistical headache, for although imported culms command a high price (Midmore 1998) locally produced culms are not widely marketed because of their virtually non-existent quality control. Indeed, when thinning bamboo clumps in order to optimise shoot production, culms may be variously converted into mulch, burnt, or used as a low-quality timber replacement around the farm. Quite simply, the scale of production does not merit their entry into energy generation (Sharma 2005) or other mainstream economic activities.

As for shoot production, species has an overriding influence on culm production, in terms of both numbers and size. Although this was not an experimental factor, we can draw some useful cross-species comparisons, as we can for the other experimental factors.

## Irrigation

In Queensland, Australia, withholding irrigation during the dry season increased culm water-use efficiency (WUE—weight of culm per unit of irrigation and rainfall) by 25% over the fully irrigated treatment, although culm biomass was not reduced and the difference between full and temporal irrigation in WUE was not significant. Withholding irrigation altogether reduced biomass yield by 40%, but that was confounded by also withholding fertiliser. Further north, in the NT, the same effect of withholding winter irrigation was evident at one of the sites—culm yield was reduced by 24% compared to full irrigation. Irrigation throughout the year at only 50% of pan evaporation reduced culm yield by 15%, not as great as withholding all irrigation during the dry season. At another site in the NT, on a lighter soil, the 50% irrigation treatment did not affect culm yield, although culm WUE (this time based upon weight of culm per unit of irrigation) was double that of the 100% irrigation treatment.

In the Philippines, in Capiz, neither lack of irrigation nor irrigation supplied only just before and during the shoot season reduced culm yield compared to the fully irrigated treatment (although both treatments had higher culm WUEs than the irrigated control). In the other site with irrigation treatments, in Ilocos Norte, culms that experienced the reduced irrigation treatments were thinner and their biomass lower.

## Fertiliser

In the NT, culm yield was unaffected by fertiliser application in the first year of measurement, and marginally enhanced in the second year—a further indication that perhaps, even for a young plantation at full irrigation, clump water demand was not being met. In Queensland, as indicated above, the withholding of fertiliser reduced culm yield in a mature plantation by 40%, but this was confounded by the concomitant absence of irrigation.

In the rainfed site of Bukidnon, withholding fertiliser reduced culm yield considerably and omitting the mulch treatment increased yield by an inordinate proportion. The latter may be due to improved access to sparse rainfall by roots; heavy mulch, while conserving soil moisture already in the soil, can also prevent entry of rainfall into the soil and root zone. Under irrigated conditions in Capiz, withholding fertiliser reduced culm yields by c. 40%, the effect being greater with application of mulch. Lack of fertiliser was also responsible for reduced culm diameter under irrigated

conditions at Ilocos Norte, as it was under conditions of no management (i.e. no irrigation, fertiliser, mulch or clump cleaning).

## Culm thinning and species

The effect of culm thinning treatment on culm biomass was closely related to the effect of species, and was tightly linked to culm thinning practices. In the small-diameter species *B. oldhamii*, thinning of culms to leave only a small number (five) from year to year constrained culm yield potential (to c. 24 t/ha/year for 12–16-year-old clumps) compared to leaving all shoots and thinning the resulting less-than-1-year-old culms at the time of harvesting the 2.5–2.8-year-old culms (c. 33 t/ha, with one year reaching 47 t/ha). However, across treatments where shoots were removed during the shoot season, there was only a weak negative relationship between the number of shoots removed and culm biomass production. With younger (3.5–7.0-year-old) clumps of *D. latiflorus* in the NT, thinning treatments did not affect individual weight of culms; most likely because complete canopy closure had not occurred. Hence, culm yield was a reflection of the number of culms harvested. Culm yield ranged from 3.5–3.7 to 6.8 t/ha/year for the treatments with SCD of 4-2-2, 2-2-2 and 4-4-4, respectively.

The commonly grown *B. blumeana* in Ilocos Norte in the Philippines responded to thinning regime only in terms of culm diameter; the lowest within-clump population (3-3 SCD) had the highest diameter, but otherwise yields were related to the number of harvested culms. The average culm yields ranged from 7 t/ha/year to slightly more than 10 t/ha/year, and reflected a probable yield constraint due to lack of water. The same species grown in Capiz, but harvested after 4–8 years from planting, had much lower culm biomass yields (averaging 1.8–5.6 t/ha/year over the ages of 6–8 years) and culm yield was depressed when culms were retained to be harvested at 4 years of age. Culm numbers harvested were low, and culms were quite thin. Yields were, however, still increasing over time, with yields for 8-year-old clumps ranging across treatments from 7 to 13 t/ha (data not presented).

*Dendrocalamus asper*, in Bukidnon, resulted in the highest-yielding species by location combination. With average culm dry weight yields of c. 44 t/ha/year over 3 years, yield was greatest in the treatment that retained the higher number of culms (80 t/ha/year, 10-10 SCD) and least in the treatment with least culms retained (22 t/ha/year, 3-3 SCD).

## Culm quality

From an economic perspective, in traditional forestry, short rotations are preferred over longer rotations, as are silvicultural practices that favour fast growth, but these may be offset by reductions in physical and mechanical properties and lumber grade recovery. In the current trials with bamboo, with modifications of silvicultural practice, culm quality was analysed only in the Philippines, on *D. asper* and *B. blumeana*. Physical and mechanical properties, such as relative density and moisture content, were not generally significantly affected by the imposition of silvicultural treatments, although differences between species were marked. Strength properties were still improving in culms older than 3 or 4 years in *B. blumeana*, but in *D. asper* those of 1–2-year-old culms were equivalent to those of 2–3-year-old culms. *D. asper*, if it were to be used for construction purposes, could be harvested at close to 2 years of age, whereas culms of *B. blumeana* should be at least 3 years old and ideally older.

For *B. blumeana*, the treatment that led to the oldest culms at harvest (4–5 years of age) overall resulted in the most suitable culms for construction or housing purposes (but that treatment had inferior shoot production compared to the well-managed control treatment with harvest of culms at a younger age). There was some indication that irrigation reduced the strength properties of bamboo culms, but this was overcome by harvesting culms 1 year older. Clearing clumps of spiny branches from ground level to 2.0 m height, to facilitate shoot counting and harvest, resulted in an additional 2.0 m of usable harvested culm. With the thick wall of the basal section of culms suiting use in the production of manufactured goods (such as tiles, using the tile-making equipment developed through this project), the clearing practice should be well received.

Physical and mechanical properties of *D. asper* were similar across treatments, allowing culms from any treatment to be used for engineered products. Anatomical properties (fibre length and cell-wall thickness) were affected by treatment; three treatments gave similar acceptable strength and comparable anatomical (and therefore pulping) properties to untreated clumps. The treatment that gave highest biomass (10-10 SCD) had comparable strength to the untreated clumps but pulping characteristics were inferior. Damaged culms (e.g. top culm portion removed) showed poorer strength properties, and should be separated at harvest from healthy culms.

A good general practice across trials was to colour-code or number retained culms according to the year of their emergence, to ensure that correct numbers of each age class were retained and were of a minimum (species-specific) age before they were harvested.

## Bamboo markets and returns in the Philippines

Surveys across distinct geographical regions revealed that bamboo shoots are of low importance throughout the food industry; knowledge of fresh shoots as a food source is minimal; and canned (imported) produce provides a secure commodity supply. It is unlikely that this situation will change without a promotional campaign.

In contrast, the engineered bamboo industry is expanding, and demand for a culm dryer and tile-making machine (the latter described in these proceedings) is increasing to ensure a consistent, good-quality product. Plans to compete with China's export of engineered products are afoot, but current production costs and lack of unique products are limiting. Replacement of timber by bamboo in low-cost Philippine housing would open wholesale markets and reduce costly imports of wood for the same purpose.

Use of net present value and benefit:cost ratios to compare silvicultural treatments within the Philippines showed that treatments with high culm numbers and irrigation, and without fertiliser application in the fertile soil of Bukidnon, were most profitable.

For the bamboo industry to expand in a sustainable manner, reliable data on the current and future supply of and demand for bamboo culms are essential. Sectoral policies that support this must be developed: inclusion of bamboo in the Integrated Social Forestry Projects of the Community-Based Forest Management Program, besides protecting degraded lands, will provide a reliable source of bamboo culms, if clumps are managed according to practices defined in these proceedings.

## Postharvest processing

The aforementioned tile-making machine, developed with assistance from this project, allows for the use of bamboo culms as if they were timber. The processes of cross-cutting, removing knots, width sizing, thickness sizing and tile length cutting, combined in a compact space, results in 20–30 mm wide tiles,

10 mm thick and 100 mm in length, that can be used for flooring, panelling and furniture and handicraft manufacture. Gaining an additional 2.0 m of culm length in *B. blumeana* through clump cleaning adds to the usable butt portion of culms for tile-making. Other silvicultural treatments did not markedly increase the usable portion (i.e. with a culm wall thickness over 1.5 cm) of the culm for tile-making; adjustable blades in the tile-making machine that accommodate culm thicknesses of 1.2–1.5 cm would be beneficial for this.

### **In conclusion**

If the outputs of the ACIAR bamboo project catalyse improved management and use of bamboo, they will have gone a long way towards achieving the anticipated outcomes: rehabilitating existing yet degraded bamboo stands, maintaining high productivity in managed plantations, optimising bamboo culm quality parameters and improving bamboo timber harvests.

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# Bamboo in the global and Australian contexts

David J. Midmore<sup>1</sup>

## *Abstract*

As a forest and plantation species (actually a group of species, but often referred to by the generic term ‘bamboo’), bamboo commands a position of great importance in Asia and one of increasing importance in Africa and Latin America. The People’s Republic of China consumes more than one million tonnes of bamboo shoots annually and global trade in bamboo products is estimated to be worth between US\$2.2 billion and US\$7.0 billion.

Although the biomass of mature bamboo does not differ markedly from that of forest tree stands, bamboo growth rates of 10–30 t/ha/year are achieved within a few years of planting; considerably quicker than most woody species. For this reason, bamboo can be harvested much earlier than forest species, providing a quicker return on capital investment. With its great potential as a timber substitute and food source, bamboo could play an important role in assisting development goals in countries with the appropriate growing environment. In addition, its role in providing ecosystem services makes it an increasingly attractive choice for a wide range of applications.

In Australia, bamboo was originally planted to provide edible shoots to the domestic and subsequently an export market, and research on production, postharvest management and marketing was developed towards shoots. Managers of bamboo plantations now are searching for uses of mature culms. While the importation of bamboo furniture and flooring into Australia is on the increase, local culm production is yet to, and is unlikely to in the short term, reach a critical volume to merit full-scale processing. At present the Australian bamboo industry is experiencing setbacks, primarily because of sustained drought, but research on maintaining clumps during water shortage, and use of bamboo in wastewater treatment, as well as ongoing productivity trials, are making a valuable contribution to the global interest in bamboo.

## **Global perspective on bamboo**

### **Geographical distribution**

Bamboo is classified as a non-timber forest product, and as such is not included in inventories of forest timber resources. Nevertheless, it is estimated that bamboo comprises approximately 40 million hectares (Mha) of forest land—about 1% of global forest area—and the area is increasing (FAO 2005). This figure is considerably greater than the 14 Mha estimated by Fu and Xiao (1996) and probably reflects improved sensing technology developments that allow for greater coverage of the earth’s surface and the greater vigilance in including bamboo, as well as a

real increase in bamboo plantation. Of the 40 Mha, Asia has 25 Mha—dominated by India with 9 Mha and the People’s Republic of China (PRC) with 5 Mha. In India and Sri Lanka, bamboo accounts for 10% of all forest cover. Latin America is home to 11 Mha of bamboo (concentrated in Brazil, Chile, Colombia, Mexico and Ecuador) and Africa (especially Ethiopia) 3 Mha. As a functional group, bamboo species stretch from the equator to the mountains of Nepal and into temperate regions proper (Fu and Xiao 1996).

### **Importance for shoots, timber and the ecosystem**

While extent of area of bamboo forests is difficult to estimate because of the often sparsely distributed nature of bamboo clumps and co-dominance of some bamboos with forest species, productivity on a global

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basis is even harder to ascertain. Quantifying the harvest of shoots as a food commodity is also fraught with error, but recently the Food and Agriculture Organization of the United Nations (FAO 2005) estimated that 3.5 million tonnes (Mt) of non-wood forest products are harvested annually in Asia for food, of which the majority are in the PRC—most being for bamboo shoots. This value concurs with reports that the PRC consumes 1.2–1.6 million tonnes of shoots annually (Vantomme et al. 2002; Collins and Keilar 2005).

But the utilisation of bamboo is more than just about harvesting bamboo for shoots—it is also about harvesting bamboo culms (or poles) as substitute materials for timber, either processed for fibre or in the natural form, and it is about provision of ecosystem services (Zhou et al. 2005) such as carbon sequestration, erosion containment, integrity of watershed hydrology, and local climate regulation. On a global scale, the gross value of world trade in bamboo was estimated 3 years ago to be anything between US\$2.5 billion and US\$7.0 billion (Hunter 2003), albeit from a relatively small number (c. 50) of the 1,500 known bamboo species. The export value of all bamboo products from the PRC was estimated to be US\$1.1 billion in 2007 (Global Wood 2008). The ecosystem services afforded add considerably to the dollar value of bamboo, but are largely not quantified. A database detailing trade in bamboo (and rattan) is managed by the International Network for Bamboo and Rattan (INBAR n.d.).

### **Growth rates compared to trees**

Bamboo is best known for its fast growth rate. It can produce harvestable culms within 4–7 years of planting, which subsequently can be harvested annually. For this reason, it is expected that, in the future, the major demand for bamboo will be for timber substitution more than for edible shoots. Recognising this potential, in recent years, there has been increasing documentation of bamboo productivity (Isagi 1994; Isagi et al. 1997; Kleinhenz and Midmore 2001; Hunter and Wu 2002; Wang 2004; Castaneda-Mendoza et al. 2005).

Focusing on the above-ground culm biomass, but excluding data for branches and leaves (and data that appear erroneous), the above-ground culm weight of the highest-yielding bamboo stands (c. 150 t/ha) is similar to that of average forest tree stands (100–160 t/ha), but does not match that of the very high values

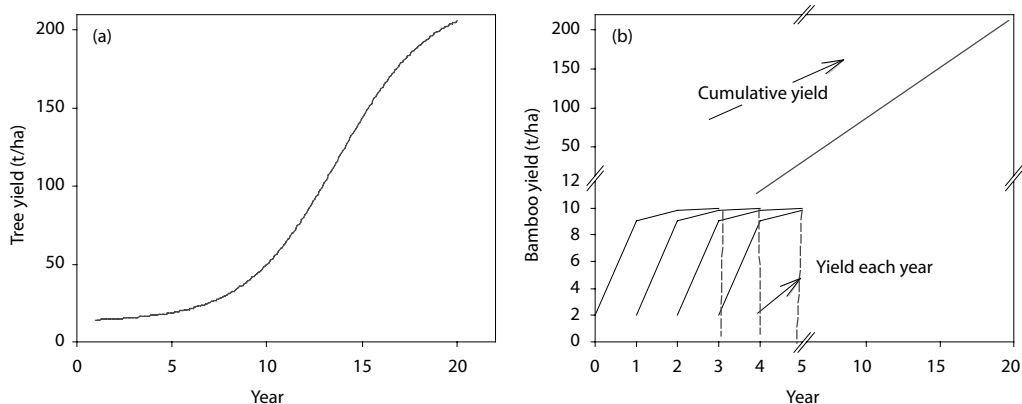
attained by some tree stands (300–1,700 t/ha; Hunter and Wu 2002). In contrast to trees that can accumulate biomass over long periods through radial and vertical extension of stems (trunks), bamboo culms lay down most of their biomass within their first year of growth, largely from current assimilation but also from redistribution from older culms and rhizomes (Magel et al. 2006), and die off after a maximum of 8–10 years, resulting in a decline in biomass of individual culms over long periods. Isagi (1994) referred to this as the biomass accumulation ratio (biomass/net annual production) and showed it to be 4.66 for a stand of *Phyllostachys bambusoides* in Japan.

On an annual basis, above-ground culm growth rates (fresh weight) of 10–30 t/ha/year have been reported (summarised by Kleinhenz and Midmore 2001), which is in line with those of woody species (Hunter and Wu 2002). Although one report with *Bambusa bambos* mentions 47 t/ha/year, productivity of bamboo on an annual basis is generally no greater than that of woody species, and bamboo is no more efficient at sequestering carbon than are woody species. However, one advantage of bamboo over trees is that culms can be harvested much sooner than trunks of woody species (Figure 1) and another is that they can be harvested annually without the environmental consequences of clear-fell. Below the ground, bamboo sequesters carbon in the form of rhizomes, and below-ground biomass is greater proportionately for monopodial (running) species at c. 43% of total biomass compared to c. 31% for sympodial (clumping) species (Kleinhenz and Midmore 2001). The rhizome therefore represents an important sink for sequestered carbon but, according to Hunter and Wu (2002), this sink is no larger than that of woody trees.

### **Potential contribution to development goals**

On a global scale, the International Network for Bamboo and Rattan is undertaking research and development on bamboo (and rattan) and emphasises the contributions that bamboo can make to the achievement of a number of the Millennium Development Goals (INBAR 2006). In particular, three goals may be addressed by investment in bamboo:

- target 1—reduce by half the population of people living on less than US\$1 per day
  - low-capital-cost industries based upon bamboo
  - minimal space with positive returns



**Figure 1.** Comparative analysis of (a) one-off harvest of tree trunks at 20 years and (b) annual harvests of culms from bamboo.

- target 9—integrate the principles of sustainable development into country policies and programs; reverse the loss of environmental resources
  - rehabilitation of degraded bamboo forests
  - ecological services
- target 11—achieve significant improvements in the lives of at least 100 million slum dwellers by 2020
  - low-cost building materials available
  - link city and rural economies.

Bamboo worldwide is therefore a group of species that currently provides considerable ecosystem services and economic returns to those countries where it is managed, and can potentially contribute to future development imperatives, given sufficient international development support.

### Australian perspective on bamboo

Bamboo is represented by only one endemic species in Australia, *Bambusa arnhemica*, which is found as a mono- or co-dominant species above the 1,200 mm isohyet in the Top End of the Northern Territory (Franklin 2004a). It is harvested in the wild state for its shoots, under permit, and sold locally and at the Sydney markets. Over the period 1996–2002, the *B. arnhemica* underwent extensive synchronous flowering, with decimation of vast tracts of mature clumps (Franklin 2004b), replaced by millions of highly competitive seedlings. The seed was also collected by people and used to establish a number of small plantations in the Northern Territory.

### The local bamboo industry

The beginning of the bamboo industry in Australia was evident through the commercial-scale planting of a few species by entrepreneurs, and a decade ago with the establishment of the Australian Commercial Bamboo Corporation (ACBC). Early research and commercial focus was on species choice, and on producing bamboo shoots to offset imports of canned shoots (Midmore et al. 1998). Approximately 250 ha were believed to be adequate to supply shoots to substitute for half of the imported quantity during the 6-month season when fresh shoots would be available. In 1997, about 25 ha of bamboo had been planted in Australia (Midmore et al. 1998) with plans for the planting of a further 60 ha. By 1999, just over 200 ha had been planted, and this increased to 350 ha by 2002 (Collins and Keilar 2005) with plans for a further 200 ha—well above that perceived to supply the Australian demand. More favourable prices overseas, in no small way due to the counter-seasonal supply advantage afforded by Southern Hemisphere Australia, underpinned the attempts to establish an export industry into the Asian (particularly the Japanese) market, but these have not been successful despite there being considerable investment in the support of the ACBC (which had around 40 members) through the application of supply-chain-management principles (Collins and Keilar 2005).

Such an expansion of the planted area of bamboo has placed great pressure on the local market, and prices of shoots have not covered costs of production, except for market-established growers. This



has created a great demand for information on the alternative markets for bamboo, especially since the importation of bamboo in its many forms has escalated since the turn of the century. Bamboo furniture items and bamboo flooring have gained market space in Australia, with most imports derived from the PRC.

#### *Research on productivity*

For the past decade, the Australian bamboo industry, still in its infancy, has benefited from research dedicated to enhancing the productivity of bamboo, initially focusing on that of shoots. Much of this has been summarised by Midmore et al. (1998) and Kleinhenz and Midmore (2002), with further information presented in these proceedings (Traynor et al. 2009; Zhu et al. 2009). The research highlighted the suitability of three species, *Bambusa oldhamii*, *Dendrocalamus asper* and *D. latiflorus*, to subtropical to tropical conditions and of *Phyllostachys pubescens* to the subtropics. Shoot yields of *P. pubescens* reached a maximum of 15 t/ha, although they ranged from 8–15 t/ha with full (total irrigation plus rainfall at c. 2,000 mm/year) and 0–8 t/ha with reduced irrigation, and responded to nitrogen fertiliser applied at rates of up to 500 kg/ha, but only when accompanied by the higher irrigation rate (Kleinhenz et al. 2003). Shoot yield of *B. oldhamii* did not exceed 2.5 t/ha, even when 9 years old. Although the clumps had not been tended until 6 years of age, our data suggest that older culms apparently contribute less to clump shoot productivity than do younger culms and that total leaf nitrogen should be >3% to ensure that growth is not limited by nitrogen deficiency. Postharvest practices for bamboo shoots should focus on hydro-cooling shoots immediately following harvest, with storage at 2 °C in heat-sealed polyvinyl chloride (PVC) film or low-density polyethylene bags. Such conditions allow for effective storage for up to 28 days (Kleinhenz et al. 2000).

Further research on strategic irrigation, thinning regimes and nutrient management is reported in these proceedings for Queensland (Zhu et al. 2009) and for the Northern Territory (Traynor et al. 2009), not only for shoot production but also for biomass.

#### *Current problems*

A recent poll (D.J. Midmore, unpublished data) has highlighted the detrimental effects of the continued drought and unreliable rainfall throughout most of Australia, with at least 50% of growers unable to achieve their desired shoot yields due to lack of water.

This has set the industry back, and the high costs of labour, especially for harvest (of shoots and culms), makes it difficult to compete with imported materials. This, and the high costs of transport associated with the distance between production and markets, have undermined the earlier efforts to promote collective interest in grower and processor groups, and has diluted the investment in lobbying for research and development support. For example, growers recognise the renewable status of bamboo, and the myriad of uses to which it can be put, but in hard times with water restrictions, and given the high water demand for shoot production, the Australian industry has been unable to exploit these otherwise attractive features of bamboo.

Information on the ability of bamboo in Australia to produce biomass under reduced water supply during drought is presented in these proceedings (Traynor et al. 2009; Zhu et al. 2009). This feature may maintain clumps in a condition that allows for commercial shoot production to resume as water supply again becomes available.

#### *Potential for wastewater management*

Because of its relatively shallow and dense root system (80% of roots are found at 0–40 cm depth; Kleinhenz and Midmore 2001) and its ability to take up more water and nitrogen than it actually needs for optimal growth, bamboo is favoured for its ability to dissipate excessive quantities of wastewater, in particular, human effluent. Pioneering trials in Queensland have successfully evaluated the performance of bamboo for on-site wastewater treatment (water from septic tanks; Kele et al. 2004) and for secondarily treated effluent (Sharma and Ashwath 2006), and similar trials with a commercial focus are planned both in Australia and overseas.

## **In conclusion**

The research that is taking place on bamboo in Australia and the Philippines is addressing the global opportunities for bamboo, and the content of these proceedings adds to the ongoing research and development experience with bamboo.

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# General overview of bamboo in the Philippines

Felizardo D. Virtucio<sup>1</sup>

## Abstract

Bamboo is a multipurpose plant. It has productive, aesthetic and protective functions. Fully harnessing these functions, bamboo could provide livelihood options, beautify landscapes and protect the environment.

In the Philippines, the many beneficial attributes of bamboo have not been properly harnessed. Bamboo stands have been depleted due to overexploitation, forest destruction and changes in land use. Plantation development has been very slow to keep pace with the increasing demand for bamboo.

The bamboo industry is still an emerging one. To hasten its progress, there is a need to accelerate plantation development of premium bamboo species, both for the production of culms and edible shoots. A strategic plan to substantially substitute wood-based products with bamboo-based products should be pursued.

This paper presents the general status and potential of bamboo for optimal development and utilisation within the Philippines.

## Status of bamboo stands

For many decades, natural stands of bamboo in the Philippines have been overexploited. The initial record of bamboo stands in 1910 was about 200,000 ha. In 1978, the total bamboo forest areas had been reduced to only 7,294 ha; a drastic decline of about 97% over the 68-year period. This tremendous decrease in bamboo forest areas may be attributed not only to overexploitation of the bamboo resource, but also to the destruction of forests and rapid changes in land use.

The national estimates of bamboo stands in 1997 ranged from 39,000–53,000 ha (OIDCI 1997). Unlike previous bamboo inventories in 1910 and 1978, the 1997 estimates must have included not only the natural stands in public forests, but also the commercial bamboo species, which are distributed throughout the countryside. Recent estimates indicate that there are more bamboo stands of commercial species on private land than on public land, with the

exception of Abra and possibly other provinces in the Cordillera Administrative Region. Examples of the distribution in three provinces are shown in Table 1.

## Species

The total number of bamboo species in the Philippines increased from 47 in 1991 to 62 in 1996 (Rojo 1999). The additional 15 species are introductions from other countries established primarily in bambusetas (bamboo gardens) at the Ecosystems Research and Development Bureau of the Philippine Department of Environment and Natural Resources. The 62 species comprise 21 endemic (13 climbers, 8 erect) and 41 introduced species. Of the total number of erect species, only eight are considered economically important, although they are sparsely distributed. These species are:

- *Bambusa blumeana* (commonly known as kawayan tinik)
- *Bambusa* sp.1 (formerly *Dendrocalamus merrilianus*) (bayog)
- *Bambusa* sp.2 (laak)
- *Bambusa vulgaris* (kawayan kiling)
- *Dendrocalamus asper* (giant bamboo)

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**Table 1.** Comparative distribution of bamboo stands on public and private land in three selected provinces (Source: Virtucio and Roxas 2003)

Province (region)	Public land		Private land		Total	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Abra (Cordillera Administrative Region)	9,617	89	1,200	11	10,817	100
Bukidnon (Northern Mindanao)	402	33	826	67	1,228	100
Davao del Norte (Davao Region)	231	5	4,251	95	4,482	100

- *Gigantochloa atter* (kayali)
- *Gigantochloa levis* (bolo)
- *Schizostachyum lumampao* (buho).

Additional introduced species that have potential for development in the Philippines include:

- *Bambusa oldhamii* (Oldham bamboo)
- *Dendrocalamus latiflorus* (machiku)
- *Guadua angustifolia* (iron bamboo)
- *Thyrsostachys siamensis* (monastery bamboo).

## Supply and demand

In 1997, the annual demand for bamboo was estimated at about 50 million culms (poles) per year. The existing bamboo stands of about 46,000 ha yield only about 36 million culms per year—hence there was a supply deficit of 14 million culms. The annual demand has been projected to increase to between 113 million and 132 million culms per year by 2015 (OIDCI 1997). With this demand projection, and current supply rates (c. 800 culms/ha), the supply deficit would require additional bamboo plantations of 150,000–166,000 ha by 2015. This is in the absence of any productivity gains to be made following research to increase yields.

The percentage distribution of the raw material production is distributed to various industries/sectors as follows: furniture and handicraft (40%); fish pens, housing and construction (25%); vegetables and fruit industries (10%); and other uses (25%).

## Bamboo-processing enterprises

There are four levels of bamboo-processing enterprise, namely: backyard; small scale; medium scale; and large scale. Relative to their potential, these enterprises were characterised and evaluated by FOSTER Asia (1997) as follows:

1. *Backyard*. This level of the enterprise operates in the house with household members as workers. It has been estimated that the average annual sales of backyard enterprises do not exceed PHP500,000 (equivalent to around US\$11,300) per business. In terms of number, the majority of the bamboo-processing undertakings and ventures in the Philippines belong to this category.
2. *Small scale*. The bamboo-processing ventures belonging to this category operate in the vicinity of houses and are located mainly in urban areas. Small-scale enterprises usually have small shops, and use both hand tools and some equipment in production operations. The assets of these businesses do not exceed PHP1 million, with estimated annual sales of PHP1–2 million.
3. *Medium scale*. This level of bamboo processing operates with a standard plant, usually located in an urban area. Its assets are close to PHP5 million. Usually, enterprises belonging to this category have the capability and expertise to produce good-quality products, design their own products and sustain volume production. They can export products directly to other countries. There are very few business ventures in this category and most of them are located in Metro Manila.
4. *Large scale*. This category of bamboo-processing enterprise operates with automated plant equipment. It employs skilled workers and produces products of export quality.

Another study (Ramirez 1999) showed that the majority of bamboo enterprises in the Philippines had very low capitalisation. Ramirez inferred that such enterprises could not afford improved technologies and hence maximum efficiency in bamboo processing was not being attained.

## Processing technologies

Achieving the long-term objective of substituting standard wood products with bamboo-based products would require application of improved technologies in bamboo processing. Considerable effort has gone into developing processes suitable for bamboo (Ganapathy et al. 1996), including contributions from the Philippines. Considering the form and nature of bamboo culms as raw materials for processing, and the need to protect and preserve raw bamboo, new technologies and applications are required to maximise their use and become an effective substitute for wood-based products. The Forest Products Research and Development Institute (FPRDI) based at College, Los Baños, Laguna, is at the centre of bamboo-processing technology development.

New bamboo products and their uses include the following, as detailed by Bello and Espiloy (1995).

### Panel boards

#### *Woven bamboo mat board*

The product constitutes two or more layers of thin, woven slivers of bamboo bonded together with adhesives. It may be used as packing material and in building construction.

#### *Corrugated woven bamboo mat board*

This product is manufactured using four sheets of woven mats which are glued together in a corrugating mould. This intermediate stage becomes a substrate that is over-laid with paper impregnated with phenol-formaldehyde (PF) resin in a hot press. The final product can be used as a roofing material for prefabricated houses.

#### *Bamboo slivers laminated board*

This is a panel board made of several layers laminated with slivers that are 0.8–1.2 mm thick and 15–20 mm wide. The slivers are longitudinally arranged to form a single-direction structurally laminated board of high strength in the longitudinal direction.

#### *Bamboo strip ply board*

This type of bamboo panel board is made of flattened sections of thick-walled culms which are planed to the required thickness, normally 5.0 mm, and laminated with glue. Ply boards made of bamboo strips have fewer layers than laminated boards consisting of bamboo slivers since flattened strips are thicker than slivers.

## Reconstituted panel products

### *Bamboo-based fibreboards*

The process and equipment used in the manufacture of bamboo-based fibreboards are the same as those used in producing wood fibreboards.

### *Bamboo-based cement-bonded particle board*

Needle-shaped bamboo particles are bonded with common silicate cement and calcium chloride as an accelerator.

### *Resin-bonded, bamboo-based particle board*

This product makes use of bamboo waste (e.g. tips, branches and residue from the manufacture of bamboo mat board and other composite panels) which is made into resin-bonded boards. The technology and equipment used to manufacture this product are similar to that for wood-based particle board.

## Production technologies

### Culm production

The assessment of bamboo resources relative to national culm requirements reveals that they are inadequate for sustained yield (as discussed above). Given the worsening status of current timber resources, there is a need to increase the areas planted to bamboo as potential substitutes for wood-based products.

There are available technologies for bamboo plantation development and management of commercial species. These technologies are considered mature and are employed in various regions in the country.

### Shoot production

Bamboo shoots have been an important source of food since early civilisation. In China, succulent shoots of many bamboo species have been traditionally used as a vegetable for more than 2,500 years. Although bamboo shoots have been consumed for their delightful flavour for thousands of years, their nutritional and medicinal values have been discovered only recently.

There are about 1,250 bamboo species around the world but only about 500 species are known to have edible shoots. Of this number, only a few produce good-quality edible shoots. In Yunnan, China, 10 elite bamboo species have been selected for commercial bamboo production. In a related study, Maoyi (1998) selected and recommended the following as the highest-priority species for edible shoot production:

*D. asper* (giant bamboo), *B. blumeana* (kawayan tinik) and *D. latiflorus* (machiku).

Table 2 lists the species that produce edible shoots recommended for development in the Philippines.

**Table 2.** Nine selected edible shoot-producing species that grow in the Philippines and other countries (Source: Virtucio and Roxas 2003)

Genus and species	Geographical distribution (countries)
<i>Bambusa</i>	
<i>B. bambos</i>	Burma, Cambodia, China, Indonesia, Laos, Malaysia, Philippines, Taiwan, Thailand, Vietnam
<i>B. blumeana</i>	China, Cambodia, Indonesia, Laos, Malaysia, Philippines, Thailand, Vietnam
<i>B. oldhamii</i>	Australia, China, Philippines, Taiwan
<i>B. species 1 (D. merrillianus)</i>	Philippines (endemic)
<i>Dendrocalamus</i>	
<i>D. asper</i>	Australia, China, Indonesia, Malaysia, Philippines, Sri Lanka, Thailand
<i>D. latiflorus</i>	Australia, Burma, China, Indonesia, Japan, Philippines, Taiwan, Thailand, Vietnam
<i>Gigantochloa</i>	
<i>G. atter</i>	Australia, Brunei, Indonesia, Malaysia, Philippines
<i>G. levis</i>	Indonesia, Malaysia, Philippines
<i>Thyrsostachys</i>	
<i>T. siamensis</i>	Burma, China, Indonesia, Philippines, Thailand

In the Philippines, the rampant practice of unrestricted shoot extraction has long been identified as one of the major causes of depleting bamboo stands of commercial species. This practice still remains a major problem since relevant technologies of clump management for shoot production have yet to be developed.

Figure 1 relates shoot emergence and mortality in four bamboo species as a function of monthly rainfall. Graphs such as this could serve as a guide in gauging when to harvest bamboo shoots for food before mortality occurs. This type of information is important for managing existing clumps both for shoot and culm production and to attain yield sustainability.

## Problems and issues

A number of problems and other issues face the bamboo industry. These include a lack of data on occurrence, species and management of bamboo, policies surrounding bamboo, plus a series of issues relating to bamboo processing.

### Bamboo production

#### *Bamboo inventory*

A systematic and accurate record of natural and plantation stands of commercial bamboos at regional and national levels is lacking.

#### *Taxonomy*

Bamboo taxonomy is still a major problem in the Philippines. Local names of many species vary with location, which often creates confusion about the true identity of a given species. For example, the common name ‘botong’ refers to *Gigantochloa levis* in Iloilo province, but *Dendrocalamus latiflorus* in the regions of Davao and Northern Mindanao. In other provinces, *G. levis* is known as ‘bolo’ in Laguna and ‘buho’ in Batangas.

In addition, two commercial bamboo species have yet to be studied for their scientific name at the species level. The first, ‘bayog’, was formerly identified as *Dendrocalamus merrillianus*, but an international bamboo taxonomist changed the genus *Dendrocalamus* to *Bambusa*. Its species name has yet to be verified. In the second case, while ‘laak’ has been tentatively named *Bambusa philippinensis*, the species name is still being verified.

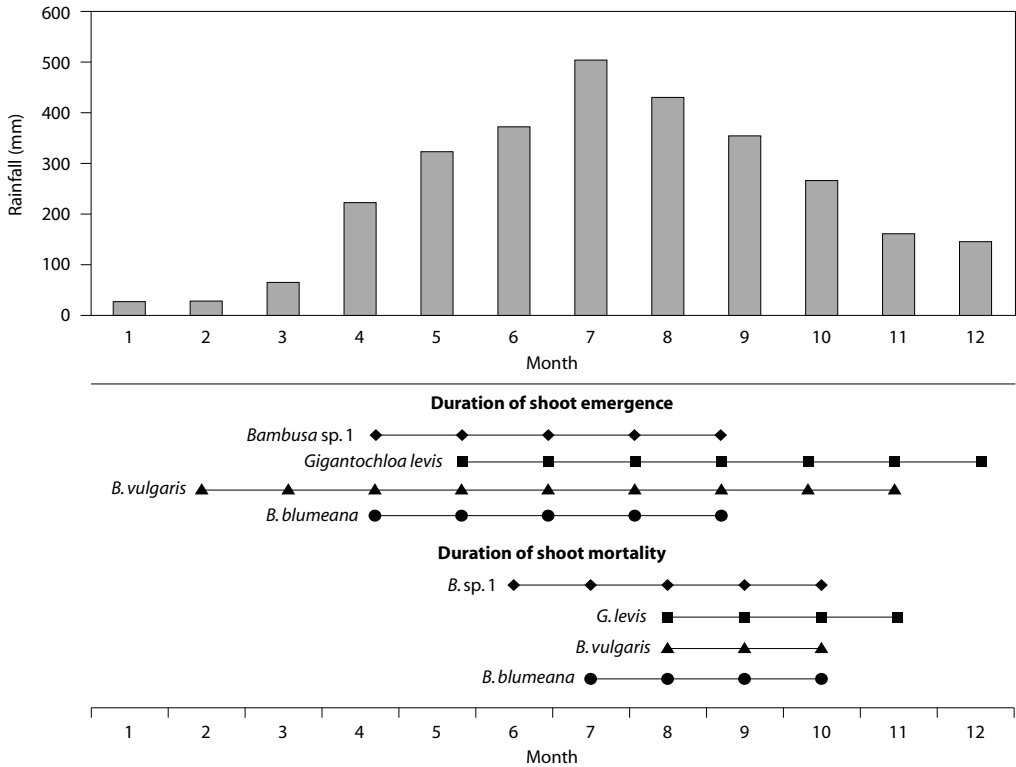
#### *Growth and yield*

Growth and yield data for some species as a function of geographical location and site quality have yet to be generated. Species included in this group are *Dendrocalamus asper* (giant bamboo), *G. levis* (bolo), *D. latiflorus* (machiku) and *B. oldhamii* (Oldham bamboo).

#### *Clump management*

Stands of climbing bamboos are dwindling. These bamboos constitute about 78% of the natural stands that are being utilised for handicraft and other purposes. Propagation and management of regeneration for clump yield sustainability have yet to be studied.

One of the major causes of depletion of commercial bamboo stands is the rampant, unregulated harvesting of edible shoots, as mentioned above.



**Figure 1.** Average monthly rainfall (1996–2000) and duration of shoot emergence and mortality occurrence for four bamboo species in a pilot plantation of bamboo in Pampanga province, Central Luzon (Source: Virtucio and Roxas 2003)

Clump management regimes to allow for both culms and shoot harvest have to be developed for selected species that produce edible shoots.

### Policies

The collection and harvesting policy for culms (Department Administrative Order 11) prescribes the harvesting of bamboo in the natural stands. Harvesting is restricted through the ‘annual allowable cut’ (AAC), which is currently calculated as  $\text{area covered by permit} \times \text{number of clumps per hectare} \times 4$  (number of culms harvested per clump). This formula needs to be revised based on clump yield sustainability and should not be uniform for all species and sites.

The harvesting and transport policy (Department Administrative Order 59) does not encourage sustainable bamboo resources management. Since this policy exempts bamboo culms harvested on private and tax-declared lands from requiring a transport permit, it is being abused. Irregularity occurs when bamboo

harvested from public land is declared as coming from private land.

### Bamboo processing

#### Current low-level utilisation

The agriculture sector is still the biggest user of bamboo (for fish pens, banana props, poultry houses, and other low-value uses). Other users include the furniture and handicraft sectors, but relatively few businesses in these sectors choose to use bamboo for their craft because of (i) uncertainty of supply and (ii) the high cost of collection and transport of culms because of the scattered locations of the bamboo sources.

#### Issues in promoting high-value utilisation

Issues being faced by the industry in moving toward high-value utilisation of bamboo include substitution, cost, image positioning, distribution, and technology

level. Since the bamboo industry is essentially a substituting industry, the following strategic directions should be pursued (FOSTER Asia 1997):

- industry positioning—in providing substitute products, the bamboo-processing industry must
  - target a critical mass of users and aim to supply popular products that all households can use for construction, décor and other applications
  - essentially be privately led with government initiatives that will enable it to take off and become sustainable
  - approximate the extent and scope of distribution prevalent in the wood industry and rationalise the channels of distribution
  - re-engineer its technology to an extent that will enable individual enterprises to compete with wood-based products domestically and internationally
- industry structure—there is a need to support small-to-medium-scale enterprises producing construction-related products such as laminated bamboo, composite and structural materials so that these enterprises can eventually become globally competitive
- market positioning—among the emerging high-value applications of bamboo, natural fibre composites and laminated bamboo are the most promising; it would be practical for the sector to target construction-related requirements.
- technology—proposed technologies for acquisition or development include
  - laminated bamboo for walls and structures
  - bamboo composites such as panel boards, wafer boards
  - structural bamboo such as hollow boards
  - flooring and roofing tiles.

## Concluding remarks

The bamboo industry may be described as an emerging industry in the Philippines. There is, therefore, a need to develop technologies in the processing and production aspects of the industry. On the processing side, there is a requirement to develop facilities to accelerate processing of engineered bamboo products as a potential substitute for wood-based products. On the production side, plantation development of selected bamboo species should be accelerated, although it takes upwards of 8–10 years before such plantations are fully productive. To attain this objective, there is an urgent need to develop optimal

management regimes both for culm and shoot production, for selected premium species. The outcomes of the project funded by the Australian Centre for International Agricultural Research (ACIAR Project No. HORT/2000/127), upon which these proceedings report, to a great extent address these needs.

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