

Improving and maintaining productivity of *Bambusa blumeana* for quality shoots and timber in Iloilo and Capiz, the Philippines

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Abstract

Experiments were conducted in Western Visayas (Region 6) in Santa Barbara, Iloilo, and Dumarao, Capiz. Two studies were set up to determine the best rehabilitation techniques for damaged and unproductive existing natural bamboo stands, and to generate effective management strategies and techniques for improving productivity of an unmanaged bamboo plantation. *Bambusa blumeana* was used in both experiments.

Results of the study on rejuvenating natural bamboo stands showed that cleaning and clearing of unmanaged clumps to free them from congestion, plus annual maintenance of a culm (pole) density of six 1-year-old, six 2-year-old and six 3-year-old culms, resulted in the highest growth rate in terms of shoot and culm production. Apart from maintaining this culm density, applying fertiliser and mulch were the other silvicultural treatments used.

The study on improving the productivity of a young bamboo plantation revealed that optimal management regimes differ depending what product is sought. If the objective is to produce culms, all shoots must be kept for new culms and all 3-year-old culms must be harvested annually. On the other hand, if edible shoots are required, an annual culm density of four shoots, four 1-year-old culms and four 2-year-old culms, together with the application of fertiliser, mulch and irrigation will result in a significantly longer duration of shoot emergence, thus increasing significantly shoot count and yield.

Introduction

Background to the region

Western Visayas, administratively known as Region 6, comprises the provinces of Aklan, Antique, Capiz, Guimaras, Iloilo and Negros Occidental. The region is bounded in the north by the Jintotolo Channel; in the east by the Visayan Sea and the mountain ranges that divide the island of Negros from north to south; in the south by Panay Gulf and Sulu Sea; and in the west by the Cuyo East Pass on the China Sea. The region has a total land area of 2,022,311 ha, which is approximately

6.7% of the total land area of the Philippines. Among its provinces, Negros Occidental is largest, comprising about 792,607 ha, followed by Iloilo at 471,940 ha, Capiz at 263,317 ha, Antique at 252,201 ha, Aklan at 181,789 ha and Guimaras Island at 60,457 ha. Of the total area, 667,881 ha are classified as forestland while the rest are classified as 'alienable' and 'disposable'.

The region has two distinct types of climate. Aklan, Capiz and the eastern part of Iloilo do not exhibit very pronounced seasons. These areas are relatively dry from December to April and wet during the rest of the year. The maximum rain periods are not very pronounced and the dry season lasts only 1–3 months. The rest of the region can be characterised as having climatic type 1, i.e. two pronounced seasons—dry from November to April and wet during the rest of the year.

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Western Visayas exemplifies a quickly developing region with two highly urbanised cities (Iloilo City and Bacolod), and includes Boracay Island, renowned as one of the world's finest beaches. A burgeoning population brought about by a high growth rate and the massive migration of people from rural areas characterises the area.

The bamboo industry

There are several species of bamboo in the region but dominant among them is *Bambusa blumeana* (kawayan tinik), which can be found practically anywhere throughout the region. In Capiz, aside from *B. blumeana*, *Gigantochloa levis* (bolo) is also abundant. In Iloilo alone, the total area planted with bamboo in both natural stands and plantations is estimated at 6,095 ha (Iloilo Provincial Agriculture Office 1999, unpublished report). Considering Iloilo's upland and forest areas, the potential area for bamboo is estimated at 58,200 ha.

The competitive advantages of the sector include the abundance of bamboo that can be easily obtained at a competitive price, which has a production volume of 2,426,478 culms (poles) per year as recorded by the Iloilo Provincial Agriculture Office. At present in Iloilo, there are 41 manufacturers comprising 9 exporters and 32 domestic producers. Their products include salad sets, chairs, beds, gazebos, plant holders, trays, candle holders, torches, picture frames, utility racks and other items. The designs vary based on the manufacturer's target market and skills. The prices also vary for low-, middle- and high-income groups.

Employment within the sector grew by 398 in 1999 and 363 in 2000. Investment in tools and equipment was on the increase from 1997 to 2000 (when data collection ceased). From one exporter in 1992, the industry has grown to nine exporters with markets in the United States of America (USA), Europe, Australia and Japan. These exporting companies are backed up by subcontractors in the countryside. Impressive development of the industry in recent years has resulted in the recognition of bamboo as the 'material of the millennium' by the Center for International Trade and Expositions Missions. Iloilo aims to be the bamboo capital of the Philippines.

The industry's export market was established because of its quality high-end products and products' design advantage. Its main strength lies in the application of appropriate raw materials treatment and processing technology. Manufacturing processes

and technology are semi-mechanised and advances in product development and product design are also considered a comparative advantage of the sector.

However, the industry also has its weaknesses and these include under-capitalisation of existing firms. The difficulty of the small firms to access funds both for upgrading tools and equipment, as well as requirements for working capital, limits their production capability. This weakness is exacerbated by a loose industry structure, wherein exporter-contractors are dependent on the production capability, product-quality consistency and delivery of small firms and subcontractors. These factors limit the rapid growth of the industry.

Recent developments in the furniture, furnishings and homeware sectors indicate that bamboo is a versatile and aesthetically pleasing raw material. In addition, with growing global consciousness about the need to protect and preserve the environment, there is a growing demand for products made of sustainable raw materials produced using environmentally friendly processes and technologies. The emerging demand for products made of bamboo and the government's thrust on promoting and encouraging export of manufactured products serve as opportunities of which the industry should take advantage.

The main threat to the growth of the industry, particularly the export market, is strong competition from countries such as China and Vietnam that manufacture low-cost, mass-produced bamboo products. In addressing this concern, Philippine firms need to increase productivity and improve their efficiency to be competitive in the global market.

Much of the bamboo industry in the Philippines is currently focused on the use of its 'timber' component for furniture, furnishings and accessories rather than for its food use (shoots). Availability of timber is declining in the Philippines, and a substantial change in this trend would take at least a decade even if fast-growing species are planted. In addition, vegetable consumption in rural areas of the Philippines is nowhere near the World Health Organization's recommended intake, although consistent efforts to change this have been implemented. Cultivation of dual-purpose species such as bamboo can alleviate these limitations to development. Environmental degradation, especially on sloping lands and river banks, is a commonly acknowledged problem in the Philippines and planting of suitable species can also help to overcome this concern.

The current study

The study described here was part of the project funded by the Australian Centre for International Agricultural Research (ACIAR Project No. HORT/2000/127) entitled *Improving and maintaining productivity of bamboo for quality timber and shoots in Australia and the Philippines*. Specifically, two experiments were implemented to: (i) determine the best rehabilitation techniques for damaged and unproductive existing natural bamboo stands; and (ii) generate effective management strategies and techniques for improving productivity of an unmanaged bamboo plantation. *Bambusa blumeana* (kawayan tinik), one of the most important bamboo species in the Philippines, was used in both parts of the study.

Rehabilitating old natural stands

The significant reduction in the quality of natural bamboo stands in the Philippines has been exacerbated by inappropriate harvesting techniques and inadequate clump management. Part of the problem of unregulated harvesting is congestion: culms are heavily and irregularly harvested and conveniently removed only from the periphery of clumps, with such clumps congested in their middle, leading to a greater proportion of dead, broken and malformed culms unsuitable for industrial use. This has resulted in low productivity of existing aged and damaged bamboo stands. This study sought to determine the most effective technique for rehabilitating old natural clumps of *B. blumeana* to improve their productivity for both shoot and timber production.

Improving plantation productivity

In parallel, a study on an existing young bamboo plantation attempted to determine the most effective treatment combination to enhance clump productivity for shoot and culm (pole) production. It was assumed that productivity could be increased with appropriate silvicultural treatments and overall management strategies. This may also overcome seasonality of shoot production, particularly in tropical environments, extending the supply of fresh shoots that are currently limited due to their short shelf life.

Materials and methods

Rehabilitating old natural stands

The study used naturally growing bamboo clumps of *Bambusa blumeana* located in Cadagmayan Norte, Santa Barbara, Iloilo. The bamboo clumps, which were at least 30 years of age, were situated in the farms of members of Cadagmayan Norte Bamboo Craft Producers Cooperative.

Annual precipitation in Santa Barbara was 1,791, 1,717, 1,532 and 1,758 mm from 2002 to 2005, respectively, or an average of 1,700 mm. In 2005, the highest monthly rainfall of 487 mm occurred in July, while the lowest rainfall of 4 mm was in February (Figure 1). In any year, the rainy season usually starts in May and ends in October.

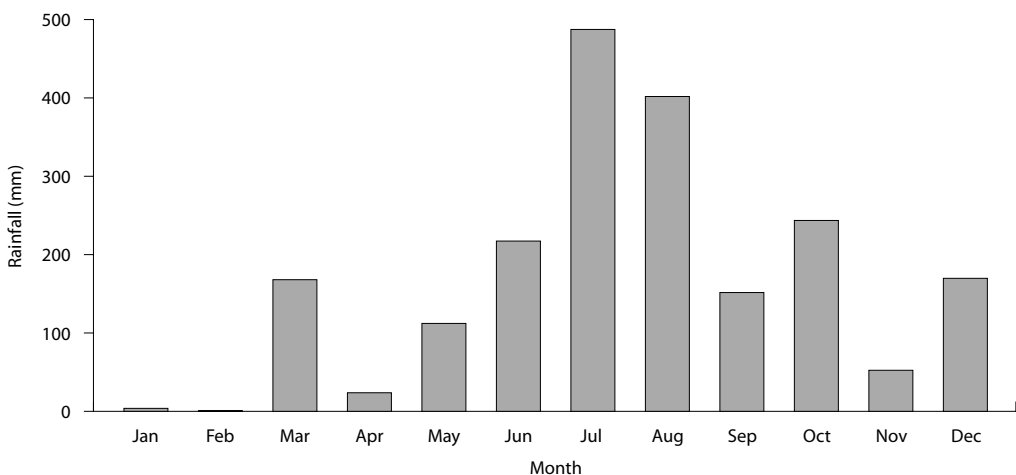


Figure 1. Total monthly rainfall in Santa Barbara, Iloilo in 2005

The soil at the experimental site is slightly acidic, with soil organic matter of varying quantities in the different blocks. Table 1 shows differences in the soil pH and organic matter content in analyses made in 2002 and 2006.

Table 1. Soil pH and organic matter content of soils sampled and analysed in 2002 and 2006 from the Santa Barbara, Iloilo experimental site

Block no.	Soil pH		Organic matter (%)	
	2002	2006	2002	2006
1	5.9	5.9	3.0	1.5
2	5.6	6.2	1.5	3.0
3	4.8	5.5	4.5	3.5
4	4.8	5.4	2.0	4.5
5	4.4	5.6	4.5	2.5

Experimental treatments and design

The design of the experiment was a randomised complete block design with 5 blocks—hence a total of 25 experimental bamboo clumps—with 5 clumps (equivalent to 5 treatments) per block. Blocks comprised different growers with the producers' cooperative.

The treatments applied are summarised in Table 2. In the control (T1), nothing was done except that all culms were harvested when they were 3 years old. A second treatment retained the typical existing farmers' practice of harvesting an average of three shoots and six culms per clump in a year, with no fertiliser or mulch (T5). The other three treatments (T2–T4) retained a set number of shoots and culms of each age per year, and removed all surplus shoots

for use as a vegetable. Fertilised treatments had 2.4 kg urea and 2 kg potassium chloride applied each year. No treatments received irrigation.

The rehabilitation of the experimental clumps was done on the basis of the identified treatments. Except for the 'farmers' practice' treatment (T5) and the control (T1), the activities consisted of cleaning or removing the clumps of their lower spines. Stumps (of harvested culms within the clumps) were cut at their base just above the first node. All debris and rotten parts of the clumps were removed, leaving the upper spines for support so that the clump would not topple over if there was strong wind. The surroundings of the clumps were likewise cleared of unwanted vegetation such as weeds and shrubs.

In bigger clumps, the cross-cut method of clearing was done by cutting across the clump, removing culms (according to treatment) to make a passageway for easier access, and subsequent cutting and removal of stumps left during the previous harvest. In smaller clumps, the lower spines were removed while mature and old culms were cut at their base and extracted from the clump.

After the first cleaning operation at the start of the experiment, fertiliser was applied to the appropriate experimental clumps. The yearly rates were equally divided into two applications; the first application being applied during the onset of the rainy season (May or June) and the second towards the end of the rainy season (October or November).

The parameters measured during the study focused on the following: site characterisation, experiment uniformity analysis, yearly measurements of new shoots and culms, and yield of shoots and culms. A uniformity analysis based upon the numbers and age of culms relative to the treatments was undertaken, with the data showing homogeneity within the site.

Table 2. Summary of treatments in the old natural stands of the Iloilo trial

Treatment	Fertiliser applied?	Mulched? ^a	Standing culm density ^b
T1 (control)	No	No	All 3-year-old culms harvested
T2	Yes	Yes	6-6-6
T3	Yes	Yes	8-8
T4	No	Yes	8-8
T5 (farmers' practice)	No	No	On average, 3 shoots and 6 culms harvested each year

^a Mulched with vegetative debris, c. 5–10 cm depth

^b Successive numbers indicate how many culms of each group are retained each year, with the same number of shoots retained once emerged, e.g. 6-6-6 means six 1-year-old, six 2-year-old and six 3-year-old culms were retained each year, as well as six newly emerged shoots

Improving productivity of a young plantation

This experiment was undertaken at an 8 ha pilot bamboo plantation located within the Capiz State University's Dumarao Campus, which included four species (*Bambusa blumeana*, *B. vulgaris*, *B. sp. 1*, and *Gigantochloa levis*), with each species growing in an area of about 2 ha. The study utilised 66 clumps of *B. blumeana* within the appropriate section. The clumps, planted in 1998, were spaced at 7 m × 7 m and were assigned to 3 blocks comprising 22 clumps per block. The clumps were located in an area that is undulating at an average slope of 18%. At the foot of the study site is a creek—the source of water for irrigation used in the experiment.

On a yearly basis, precipitation in Dumarao, Capiz, is higher than in Iloilo. Annual precipitation was 2,478, 2,208, 2,990 and 3,018 mm from 2003 to 2006, respectively, or an average of 2,674 mm. Data for 2005 are presented in Figure 2.

In 2002, the soil was sampled and was found to be relatively acidic with a pH of 4.5. However, following annual application of 2.5 kg lime/clump, this had significantly improved by 2006 when the pH was 5.2. The soil is a sandy loam with 54.2% sand, 30.5% silt and 15.3% clay. The particle density is 2.70 and bulk density is 1.40 g/cc. Other soil chemical properties at the beginning of the experiment included: organic matter content of 3.5%; total nitrogen (N) of 0.7%; available phosphorus (P) of 0.89 parts per million (ppm); and exchangeable potassium (K) of 27 ppm.

Experimental treatments and design

The experiment was laid out in a randomised complete block design, with 11 treatments and 3 replications, and 2 clumps per treatment.

The treatments started in November 2001 (experiment uniformity/cutting into desired density based on identified treatment) until the third-quarter of 2002 when irrigation treatment was initially applied. Details of each treatment are given in Table 3.

Essentially the treatment combinations considered were fertiliser application, irrigation, culm thinning or cutting intensity, and mulching. These treatments were considered to form part of the plantation management regime, the rate, degree or intensity of which was the subject of the experiment to determine which combination would be most effective in improving productivity of the existing young bamboo plantation.

Inorganic fertiliser was applied at a rate of 2.6 kg urea, 2.0 kg potassium chloride and 0.25 kg phosphorus per experimental clump each year, split into two equal applications: the first during the onset of the rainy season, usually in May; and the second in November. Mulching of experimental clumps was done after each fertiliser application. Initial mulch material used during the first application of fertiliser in 2001 was rice hulls; subsequent mulching used bamboo foliage and other weeds and grasses gathered between the clumps after weeding.

The irrigation treatment utilised a set-up consisting of irrigation pipes connected to sprinklers (with one sprinkler per clump) with irrigation possible

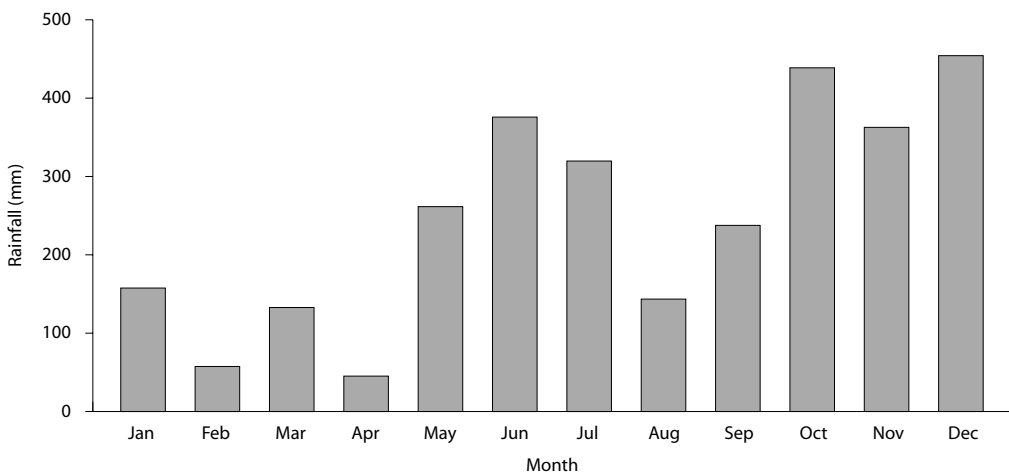


Figure 2. Total monthly rainfall in Dumarao, Capiz in 2005

Table 3. Summary of treatments in the young plantation of the Capiz trial

Treatment	Irrigation supplied?	Fertiliser applied?	Mulched?	Standing culm density ^a
T1 (control)	Yes	Yes	Yes	4-4
T2	No	Yes	Yes	4-4
T3	Strategic ^b	Yes	Yes	4-4
T4	Yes	No	Yes	4-4
T5	Yes	No	No	4-4
T6	Yes	Yes	Yes	3-3
T7	Yes	Yes	Yes	3-3-3
T8	Yes	Yes	Yes	4-4-4
T9	Yes	Yes	Yes	Harvest all 3-year-old culms; retain all shoots
T10	Yes	Yes	Yes	6-6, then harvest all 3-year-old culms
T11	Yes	Yes	Yes	2-year clear-fell ^c

^a Successive numbers indicate how many culms of each group are retained each year, with the same number of shoots retained once emerged, e.g. 4-4-4 means four 1-year-old, four 2-year-old and four 3-year-old culms were retained each year, as well as six newly emerged shoots

^b Experimental clumps were irrigated 10 weeks before expected start of shoot season

^c Clear-felling every 2 years, leaving 8 shoots per alternate year and harvesting culms between 2–3 years of age

year-round. The total amount of water applied in a single application was around 250 L per clump, i.e. 1-hour irrigation of experimental clumps when needed according to refill point from tensiometer measurements at a rate of 4.15 L/minute/clump.

The thinning intensity was based on the number of culms to be retained annually, taking into account the age and the number of culms in a clump. One of the treatment combinations (T11) comprised a 2-year felling cycle.

Results and discussion

Rehabilitating old natural stands

The experiment aimed to determine if there were differences in the production of shoots and growth of clumps between treatments. In the control treatment (T1; no cutting, no fertiliser or mulch, harvest after 3 years), the clumps were swathed by spines ranging from 1 m to as high as 2 m from ground level. Different sizes and uneven distribution of culms were observed, with most of the younger culms found on the periphery of the clumps, indicating that the clumps were quite congested with limited space for shoot growth in the inner portion. Consequently, farmers usually cut only the upper portion of the clump, cutting the culms just above the spines, hence leaving ‘stumps’ as high as 2–3 m standing within the clump, which through time are consumed by termites.

Shoot production

Table 4 shows three essential parameters considered in shoot production; the data shown cover a 5-year period. From 2002–2006, the average number of emerging shoots ranged from 7.9 (T1) to 9.7 (T5) per clump, while T2 showed the most consistent number of shoots over time. These values are similar to those of Binoya (1998) who showed that rehabilitated clumps produced an average of 8.17 shoots a year as compared to 7 shoots a year in non-rehabilitated and unmanaged clumps. Although T5 had the highest average, this treatment—the farmers’ practice—is considered to be too ‘erratic’ in terms of the number of shoots and culms harvested and retained in a year. Furthermore, while T5 had the highest number of shoots in 2002, in later years the number of shoots that emerged had significantly reduced. This is also true for T3, which produced the second highest average number of shoots within the 5-year period; but looking at the yearly average, it started off with a high number followed by a reduced number for the next 3 years.

The average shoot yield ranged from nothing (T1, which had no shoot harvest) to a high of 3.6 kg/clump (T5). While T5 had the highest average shoot yield, it is essentially an arbitrary number depending on how many shoots the farmers decide to harvest in a given year. T2, which gave the second highest average yield, showed more consistency with a relatively higher yield than the other treatments. Retaining 6 shoots

Table 4. Shoot production and mortality in the Iloilo trial

Parameter	Treatment ^A	2002	2003	2004	2005	2006	Average over 5 years ^B
Average number of emerged shoots per clump	T1	9.0	9.2	7.8	7.8	5.8	7.9 a
	T2	8.6	8.2	9.4	9.4	7.4	8.6 a
	T3	11.6	7.8	7.6	7.6	10.2	9.0 a
	T4	10.4	9.0	8.6	8.6	4.0	8.1 a
	T5	14.4	9.6	9.0	9.0	6.4	9.7 a
Average shoot yield per clump (kg/clump)	T1 ^C	0.0	0.0	0.0	0.0	0.0	0.0 c
	T2	2.6	2.2	3.4	2.2	2.4	2.6 a,b
	T3	3.6	0.8	0.8	0.8	2.2	1.6 b
	T4	3.6	2.6	0.8	2.4	0.0	1.9 b
	T5	5.4	4.6	4.4	3.8	0.0	3.6 a
Average shoot mortality per clump (number)	T1	0.6	0.4	0.0	0.0	0.0	0.2 b
	T2	0.6	1.0	2.0	2.0	0.2	1.2 a
	T3	3.4	0.6	0.4	0.6	0.8	1.2 a,b
	T4	3.2	1.2	0.2	0.2	0.2	1.0 a,b
	T5	3.4	2.2	1.6	0.6	0.0	1.6 a

^A See Table 2 for treatment details

^B Averages with the same letter are not significantly different at $P = 0.05$

^C No shoots were harvested in this treatment

and 18 culms (6 culms each for 1–3-year-old culms) yielded an average of 2.6 kg of shoots per clump a year for 5 years.

Annual average shoot mortality ranged from 0.2 (T1) to 1.6 shoots/clump (T5). The data in Table 4 show that, except for T2, shoot mortality was higher in the first 2 years compared to the third to fifth years. Although shoot mortality in T2 increased from 2002 to 2004, in 2006 it was significantly reduced (to 0.2 average mortality). In addition, shoot mortality occurred during the late shoot season in September and October (data not shown).

Table 5 shows the average weight and size of shoots produced in the Iloilo trial. Based on average values, the average shoot weight harvested ranged from 1,096 g to 1,476 g, with the greatest weight from T3 followed by T2. There were no significant differences in average shoot height or diameter between treatments. At 29–30 cm tall and 10–11 cm in diameter, these are relatively large shoots and are on a par with those produced by *B. blumeana* under its natural conditions.

Culm production

Summary data on the number of culms per clump per treatment are presented in Table 6. The average number of culms per clump of *B. blumeana* over the

5 year trial ranged from 22.2 to 33.4. Significant differences as affected by the treatments applied cannot be construed from these data since in the long term there will be a fixed number of culms retained as prescribed for each treatment. What is shown in Table 6 are the numbers of culms before harvesting took place. Differences between the culms retained and the total number of culms before harvest would be more important in trying to determine which of the treatments would be more effective in producing more culms.

The study by Binoya (1998), comparing growth between rehabilitated and non-rehabilitated clumps, showed that in non-rehabilitated clumps the average number of culms was 19.0, while 2 years after rehabilitation, the average number of culms was 21.4, with an improvement in culm diameter from 8.00 cm (for non-rehabilitated clumps) to 12.15 cm (for rehabilitated clumps). This reinforces the idea that rehabilitating unmanaged clumps of *B. blumeana* results on the whole in an improvement in clump growth in terms of the number and size of the culms. Growth trends for both culm and shoots in the experimental clumps show that, with certain limits in the number of retentions, this would result in improved production.

Table 5. Weight, height and diameter of harvestable shoots in the Iloilo trial

Parameter	Treatment ^a	2002	2003	2004	2005	2006	Average over 5 years
Average weight per shoot (g)	T1	1,200	970	1,000	1,000	2,500	1,334
	T2	1,000	1,000	1,000	2,800	1,500	1,460
	T3	950	950	980	2,300	2,200	1,476
	T4	1,000	1,000	1,500	980	1,000	1,096
	T5	980	1,200	1,500	1,000	1,500	1,236
Average shoot height (cm)	T1	30	28	31	29	30	30
	T2	28	30	30	30	29	30
	T3	28	27	29	30	29	29
	T4	30	29	30	28	27	29
	T5	29	30	30	29	28	29
Average shoot diameter (cm)	T1	11	12	10	12	12	11
	T2	10	10	12	11	11	11
	T3	8	11	11	10	11	10
	T4	10	12	12	11	10	11
	T5	10	11	12	12	10	11

^a See Table 2 for treatment details

Table 6. Average number of culms per clump in the Iloilo trial

Treatment ^A	2002	2003	2004	2005	2006	Average over 5 years ^B
T1	30.4	21.2	30.4	24.8	17.6	24.9 b
T2	30.8	22.4	26.2	27.4	18.8	25.1 b
T3	34.2	19.8	23.8	23.8	26.6	25.6 b
T4	32.8	17.8	25.0	22.8	12.6	22.2 b
T5	48.0	30.8	36.0	36.8	15.6	33.4 a

^A See Table 2 for treatment details

^B Averages with the same letter are not significantly different at $P = 0.05$

Improving productivity of a young plantation

Shoot production

According to Virtucio and Roxas (2003), *B. blumeana* (kawayan tinik) has been recommended as one of the priority species for production of shoots. In the Philippines, it is one of the major sources of edible shoots, which are usually collected from cultivated groves in villages and plantations. In a study conducted by Tamolang et al. (1980), the shoots of *B. blumeana* are some of the best in terms of quality and acceptability of taste. The species also yields as many as 6–7 edible shoots per clump in a year (Virtucio and Roxas 2003).

Results of the current study reveal a significant positive response of shoot production to fertiliser

application and irrigation (Table 7). In the time series data on the average number of shoots emerging within a 5-year period, annual average total shoot production ranged from 2.6–8.1 shoots per clump, with the two lowest averages (2.6 and 3.6) yielded by two treatments without fertiliser application (T4 and T5, respectively). This confirms the results of the study by Virtucio and Roxas (2003) on the growth and yield of bamboo in fertilised and unfertilised clumps.

The analysis of variance shows (Table 7) that T4 had significantly fewer emerged shoots than all other treatments. The time series data show a positive response of the experimental clumps to the treatment combinations applied. As a general trend, most treatments increased in shoot number in the second and third years of the trial (2003 and 2004),

Table 7. Shoot production and mortality in the Capiz trial

Parameter	Treatment ^A	2002	2003	2004	2005	2006	Total	Average over 5 years ^B
Average number of emerged shoots (per clump)	T1	5.0	6.2	7.8	6.2	7.1	32.3	6.5 a
	T2	4.2	5.0	5.5	5.0	4.5	24.2	4.8 a
	T3	5.2	5.5	5.7	3.7	5.8	25.9	5.2 a
	T4	3.3	2.5	3.0	1.8	2.6	13.2	2.6 b
	T5	4.7	3.0	3.3	3.2	4.0	18.2	3.6 a
	T6	6.0	11.8	12.2	5.3	5.0	40.3	8.1 a
	T7	4.0	9.3	10.0	7.0	6.3	36.6	7.3 a
	T8	5.0	5.5	5.5	5.7	5.8	27.5	5.5 a
	T9	5.0	7.3	7.7	4.7	5.7	30.4	6.1 a
	T10	5.0	8.7	9.2	4.8	4.6	32.3	6.5 a
	T11	4.5	5.5	5.5	4.2	4.0	23.7	4.7 a
Average shoot yield per clump (kg/clump)	T1	1.7	0.8	1.0	3.5	0.3	7.3	1.5 a
	T2	1.0	1.0	0.2	2.2	0.0	4.4	0.9 b
	T3	1.2	0.7	0.5	2.3	0.5	5.2	1.0 a
	T4	0.5	0.2	0.3	1.0	0.0	2.0	0.4 b
	T5	1.7	0.3	0.2	2.2	0.0	4.4	0.9 b
	T6	4.2	2.8	2.2	9.2	0.7	19.1	3.8 a
	T7	1.5	2.0	1.3	4.8	1.3	10.9	2.2 a
	T8	1.7	0.3	0.7	2.7	0.7	6.1	1.2 a
	T9	1.8	1.7	0.3	3.8	0.0	7.6	1.5 a
	T10	1.5	0.8	0.2	2.5	0.0	5.0	1.0 a
	T11	0.5	0.3	0.0	0.8	0.0	1.6	0.3 b
Average shoot mortality per clump (number)	T1	2.3	4.3	3.0	3.0	3.3	15.9	3.2 a
	T2	2.0	2.3	3.0	2.0	2.7	12.0	2.4 a
	T3	2.3	2.0	2.3	1.7	3.0	11.3	2.3 a
	T4	1.7	1.0	1.0	0.7	1.3	5.7	1.1 b
	T5	2.3	1.0	1.3	1.3	1.7	7.6	1.5 b
	T6	3.0	3.7	3.3	1.7	2.7	14.4	2.9 a
	T7	2.0	3.0	2.7	3.0	3.3	14.0	2.8 a
	T8	2.0	2.0	2.7	2.7	3.3	12.7	2.5 a
	T9	2.0	2.3	1.7	2.0	3.0	11.0	2.2 a
	T10	2.7	2.3	2.0	2.0	2.3	11.3	2.3 a
	T11	1.7	2.0	1.3	2.0	2.7	9.7	1.9 b

^A See Table 3 for treatment details

^B Averages with the same letter are not significantly different at $P = 0.05$

then decreased in 2005. Results then varied in 2006. The reduction in the emergence of shoots in 2005 and 2006 was common to all treatments in the experiment and was not due to lack of irrigation.

The average shoot weight per clump ranged from 0.3 kg (T11) to 3.8 kg (T6). This yield maximum occurred in the treatment in which the fewest culms were retained. Shoot mortality occurred during the late shoot season from September to October. Shoot

mortality on average ranged from 1.1 (T4) to 3.2 (T1) shoots per clump (Table 7).

From the data gathered during the shoot season, the treatment combinations with fertiliser and irrigation resulted in a longer duration of shooting. In the time series data on shoot emergence, a significant positive response in terms of its duration was evident in each year. Data from 2002, 2003 and 2004 are presented to illustrate this (Figures 3–5, respectively).

In 2002, shoot emergence spanned from January to September with the bulk in April and May. Emergence of shoots after May was low, with only a few shoots emerging in August and September (Figure 3). In 2003, the duration of shoot emergence was similar to that of 2002, but the total number of shoots that

emerged was markedly greater (Figure 4), except for T4 and T5 which did not receive fertiliser. The duration of emergence was more expansive in 2004 and varied from 5–10 months among treatments (Figure 5), with the shortest duration of 5 months for treatments without fertiliser.

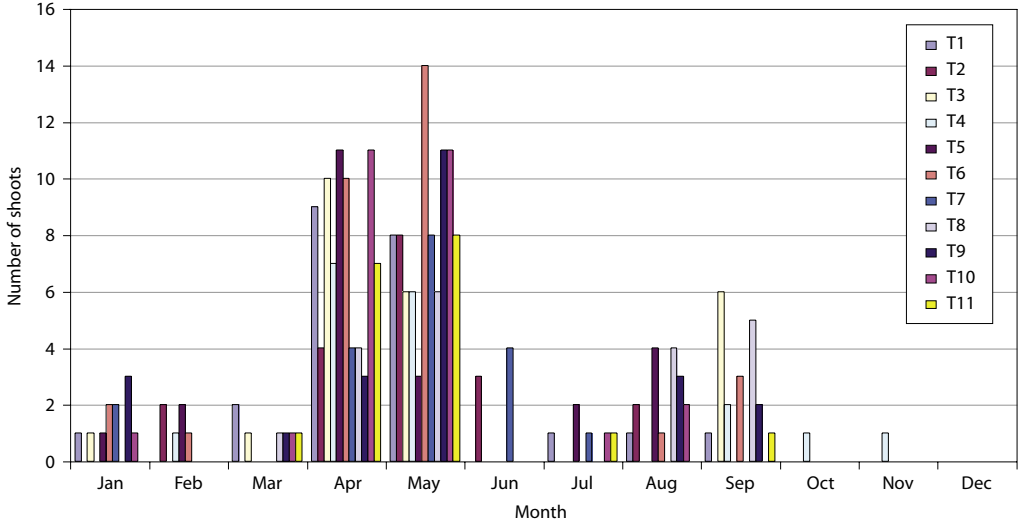


Figure 3. Monthly total shoot count per treatment in 2002 in the Capiz trial. Note: see Table 3 for treatment details.

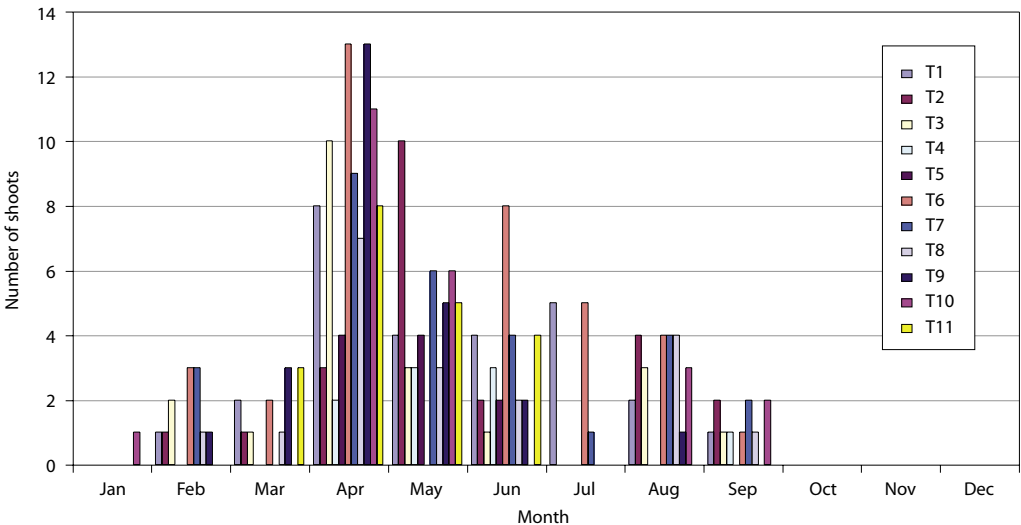


Figure 4. Monthly total shoot count per treatment in 2003 in the Capiz trial. Note: see Table 3 for treatment details.

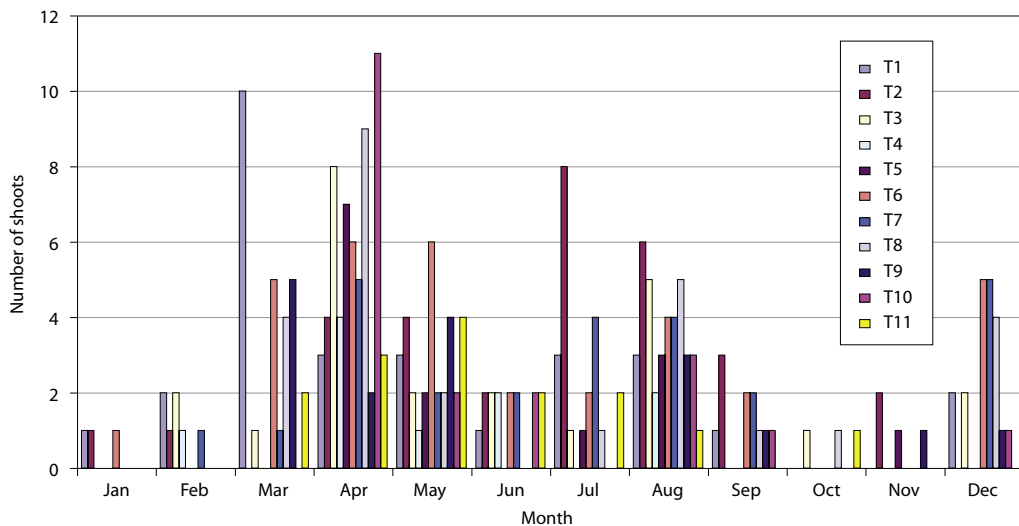


Figure 5. Monthly total shoot count per treatment in 2004 in the Capiz trial. Note: see Table 3 for treatment details.

Clearly, the effects of fertiliser and irrigation on the emergence and overall production of shoots are significant (at $P = 0.10$). Lack of irrigation reduced shoot numbers and shoot yield (compare T2 and T3 to T1 in Table 7) as did lack of fertiliser as seen in the comparisons of T4 and T5 with T1. The positive response of shoot emergence and survival to rainfall was studied by Quimio (2002), as cited by Virtucio and Roxas (2003). By examining the rainfall pattern in Dumarao, Capiz (Figure 2), shoot emergence in the non-irrigated treatment (T2) coincides with periods of most rainfall, which concurs with Virtucio and Roxas (2003) who found that, in general, the pattern of shoot emergence is affected by monthly rainfall pattern. This strong response to rainfall was offset by irrigation which brought forward the timing of shoot emergence.

Culm production

Culm growth. Several studies have been conducted on bamboo growth and yield, but while their focus was mainly on the effects of site quality and silvicultural treatments, studies on the effects of culm population, particularly on limiting the number of culms of particular ages retained in the clump, are lacking. In this trial, culm density was considered to be one of the limiting factors of growth in the *B. blumeana* plantation. T1, which had a culm density of four shoots, four

1-year-old culms and four 2-year-old culms (or a total of 8 culms per clump), was identified as the control treatment because, at the start of the experiment, the plantation had an average of 7.33 culms per clump. A study of productivity in different provinces conducted by the Ecosystems Research and Development Bureau (ERDB) under the National Bamboo Research and Development Project from 1988–1993 (ERDB 1998) revealed that the Capiz plantation yielded 7 culms per clump of *B. blumeana*, which was much less than the highly productive Surigao del Sur (Region 13) plantation which yielded 19 culms per clump, Pampanga (Region 3) with 16 and Cebu (Region 7) with 12. Other plantations in Bukidnon (Region 10) and La Union (Region 1) yielded 8 and 6, respectively. Hence, the plantation at the start of the experiment in 2001 was typical of the region, but with room to improve in terms of matching the species potential of producing more shoots and culms under improved conditions.

Estimated culm yield. One estimate of the yield is the number of culms harvested per clump. As shown in Table 8, the average number of culms harvested per clump from 2004–2007 ranged from 2.3 to 4.4. There were no significant differences among treatment means; T11 at 4.4 culms harvested per clump had the highest value, but this was the treatment with the biennial harvest cycle.

Table 8. Average number of culms harvested per clump in the Capiz trial from 2004 to 2007

Treatment ^a	2004	2005	2006	2007	Total	Average over 4 years
T1	3.0	3.3	4.0	3.8	14.1	3.5
T2	3.2	3.3	3.5	3.3	13.3	3.3
T3	2.5	3.7	4.0	3.2	13.4	3.6
T4	2.0	2.5	2.5	2.2	9.2	2.3
T5	2.2	2.8	2.5	2.7	10.2	2.6
T6	2.5	3.2	3.0	2.5	11.2	2.8
T7	– ^b	2.8	3.0	3.0	8.8	2.9
T8	2.5	2.7	3.2	3.5	11.9	3.0
T9	3.2	3.7	3.2	3.3	13.4	3.4
T10	3.2	4.0	3.8	4.0	15.0	3.8
T11 ^c	–	3.7	–	5.0	8.7	4.4

^a See Table 3 for treatment details

^b No culms were available for harvest

^c Treatment of 2-year felling cycle, therefore no culms in alternate years

Other culm parameters were considered in the experiment, including average length and diameter of harvested culms (Table 9). The length of culms harvested averaged 9.2 m (T7) to 11.4 m (T11). T7, with three 1-, 2- and 3-year-old culms, had significantly shorter culms than other treatments. In most cases, there was a steady increase in the length and diameter of culms harvested over the course of the experiment. Culm diameters were greatest in T6, that with the fewest culms (3-3), and least in the treatments with more culms of the 1-, 2- and 3-year-old classes (T7 and T8), but differences were not statistically significant.

In the estimation of the above-ground culm biomass, both the fresh and dry weights of harvested culms were measured in 2006 and 2007 and data are presented in Table 10. The highest average fresh weight was achieved in T9 (26.1 kg/culm), with the lowest in T7 (16.9 kg/culm). T3 had the highest average dry weight (20.3 kg/culm).

Based on the harvested culm data, the total culm production on a per hectare basis was estimated and is shown in Table 11. From these estimates (given spacing of 7 m × 7 m or a total of 204 clumps/ha), the number of culms/ha ranged from a low of 1,190 (T7) to a high of 2,177 (T10). Although there were no significant differences among the treatment means, T9 was estimated to have a total of 2,041 culms/ha and the largest volume among the treatments at 40.2 m³/ha. It is interesting to note that, while the lack of fertiliser (T4 and T5) had a depressive effect on

culm volume and yield per unit area, the same was not evident with either lack, or strategic application, of irrigation (T2 and T3, respectively). Also apparent was the tendency for treatments that had 3-year-old culms retained (i.e harvest of 4-year-old culms—T7 and T8) to depress culm yield per unit area. Overall, the culm biomass yields (that did not include branches and leaves) were quite low (on average across treatments of slightly less than 4 t/ha/year) compared to other published data (Kleinhenz and Midmore 2001), but the young age of plants and poor site characteristics are in part responsible for this.

Other factors such as fertiliser application and overall site quality and their effects on the growth and yield of bamboo have been studied thoroughly under the National Bamboo Research and Development Project of the Ecosystems Research and Development Bureau at the Pampanga Pilot Bamboo Plantation (Quimio 2002, as cited by Virtucio and Roxas 2003). That study, which utilised a 6-year-old plantation of *B. blumeana* (among three other species) for 3 years, revealed a better growth response when plants were treated with fertiliser than without fertiliser. The fertiliser treatment considered different levels of nitrogen and phosphorus and a fixed level of potassium.

As to site quality, rainfall has been considered as one of the most important factors that influences bamboo growth (Virtucio and Roxas 2003). In the regional comparative data gathered under the National Bamboo Research and Development Project, the site in Surigao del Sur (Region 13) was considered as the

Table 9. Length and diameter of culms harvested during the Capiz trial

Parameter	Treatment ^A	2004	2005	2006	2007	Average over 4 years ^B
Average length (m)	T1	6.9	9.2	12.6	13.5	10.6 a
	T2	7.4	9.4	12.9	14.5	11.1 a
	T3	6.6	9.0	11.8	14.5	10.5 a
	T4	7.0	8.7	11.6	13.1	10.1 a
	T5	6.7	8.7	12.1	14.1	10.4 a
	T6	6.6	10.0	11.1	15.1	10.7 a
	T7 ^C	0.0	7.0	8.3	12.2	9.2 b
	T8	8.4	7.0	10.2	18.0	10.9 a
	T9	6.8	10.4	13.2	14.7	11.3 a
	T10	6.9	9.4	12.7	15.0	11.0 a
	T11 ^D	–	9.4	–	13.3	11.4 a
Average diameter (cm)	T1	5.6	6.4	7.4	7.6	6.8 a
	T2	6.0	6.7	7.4	7.7	7.0 a
	T3	5.3	6.4	7.6	8.2	6.9 a
	T4	5.9	6.4	7.3	7.5	6.8 a
	T5	5.3	7.0	7.3	8.0	6.9 a
	T6	5.6	7.1	7.5	8.7	7.2 a
	T7	0.0	5.9	6.5	7.0	6.5 a
	T8	6.5	6.0	6.8	7.6	6.7 a
	T9	5.7	6.9	8.1	7.9	7.2 a
	T10	5.5	6.6	7.5	8.1	6.9 a
	T11 ^D	–	6.9	–	7.3	7.1 a

^A See Table 2 for treatment details

^B Averages with the same letter are not significantly different at $P = 0.05$

^C No culms were available for harvest

^D In this treatment, culms were only harvested in alternate years

most productive (with the site in Dumarao as one of the sites with low productivity) and this can be attributed to the effect of annual rainfall and duration of monthly rainfall. Irrigation, while enhancing shoot yield, did not have any effect on culm biomass.

Conclusions

Rehabilitating old natural stands

Management of natural bamboo stands requires certain clump management practices to show improved productivity. It is typical in the rural areas of Iloilo, if not the whole Philippine setting, for unmanaged clumps to be congested, particularly with old culms/stumps. As shown in this study, the cleaning and clearing of unmanaged clumps to free them from this congestion, coupled with annual maintenance of six new shoots, six 1-year-old culms,

six 2-year-old culms and six 3-year-old culms, and the application of fertiliser (at a rate of 2.4 kg urea and 2.0 kg potassium chloride per clump per year) and mulch, resulted in the highest growth in terms of shoot and culm production among the experimental clumps. This is in contrast to the production level monitored for unmanaged/unrehabilitated clumps and other treatments having more shoot and culm retention in each year, that is, retention of eight shoots, eight 1-year-old culms and eight 2-year-old culms. This was achieved on clumps that were 30 years of age, i.e. mature clumps.

Bamboo as a commodity is a significant contributor to the regional economy. Existing natural bamboo stands are the major source, if not the only source, of raw materials for bamboo cottage industries. However, because of its relatively natural abundance, clump management (as to the application of certain silvicultural treatments for sustained productivity), natural or

otherwise, is essentially ‘unheard of’ even among the rural upland farmers. Frequent harvesting of culms has left them in a poor condition when compared to what they were before harvesting began.

Unmanaged bamboo stands can be described as clumps growing in patches with non-uniform production of culms, clumps damaged by improper harvesting methods, reduced production of culms,

Table 10. Fresh and dry weights of culms harvested in 2006 and 2007 during the Capiz trial

Parameter	Treatment ^a	2006	2007	Average over 2 years
Average fresh weight (kg/culm)	T1	23.8	23.4	23.6
	T2	23.3	24.3	23.8
	T3	24.0	26.0	25.0
	T4	19.4	20.6	20.0
	T5	21.5	25.0	23.3
	T6	22.4	29.1	25.8
	T7	13.8	19.9	16.9
	T8	15.8	25.1	20.5
	T9	27.1	25.0	26.1
	T10	24.1	27.6	25.9
	T11	— ^b	21.3	21.3
Average oven dry weight (kg/culm)	T1	14.5	19.0	16.8
	T2	15.7	19.0	17.4
	T3	18.9	21.6	20.3
	T4	14.0	12.2	13.1
	T5	9.0	14.6	11.8
	T6	13.8	20.0	16.9
	T7	10.0	13.1	11.6
	T8	11.8	17.3	14.6
	T9	18.5	17.2	17.9
	T10	13.0	20.0	16.5
	T11	— ^b	15.9	15.9

^a See Table 3 for treatment details

^b No harvest

Table 11. Total culm production (cumulative total 2004–2006) on a per hectare basis in the Capiz trial

Treatment ^a	No. of culms/ha (at 204 clumps/ha)	Volume (m ³ /ha)	Total dry weight (t/ha)
T1	2,109	34.9	14.58
T2	2,041	34.8	14.52
T3	2,143	33.4	13.93
T4	1,497	20.4	8.53
T5	1,633	24.2	10.12
T6	1,803	30.3	12.64
T7	1,190	12.7	5.28
T8	1,395	17.7	7.37
T9	2,041	40.2	16.80
T10	2,177	35.0	14.61
T11	1,531	17.5	7.31

^a See Table 3 for treatment details

and an abnormal distribution of culm age classes in a clump. This study has shown that rehabilitating unmanaged clumps can serve as a means of trying to bring back damaged and less productive clumps to their productive state, thus ensuring a stable supply of bamboo raw materials in the future.

While this study has shown a significant positive response to the application of rehabilitation treatments, the harvesting regime of retaining a certain number of shoots and culms of *B. blumeana* may only hold true for the Santa Barbara site and its soil and climatic conditions, i.e. the optimal management strategy may be site-specific.

Improving productivity of a young plantation

Improving productivity of an existing unmanaged and relatively low productivity young *B. blumeana* plantation is achievable through the application of fertiliser and irrigation treatments as indicated by the results of this study.

Among the treatment combinations applied, the combination of applying fertiliser (fixed level of nitrogen, phosphorus and potassium specific to the Dumarao, Capiz, site requirement) leaving all shoots (T9) and harvesting 3-year-old culms was the management regime that resulted in the highest growth and yield of the plantation. This may hold true only if the objective of plantation management is to produce culms.

On the other hand, if the objective is to produce edible shoots (for food production) and culms (for pole production), management decisions must consider how many shoots to harvest and how many to retain and grow further into high-quality culms. For Dumarao and with other sites with similar characteristics, the 4-4 combination (maintain four shoots, four 1-year-old culms and four 2-year-old culms) coupled with the application of fertiliser and irrigation will result in a significantly longer duration of shoot emergence and yield. Subsequently, being able to prolong the shoot emergence in a year will

certainly increase the supply of edible shoots in the market, even in those months that were previously considered by many as 'off season'.

Comparison between the two trials highlights the different optimal culm numbers with respect to clump age. At the Dumarao site (clumps 3–7 years of age through the trials), it was at times difficult to achieve the desired culm number for each treatment (no shoots could be harvested for consumption), whereas in the Iloilo trial, the bigger, older clumps produced more shoots; enough to satisfy the number of culms dictated by the treatment requirements and some for consumption. Even with time in the Capiz trial, the number of shoots did not increase, suggesting an overriding debilitating effect on growth. Shoot diameter at the Capiz site was only one-half that at the Iloilo site.

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Development of the bamboo tile-making machine

Jose A. Zafaralla and Stanley C. Malab¹

Abstract

A machine was developed for processing *Bambusa blumeana* (kawayan) butts (the lower 1–2 m portion of the bamboo culm) into solid, flat, bamboo tiles that are durable for flooring, parquets, panels and various uses in the furniture and handicraft industries. The technical performance and economic viability of this bamboo tile-making machine were subsequently evaluated.

The machine can undertake five major operations with only one source of power: cross-cutting, removing knots, width sizing, thickness sizing and tile length cutting. It has a minimum work space requirement of 9 m². The machine can produce tiles 20–30 mm wide × 10 mm thick × 100 mm long in 25 seconds with a precision of 86–92%. The conversion output per butt is 69%. Only one operator is needed to operate the machine. The processing speed can be increased as the operator becomes more skilled.

The eventual commercialisation could benefit small-scale bamboo producers since the cost of fabricating the machine is only US\$538. The rate of return is computed at 23.4% with a payback period of 255 days for split bamboo butts, and at 16.9% with a payback period of 337 days for processing whole bamboo butt.

The bamboo tile is an engineered construction material that is versatile, eco-friendly and can be adapted to individual specifications. In this regard, the tile-making machine and other bamboo technologies are the key to the promotion of bamboo as a valuable renewable resource.

Introduction

Bamboo can play a dominant role as an important non-timber raw material for a variety of products and uses that contribute to the reduction of timber consumption, enhance environmental protection, promote poverty alleviation and accelerate sustainable development of rural economies. In almost all regions of the Philippines, there are different bamboo species luxuriantly growing along rivers, gullies, farm boundaries, hillsides and even backyards, but utilisation and processing technologies are still very poor in the Philippines.

There are now more than 62 species of bamboo growing in the Philippines (Rojo 1999). The commercially exploited species are mainly the erect species, which include *Bambusa blumeana* (kawayan tinik), *Dendrocalamus asper* (giant bamboo), *Dendrocalamus latiflorus* (botong), *Bambusa* sp. 1

(bayog) and *Schizostachyum lumampao* (buho). The most important is *B. blumeana* because of its versatility, especially for house construction, handicrafts and furniture-making (Espiloy 1999).

Bamboo has become an integral part of the culture of the Filipinos. The unique strength properties of bamboo coupled with Filipino innovativeness has enabled the versatility of the plant to be exploited for many industrial and architectural uses. Bamboo is used for housing construction (posts, purlins, rafters and trusses), laminated mat boards, ladders, furniture and handicraft articles. The versatile nature and innumerable uses have earned bamboo the accolade as the best substitute for wood for the construction and furniture industries.

Bamboo is a grass rather than a wood. As a grass, bamboo regenerates faster than wood. It offers advantages over many conventional building materials. Its hardness, stability and strength are its remarkable qualities (Zen Bamboo 2004). The hardness of bamboo depends on what time of the

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year it is harvested, its age and the amount of rain it received during the growth season. The average hardness is comparable with *Quercus* spp. (oak) and *Pterocarpus indicus* (narra), and slightly higher when used horizontally in construction (Alipon et al. 2001; Greenwood 2002). It possesses excellent strength properties, especially tensile strength (Espiloy 1999).

In the provinces of Ilocos Sur, Ilocos Norte, La Union and Pangasinan (which comprise Region 1 of the Philippines), the construction, furniture and handicraft industries combined require about 330,000 bamboo culms (poles) every year. Stand-owners exported from the region 1.2 million bamboo butts (the lower 1–2 m of the bamboo culm) and 450,000 culms in 1996 with an estimated value of PHP40 million (Battad et al. 1999). This figure indicates the availability of materials that can be processed or converted into new products, adding considerable value to the bamboo.

Bamboo tile is a relatively new product for interior construction design in the Philippines. It is an engineered bamboo product excellent for flooring, wall panels and furniture components. It has not been explored widely for architectural designs because of a lack of a variety in the size of tiles produced by appropriate bamboo machines. Bonoan and Vivencio (1999) classified the common tools for bamboo processing in the Philippines as follows: 1. cutting/splitting tools—bowsaw for cross-cutting, coping saw for curved lines and fine cuts, knives for cleaving, shaving, boring and chamfering, chisel, chip cutter and splitter; 2. surface preparation tools—plane, sander, scraper, shaver and sizer; 3. joining/separating tools—hammer, scissors, gimlet and spokeshave; and 4. other useful tools—electric drill, higo (a locally fabricated tool for removing the outer skin of bamboo culms), board, clamp and vice. Recently, Zafaralla and Malab (2000) developed a machine similar to a wood lathe that semi-automatically converts difficult-to-clean bamboo butts with nodes, knots and scars, into uniformly sized, clean culms of a desired length and diameter. To date, a combination of machines that can efficiently produce bamboo tiles of different sizes, and that is affordable and can be operated by small farmers at the village level, is not available in the local market.

To meet the identified need, the present study was conducted to develop a versatile, low-cost machine capable of performing different operations ranging from cutting bamboo culms through to producing the desired finished product. Outputs would include a

range of bamboo slats and tiles for the construction, interior design, furniture and handicraft industries. Specifically, we aimed to: 1. design and determine the cost of constructing the machine; 2. quantify the production output; and 3. assess the economic viability of the machine.

Materials and methods

Design and fabrication

The basic considerations in the design of the bamboo tile-making machine were the availability of standard parts in the locality, limitations of a regional university's workshop and other nearby private machine shops to fabricate non-standard parts, availability of raw materials for the test operations, and instruments for testing the finished product. The standard parts procured were: 746 W (1 hp) electric motor; 6.4 mm (1/4 inch) angle bars; round and square bars of different sizes; different pulley combinations; carbide-tooth circular saws of different diameters; bolts of various sizes; and v-belts.

The design of the machine was focused on producing bamboo splits and subsequently tiles of equal thickness from the round and hollow bamboo culms (poles). The basic operations considered were: cutting the culms to the desired length; removing the outer knots; width sizing; thickness sizing; and tile length cutting. The machine was designed to perform all five different operations to produce tiles using only one source of motor and assembly. The motor was shifted through the operations via a shafting mechanism. The speeds of the pulleys and circular saws were based on basic engineering computations to attain maximum efficiency and precision of the machine (Walker 1977; Wagner 1980).

After the materials were specified and purchased, individual parts were put together first before the parts were assembled to form the whole model. The method of construction was based on the working drawings prepared beforehand.

Testing and evaluation

The culms used during the test runs were harvested during the Mariano Marcos State University – Philippine Council for Agriculture, Forestry and Natural Resources Research and Development – Australian Centre for International Agricultural Research (MMSU-PCARRD-ACIAR) project *Improving and maintaining productivity of bamboo*

for quality timber and shoots in Australia and the Philippines (ACIAR Project No. HORT/2000/127). To produce the desired thickness of tiles, only the butt portion (1–2 m from the base) of the bamboo culm was used for the study. The culms were 3 years old and air-dried for 6 months. The relative strength of *Bambusa blumeana* (kawayan tinik) was compared with a number of medium-strength woods using secondary data (Alipon et al. 2001; Malab et al. 2001).

The five operations of the machine were performed one at a time starting from culm cross-cutting, to removing knots, width sizing, thickness sizing and finally to tile length cutting. Any mechanical malfunctioning of the component parts of the machine was checked and adjustments made. The machine was tested and evaluated for its precision, production output, percentage culm utilisation, and cost and return in processing whole butt and pre-split raw materials.

All relevant data were analysed using the analysis of variance and simple regression method.

Results and discussion

Comparison of the mechanical strength of bamboo and premium wood species

The basic considerations for processing *B. blumeana* into tiles were established based on the observations made during the process of design, fabrication and test operation of the tile-maker. These are presented below

The first step in producing premium bamboo tiles is to select the finest raw material available. The materials selected should be those harvested before the rapid growth season. Bamboo harvested during the rainy season is softer than at other times of the year because of the accumulation of starch and fast elongation of cells. Choosing materials harvested at the appropriate time ensures quality strips that have the proper strength and hardness required for flooring and panelling (Alipon et al. 2001). Any type of bamboo can be processed by the tile-maker as long as it has a culm thickness of no less than 1.5 cm. The butt portion (1–2 m from the base) of the bamboo culm is preferred. It is very important that the culms be more than 3 years old, air-dried and have moisture content of approximately 10–12%.

Based on the bamboo culms harvested and tested for strength and hardness at the Forest Products Research and Development Institute Laboratory,

the mechanical properties of bamboo and secondary data of comparable wood samples are presented in Table 1. *B. blumeana* has an average density of 0.60 g/cm³ while the medium hardwood has 0.55–0.64 g/cm³. In terms of compression to grain, *B. blumeana* butt is 39.9 MPa while the medium hardwood ranges from 23.8 to 55.9 MPa. The mechanical properties of *B. blumeana* appear to be comparable to some medium hardwood species such as *Acacia* spp. and big-leaf mahogany (*Swietenia macrophylla*). In China, bamboo is extensively used for flooring and panelling (e.g. Zen Bamboo 2004).

Features of the bamboo tile-making machine

The tile-making, five-in-one machine is the first of its kind in the country. It is constructed to perform the five major operations necessary to produce bamboo tile using only one source of power. It weighs approximately 150 kg and its dimensions are 1.5 m wide × 1 m long × 1.5 m high. It requires a workspace of 9 m² to provide room for mobility.

The first operation is cross-cutting the culm to the desired length. During this process, the culm is held firmly by a canvas belt connected to a foot-lever mechanism. The machine has an adjustable stopper to determine the desired length. For the second operation—removing knots—culm-feeding is re-oriented by 90°, the culm is held firmly by a hand lever and the outer knots are removed using the same cutting blade.

The third operation is cutting the culm into splits. The cleaned culm passes through double circular cutters. The cutters can be adjusted to attain split widths of 20, 25 and 30 mm. The machine can process culms as small as 50 mm to as large as 158 mm in diameter of any length.

The fourth operation is to cut the splits to the desired thickness. The bamboo splits are fed automatically to double circular cutters set 10 mm apart to produce a uniform thickness in one pass. This operation can produce uniform thickness of splits of any length.

The fifth operation is to cut the splits to the desired length of the tiles. Ten splits can be fed to the cutter in one pass. An adjustable stopper is set to hold the splits to be cut to the desired length of tile. The schematic diagram of the different operations is shown in Figure 1.

Table 1. Mechanical properties of *Bambusa blumeana* (kayawan tinik) used in the test operation of the bamboo tile-making machine compared with various woody species

Species ^a	Strength group	Moisture (%)	Relative density (g/cm ³)	Static bending ^b			Compression parallel to grain MCS ^c (MPa)		Shear parallel to grain (MPa)	
				MOR(MPa)	SPL (MPa)	MOE (GPa)	Internode	Node	Internode	Node
<i>B. blumeana</i> culm butt d		12	0.57	88.9	41.9	9.7	39.9	38.4	2.4	2.3
<i>B. blumeana</i> , mid section ^d		11	0.63	59.2	30.8	9.9	44.9	41.1	1.8	3.1
<i>Chloroxylon swieteniae</i>	High	Green	0.74	100.0	69.5	14.0	55.9		12.8	
<i>Acacia magnum</i> ^e	Medium-high	Green	0.61	64.6	39.2	10.8	30.2		8.6	
<i>Acacia crassicarpa</i> ^e	Medium	Green	0.62	74.4	42.4	11.3	23.8		8.4	
<i>Acacia cincinnata</i> ^e	Medium	Green	0.64	60.2	32.2	9.6	27.2		9.4	
<i>Swietenia macrophylla</i> ^e	Medium	12	0.55	74.4	47.7	8.9	45.2		—	

^a Location of growth in the Philippines: *B. blumeana*—Mabalang, Batac, Ilocos Norte, Region 1; *C. swietenia* and *S. macrophylla*—Makiling, Calamba, Laguna, Region 4A; *Acacia* spp., Agusan del Sur, Region 13

^b MOR = modulus of rupture; SPL = stress at proportional limit; MOE = modulus of elasticity

^c MSC = maximum crushing strength

^d Source: Alipon et al. (2001)

^e Source: Alipon et al. (1998)

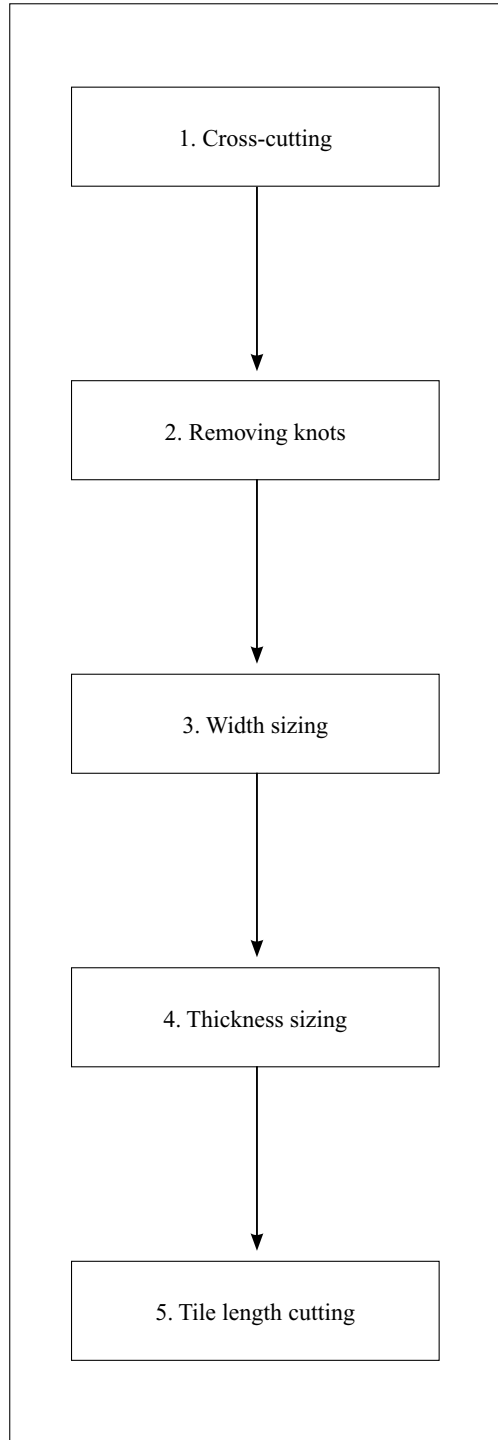


Figure 1. Steps in bamboo tile production using the five-in-one tile-making machine

Performance of the tile-maker

Production time

The tile production performance was evaluated in nine batches with an increment of 10 culms per batch. In the first batch, 10 cylindrical bamboo culms were processed. Five operations were performed in succession: cross-cutting, removing outer knots, width sizing (25 mm), thickness sizing (10 mm) and tile length cutting (100 mm). After the width-sizing operation, some slats were not completely separated from each other and this had to be completed manually. The motor and belts were shifted after each of the five machine operations. The time taken for each operation and shifting of motors and belts was noted. The number of splits and tiles made was counted. In the second batch, the same process was done as in the first batch except that 20 pieces of culm were processed. The number of culms was increased by 10 until it reached 80 culms in the eighth batch, then 100 culms were processed in the ninth batch. All culms had diameters in the 90–130 mm range and were cut to 220 mm long.

The total operation time for the first batch (10 culms) was 33.4 minutes. For this batch, 39 splits of 220 mm long were made. Cutting these splits into 100 mm lengths yielded 63 pieces of acceptable 100 mm long tiles; 15 pieces did not pass the lower quality limit, and were rejected. Hence for this trial, the production rate was 31.8 seconds per tile. Results for all nine batches are shown in Table 2. There were no significant differences between batches, thus the time taken to produce a tile was not significantly

affected by the number of culms per batch. However, the trend was for a decrease in processing time per tile as the size of the batch increased to a minimum in the ninth batch of 25.2 seconds per tile.

A comparison of production performance output was also made between processing whole butt and bamboo splits. Diameters of culm samples used were in the 71–80 mm range and they were 215 mm long. In the whole butt process, 20 pieces were used and the same processes applied as in the previous section. The same number was used for the bamboo splits process. After cutting the culms to 215 mm in length, the culms were split into four or five equal parts using a manual splitting machine. After this, the splits were processed through the tile-maker's width sizer, thickness sizer and finally the tile cutter. Test results are shown in Table 3. The total production time was 29.9 minutes for the whole butt process and 65.4 minutes in the bamboo splits process. The latter process required more time because more operations were involved. However, it yielded a higher recovery of tiles, 68.8%, compared to 64.8% in the whole butt process. The production output of the machine was significantly affected by culm type. Processing of whole butts required 25.6 seconds per tile while splitting the culms by splitter machine before feeding to the sizer of the tile-maker consumed 24.4 seconds per tile, which is even faster than 25.2 seconds per tile in Table 2. Furthermore, in the whole butt process, 12.3 m length of butt was required to produce 1 m² tiles compared to 9.6 m with the bamboo splits. The processing speed can be increased further as the operator becomes more skilled.

Table 2. Time taken for the various operations of the bamboo tile-making machine by batch

Operation	Time taken/batch (minutes)								
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Cross-cutting	4.5	6.0	9.8	12.1	16.2	19.6	23.4	27.1	34.6
Removing knots	4.4	7.5	10.6	15.0	18.1	18.4	20.1	21.8	25.2
Width sizing	7.2	15.8	22.0	31.5	38.2	44.0	50.2	56.4	68.8
Separating splits	4.1	9.1	12.2	18.2	21.8	24.4	27.5	30.6	36.8
Thickness sizing	4.8	10.3	15.9	20.5	24.7	27.8	31.4	35.1	42.4
Motor and belt shifting	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
Tile length cutting	4.1	8.6	13.0	16.3	20.2	24.0	27.8	31.6	39.3
Total operation time	33.4	61.6	87.8	117.9	143.5	162.5	184.7	206.9	251.4
Output									
Number of splits	39	68	114	136	252	298	344	390	482
Number of tiles	63	125	183	250	311	366	424	482	598
Production time (minutes per tile)	0.53	0.49	0.48	0.47	0.46	0.44	0.44	0.43	0.42
Production time (seconds per tile)	31.8	29.6	28.8	28.3	27.7	26.6	26.1	25.8	25.2

Table 3. Time taken for the various operations of the bamboo tile-making machine in processing whole bamboo butt and bamboo splits into tiles

Particulars	Whole butt	Bamboo splits
Materials		
Culm diameter (mm)	71–80	71–80
Tile size (mm)	25 × 100 × 10	25 × 215 × 10
Operations (minutes)		
Cross-cutting	1.6	2.9
Removing knots	3.3	5.9
Culm splitting	–	8.0
Width sizing	10.2	20.0
Cleaning and separating splits	5.0	6.1
Thickness cutting	6.0	13.8
Tile cutting	3.8	8.7
Total production time	29.9	65.4
Potential no. of tiles	108	234
Actual no. of tiles made	70	161
Percentage conversion (%)	64.8	68.8
Production time (s/tile)	25.6	24.4
Required no. of tiles/m ²	400	400
Production time (hours/m ²)	2.84	2.71
Required culms (m/m ²)	12.29	9.61
Area of tile produced/day (m ² /day)	2.81	2.96

Machine precision

The precision of the machine was evaluated using 50 sample tiles per width size (20, 25 and 30 mm) in five trials of ten tiles per trial. The precision was determined by counting the number of tiles that fell below the lower quality limit considered as rejects as determined by the formula: average width minus standard deviation. The cutting precision of the machine ranged from 86% to 92% (Table 4) but was not significantly affected by the size of the tiles.

Culm conversion to tiles

The percentage conversion of culm butts and splits into tiles is shown in Table 5. If culms were split (either manually or with a splitter machine) before

being fed into the width sizer, significantly more tiles were produced than if unsplit culms were used (68.8% compared to 64.8%, respectively). In addition, smaller diameter culms of 60–70 mm and 71–80 mm had significantly lower recoveries of 63.0% and 64.8%, respectively, compared to the bigger diameter culms of 81–90 mm (67.2%) (Table 5). The percentage conversion shows the actual number of tiles made compared to the potential. The potential number of tiles is the surface area of the round culm at 1 cm deep from the outer skin divided by the area per tile.

Table 4. Number of rejected tiles, actual width of tiles and precision of the bamboo tile-making machine in cutting 50 tiles per width size

Tile size (mm)	Actual width (mm)	No. of rejected tiles	Precision (%)
20 × 10	19.44	5	90
25 × 10	25.67	4	92
30 × 10	29.97	7	86
Coefficient of variation			6.5

Table 5. Percentage conversion of culms by the bamboo tile-making machine as affected by the type of raw materials and diameter of culms

Treatment	Percentage conversion ^A
Type of material	
Whole bamboo butt	64.8 b
Bamboo splits	68.8 a
Diameter of culms (mm)	
60–70	63.0 b
71–80	64.8 b
81–90	67.2 a
Coefficient of variation	3.4

^A Means marked with same letter in each group are not significantly different from each other using Duncan's multiple range test

Cost of fabrication and projected rate of return

The fabrication cost, production cost and rate of return on the bamboo tile-making machine are shown in Table 6. The cost of fabricating the tile-maker is US\$538.46 based on the exchange rate of US\$1 to PHP52. The machine is assumed to operate for 8 hours/day. Based on the processing speed, it takes 25.6 seconds to produce one tile of 25 mm × 100 mm × 10 mm from a whole bamboo butt and

24.4 seconds per tile from bamboo splits (Table 3). The added costs are the following: electricity, \$0.43; opportunity cost of capital, \$0.40; machine depreciation cost, \$0.11; repair and maintenance cost, \$0.36; labour cost, \$3.84/day; cost of bamboo materials, \$3.19 for whole butt and \$2.78 bamboo splits. The gross income from processing whole bamboo butt is \$9.57 with total input of \$7.97. The net income is \$1.60 while the net income from processing bamboo splits is \$2.11, higher by 31.88%. Likewise, the rate of return is 16.94% for whole butt operation and 23.35% for processing bamboo splits into tiles. It takes longer, from 255 days to 337 days, to attain break-even for processing the whole butt than splitting before passing through the tile sizers. The break-even output for whole butt is 990 m² while bamboo splits attain break-even output after producing 755 m².

Conclusion and recommendation

The design and fabrication of the bamboo tile-making machine is another innovation for the bamboo industry in the Philippines. It brings bright prospects for the improved utilisation of bamboo as a construction and architectural material in addition to its use in the furniture and handicraft industries. The machine facilitates the processing of bamboo into tiles for flooring, parquet, panelling and various uses in

Table 6. Partial cost and return analysis in US\$ of one bamboo tile-making machine in processing splits and butts for tile production

Particulars	Whole butt	Bamboo splits	Percentage increase/decrease
Machine cost	538.46	538.46	
Variable costs (US\$/day)			
Bamboo butts/splits	3.19	2.78	-12.85
Labour	3.84	3.84	
Fixed costs (US\$/day)			
Electricity	0.43	0.43	
Opportunity cost	0.04	0.04	
Depreciation	0.11	0.11	
Repair and maintenance	0.36	0.36	
Total input cost (US\$/day)	7.97	7.56	-5.14
Gross income (US\$/day)	9.57	9.67	+1.03
Net income (US\$/day)	1.60	2.11	+31.88
Rate of return (%)	16.94	23.35	+37.86
Break-even point (days)	337	255	-24.17
Break-even output (m ²)	990	755	-23.74

furniture and handicraft manufacture. The butt portion of bamboo, which in *B. blumeana* (kawayan tinik) and *Dendrocalamus asper* (giant bamboo) usually comprises 30% of the culm, can now be processed into beautiful, high-quality tiles, which have a natural appearance and soft colour that add an ambience of coolness in summer. Another step in quality assurance for bamboo products is ensuring that culms are properly dried before processing.

Currently, the machine is designed for village operations and it is recommended for pilot-testing with furniture manufacturers and in areas with sufficient bamboo stands. In parallel to the production of bamboo tiles as product components in the building construction, it is recommended that the concept of using tiles be introduced to architects as they consider their materials for the construction industry.

The bamboo tile is an engineered construction material. It is a versatile, eco-friendly material that it can be architecturally designed to suit an individual's specifications. In this regard, the tile-making machine and other bamboo technologies are the key to the promotion of bamboo as a valuable renewable resource.

Acknowledgments

We thank Professor David Midmore of Central Queensland University for his encouragement and advice in the preparation of this paper, and the Australian Centre for International Agricultural Research (ACIAR) for funding part of this research through ACIAR Project No. HORT/2000/127.

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