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

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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

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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.

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[1]

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[1]

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 that 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

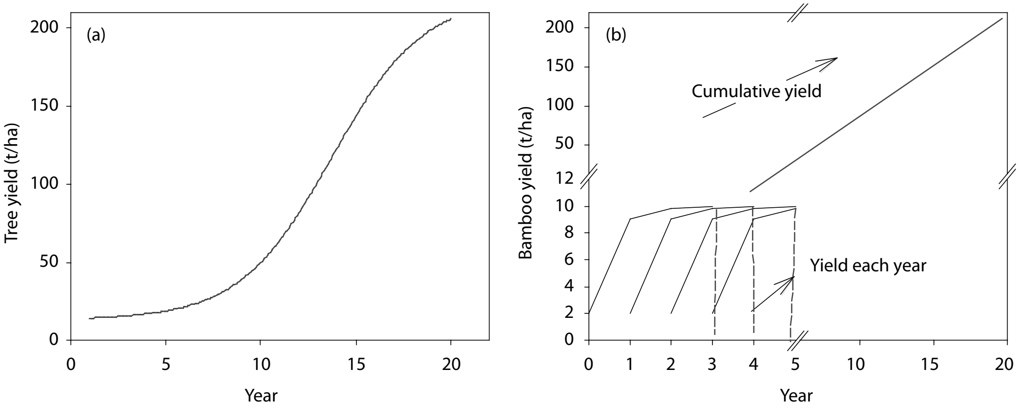

Figure 1. Comparative analysis of (a) one-off harvest of tree trunks at 20 years and (b) annual harvests of culms from bamboo.

- 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[1]

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 bambuseta (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)
Bambusa	
B. bambos	Burma, Cambodia, China, Indonesia, Laos, Malaysia, Philippines, Taiwan, Thailand, Vietnam
B. blumeana	China, Cambodia, Indonesia, Laos, Malaysia, Philippines, Thailand, Vietnam
B. oldhamii	Australia, China, Philippines, Taiwan
B. species 1 *(D. merrillianus)*	Philippines (endemic)
Dendrocalamus	
D. asper	Australia, China, Indonesia, Malaysia, Philippines, Sri Lanka, Thailand
D. latiflorus	Australia, Burma, China, Indonesia, Japan, Philippines, Taiwan, Thailand, Vietnam
Gigantochloa	
G. atter	Australia, Brunei, Indonesia, Malaysia, Philippines
G. levis	Indonesia, Malaysia, Philippines
Thyrsostachys	
T. siamensis	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.

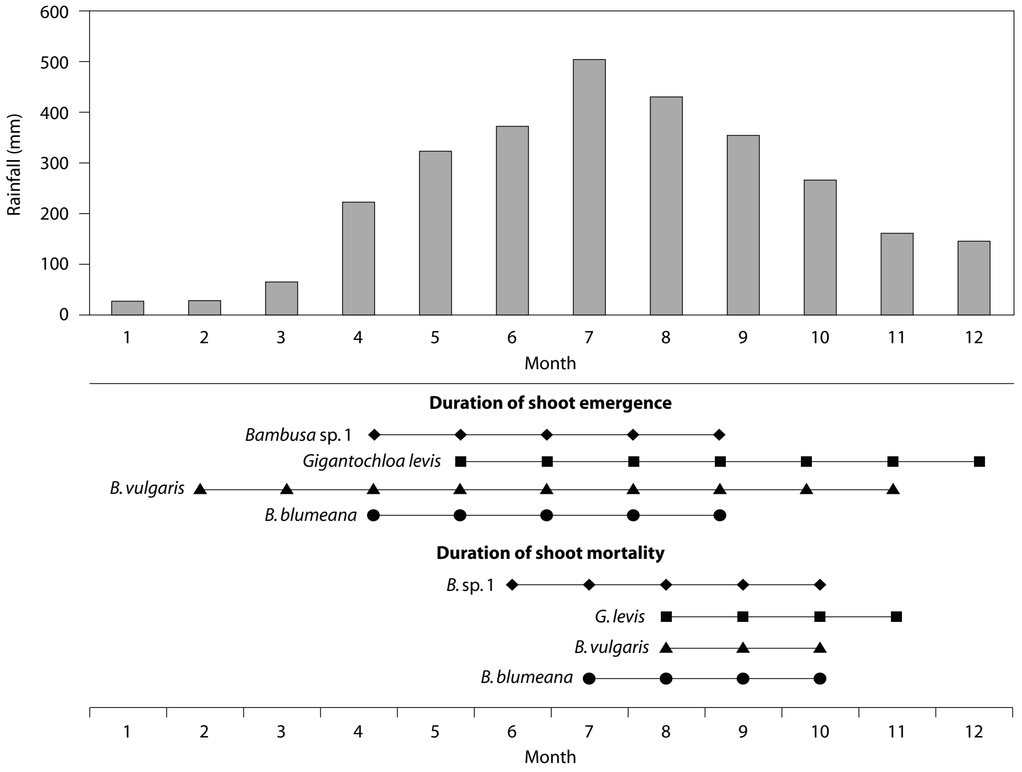

Figure 1. Average monthly rainfall (1996–2000) and duration of shoot emergence and mortality occurrence for four bamboo species in a pilot plantation of bamboo in Pampanga province, Central Luzon (Source: Virtucio and Roxas 2003)

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 area covered by permit × number of clumps per hectare × 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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Improving productivity of a previously unmanaged *Bambusa blumeana* plantation for culms and shoots in Ilocos Norte, the Philippines

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Abstract

The productivity of a previously unmanaged *Bambusa blumeana* (kawayan tinik) plantation was assessed over 5 years. We studied the combined effects of cleaning, irrigation, application of inorganic fertiliser, mulch and organic matter, and varying culm density regimes on the production of good-quality culms (poles) and shoots.

Generally, irrigation significantly improved the productivity index, shoot emergence and number of shoots per clump. The average shoot production of six shoots per clump from all treatments is within the range of shoot production of *B. blumeana* in areas with distinct dry and wet seasons. The clumps that received irrigation during the shoot stage had culms with a significantly larger diameter than those without irrigation. The older culms (3 and 4 years) produced far fewer shoots than the younger ones, hence it is better to harvest these culms for pole production rather than rely on them for shoot production. The combined effect of the various silvicultural operations with three, four, or six culms per age group was not consistent for growth response, but the quality of culms in the clumps with 16 culms per clump (four culms of each age group; 1, 2, 3 and 4 years) produced the highest number of culms and most superior strength properties. Extending the age of the culms from 3 years to 4 years improved their physical properties appropriate for construction purposes.

Overall, this study provided a strategy by which it is possible to predict productivity of *B. blumeana* clumps in terms of both culms and shoots by retaining specific numbers of different-aged culms. Combined with other silvicultural treatments, this should allow both natural stands and unmanaged plantations to become productive in a way that is sustainable.

Introduction

There are 62 species of bamboo identified in the Philippines (Rojo et al. 2000) and, of these, 28 are found in the Ilocos Region (Region 1). Intensified interest in bamboos has resulted in their emergence as the best substitute for wood in various applications. There are more than 1,500 listed uses for bamboo in the furniture, handicraft and construction industries, as well as it being a source of food, biofuel and environmental protection. *Bambusa blumeana*, locally known as kawayan or kawayan tinik, dominates the bamboos luxuriantly growing from backyards to hillsides and mountainsides, but with its intensive utilisation, the diminishing supply of high-quality raw materials now threatens the survival of the industry.

Background to the Ilocos Region

The Ilocos Region—comprising the provinces of Ilocos Norte, Ilocos Sur, La Union and Pangasinan—is located on the north-western coast of Luzon island.

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The region is bounded in the west by the South China Sea and in the east by the Central Cordillera mountain range, and has a land area of 12,840 km^2. In 2000, the region's human population was 4,174,100, representing an increase of 8.86% since 1995. Pangasinan had the largest population with 2,178,412 or 57.3%, followed by La Union, Ilocos Sur and Ilocos Norte with 15.7%, 14.3% and 12.7%, respectively.

The region has prime agricultural land planted with important crops such as tobacco, rice and vegetables. A total of 810,062 ha of land, where most of the bamboos are found, is classified as alienable and disposable, while the forestland covers 473,957 ha.

The bamboo industry in Ilocos

Of the different bamboo species that abundantly grow in the Ilocos Region, only three genera are economically important: *Bambusa, Dendrocalamus* and *Schizostachyum*. Species in these genera are prized for their multiple uses, primarily for low-cost house construction, soil and stream bank protection, furniture, handicrafts and food (shoots). Most furniture and handicraft products are locally sold but some are taken to neighbouring provinces and to Manila. Very small volumes are exported to the United States of America and Europe. Edible shoots are sold in local marketplaces and consumed at the household level. There is a formal marketing system for culms but not for shoots, which are harvested in quantities that supply local demand. Shoots are harvested only at the start of the rainy season as no new shoots emerge during the start of the dry season, a time when other vegetables are also in short supply. There is a strong indication that poor management practices may have contributed to the low production of culms and shoots (Virtucio and Roxas 2003).

The bamboo industry in the region is considered traditional but continues to expand as it provides income and generates employment for farmers, stand-owners and bamboo traders in the countryside. Farmers harvest culms and shoots from natural stands, which are basically left in their wild state. A study in the Ilocos Region in 1996 showed an average price of PHP51/culm and total sales during the year amounting to PHP22.012 million (Battad et al. 2000). *B. blumeana* culms are taken to Bulacan (78%), Pampanga (14%), Tarlac (1%) and Rizal (1%) (all provinces in other regions) mainly for furniture manufacture. The remaining 6% are used locally for domestic purposes such as house construction and repair, trellises for fruits and vegetables, and for the fishing industry. At current prices, the aggregate of Ilocos Region figures could be staggeringly high. But in 2005, the price of culms delivered to the E-kawayan Processing Center in Ilocos Norte ranged from PHP75 to PHP90 depending on their diameter, and provided that they were at least 6 m long (Malab and Zafaralla 2005).

The *B. bambusa* (kawayan) industry in the region generates employment and income for stand-owners, shipper-traders and their agents, loaders and unloaders, freight truck owners and drivers, processors, ambulant vendors, store-owners and sales persons. Kawayan shipper-traders operating in the region number 111 and are assisted by 58 shippers' agents. Of the 309 stand-owners interviewed in 2000 (Battad et al. 2000), 187 sold stumps and culms.

Processors use *B. blumeana* culms to make three types of products: furniture, handicrafts and baskets. The processors may either be primary or secondary processors or both. Primary processors are those who make *B. blumeana* poles, splits and strips of different sizes for the manufacture of sawali (bamboo mats), handicrafts and baskets, including backpacks, kaing (carriers) and hampers. The primary processors either sell their products or are contracted by the secondary processors who make finished products such as lampshades and wall decorations. In some instances, primary processing is done by hired workers in the shops of secondary processors.

Bamboo resources in Ilocos

Most of the species of bamboo with commercial value are found along the coastlines of the four provinces of the Ilocos Region. The preferred sources of raw materials are commercial bamboo plantations but there are not enough to supply the demand of various industries. In 2000, there were only an estimated 1,748 ha of commerical bamboo plantations, which consisted of four major species. Intra-regional demand greatly outstrips supply, with the regional self-sufficiency rating for *B. blumeana* at only 32% (Virtucio and Roxas 2003). However, the data of Virtucio and Roxas most likely only considered supply from the plantations, and did not include supply from farmers' own smallholdings. Large areas of bamboo plantations need to be established to supply the increasing demand for culms and shoots (Malab et al. 1999; Battad et al. 2000). As an example, Pangasinan cannot supply enough bamboo for its more than 1,000 primary processors, and currently sells only 14% of its raw material production to other provinces. New plantations should be established to increase that share, as well as provide adequate bamboo resources to local processors.

Another logical source from which to harvest more bamboo are the natural stands of *B. blumeana* that are found all over the provinces of the Ilocos Region and in other areas of the Philippines. These natural stands are a ready source of raw materials if properly managed. They require only a short time and less investment than newly established plantations before returning profits.

Better resource use and, in particular, appropriate silvicultural practices need to be given top priority to meet the current and projected demand for raw materials and products.

Ensuring sustainable production

Currently, due to the high demand for bamboo raw materials for a variety of uses, existing bamboo stands are overexploited and there are limited replanting and rehabilitation activities. Hence, more people need to be encouraged to engage in a sustainable bamboo production industry to meet the supply and demand for bamboo (Virtucio and Roxas 2003).

There is no decisive policy regulating the utilisation of bamboo in the Ilocos Region. It is estimated that 303,160 natural clumps of *B. blumeana* are exploited every year with a minimum of four culms harvested from each. However, in Ilocos Norte, some municipalities promulgated and enacted an ordinance pertaining to control the harvesting of bamboo shoots and culms. For example, in Batac, Ilocos Norte, where the current study was located, cutting, harvesting or gathering bamboo shoots by any means except for research purposes is prohibited in natural stands.

The current study

Considering the conditions and requirements discussed above, the current research was conducted within the framework of the Australian Centre for International Agricultural Research (ACIAR) and the Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD) project entitled *Improving and maintaining productivity of bamboo for quality timber and shoots in Australia and the Philippines* (ACIAR Project No. HORT/2000/127). The objective of the study in Ilocos Norte was to identify optimal clump management protocols that result in improved productivity of an unmanaged *B. bambusa* plantation.

Location of the study

The study was conducted in Ilocos Norte. This province is located between latitudes 17°48′ and 18°29′ north and longitudes 120°25′ and 120°58′ east, occupying the coastal plain in the north-western corner of Luzon. It is bounded in the east by the provinces of Cagayan (Cagayan Valley Region), and Kalinga and Apayao (Cordillera Administrative Region; CAR), in the south-east by Abra (CAR), in the south by Ilocos Sur, and in the west by the South China Sea. Ilocos Norte is a second-class province. It is made up of one city, 22 municipalities and 557 barangays (villages). The present seat of government of the province is located at Laoag City, which is approximately 487 km north of Manila. In general, the province is rugged and rocky with mountains that run from the north-west to the Cordilleras in the east.

Ilocos Norte has a type 1 climate characterised by two pronounced seasons, wet and dry. The dry season lasts from October to May and the wet season from June to September. Rainfall in Ilocos Norte is principally brought about by the south-west monsoon. Tropical cyclones and thunderstorms also contribute to the rainfall received in the province. The average annual rainfall is 1,500 mm, 85% of which falls during July and August.

Characteristics of B. blumeana

Bambusa blumeana is native to the Philippines and has a leafy branchlet with an enlarged top portion beset with thorns. The base of the clump is densely set with seemingly impenetrable spiny branches and branchlets. The spiny branches hold the plant firmly during strong winds, preventing the culms (poles) from lodging. The culm is almost solid at the base and thick-walled to the middle portion and can reach a diameter of 15 cm. The internodes range from 5 cm long at the base to about 35 cm at the middle and top portions of the pole. A robust culm can reach 20 m long. *B. blumeana* is one of the seven major species recommended for shoot production in Yunan, China, and is still considered as the best species for shoots in the Philippines (Rojo 1999). As a grass, it regenerates faster than wood, has a very short growth cycle, and can be harvested 4 years after planting.

Materials and methods

The experimental site was established in 2001 in an unmanaged plantation located at the experimental site of the Mariano Marcos State University (MMSU) in Batac, Ilocos Norte, and planted at 204 clumps/ha. The experimental plantation was originally set up in 1992 to demonstrate strategies for bamboo plantation establishment. Various studies on watershed management had also been conducted at the site.

Data on the soil were obtained during the current experiment. The site has soil with pH ranging from 7.0–7.3, organic matter of 0.86–1.2%, phosphorus content of 288–339 parts per million (ppm) and potassium content of 91–135 ppm. Rainfall was quite high in 2001, reaching 2,500 mm as a result of two strong typhoons that occurred in July and September. Total rainfall data recorded during the other years of the study were 1,852 mm in 2002, 1,760 mm in 2003, 2,016 mm in 2004, 1,734 mm in 2005 and 1,984 mm in 2006.

Plant material and experimental treatments

In the unmanaged plantation of *Bambusa blumeana*, 13 treatments were established in May 2001. Each plot comprised two clumps, replicated in three blocks. A summary of each treatment is provided in Table 1. Factors under investigation included use of irrigation, application of fertiliser organic matter and mulch, number of culms of different ages retained in a clump (standing culm density; SCD) and annual clump cleaning. Details of these factors are given below.

Plantation management

Seventy-eight clumps were chosen. The diameter and age of each culm were measured for uniformity testing and all but treatment 13 (T13) were 'cleaned'. Cleaning the clumps involved removing all culms older than 4 years plus any other culms that were dead, broken or defective (e.g. rotting or eaten by rats when young), and removing low, spiny branches from retained culms. Clump cleaning improved the workability of clumps and provided more space for emerging shoots and growing culms. It also facilitated future activities, such as harvesting shoots and culms. Clumps were then cleaned annually (except for T13) throughout the trial.

Analysis of variance (ANOVA) and analysis of covariance (ANOCOVA) statistical analysis methods were used to verify a priori differences in culm diameter. The diameter readings for all the standing culms for each age class in all plots were not significantly different from each other.

Table 1. Summary of experimental treatments on a previously unmanaged *Bambusa blumeana* plantation in Batac, Ilocos Norte[a]

Treatment	Irrigation supplied?	Fertiliser applied?	Organic matter applied?	Mulched?	Standing culm density[b]
T1	Continuous	Yes	Yes	Yes	4-4-4 (12 culms)
T2	No	Yes	Yes	Yes	4-4-4
T3	Strategic[c]	Yes	Yes	Yes	4-4-4
T4	Continuous	No	No	Yes	4-4-4
T5	Continuous	No	No	No	4-4-4
T6	Continuous	Yes	Yes	Yes	3-3-3 (9 culms)
T7	Continuous	Yes	Yes	Yes	3-3-3-3 (12 culms)
T8	Continuous	Yes	Yes	Yes	4-4-4-4 (16 culms)
T9	Continuous	Yes	Yes	Yes	Keep all younger, but harvest 3-year-old culms
T10	Continuous	Yes	Yes	Yes	3-3 (6 culms)
T11	Continuous	Yes	Yes	Yes	8 per 2-year cycle (4-4 for first year)
T12	No	Yes	Yes	Yes	No harvesting, cleaning only
T13	No	No	No	No	No harvesting

[a] All treatments except for T13 received annual clump cleaning

[b] Successive numbers indicate how many culms of each age group are retained each year, with thinning taking place just before the shoot season, e.g. 4-4-4 means four 1-year-old, four 2-year-old and four 3-year-old culms.

[c] Just before shoot season

Fertiliser, organic matter and mulch

Fertiliser treatments comprised 250 kg nitrogen (N)/ha, where N = potassium (K), split into two applications—the first at the onset of the rainy season and the second 2 months after the first. The treatments requiring organic matter received 0.2 m^3 of chicken manure and 0.4 m^3 of sawdust annually per clump, applied before the rainy season. Mulch was collected from the accumulated bamboo leaves and other debris that could be found around the clump. The 78 treatment plots were arranged in a randomised complete block design. Before the application of treatments, soil and leaf samples were collected from each treatment plot. Soil samples were taken from soil depths of 0–12 cm and 12–25 cm to derive relationships for nutrient-sufficiency levels.

Irrigation

A drip-irrigation system was installed in December 2001 but its use was discontinued in April 2002 due to very low water pressure from the source. To continue the irrigation treatments, watering was done through a centrifugal pump drawing water from a nearby creek bed; pumping and distributing the water over the surface of irrigation plots through a 3.73 cm polyvinyl chloride (PVC) pipe. Irrigation treatments were stopped in April 2003 before the shoot season and discontinued thereafter due to water shortage at the site.

Harvesting

During the shoot season, shoots that emerged were recorded. Shoots that were intended to remain for that year were marked and their height and diameter measured. Those to be harvested were cut. Selections for new culms were made in the middle of the shoot season and at least one good-sized shoot was left at the middle and at the edge of each clump.

Culms were harvested in April each year, according to the treatment designations. Culm length and diameter at 1.25 m from the base were recorded. Culms were sent to the Forest Products Research and Development Institute (FPRDI) for in-depth analyses (see Alipon et al. 2009). In 2002 and 2005, data were also collected on the origin of shoots with respect to the age of the standing (mother) culms for all treatments. A certain amount of digging into the soil was necessary to follow the rhizome to be certain where each shoot originated.

Quality testing

Mature culms were harvested every year from 2003 to 2006. The culms were tested for physical and chemical properties as a separate study under the same research project at the FPRDI, Los Baños, Laguna (see Alipon et al. 2009). Separate testing on the density of culms was conducted at MMSU during the fifth year (2006) of the experiment. The culms harvested during the 2004 season were subjected to kiln-drying using the MMSU bamboo kiln dryer (Zafaralla and Malab 2003). The culms were air-dried for 10 days and placed in the kiln for 5 days to determine the effect of the treatments on the moisture content and drying time. The moisture content was determined using the FPRDI's wood/bamboo moisture meter.

Data analysis

All sets of data in the unmanaged plantation were analysed as a single-factor experiment ($n = 13$) with ANOVA, and means separated with least significant difference (LSD) test ($P = 0.05$). Data were analysed with Systat 11 (Systat Software Inc. 2004, San Jose, California, United States of America).

Results

Shoot production and rainfall

Shoot emergence every month was observed from 10 months after initial treatment set-up. Table 2 shows the trend in monthly shoot production in relation to rainfall for two representative years, 2002 and 2003. Variable peaks in the monthly production of shoots were found across years. There were two peak months of shoot production during the first year (2002). The first rain in 2002 was in February, which is unseasonal. There was virtually no rain in March or April but shoot emergence was substantial in April. Rain was heavy in May, a little lighter in June and heaviest in July when emergence was very low. Rainfall was lower in August but increased in September and shoot emergence peaked again in October. The high shoot emergence in April may have been caused by the unseasonal rain in February and the irrigation treatments that began in December 2001. In the following year (2003), the trend followed the expected pattern of shoot emergence, i.e. with maximum shoot production coinciding with the first part of the rainy season (Table 2). Rainfall started in May and increased in June, while shoot emergence was at its maximum in June through July. No more shoots emerged after this peak.

Table 2. Monthly rainfall and total shoots emerged across all treatments, 2002 and 2003

Month	2002		2003	
	Rainfall (mm)	No. of shoots	Rainfall (mm)	No. of shoots
January	0.0	0	3.9	0
February	14.6	0	0.0	0
March	1.0	4	0.0	0
April	0.0	87	14.0	0
May	351.2	3	304.6	58
June	211.2	2	486.5	142
July	854.6	7	128.0	142
August	136.0	5	522.5	0
September	180.4	49	240.4	0
October	90.0	80	10.0	0
November	13.4	0	50.0	0
December	0.0	0	0.0	0
Total	1,852.4	237	1,759.9	342

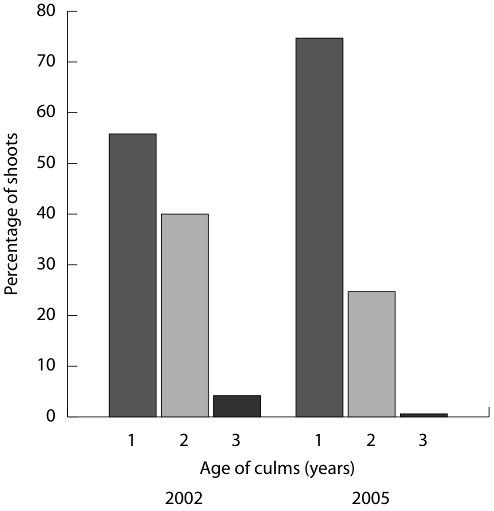

Figure 1. Percentage of shoots emerging from mother culms of different ages in 2002 and 2005. Note: Differences between bars in each year are significantly different at the 1% level.

Effect of culm age on shoot production

This parameter was measured only twice—at the start and close to the end of the experiment (Figure 1). In 2002, 55.8% of shoots were produced by the 1-year-old mother culms, while the 2-year-old and 3-year-old culms produced significantly fewer shoots—40.0% and 4.2%, respectively. In 2005, the same trend was noted but 74.7% of the shoots were produced by 1-year-old mother culms, only 24.7% by the 2-year-old culms, while almost none (0.6%) by the 3-year-old culms. Across treatments in 2005, significant differences in the numbers of shoots produced were observed in only 2-year-old mother culms: T8 and T9 (see Table 1 for treatment details) yielded significantly higher numbers of shoots (Figure 2).

Shoot emergence

Table 3 shows the average number of shoots that emerged per clump per treatment in all years. No consistently significant improvement in shoot emergence was observed. Nevertheless, during 2002 and 2003 the clumps that received irrigation generally produced more shoots than those that did not (Table 3). Those treatments that did not receive irrigation (T2, T12 and T13) produced significantly fewer shoots during 2003 (as did T2 and T13 also in 2002), although three irrigated treatments—T4, T5 and T6, two of which did not receive fertiliser—also had fewer shoots than the control (T1). After all irrigation treatments were stopped in 2003, no significant differences were observed among all treatments. The combination of cleaning, mulch and fertiliser application, but without irrigation, did not improve shoot production over the ‘do nothing’ treatment (T12 versus T13). Further, fertiliser application without irrigation had a negative effect on shoot production (T2 and T12). Not harvesting shoots or culms in T12 probably also negatively affected shoot production due to overcrowding.

Clump productivity index

Clump productiveness was measured as the productivity index (PI), which was calculated as the number of shoots that emerged in each clump divided by the total number of culms in each clump. The PI was greater than 1.0 when, on average, one culm produced more than one shoot. Irrigation together with fertiliser application generally improved the PI of the clumps (Table 4). Fertiliser application without irrigation had a negative effect on PI of the clumps (T2 and T12). In 2006, 2 years after irrigation treatments were stopped, the PI did not differ significantly between treatments (Table 4). Nevertheless, it is noteworthy that the PIs of T12 and T13 were markedly lower than that of the control (T1), most likely due to the large number of non-harvested culms that had accumulated in T12 and T13.

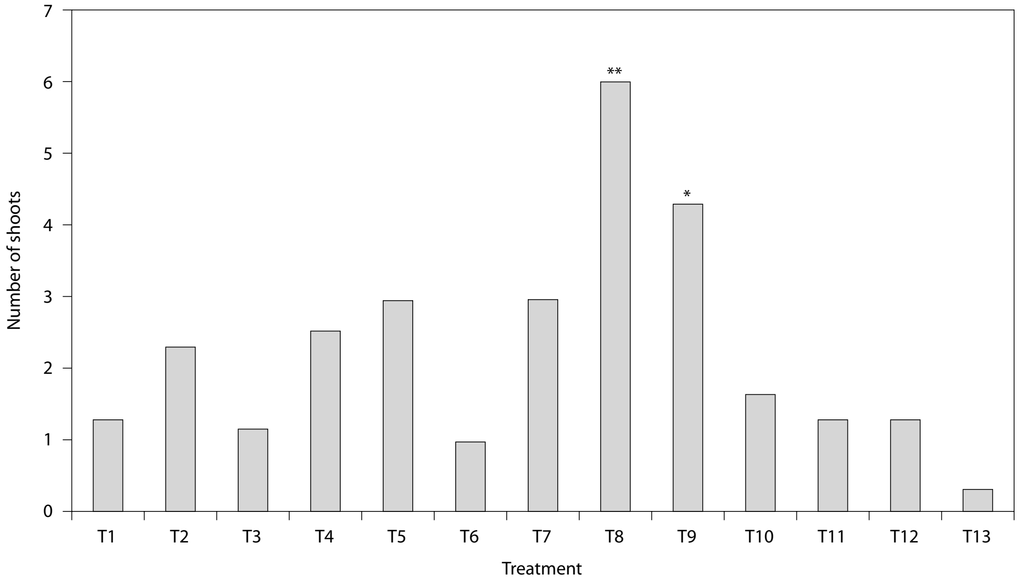

Figure 2. Effects of silvicultural treatments on the number of shoots that emerged from 2-year-old culms sampled in 2005. Note: see Table 1 for treatment details; bars marked ** and * are significant at the 1% level and 5% level, respectively, compared to the control (T1), using the least significant difference (LSD) test.

Table 3. Number of new shoots produced per clump per year as affected by silvicultural treatments[a]

Treatment[b]	2002	2003	2004	2005	2006
T1	5.2	5.3	7.8	4.8	6.3
T2	2.8*	3.3*	5.0	4.0	3.7
T3	3.2	4.5	5.5	8.6	8.0
T4	2.4*	2.8*	6.2	5.0	4.3
T5	4.5	2.6**	5.2	6.8	5.7
T6	4.2	2.8*	4.3	3.8	5.7
T7	3.2	5.0	4.7	7.7	5.6
T8	3.5	5.3	5.5	5.8	6.0
T9	3.7	6.2	4.0	9.0	7.0
T10	4.7	3.8	4.7	7.2	6.0
T11	1.9**	3.6	4.7	7.2	6.0
T12	3.2	3.0*	4.3	5.3	4.3
T13	1.7**	2.8*	4.3	4.2	5.0

[a] Means in each column (year) marked with * are significant at the 5% level and ** are significant at the 1% level compared to the control (T1), using the least significant difference (LSD) test

[b] See Table 1 for treatment details

Table 4. Productivity index[a] as affected by silvicultural treatments[b]

Treatment[c]	2002	2003	2006
T1	0.86	0.90	0.53
T2	0.44*	0.56*	0.31
T3	0.53*	0.75	0.67
T4	0.39*	0.47*	0.36
T5	0.75	0.45*	0.47
T6	0.70	0.94	0.63
T7	0.70	1.09	0.47
T8	0.58	0.95	0.29
T9	0.61	1.03	0.58
T10	0.78	0.65	0.50
T11	0.31**	0.82	0.75
T12	0.25**	0.47*	0.17
T13	0.11**	0.27**	0.17

[a] Productivity index = number of shoots per clump divided by the number of culms in each clump

[b] Means in each column (year) marked with * are significant at the 5% level and ** are significant at the 1% level compared to the control (T1), using the least significant difference (LSD) test

[c] See Table 1 for treatment details

Diameter of standing culms

Culm diameter 30 cm from the base was measured during the fourth year of the experiment (in 2005). Given their emergence timing, the 3- and 4-year-old culms had received the irrigation treatments from December 2001 until April 2003. Generally the culms from the control (T1) had a larger diameter than those in the 'do nothing' treatment (T13) (Table 5). Various combinations of silvicultural treatments gave variable diameter responses. The diameters of the 3- and 4-year-old culms in T2 (no irrigation) were significantly smaller than the culms from the control plots (T1). Interestingly, culm walls in T5 (irrigated, but not supplied with fertiliser, mulch or organic matter) were also significantly thinner than T1, whereas those in T4 were not. The only difference between T4 and T5 was that T4 was mulched. Hence, better soil moisture retention may have contributed to the result. In the 1- and 2-year-old culms, there were no significant differences between any treatments. The application of fertiliser, organic matter, mulch and cleaning the clump without irrigation did not produce bigger diameter culms than those irrigated plus the various silvicultural treatments (T1 versus T12). The treatments with six (T10) or nine (T6) culms per clump that received all silvicultural treatments consistently exceeded the diameter of the 3- and 4-year-old culms in the control but this was not statistically significant.

Culm wall thickness

Bamboo culm walls in all treatments were thicker at the base than at the top (Table 6). Treatments that did not include any culm thinning (T12 and T13) had very significantly thinner culm walls than the control (T1). T11, which had 2-year thinning cycle, also produced culms with significantly thinner walls than T1. Increasing the number of culms per clump from 12 to 16 (T1 and T8, respectively) produced thinner walls at the top of the culm—from an average of 1.51 cm at the top and 2.43 cm at the base (T1) compared to 1.13 cm at the top and 2.02 cm at the base in T8, respectively. The treatment without fertiliser, mulch and organic matter (T5) that led to narrow culm diameter also led to thinner culm walls at the top, as did T10. Although the results were not totally consistent, it appears that overcrowding of culms has a detrimental effect on culm wall thickness.

Table 5. Diameter of standing culms during the fourth year (2005) of the experiment as affected by silvicultural treatments[a]

Treatment[b]	Diameter (cm)			
	1 year old	2 years old	3 years old	4 years old
T1	7.59	8.04	7.17	7.39
T2	7.65	7.15	6.58**	5.99**
T3	7.50	7.90	6.60*	6.69
T4	7.80	7.26	6.86	6.72
T5	7.49	6.91	5.80**	5.72**
T6	7.22	7.35	8.09	7.46
T7	7.37	7.67	6.77*	6.98
T8	7.16	7.18	7.60	6.72
T9	7.28	7.28	7.31	7.32
T10	7.76	7.59	7.95	8.14
T11	7.42	7.49	7.30	7.05
T12	7.37	7.61	6.77*	6.90
T13	7.83	7.67	5.98**	6.40*

[a] Means in each column (year) marked with * are significant at the 5% level and ** are significant at the 1% level compared to the control (T1), using the least significant difference (LSD) test

[b] See Table 1 for treatment details

Table 6. Culm wall thickness of harvested 4-year-old culms as affected by silvicultural treatment[a]

Treatment[b]	Culm wall thickness (cm)	
	Top	Base
T1	1.51	2.43
T2	1.49	2.28
T3	1.36	2.29
T4	1.49	2.45
T5	1.34*	2.23
T6	1.54	2.49
T7	1.61	2.40
T8	1.13**	2.02*
T9	1.39	2.30
T10	1.30*	2.19
T11	1.25*	2.16*
T12	1.11**	2.00**
T13	0.98**	1.98**

[a] Means in each column (year) marked with * are significant at the 5% level and ** are significant at the 1% level compared to the control (T1), using the least significant difference (LSD) test

[b] See Table 1 for treatment details

Calculation of culm and shoot yields

The computation for shoot and culm yield is quite straightforward using the results of this study. Given a 1 ha bamboo plantation spaced at 7 m × 7 m, there will be a total of 204 clumps/ha. In the different combination of treatments, the 4-4-4 is preferred for the manufacture of bamboo tiles because it meets the culm-thickness requirements for processing. The potential harvest of culms is 4 culms per clump or a total harvest of 816 culms/ha/year. Average shoot production in the 4-4-4-4 scheme was 5.2 shoots per clump throughout the experiment. Culm yields, computed from the number of culms harvested per hectare and from the volume/density relationship of individual culms, gave an annual dry culm yield of 10–12 t/ha for the control (T1; the optimally managed treatment) down to 7–8 t/ha for treatments with more standing culms per clump (e.g. T8) or fewer culms harvested per year (e.g. T7). Likewise, the potential number of shoots would be higher in the 4-4-4 and 4-4-4-4 than the 3-3-3 culm density per clump. If four shoots are marked and allowed to grow for the next harvest of culms, two will be left for shoot production. For each hectare, potentially c. 300–400 shoots can be produced for food.

Moisture content and density of kiln-dried culms

The moisture content (MC) of the culms harvested in 2006 (butt and middle portions) that were cut into 2.5 m lengths and kiln-dried was not significantly affected by the various clump treatments. The MC after drying for 5 days in the MMSU bamboo kiln dryer ranged from 31% to 51%, as shown in Figure 3. Likewise, the average density of the culms ranged from 0.3 g/cm^3 to 0.59 g/cm^3 and was not influenced by the treatment combinations. It is important to note, however, that the density of the culms generally increased from the younger to the older culms (Figure 4).

Culm quality testing

The effects of silvicultural management on the basic properties of bamboo were studied at FPRDI by Alipon et al. (2009).

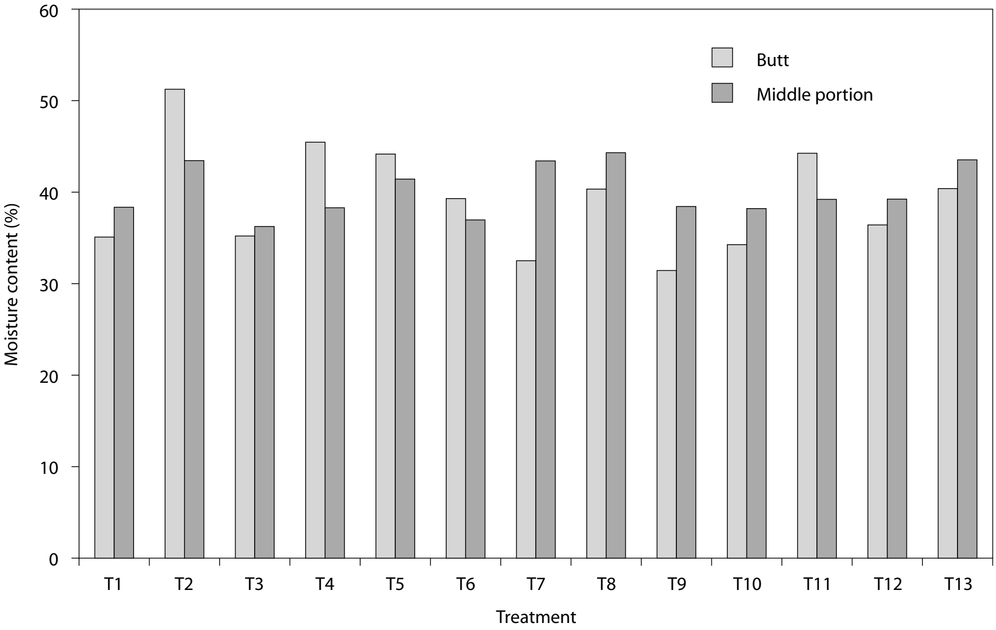

Figure 3. Moisture content of the butt and middle portions of kiln-dried culms harvested in 2006. Note: see Table 1 for treatment details.

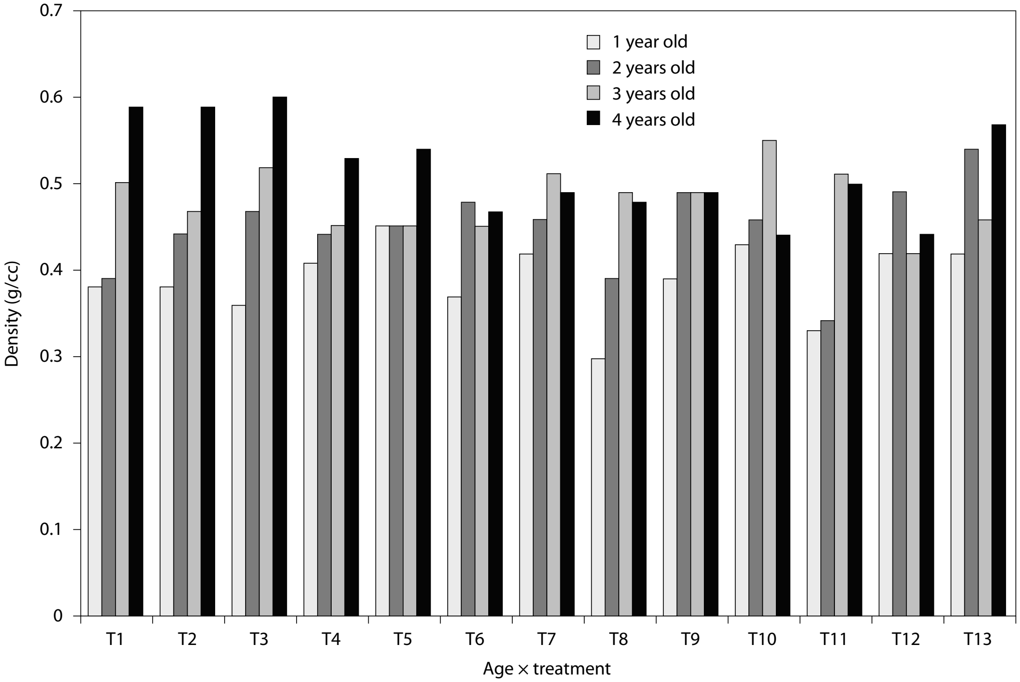

Figure 4. Density of harvested culms by age as affected by silvicultural treatments harvested at one time in 2006. Note: see Table 1 for treatment details.

Discussion

The production of good-quality, improved *B. blumeana* (kawayan tinik) is possible using the results of this project. It is possible to achieve sustainable production and supply of shoots and culms from previously unmanaged bamboo plantations. The application of silvicultural treatments, starting with cleaning and irrigation, indicated that shoot production can be increased and sustained, and the diameter and wall thickness of culms are improved compared to the 'do nothing' clumps (T13).

Optimising production

Shoots

Water availability was apparently very important for the emergence and growth of new shoots. First, it was evident that shoots emerged after the first showers of rain. During the first year of our experiment, unseasonal rain occurred in February 2002, which was still a part of the dry season. No rain followed in March and April, but shoot production was substantial and attained its peak in May. The early rains plus the irrigation treatments probably provided substantial moisture to the soil, which initiated early shoot emergence. Our findings support those of Uchimura (1980) and Fernandez et al. (2003) that bamboo shoots usually emerge during the onset of the rainy season and very few shoots arise during the dry season when soil moisture is at its lowest. The availability of soil moisture and the decrease in temperature during rainy months influenced the emergence of shoots. In general, shoot emergence and its duration are affected by monthly rainfall (Virtucio and Roxas 2003).

Second, cleaning, irrigation and other silvicultural treatments significantly improved shoot emergence and production compared to the 'do nothing' treatments. This observation corroborates the findings of Rosario and Samsam (2004) that cleaning and sanitation cutting, and application of complete fertiliser, improved shoot production and culm production in old *B. blumeana* stands. Omitting fertiliser, mulch and organic matter suppressed shoot production in some years in our study. However, irrigation was also necessary for improved shoot production. As seen in

Table 3, treatments without irrigation (T2 and T13) produced fewer shoots than those with continuous irrigation (T1). Overall in our study, the average shoot production of 5.9 in T1 (the optimally treated clumps) was slightly lower than the 6–7 shoot per clump average production in *B. blumeana* as reported by Virtucio and Roxas (2003).

The age of mother culms is also critical to shoot production. Our findings indicate that 1-year-old mother culms produce significantly higher numbers of shoots every year than older culms, regardless of treatment. The important implication of this observation strengthens our conclusion that it is advantageous to harvest, for whatever purpose, the 3-year-old and older culms of *B. blumeana* rather than keep them for shoot production.

Culms

The influence of silvicultural treatments tested was evident on culm diameter and wall thickness but not on the length (not reported upon) of harvested culms. Diameter differences were clear only in the clumps that received cleaning, irrigation and mulch. Culm wall thickness appears to be influenced primarily by congestion within the clump. Treatments in which no culms were harvested (regardless of cleaning) had significantly thinner-walled culms. No clear trend could be drawn from the various culm densities per clump, except that culm density generally increased with age. Subsequent quality testing indicated that harvesting 4-year-old rather than 3-year-old culms produced better-quality (denser) culms for construction purposes (Alipon et al. 2009).

Zafaralla and Malab (2003) indicated that culms with 1.5 cm wall thickness, regardless of overall culm diameter, are appropriate materials for bamboo tile production through the MMSU bamboo tile-making machine (see also Zafaralla and Malab 2009). A separate observation by Alipon et al. (2009) was that the relative density and mechanical properties of 4–7-year-old culms or culms without treatment were higher than those of 3–4-year-old culms with or without treatment. This shows that the strength of culms continues to increase as they mature from 3 to 4 years old and above. It was established that, as far as sustainability and income generation are concerned, 3–4 years old is the appropriate age to harvest *B. blumeana* culms, but if specifically required for construction and other structural purposes, it would be better to delay harvest until 4–7 years.

Combination of shoots and culms

Unfortunately, because the irrigation part of our trial ended early, it is difficult to make firm recommendations in relation to its influence, and further trials may be helpful in this regard.

Overall, it appears in *B. blumeana* that both shoot and culm production benefit from annual clump cleaning (removal of dead and defective culms and low spiny branches of retained culms) and annual retention of only a set number of culms. Overcrowding appears to be of detriment to the clump productivity index and culm wall thickness. Results also indicate that applying fertiliser, organic matter and mulch also improve shoot and culm development, but if the aim is only to produce high-quality culms as opposed to harvesting edible shoots, it may be possible to forgo the fertiliser and organic matter provided that mulch is still applied.

Collectively, the results of this study in Ilocos Norte provide relevant information for the effective management of existing *B. blumeana* clumps that can be a ready source of food and raw materials for various uses.

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Managing clumps of *Dendrocalamus asper* in Bukidnon, the Philippines

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Abstract

The productivity of *Dendrocalamus asper* (giant bamboo) in response to different fertiliser and mulch applications and to harvesting intensity was assessed over a period of 6 years. Edible bamboo shoot production was increased by fertiliser and mulch treatments; more shoots were also produced from clumps with higher numbers of 1- and 2-year-old culms. The treatment with retention of all shoots and culms caused congestion and reduced shoot production. The harvesting of edible shoots was antagonistic to achieving high culm yield; a high biomass yield was achieved only if most shoots were retained to produce 2-year-old culms for harvest. Average culm dry weight biomass yields were over 40 t/ha/year.

Introduction

Status of bamboo in Bukidnon

There are many native and introduced species of bamboo in Northern Mindanao (Region 10, the Philippines) and the most commercially important is *Dendrocalamus asper* (giant bamboo). *D. asper* is the Philippines' tallest and largest bamboo species and supports industries as diverse as tomato stakes, poultry floors and engineered bamboo products that replace timber. Because of its thick culm wall, *D. asper* lasts longer than other bamboos such as *Bambusa* and *Gigantochloa* species. One culm (or pole) of *D. asper* that is 23 m long and 16–18 cm in diameter can be made into at least 100 split sticks measuring 2.5 cm × 350 cm, and is worth PHP200.

According to a survey of barangay (village) captains and meetings in 2001, about 1,228 ha were planted to bamboo in Bukidnon, Northern Mindanao (Virtucio and Roxas 2003). About 87% of that area was *D. asper*, while the remaining 13% included *Bambusa blumeana*, *B. vulgaris*, *Gigantochloa levis* and other related species. The annual harvest of *D. asper* in Bukidnon was estimated at 535,000 culms.

Dendrocalamus asper is now included as a reforestation species in government-initiated projects established along rivers, creeks and other riparian zones. The local government of Bukidnon promoted its planting by providing planting propagules to various municipalities in the province, particularly along the Maradugao River. This effort has greatly benefited from new technologies for the propagation of *D. asper*. The new technology using branches adds considerably to the conventional way of raising planting stocks through culm cuttings and offset rhizomes.

Despite increased plantings of *D. asper*, the total resource is rapidly dwindling. Harvesting is unregulated and, too often, the urgent demand for poles has led farmers to harvest immature culms, leading to the poor quality of bamboo products. Overharvesting also leaves the clump without the capacity to re-grow; hence, production in subsequent seasons may also be affected.

Effects of fertiliser on bamboo

Fertiliser generally increases shoot production in *B. blumeana* (kawayan tinik) and *B. vulgaris* (kawayan

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kiling). For *B. bambusa*, nitrogen (N) fertiliser enhanced both shoot number and culm yield, although it did not significantly increase culm diameter or height (Tiongco 1997). In contrast, phosphorus (P) application alone had no significant effect on culm production in the two species. Optimum culm production in *B. blumeana* required a combination of 80–160 kg N/ha/year and 30 kg P/ha/year. Virtucio et al. (1992) showed that fertiliser application significantly increased shoot production in *B. blumeana* var. *philippinensis* (bayog) and A.B. Lapis and F.D Virtucio (1985, unpublished report) found an increased response to inorganic fertiliser. Working with *B. blumeana*, Hoanh (1992) showed that 300–400 g of complete (14-14-14) fertiliser per clump increased shoot number but the diameter and height of culms were not affected.

Kleinhenz and Midmore (2001) claimed that fertilisation is effective only when water supply is sufficient and that application should be done when photosynthesis rates are high (i.e. at the onset of the shooting season). They further claimed that inorganic fertilisers that have a low possibility of leaching are effective.

Harvesting methods

Sharma (1980) noted that bamboo forests in the Asia–Pacific regions of India, Bangladesh and Burma were generally managed according to the 'culm-selection method'. In this method, poor-quality culms are removed and one or two mature culms are retained adjacent to the new culms for stability. In Burma, bamboo plantations are also divided into sections and felling is rotated so that a section is clear-cut and is then left for 2, 3 or 4 years, depending on the felling cycle. Sharma (1980) further revealed that, in Japan, selective methods of harvesting were carried out in autumn with cutting cycles varying from 3–5 years for *Phylostachys reticulata* and 5–10 years for *P. edulis*.

In the Philippines, both methods are used (Virtucio and Tomboc 1994). In natural stands of *Schizostachyum lumampao* (buho), both moderate thinning of culms aged 3 years and older, and clear-felling on a 2-year cycle, are optimal harvesting regimes. Virtucio et al. (1992) prescribed light thinning of culms aged 4 years and older and clear-felling cycles of 2 years for natural stands of *B. blumeana*.

Also in the Philippines, Manipula et al. (1996) compared the culm productivity of *Bambusa* sp. 2 (laak) in flatland and hillside sites in Davao del Norte (Region 11). Their results showed that cutting all 3-year-old culms, including defective ones, gave the most culms per clump at both sites. At the hilly site, harvesting all 2-year-old culms produced the same yield.

Basio et al. (1988) evaluated culm production in *Gigantochloa levis* (botong) and *Bambusa* sp. 2 (laak) at a 5 ha plantation at the Twin Rivers Research Center in Davao del Norte. Surprisingly, they found that more good-quality culms were produced by clear-cutting than selective thinning because there were more usable culms. With selective thinning, the rejects consisted of the immature and crooked poles, and it was noted that, during selective harvesting, the shoot tips of young culms were cut or damaged. Biomass production after clear-cutting was reduced so this was a disadvantage of that harvesting method.

Systematic management of existing bamboo clumps in Bukidnon is the next challenge. Our attention now should focus on managing the soil and water resources, expanding the planted area and protecting the bamboo resource to increase productivity and generate income from culms and edible shoots. There is a critical need to properly manage and harvest the clumps to sustain the supply of shoots and culms.

In this paper, information is presented on objective management practices to sustain the increasing demand for bamboo products. This information comes from research to improve edible shoot and culm production from *D. asper* plantations in Bukidnon. Management of mineral nutrient inputs and thinning regimes is within the reach of most owners of bamboo resources, and these variables were studied. Due to limited access to irrigation and because Bukidnon normally has a favourable annual rainfall distribution (monthly rainfall >100 mm), irrigation water supply was not studied.

Materials and methods

An unmanaged plantation of *Dendrocalamus asper* (giant bamboo) located at Impalutao, Impasugong, Bukidnon, Northern Mindanao was selected for the study. It was established in 1986 on a 7 m × 7 m grid, so it was 15 years old and had a full canopy when the project started in 2001. The immediate surrounding vegetation included *Chromolaena* sp., ferns, carabao grass and small trees of *Cassia spectabilis*. The plantation was within the former Impalutao Reforestation Project (Department of Environment and Natural Resources; DENR) but is now under the Center for Ecological Development and Recreation (DENR and the Impasugong local government unit).

Existing clumps in the plantation were inventoried and the experimental site was selected. Soil samples

(0–10 and 10–20 cm) were taken. The study used a randomised complete block design with three replicates. Treatments varying the rates of fertiliser and mulch application and harvesting methods were assigned to clumps and, in March 2001, existing culms were thinned to match the prescribed treatment (Table 1). Weather recordings were started, with maximum and minimum temperatures, solar radiation and rainfall collected for the duration of the experiment. The soil was re-sampled in 2006 (0–25 cm).

Full treatments were imposed in March 2001. Mulch and fertiliser were applied before each shoot season, which commenced in June. The mulching materials were corn leaves, stalks and cobs as these were readily available in the area. A mixture of complete (14-14-14) fertiliser, urea and muriate of potash were applied at the rate of 240 kg N, 50 kg P and 240 kg K per hectare per year.

Shoots were harvested from June to September each year, starting in 2001. The number of shoots retained for culms according to treatment was set in October each year, with culling of excess culms. These were not included in calculations of biomass. Culms were harvested annually (or otherwise, according to treatment) every March or April when precipitation was at its lowest. A chainsaw was used but sometimes when there was difficulty, an axe and machete were employed to cut the culms, leaving stumps about 0.5 m above the ground that were later cleaned off with the chainsaw. Due to the large size of the *D. asper* culms, carabaos (water buffalo) were used during the harvesting operation.

Throughout the trial, the number of shoots was recorded. Where harvested, the weight of shoots was also recorded. The number, diameter and length of fully grown, <1-year-old culms were recorded before the next shoot season. On occasions, samples of shoots and leaves were collected for quantification of nitrate and nitrogen contents, respectively (Traynor and Midmore 2009). Monitoring of shoot production usually started during the early part of June and ended in late September or early October. Shoots that emerged were counted every other day during the heavy shooting period and weekly thereafter. Total biomass was assessed only once, during the harvesting of culms in 2006. Samples subjected to oven-drying were taken from different plant parts such as leaves, branches and culms. For nitrogen concentration of leaves, the young fully expanded leaves of a 1-year-old culm were collected, oven-dried and sent to the laboratory for analysis. Data were analysed with Systat statistical software (Systat Software Inc. 2004, San José, California, United States of America).

Results

Climate

Bukidnon has a cool and moist climate throughout the year. From 2001–2005, the maximum monthly average temperature reached 32.6 °C and the minimum was a cool 12.2 °C. The annual average temperature was 23.5 °C.

Bukidnon is classified as climatic type III, with an almost even distribution of rainfall and no pronounced dry season. There were no periods of drought and only minor peaks of rainfall during the experimental period (Figure 1), although March and April were drier than usual in 2002 and 2003, as was December in 2002 and 2004.

Table 1. Summary of experimental treatments on an unmanaged *Dendrocalamus asper* plantation in Impalutao, Bukidnon

Treatment	Fertiliser applied?	Mulched?	Standing culm density[a]
T1	Yes	Yes	6-6
T2	No	Yes	6-6
T3	Yes	No	6-6
T4	No	No	6-6
T5	Yes	Yes	Keep all new culms; harvest all ≥3-year-old culms
T6	Yes	Yes	10-10
T7	Yes	Yes	6-6-6
T8	Yes	Yes	4-4
T9	No	No	No harvesting; only mark the culms
T10	No	No	Harvest all 3-year-old culms

[a] Successive numbers indicate how many culms of each age group were retained each year, with thinning taking place just before the shoot season, e.g. 6-6 means six 1-year-old and six 2-year-old culms; 6-6-6 retained six 3-year-old culms as well.

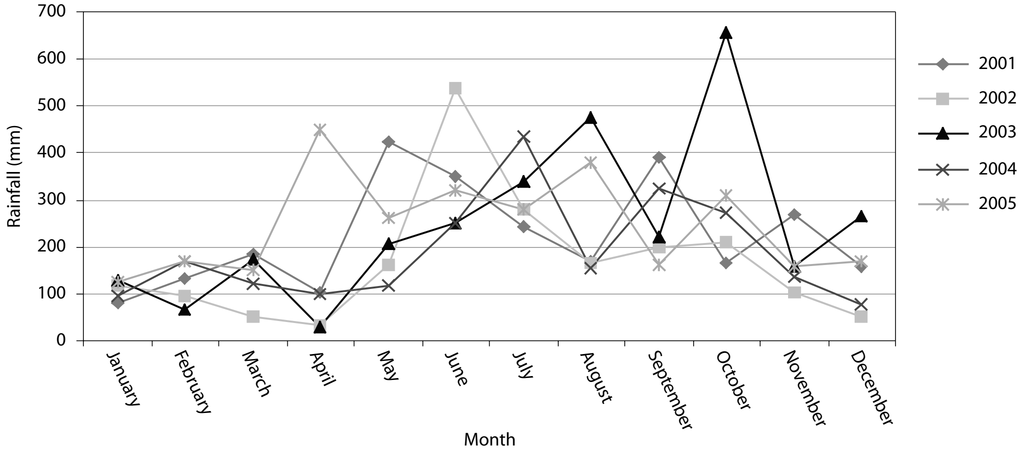

Figure 1. Rainfall pattern in the experimental area (Source: Northern Mindanao Integrated Agricultural Research Center (NOMIARC) Agromet Station)

Soil characteristics

The soil was a sandy clay with a pH range of 5.0–5.5 (Table 2).

After 6 years, there were some changes in soil properties in the experimental site (Table 3). Soil pH was unchanged, but organic matter increased in all treatments. The addition of mulch caused the greatest increase in organic matter but there was an effect of not harvesting culms in T9. Possibly the fallen leaf matter of unharvested culms resulted in a surrogate mulch effect. There was also a notable increase in available P in fertilised treatments (except T1) and a decrease in exchangeable K in non-fertilised treatments Quite possibly, fertiliser rates were not in balance with nutrient removal in the harvested shoots and culms. Consistently, the soil pH, organic matter, available P and exchangeable K were lower in T10, the treatment without management, than in other treatments.

Shoot characteristics

Shoot emergence started in early June, peaked in late July, tapered off in August and ended in late September or early October, depending on precipitation. Indeed, precipitation influenced shoot production as practically no shoots emerged during drier months.

It generally took 2 months for shoots to grow to full height although for some culms it took only 1 month. Based on observation, precipitation also enhanced the rate of culm elongation. Shoots elongated fastest 3–5 weeks after shoot emergence and the quickest rate was 37 cm/day. Representative measurements of harvested shoots are shown in Table 4. There was an immediate and large increase in all shoot characteristics in T1. Based on the range of treatment combinations, the result suggests that the fertiliser rate and mulch and harvesting regime are in harmony in this treatment; in fact, this selection was the basis of a theoretical best-management control for this experiment.

Influence of treatment on shoot production

There were variations in annual numbers of shoots produced, as seen in Figure 2. During the first year (2001), the average shoot production across all treatments was 3.83 per clump. It more than doubled during the second year (2002) to 10.47 but declined to 4.8 in the third year (2003). Then, after 2 years of increase in 2004 and 2005, shoot production dropped in 2006.

Table 2. Initial soil test results from the experimental area (average of three replicates)

Soil pH		Organic matter (%)		Available phosphorus (ppm)		Exchangeable potassium (ppm)	
0–10 cm	10–20 cm	0–10 cm	10–20 cm	0–10 cm	10–20 cm	0–10 cm	10–20 cm
5.2	4.75	>6.9	2.95	4.3	1.1	121	96

Table 3. Soil test (0–25 cm) results after 5 years of treatment application

Treatment[a]	Soil properties			
	Soil pH	Organic matter (%)	Available phosphorus (ppm)	Exchangeable potassium (ppm)
T1	5.16	8.10	3.9	80.4
T2	5.27	8.50	4.0	76.0
T3	5.17	7.46	8.7	80.4
T4	5.36	7.63	2.2	75.0
T5	5.23	9.42	13.6	106.8
T6	5.29	8.97	7.7	111.9
T7	5.23	9.07	4.6	104.0
T8	5.15	8.71	6.3	103.8
T9	5.23	8.21	2.0	71.0
T10	5.09	7.43	1.7	65.3

[a] See Table 1 for treatment details

Table 4. Treatment effects on the size and weight of edible shoots after the first treatment application in 2001

Treatment[a]	Diameter (cm)			Height (cm)	Gross weight (kg)	Net weight[b] (kg)
	Base	Middle	Top			
T1	21.5	15.0	8.7	63.0	7.60	4.50
T2	15.4	12.0	6.0	43.0	3.20	1.70
T3	17.5	14.0	8.6	42.0	3.90	1.60
T4	14.0	10.5	6.5	35.0	2.05	1.15
T5	15.0	10.5	6.8	32.5	2.50	1.20
T6	18.7	13.0	7.1	48.0	2.15	1.15
T7	16.2	11.0	5.9	39.0	2.95	1.80
T8	16.4	11.5	6.4	27.0	1.25	0.75
T9	13.0	10.5	6.5	29.0	1.50	0.85
T10	10.0	7.9	5.8	29.0	1.22	0.75

[a] See Table 1 for treatment details

[b] Weight of shoots after removal of sheath and woody parts that are usually not included during cooking

Comparing T1–T4, where the culm harvesting was 6-6, there was an increase in shoot number in 2002, 2004 and 2005 in response to either fertiliser or mulch but no extra response to both combined. Shoot production was good in T6, T7 and T10, possibly reflecting the maintenance of a larger clump by retaining more culms after harvesting. Treatments 8 and 9 produced fewer shoots, possibly because the clump was too small or poorly managed, respectively.

Influence of treatment on culm number

About 20% of the shoots that were produced died before elongating into culms, but surviving culm number per clump was directly proportional to shoot production. Consequently, in some years, there were increases in culm number in response to fertiliser and mulch, and there was a positive response to the harvest regimes of 10-10 (T6) particularly and 6-6-6 (T7) in some years. This result seems to suggest that retaining more culms each year promotes culm survival in later years. In contrast, on average only 2.7 culms survived annually per clump in T9 (with no harvesting) and 3.2 culms survived in T5 where all shoots were retained for culm production.

The culm number in most treatments was generally insufficient to provide for the assigned harvesting strategy (Figure 3). T6 produced the highest average number of harvested culms of 7.72 per clump, although 10 culms were intended to be left annually. T3 produced an average of 5.61 culms per clump and 6 culms were intended to be left annually.

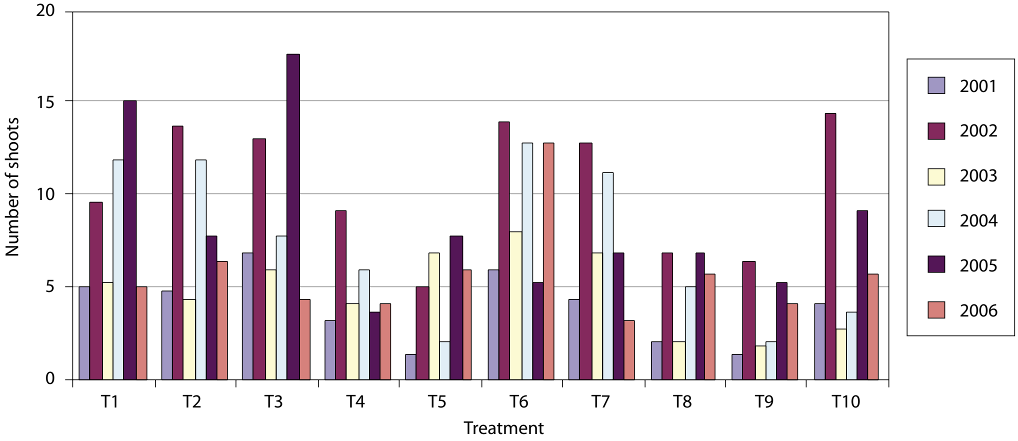

Figure 2. Number of shoots produced per clump of *Dendrocalamus asper* as influenced by treatment over a 6-year period. Note: see Table 1 for treatment details.

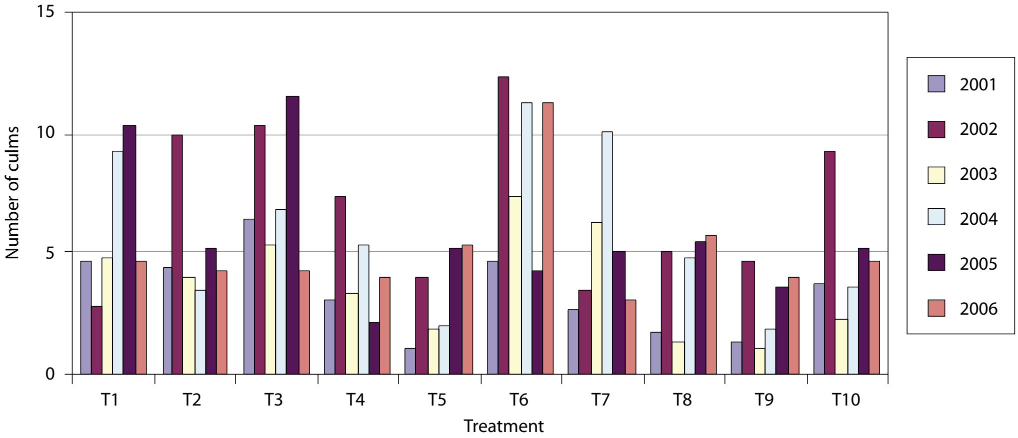

Figure 3. Annual number of shoots per clump of *Dendrocalamus asper* that survived to produce culms (counted in October each year before culling) as influenced by treatment over a 6-year period. Note: see Table 1 for treatment details.

Influence of treatment on internodal culm diameter

Culm diameter was measured at about 1 m above the ground. The greatest diameter recorded was 17.60 cm in T6 in the sixth year of treatment (Figure 4). The smallest diameter was 13.20 cm in T9.

On average, T6 and T3 produced the biggest diameter culms with 16.56 cm and 16.28 cm, respectively. No significant differences were observed between treatments for culm diameter during years 1 and 2 but thereafter (2003–2006) T6 and T7, and T3 in the fifth and sixth years, produced culm diameters significantly greater than in T10.

Influence of treatment on culm height

The tallest culm measured 24.8 m in T6 in 2005 while the shortest was 17.9 m in T4 in 2001 (Figure 5). In the first year T4 had significantly shorter culms ($P = 0.05$) than T1, while in the first year, T7 had the tallest, and in the second, third, fifth and sixth years, T6 had the tallest culms; always significantly taller than those of T1.

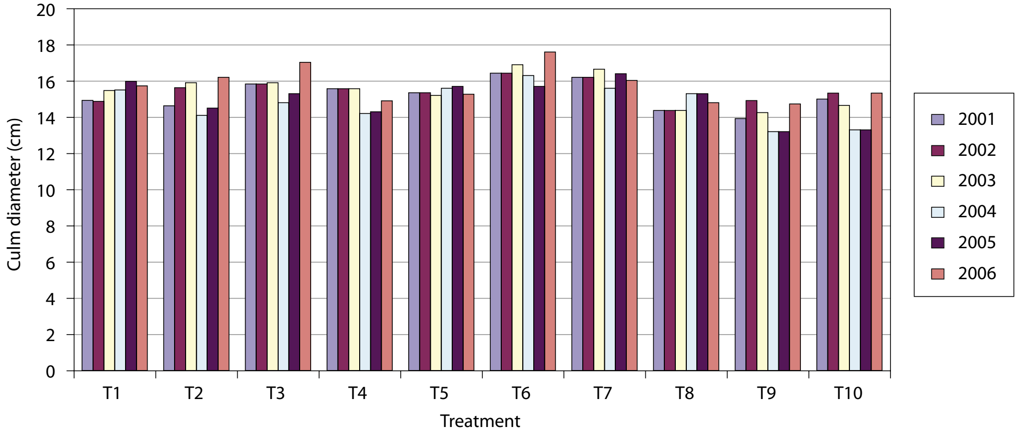

Figure 4. Average culm diameter of *Dendrocalamus asper* as influenced by treatment over a 6-year period. Note: see Table 1 for treatment details.

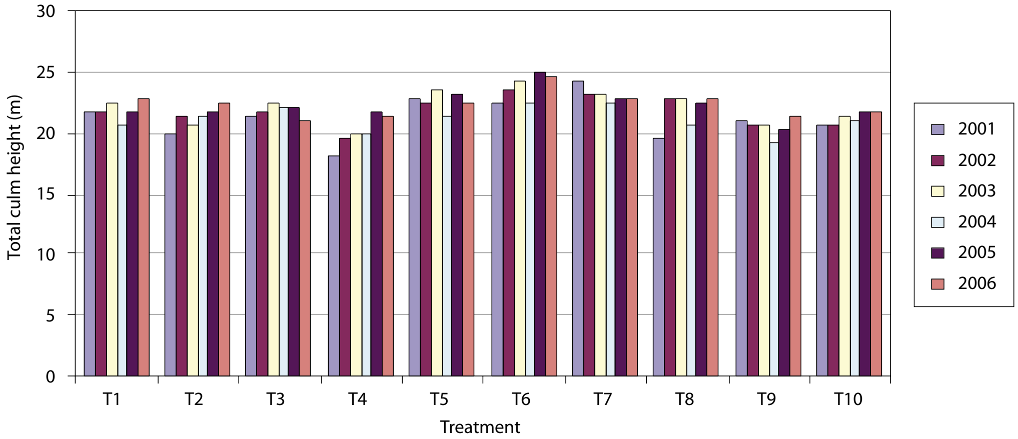

Figure 5. Average height of culms as influenced by treatment over a 6-year period. Note: see Table 1 for treatment details.

Total N content of leaves and nitrate content of shoots

Analysis of shoot nitrate concentration was undertaken in 2002 and 2003, and of total N concentration in leaves in 2004 and 2006 (Table 5).

Great variation was observed between treatments for nitrate concentration in the shoots. The highest was 196 parts per million (ppm) for T6 while the lowest was 31 ppm for T7 in 2003. Essentially, shoot nitrate was increased by the application of fertiliser with the exception of T7. In T7 where six 1-, 2- and 3-year-old culms were retained, resulting in a bigger clump, less N in the plant may have been mobile to transfer into new culms.

Leaf total N (%) in contrast to shoot nitrate did not show such marked differences between treatments (Table 5). There were ranges of 2.44–3.11% in 2004 and 2.54–3.28% in 2006. T8 had the highest leaf N for 2004, while T6 was the highest in 2006. There was a smaller response to fertiliser N than was apparent for shoot nitrate.

Table 5. Shoot nitrate content and total nitrogen concentration (% N) in young, fully expanded leaves from a 1-year-old culm as influenced by treatment

Treatment[a]	2002 Shoot nitrate	2003 Shoot nitrate	2004 Leaf % N	2006 Leaf % N
T1	166.0*	160.67**	2.80	3.14
T2	89.5	91.47	2.79	2.92
T3	164.0*	139.83*	2.61	3.08
T4	73.0	72.40	2.39	2.97
T5	172.5+	122.23	2.55	3.26
T6	165.5*	195.63**	2.55	3.28
T7	79.1	30.65	2.77	2.94
T8	118.9	110.22	3.11**	3.02
T9	62.0	59.38	2.68	2.54*
T10	55.5	45.40	2.44	2.99

[a] See Table 1 for treatment details

Note: Symbols indicate significant differences between treatment means and T10: + = $0.10 > P > 0.05$; * = $0.05 > P > 0.01$; ** = $0.01 > P > 0.001$

Above-ground biomass

The above-ground biomass of *D. asper* was estimated from samples taken during the harvesting of culms in 2006. On average, one 2-year-old culm weighed 59.43 kg when oven-dried, including the leaves and branches (Table 6). The highest above-ground biomasses of 78.8 kg and 75.2 kg per culm were in T3 and T6, respectively. Culm biomass generally responded to fertiliser but not to mulch—indeed, in the comparison between T1 and T3 not applying mulch improved culm yield considerably.

The total biomass/ha/year was calculated using the number of culms harvested in each treatment, multiplied by the dry weight per culm for that treatment in 2006, and then multiplied by the number of clumps per hectare, to get a time series of biomass from 2004 to 2006. The result is presented in Table 7. Component parts (leaves, branches and culms) are also presented in Tables 8, 9 and 10, respectively. There were substantial responses to fertiliser and harvesting regime in all components of biomass although results were not consistent. There was no response to mulch, indeed not using mulch in T3 led to high biomass. In particular, treatments that promoted culm number also had high biomass, which may be in small part a reflection of the biomass calculation method, but indicates that culm number per clump and per hectare are the prime drivers of biomass yield in *D. asper*.

Discussion

Shoot production and culm harvest biomass in *D. asper* were increased by the application of fertiliser, confirming the claim of Hoanh (1992) made for *B. blumeana* that fertiliser application enhances growth and yield, although the magnitude of responses was not consistent across years in our study.

The benefits of mulch were much less than fertiliser probably because the major role of mulch is to conserve soil water against evaporation and, under the local conditions, mulch may have prevented light rainfall from entering the soil. In Bukidnon, rainfall was evenly distributed throughout the trial period. Minor beneficial effects of mulch may be associated with the cycling of nutrients in the corn mulch.

Compared to other species (e.g. Kleinhenz and Midmore 2001; other papers in these proceedings), *D. asper* is not a prolific producer of shoots (Figure 2). Retaining 10 culms rather than 6 culms per year appeared more favourable for shoot production (T6), as was maintaining a high number of culms that included 3-year-old culms (T7). In contrast, leaving only a few culms (T8) or leaving all culms unharvested (T9) led to depressed shoot production.

Since it was difficult to maintain the number of culms to satisfy treatment requirements (see Figure 3), the effects of treatments on shoot number was mirrored by that on culm number. For culms, T6 (ten 1-year-old and ten 2-year-old culms) led to greatest culm height, and T4, that without fertiliser or mulch, the shortest. In terms of biomass produced, T6 and T3 (6-6 thinning, fertiliser, but no mulch) yielded the most. However, the high biomass yield of T6 was in part due to the high number of culms—if shoots had been removed for consumption, the biomass would have been severely reduced. Thus, this species is unlikely to support both high shoot and high biomass production—one was at the expense of the other.

Based on our results (Table 6), one culm of *D. asper* yielded 59.4 kg oven-dry weight so, on average, a 1-ha *D. asper* plantation yields a total dry biomass of 53.3 t annually if the annual culm harvest is 4.4 culms per clump with a 7 m × 7 m planting distance. That 4.4 is the average culm number per clump in 3 years across treatments, for there were years in which production was lower than 4.4 culms per clump and there were also years in which production was much higher. Culms comprised 76–88% of total above-ground biomass (Table 6), ranging therefore from 38–55 t/ha/year across years (Table 10).

Table 6. Above-ground dry biomass (kg) of single culms as influenced by treatment; averages for three replicates. Values in parentheses are the percentage (%) contribution of each component to the treatment total.

Treatment[a]	Plant part			
	Leaves	Branches	Culm	Total
T1	3.67 (6)	3.72 (7)	49.55 (87)	56.94
T2	6.09 (12)	6.48 (12)	40.10 (76)	52.67
T3	6.14 (8)	8.10 (10)	64.60 (82)	78.84
T4	1.99 (4)	4.23 (8)	47.07 (88)	53.29
T5	3.80 (7)	4.67 (8)	48.77 (85)	57.24
T6	3.10 (4)	8.10 (11)	64.04 (85)	75.24
T7	2.88 (5)	6.51 (10)	54.52 (85)	63.91
T8	4.85 (8)	6.44 (11)	49.71 (81)	61.00
T9	2.83 (6)	4.76 (11)	37.64 (83)	45.23
T10	3.87 (8)	3.91 (8)	42.11 (84)	49.89
Average[b]	3.92 (7)	5.69 (10)	49.81 (84)	59.43

[a] See Table 1 for treatment details

[b] Figures in this row do not match the totals due to rounding

Table 7. Annual total biomass production (t/ha dry weight) of *Dendrocalamus asper* at 7 m × 7 m planting distance as affected by treatment

Treatment[a]	2004	2005	2006	Average/ treatment
T1	63.2	37.9	63.2	54.8
T2	37.8	56.8	37.8	44.1
T3	102.5	102.5	85.4	96.8
T4	30.9	61.8	41.2	44.6
T5	12.3	49.4	24.7	28.8
T6	67.7	129.4	90.6	95.9
T7	40.1	40.1	53.5	44.6
T8	22.8	45.6	11.4	26.6
T9[b]	–	–	–	–
T10	41.4	72.4	20.7	44.8
Average/ year	46.5	66.2	47.6	53.4

[a] See Table 1 for treatment details

[b] No harvesting was done in T9

Table 8. Annual total leaf dry weight (t/ha) *Dendrocalamus asper* at 7 m × 7 m planting distance as affected by treatment

Treatment[a]	2004	2005	2006	Average/ treatment
T1	3.9	2.3	3.9	3.4
T2	2.3	3.5	2.3	2.7
T3	6.3	6.3	5.3	6.0
T4	1.9	3.8	2.5	2.7
T5	0.8	3.0	1.5	1.8
T6	4.2	8.0	5.6	5.9
T7	2.5	2.5	3.3	2.8
T8	1.4	2.8	0.7	1.6
T9[b]	–	–	–	–
T10	2.5	4.5	1.3	2.8
Average/ year	2.9	4.1	2.9	3.3

[a] See Table 1 for treatment details

[b] No harvesting was done in T9

The high biomass production of culms of *D. asper* raises some interesting questions. The experiment provided some preliminary evidence that fertiliser was beneficial and promoted by a harvest regime that left a large clump of up to 20 culms of 1 and 2 years of age. However, shoot production was variable between years. It is reasonable to consider that nutrition, particularly N, limited shoot production and culm survival in some years. In nearly all measurements of N, nutrition levels were slightly below optimum N leaf concentrations of >3% (Table 5). So, in future, it may be reasonable to explore an option for better plant N nutrition to obtain a sustainable level of shoot production over the life of the plantation. This appeared to be the best strategy because once a culm survived it was a major contributor to biomass and clump production.

Table 9. Annual total branch dry weight (t/ha) of *Dendrocalamus asper* at 7 m × 7 m planting distance as affected by treatment

Treatment[a]	2004	2005	2006	Average/ treatment
T1	7.2	4.3	7.2	6.2
T2	4.3	6.5	4.3	5.0
T3	11.7	11.7	9.7	11.0
T4	3.5	7.0	4.7	5.1
T5	1.4	5.6	2.8	3.3
T6	7.7	14.7	10.3	10.9
T7	4.6	4.6	6.1	5.1
T8	2.6	5.2	1.3	3.0
T9[b]	–	–	–	–
T10	4.7	8.2	2.4	5.1
Average/ year	5.3	7.5	5.4	6.1

[a] See Table 1 for treatment details
[b] No harvesting was done in T9

Table 10. Annual total culm dry weight (t/ha) of *Dendrocalamus asper* at 7 m × 7 m planting distance as affected by treatment

Treatment[a]	2004	2005	2006	Average/ treatment
T1	52.1	31.3	52.1	45.2
T2	31.2	46.8	31.2	36.4
T3	84.5	84.5	70.4	79.8
T4	25.5	51.0	34.0	36.8
T5	10.2	40.7	20.4	23.8
T6	55.8	106.7	74.7	79.1
T7	33.1	33.1	43.1	36.4
T8	18.8	37.6	9.4	21.9
T9[b]	–	–	–	–
T10	34.1	59.7	17.5	37.1
Average/ year	38.4	54.6	39.3	44.1

[a] See Table 1 for treatment details
[b] No harvesting was done in T9

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

Conrado B. Marquez[1]

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 at181,789 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.

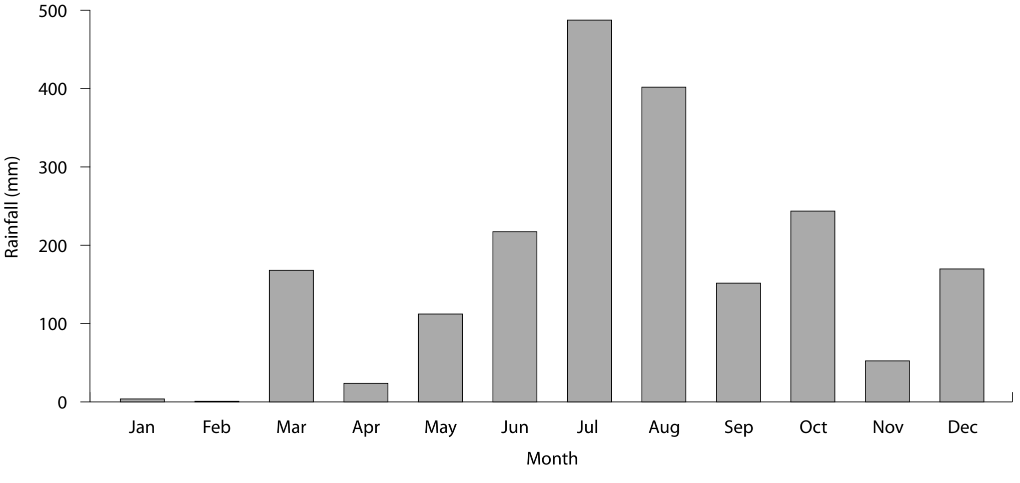

Figure 1. Total monthly rainfall in Santa Barbara, Iloilo in 2005

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

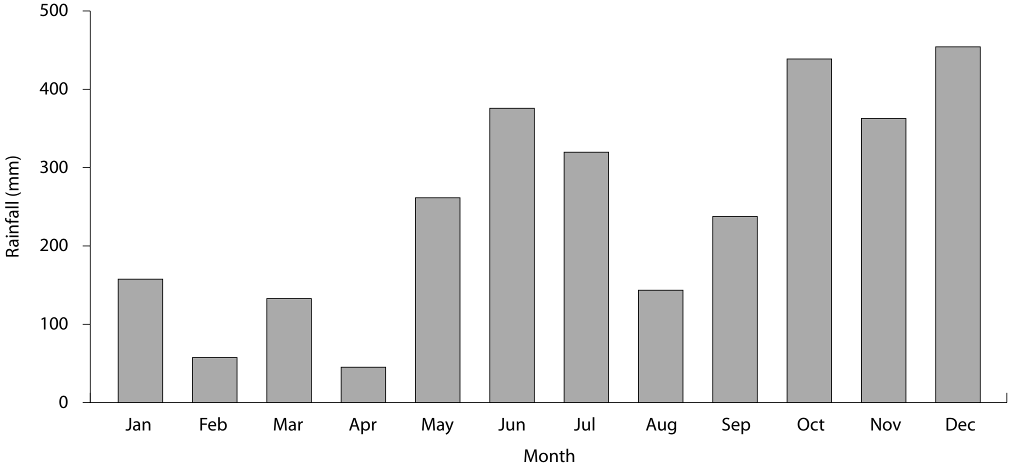

Figure 2. Total monthly rainfall in Dumarao, Capiz in 2005

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.

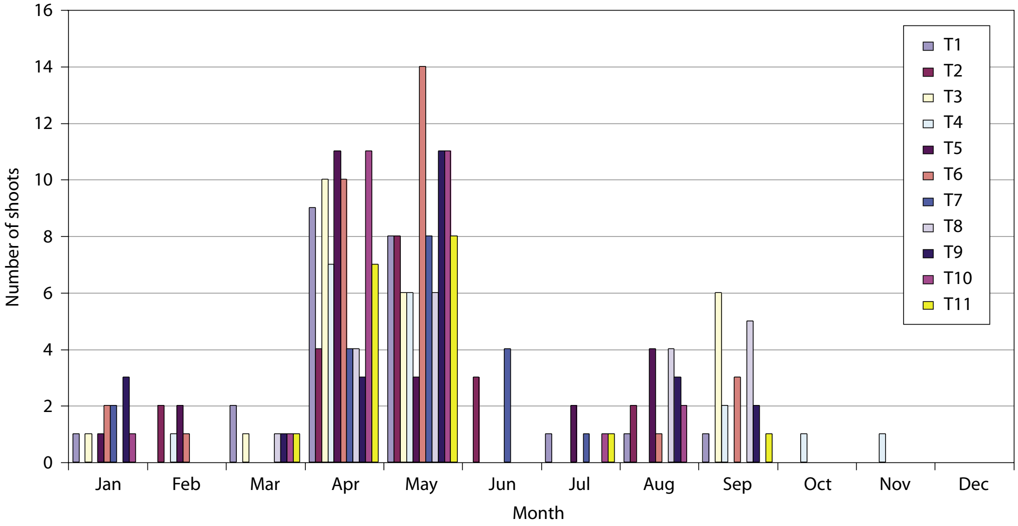

Figure 3. Monthly total shoot count per treatment in 2002 in the Capiz trial. Note: see Table 3 for treatment details.

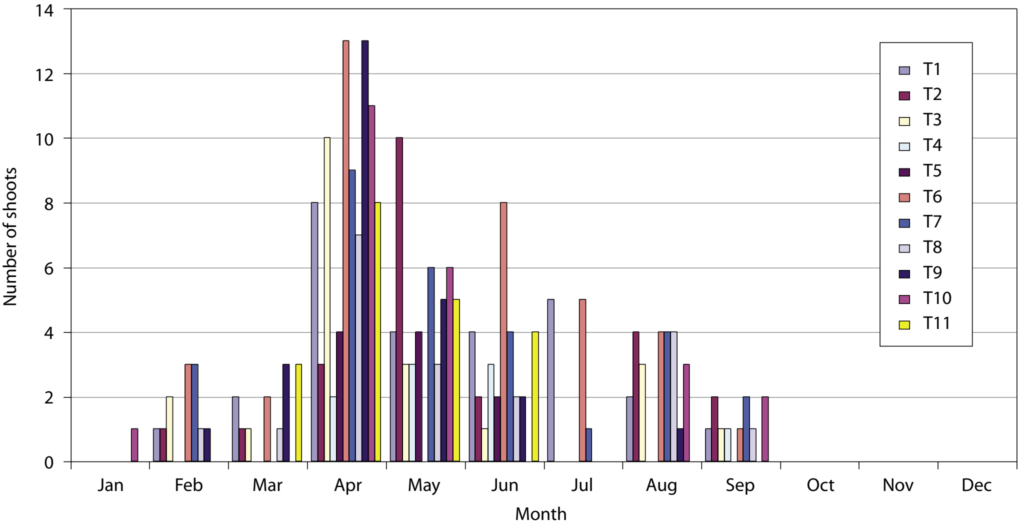

Figure 4. Monthly total shoot count per treatment in 2003 in the Capiz trial. Note: see Table 3 for treatment details.

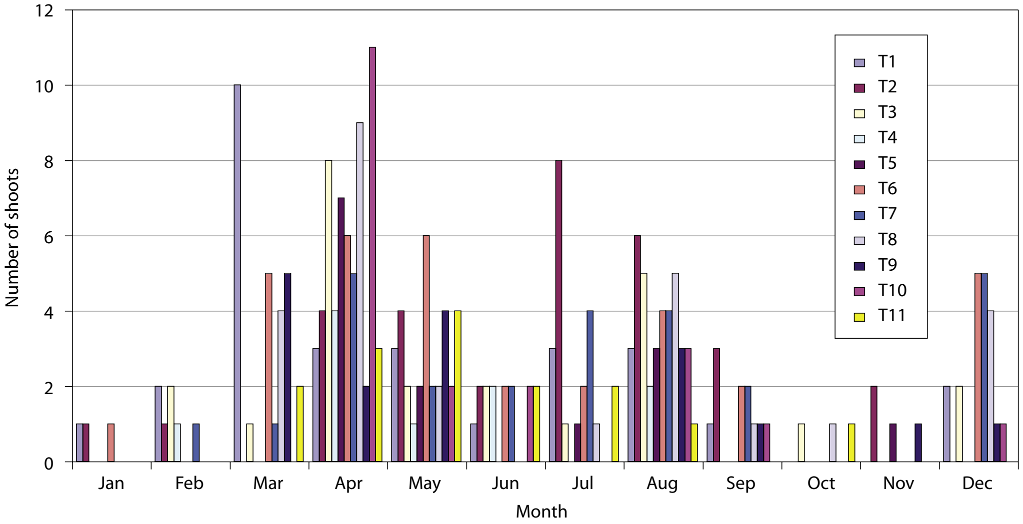

Figure 5. Monthly total shoot count per treatment in 2004 in the Capiz trial. Note: see Table 3 for treatment details.

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 m^3/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 that 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

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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 m^2. 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, knifes 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/cm^3 while the medium hardwood has 0.55–0.64 g/cm^3. 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 m^2 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
B. blumeana culm butt [d]		12	0.57	88.9	41.9	9.7	39.9	38.4	2.4	2.3
B. blumeana, mid section[d]		11	0.63	59.2	30.8	9.9	44.9	41.1	1.8	3.1
Chloroxylon swietenia[e]	High	Green	0.74	100.0	69.5	14.0	55.9		12.8	
Acacia magium[e]	Medium–high	Green	0.61	64.6	39.2	10.8	30.2		8.6	
Acacia crassicarpa[e]	Medium	Green	0.62	74.4	42.4	11.3	23.8		8.4	
Acacia cincinnata[e]	Medium	Green	0.64	60.2	32.2	9.6	27.2		9.4	
Swietenia macrophylla[e]	Medium	12	0.55	74.4	47.7	8.9	45.2		–	

[a] Location of growth in the Philippines: *B. blumeana*—Mabaleng, 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)

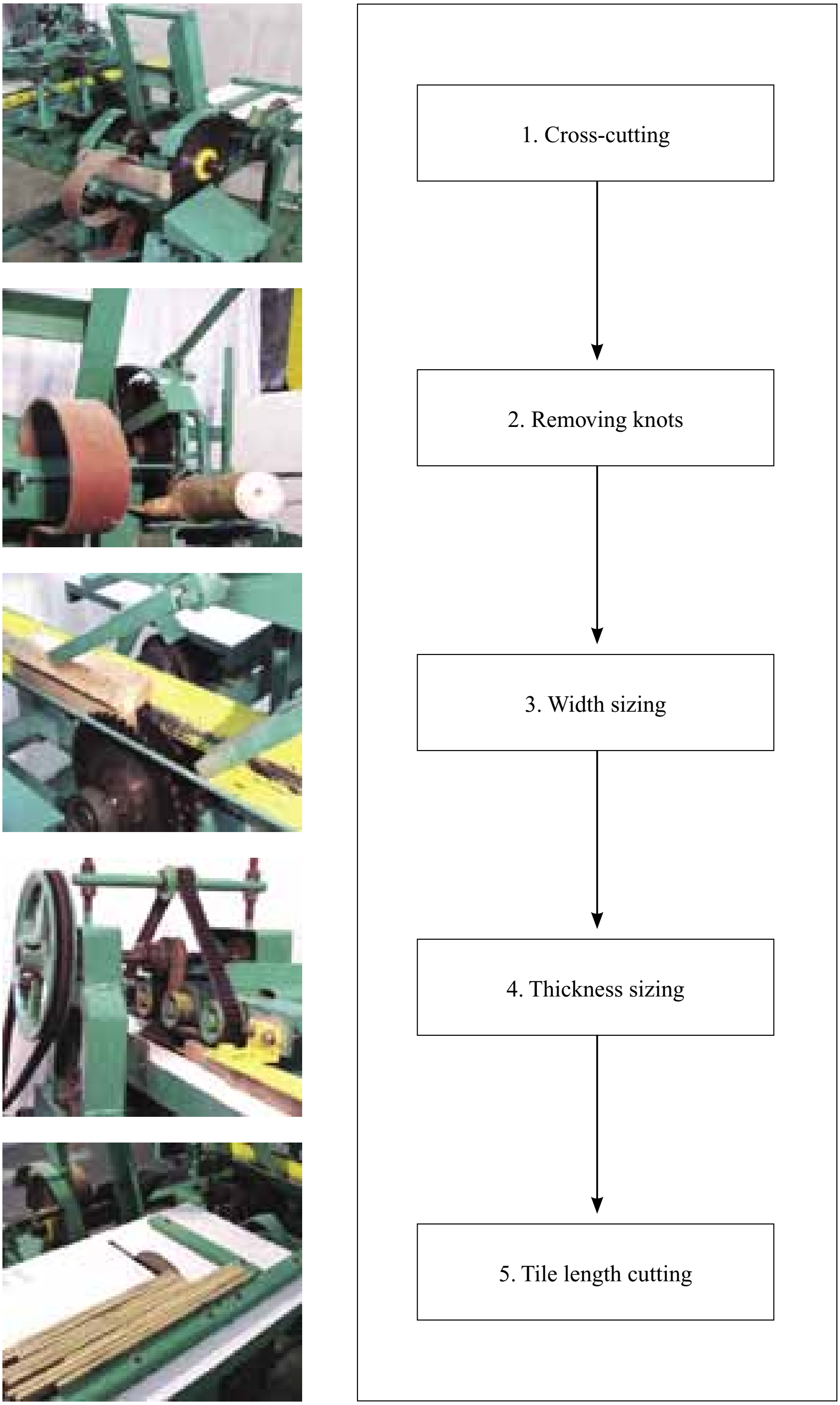

Figure 1. Steps in bamboo tile production using the five-in-one tile-making machine

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 m^2 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 m^2 while bamboo splits attain break-even output after producing 755 m^2.

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

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Effect of silvicultural management on the basic properties of bamboo

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Abstract

Bambusa blumeana (kawayan tinik) and *Dendrocalamus asper* (giant bamboo) culms (poles) from plantations established for 9 and 15 years before silvicultural treatment, respectively, were harvested and assessed after several years of management. The *B. blumeana* trial involved 13 silvicultural treatment combinations, i.e. irrigation, fertiliser, mulch, organic matter and number of culms retained. All practices except irrigation were also applied to *D. asper* in 10 combinations.

The basic properties—physical, mechanical, anatomical and chemical—of the two species were evaluated. These properties could serve as a guide in the selection of plantation management practices that could enhance the efficiency and promote the use of bamboo culms.

The culm wall thickness and diameter of treated culms were higher than untreated ones although not significantly in all of the treatments. The effects of treatment on the basic properties of culms were not consistent; either significantly lower, higher or similar to the control. Silvicultural treatments, therefore, did not markedly influence the basic properties of culms. Greater differences were evident between species, although that effect was confounded with production sites.

The best treatments for farmers to adopt to regenerate old bamboo clumps for sustainable and quality culms are recommended. For *B. blumeana*, this includes cleaning the base of the culms, applying mulch, organic matter and fertiliser and maintaining four 1-year-old, four 2-year-old, four 3-year-old and four 4-year-old culms (4-4-4-4 standing culm density; in total 16 culms). For *D. asper*, the recommended treatment includes applying fertiliser but no mulch, and retaining six 1- and 2-year-old culms (6-6 standing culm density). There was little difference in the basic properties between *D. asper* culms that were nearly 2 years old at harvest and those that were 3 years old.

Introduction

In recent years, bamboo has come to be recognised as a very important non-wood resource. This is due to both the rapid destruction of tropical rainforests and the unrelenting demand for raw materials by wood-based industries. Both in the Philippines and abroad, interest in bamboo continues to heighten. Because of its strength, straightness and lightness combined with extraordinary hardness, size range, abundance, easy propagation and rapid growth, bamboo is suitable for an almost endless variety of purposes (Espiloy et al. 1999).

Most studies on bamboo focus on growth and yield as affected by management practices. Reports indicate that various silvicultural practices have marked effects on the shoots, culm diameter and height of bamboo (Hoanh 1992; Virtucio et al. 1990) and this is supported by the agronomic papers in these proceedings. However, there is very limited information on the properties of culms subjected to these silvicultural treatments. In one Philippines example, Fernandez (2005) studied the growth performance of two bamboo species—namely *Dendrocalamus asper* and *Gigantochloa levis*—using organic fertilisers. The effects on physical and mechanical properties were not significant, probably due to young age of the culms (1.5 years old).

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Generally, restrictions in the processing of raw materials are associated with uncertainty about their properties. Therefore, a thorough understanding of the relationship between structure, properties, behaviour in processing and product qualities is necessary for promoting the use of bamboo (Liese 1992).

Basic properties can be used to indicate the quality of culms as well as the relative suitability of different bamboo species for specific uses. Evaluating the properties of culms from plants that have undergone various silvicultural treatments would help promote their optimal use. The present study was undertaken to determine the anatomical, chemical, physical and mechanical properties of *Bambusa blumeana* (kawayan tinik) and *Dendrocalamus asper* (giant bamboo) grown in the Philippine provinces of Ilocos Norte and Bukidnon, respectively, with and without silvicultural treatment.

Materials and methods

Plant materials

Plantations of *B. blumeana* and *D. asper* were established in 1992 and 1986—9 years and 15 years, respectively, before the current trials began in 2001.

Ilocos Norte site, Bambusa blumeana

In 2001, 5 culms of 4–7-year-old *B. bambusa* were collected from each of 3 blocks (15 in total) at the experimental site in Mabaleng, Batac, Ilocos Norte, Region 1. These culms were a subsample of those removed in the process of setting up the experimental treatments of Malab et al. (2009).

From 2002 to 2004, a total of 115 3-year-old *B. blumeana* culms were collected from the plantation (3 culms per treatment × 13 treatments × 3 years, but for two treatments, only two culms were available). These culms had undergone silvicultural treatment for 1–3 years, respectively. Data from these samples are reported elsewhere (M.A. Alipon 2008, unpublished final report to the Australian Centre for International Agricultural Research; ACIAR).

In 2005, a total of 117 culms (3 culms per treatment × 13 treatments × 3 age classes) were collected from the same plantation. These culms had undergone 1–2, 2–3 or 3–4 years of treatment, respectively. Henceforth in this paper, these culm age groups will be abbreviated to 1, 2 and 3 years old, respectively. In actuality, the 1–2 years of treatment were much closer to having had 2 years of treatment and the 2–3 years of treatment were much closer to having had 3 years of treatment.

Details of the treatments imposed in Ilocos Norte are presented in Malab et al. (2009) and are summarised in Table 1.

Table 1. Summary of experimental treatments on an unmanaged *Bambusa blumeana* plantation in Ilocos Norte, the Philippines (Malab et al. 2009)

Treatment	Irrigation supplied?	Fertiliser applied?	Organic matter applied?	Mulched?	Standing culm density[a]
T1	Continuous	Yes	Yes	Yes	4-4-4 (12 culms)
T2	No	Yes	Yes	Yes	4-4-4
T3	Strategic[b]	Yes	Yes	Yes	4-4-4
T4	Continuous	No	No	Yes	4-4-4
T5	Continuous	No	No	No	4-4-4
T6	Continuous	Yes	Yes	Yes	3-3-3 (9 culms)
T7	Continuous	Yes	Yes	Yes	3-3-3-3 (12 culms)
T8	Continuous	Yes	Yes	Yes	4-4-4-4 (16 culms)
T9	Continuous	Yes	Yes	Yes	Keep all younger, but harvest all 3-year-old culms
T10	Continuous	Yes	Yes	Yes	3-3 (6 culms)
T11	Continuous	Yes	Yes	Yes	8 per 2-year cycle (4-4 for first year)
T12	No	Yes	Yes	Yes	No harvesting, cleaning only
T13	No	No	No	No	No harvesting

[a] Successive numbers indicate how many culms of each age group are retained each year, with thinning taking place just before the shoot season, e.g. 4-4-4 means four 1–2-year-old, four 2–3-year-old and four 3–4-year-old culms. Indeed the 1–2-year-old culms were almost all nearly 2 years old at harvest, and so on for 2–3- and 3–4-year-old culms.

[b] Just before shoot season

Bukidnon site, Dendrocalamus asper

In 2005, 30 *D. asper* culms aged 2 years were collected from the experimental site in Impalutao, Imapsugong, Bukidnon, Region 10. In 2006, two more sets of 30 culms, 1 and 2 years old, were likewise harvested. Treatment details are provided in Decipulo et al. (2009) and summarised in Table 2.

Sample preparation

Each bamboo culm was cut into three equal portions to represent the butt (base), middle and top. Samples for anatomical, chemical, physical and mechanical properties were taken from each height level.

The standard procedures of the American Society for Testing and Materials (ASTM 1998) for testing small clear specimens of timber and the Indian Standard 6874 (IS) (Anonymous 1973) were followed as far as practicable. Since bamboo species from different regions vary in shape and configuration, slight modifications of test procedures were made.

Physical properties

Shrinkage

Blocks measuring 25 mm × 102 mm × actual thickness were cut from the green samples, then oven-dried and re-measured to determine shrinkage values. Changes in dimensions were measured using a dial gauge, to an accuracy of 0.0254 mm, at pre-determined points across the surface areas.

Moisture content and relative density

Fresh specimens measuring 25 mm × 25 mm × actual thickness were weighed, then their volume was determined by the 'water displacement method'. The samples were then oven-dried at 103 ± 2 °C until a constant weight was attained and that weight was recorded. Maximum moisture content was calculated as the percentage difference between the fully saturated fresh and oven-dry weight, i.e. [(fresh weight of sample minus oven-dry weight of sample / oven-dry weight of sample) × 100%]. The relative density (i.e.specific gravity) of each sample was determined as the ratio of the oven-dry weight to its volume when green.

Mechanical properties

Static bending

Samples in this test consisted of cross-sectioned pieces of culm. For each fresh (green) sample, the weight, diameter, length and culm wall thickness were measured. The outside culm diameter multiplied by 14 determined the span between supportive saddles provided at each end of the sample. Load was applied at the mid-span/mid-internode of the specimen at a uniform rate of motion of a movable crosshead and calculated using the formula shown in equation (1):

$$N = \frac{ZL^2}{6d} \qquad (1)$$

where:
N = rate of motion of movable head (mm/minute)
Z = unit rate of fibre stress per mm of outer fibre length per minute = 0.0015
L = span (mm)
d = depth or average outside diameter of specimen (mm).

Table 2. Summary of experimental treatments on an unmanaged *Dendrocalamus asper* plantation in Bukidnon, the Philippines (Decipulo et al. 2009)

Treatment	Fertiliser applied?	Mulched?	Standing culm density[a]
T1	Yes	Yes	6-6
T2	No	Yes	6-6
T3	Yes	No	6-6
T4	No	No	6-6
T5	Yes	Yes	Keep all new culms; harvest all ≥3 years old
T6	Yes	Yes	10-10
T7	Yes	Yes	6-6-6
T8	Yes	Yes	4-4
T9	No	No	No harvesting; only mark the culms
T10	No	No	Harvest all 3-year-old culms

[a] Successive numbers indicate how many culms of each age group were retained each year, with thinning taking place just before the shoot season, e.g. 6-6 means six 1–2-year-old and six 2–3-year-old culms; 6-6-6 retained six 3–4-year-old culms as well.

Mid-span deflections of the specimens were measured to the nearest 0.0254 mm with a dial gauge. The load-deflection curve was plotted so that the load and deflection of elastic limits could be determined. Stress at proportional limit (SPL), modulus of rupture (MOR) and modulus of elasticity (MOE), all in MPa, were calculated from the data obtained, using the formulae shown in equations (2), (3) and (4), respectively:

$$\mathrm{SPL} = \frac{2.546\, PLd_o}{(d_o^4 - d_i^4)} \tag{2}$$

$$\mathrm{MOR} = \frac{2.546\, WLd_o}{(d_o^4 - d_i^4)} \tag{3}$$

$$\mathrm{MOE} = \frac{0.424\, PLd^3}{(d_o^4 - d_i^4)\,\Delta} \tag{4}$$

where:
P = load at proportional limit (N)
W = maximum load (N)
L = span (mm)
d_o = outer diameter (mm)
d_i = inner diameter (mm)
Δ = deflection at proportional limit (mm)

Compression parallel to grain

Cylindrical culm specimens (including node and internode) were tested while still green. Culm wall thickness multiplied by 10 determined the length of the specimen; a slight modification of the Standard for Testing Small Clear Specimens of Timber (ASTM D-144) 1998 as followed at the Forest Products Research and Development Institute (FPRDI). Dimensions and weights of specimens were taken before the test. Care was taken in making the ends on which load was applied flat and perpendicular to the longitudinal axis of the specimen so that stresses were distributed evenly over the entire area. Load was applied at a uniform rate of 0.003 mm per mm of specimen length per minute. Only the maximum load (W) was recorded from the obtained data. The maximum crushing strength (MCS) of each specimen was determined using equation (5):

$$\mathrm{MCS} = \frac{1.273\, W}{(d_o^4 - d_i^4)} \tag{5}$$

After each test for static bending and compression parallel to grain, a sample of approximately 25.0 mm long and 25.0 mm wide was cut from the tested specimens for moisture content determination.

Shear test

Shearing stress (SS; in MPa) was measured by loading the specimen at a constant rate of 0.5 mm/minute until the maximum load was reached or when failure occurred. Shearing stress was calculated using equations (6) and (7) for samples with culm diameter less than 50 mm and greater than 50 mm, respectively:

$$\mathrm{SS} = \frac{W}{2\,tl} \tag{6}$$

or

$$\mathrm{SS} = \frac{W}{tl} \tag{7}$$

where:
W = maximum load (N)
t = culm thickness (mm)
l = length of shearing area (mm).

Anatomical properties

Fibre and vessel measurements

From each sample, matchstick-sized splints were prepared and macerated in equal volumes of 60% glacial acetic acid and 30% hydrogen peroxide. That mixture was heated in a water bath for about 1–2 hours or until the macerated material turned whitish and soft. The samples were washed with running water until they were acid-free, then soaked in 50% ethanol. Before measuring the fibre and vessel elements, the test tube containing the sample was shaken to separate the different structural elements. Fifty determinations per sample were made using a binocular microscope. Fibre length, width, lumen diameter and cell wall thickness, as well as the vessel element length and diameter, were evaluated.

Distribution of fibrovascular bundles

Portions of each transverse section per sample were smoothed with a razor blade until the fibrovascular bundles were visible under a hand lens. The bundles' frequency per unit area (no./mm^2) was determined directly using a calibrated magnifier ('scale loupe') at ×20 magnification. Twenty observations per sample were made.

Chemical properties

The starch content of samples was determined using the method developed by Humphrey and Kelly (1961). Other chemical components were analysed following the Technical Association of the Pulp and Paper Industry's (TAPPI 1995) test methods. All computations were based on the sample's oven-dry weight.

Ash content

The sample was ignited in a muffle furnace at 575 ± 25 °C. The residue after heating was weighed and calculated as percentage ash (TAPPI test T211-om-85).

Alcohol–benzene solubility

The sample was extracted for no less than 4–5 hours with a mixture of ethanol and benzene in a Soxhlet apparatus. The residue after drying was weighed and calculated as percentage solubility (TAPPI text T204-om-88).

Hot water solubility

The sample was extracted with water under reflux in a boiling water bath for 3 hours. Weight loss was calculated as percentage solubility (TAPPI test T207-om-93).

Starch content

A colorimetric method was used, which depends on the reaction of the amylose in the sample with iodine. A standard reference curve was obtained using analytical reagent (AR) grade potato starch wherein varying quantities of starch were weighed and treated using the following procedure. The sample was treated with 7.2 M perchloric acid, allowed to react for 10 minutes, transferred to a 50 mL volumetric flask and diluted with distilled water to the 50 mL mark. The solution was centrifuged and a 10 mL aliquot was placed in a 50 mL volumetric flask together with a drop of phenolphthalein and made alkaline with sodium hydroxide. Acetic acid was added to discharge the colour, followed by 10% potassium iodide and 0.1 N potassium iodate. The colour was allowed to develop for 15 minutes, brought to volume with distilled water and the absorbance measured at 650 nm using a blank prepared without starch. The percentage starch was calculated based on the standard reference curve.

Statistical analyses

The data gathered were statistically analysed using a randomised complete block design using Systat (Systat Software, Inc. 2005, San Jose, California, USA). Only those properties that had significant differences between treated and untreated samples are presented in Figures 1–22.

Results and discussion

Bambusa blumeana before treatment

Physical and mechanical properties

The decrease in dimensions of wood as it loses moisture during drying is technically known as shrinkage. It is an important property that relates to dimensional changes in wood when exposed to varying atmospheric conditions. From a practical point of view, shrinkage affects the utilisation of wood, especially in uses where dimensional stability is a major consideration such as in furniture, woodcrafts and parquetry flooring. Relative density is a measure of the amount of cell wall substance in plant material—an indicator of the material's strength properties. In pulp and paper, it is used to indicate pulp yield. In general, the higher the relative density, the greater the pulp yield. It also affects drying rate, paintability, glueability and many other working properties of wood. It is considered to be the most important property affecting the overall utilisation and conversion of wood (Wilkins 1989). Moisture content (MC) refers to the amount of water present in wood, and largely affects drying schedules of the material. It is an important property to consider when determining the yield of material from fresh bamboo culms and from various aspects of bamboo processing (Latif et al. 1993).

For physical properties, shrinkage (data not shown) and relative density (Figure 1) generally increased from culm butt to top, whereas moisture content (MC; Figure 2) showed the reverse trend (i.e. a general decrease from butt to top). The MC result was expected as there is an inverse relationship between MC and relative density.

Culm wall thickness was in the ranges of 12–29 mm, 7–15 mm and 5–9 mm at the butt, middle and top, respectively (data not presented).

For mechanical properties, the attributes of static bending—modulus of rupture (MOR), modulus of elasticity (MOE) and stress at proportional limit (SPL)—generally decreased from butt to top (Figure 3). Results for maximum crushing strength were variable, but generally increased from butt to top (Figure 4). Shearing stress generally decreased from butt to top; notably at the internodes, the shearing stress was much higher in the butt than the top.

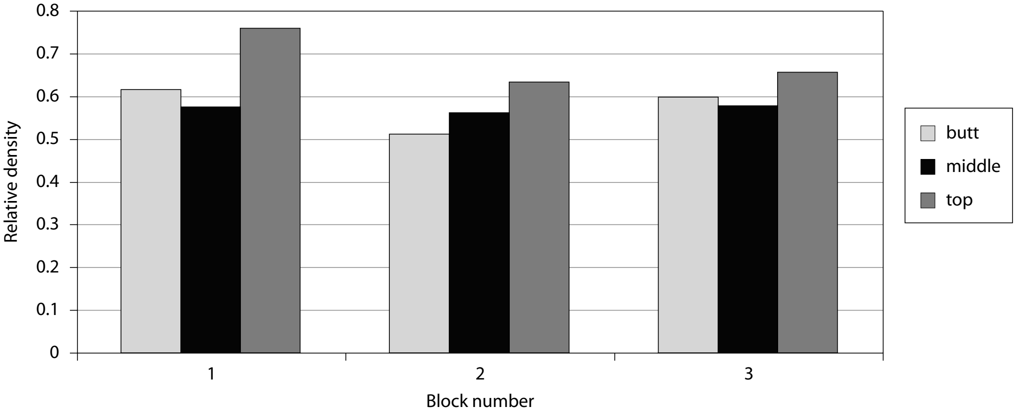

Figure 1. Relative density of untreated 4–7-year-old *Bambusa blumeana* culms at different height levels

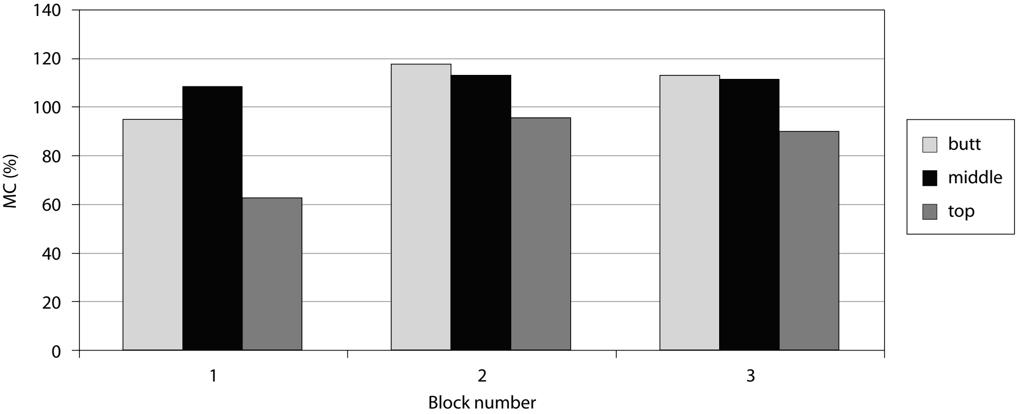

Figure 2. Moisture content (MC) of untreated 4–7-year-old *Bambusa blumeana* culms at different height levels

Anatomical properties

Fibre length in the culm decreased from butt to top while other anatomical properties showed no consistent trend (Figure 5), which confirms the findings of Latif and Liese (2002) for the same species (4-year-old culms). The longest fibres in the butt portion (averaging 2.77 mm) were slightly longer than those reported by Latif and Liese (2002) and decreased in length to 2.35 mm in the middle and 2.28 in the top portion.

The fibrovascular frequency in the peripheral, central and inner sections of the culm ranged from 7.07–10.33/mm^2, 3.07–5.60/mm^2 and 1.93–4.93/mm^2, respectively. The values at the top were higher than those of the middle and butt.

Chemical properties

Ash represents the non-volatile, non-combustible inorganic matter and is a measure of the mineral salts and other inorganic matter in the tested material. High ash content is undesirable if the material is to be used for making machine-intensive products and for the manufacture of dissolving pulp (Escolano 1973). Hot water extractives comprise tannins, gums, sugar, starches and colouring materials (TAPPI 1995). Such compounds, together with those extracted in the alcohol–benzene solubility test, also provide an indication of wood quality. They affect the natural durability of wood, pulping processes and chemical recovery. Pitch problems in processing and bleaching have been attributed to certain extractives. Hence, low

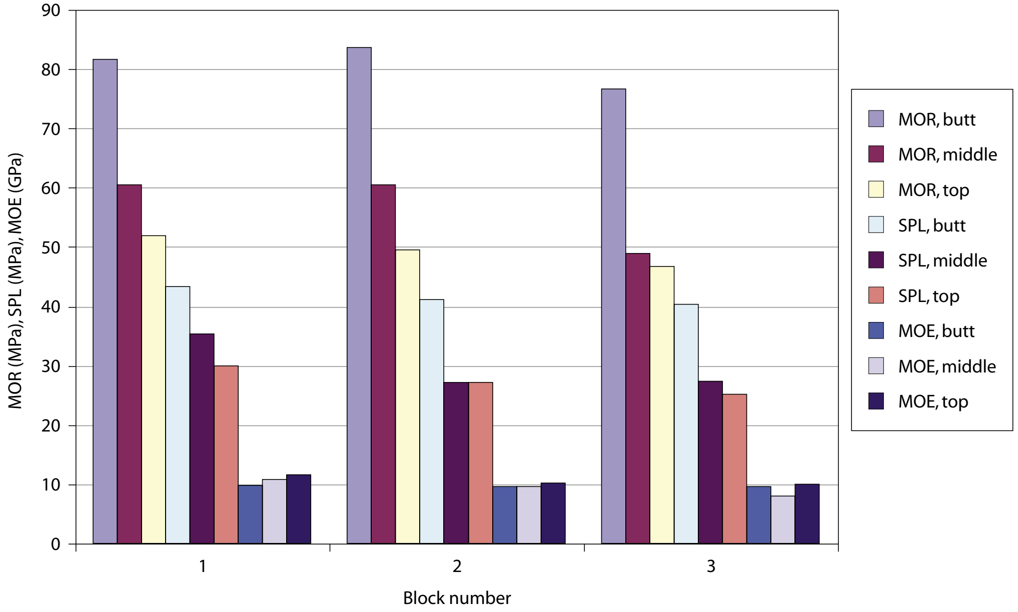

Figure 3. Static bending properties of untreated 4–7-year-old *Bambusa blumeana* culms at different height levels. Note: MOR = modulus of rupture; SPL = stress at proportional limit; MOE = modulus of elasticity.

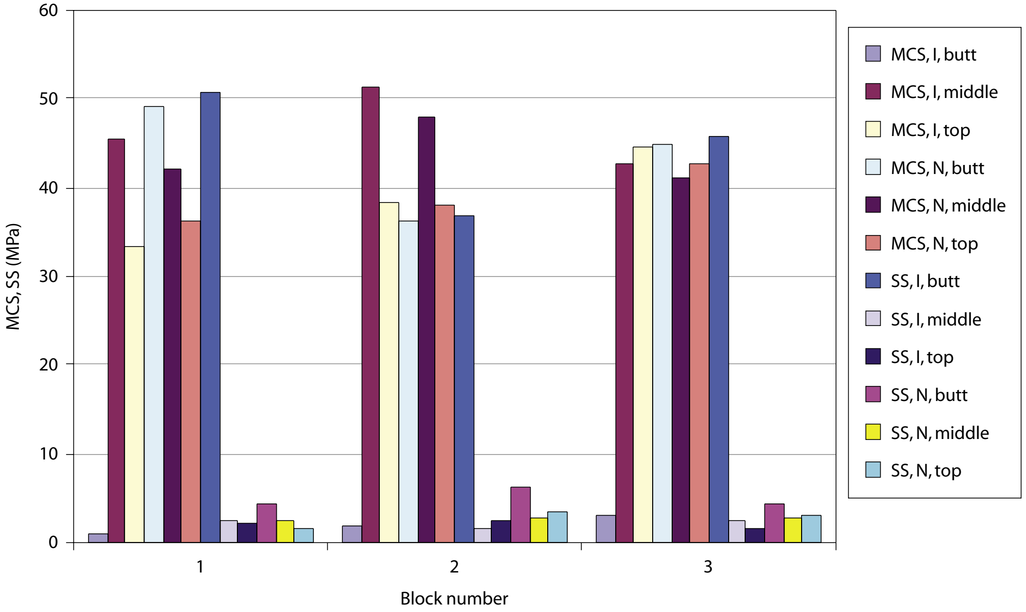

Figure 4. Maximum crushing strength and shearing stress at the internodes and nodes of untreated 4–7-year-old *Bambusa blumeana* culms at different height levels. Note: MCS = maximum crushing strength; SS = shearing stress; N = node; I = internode.

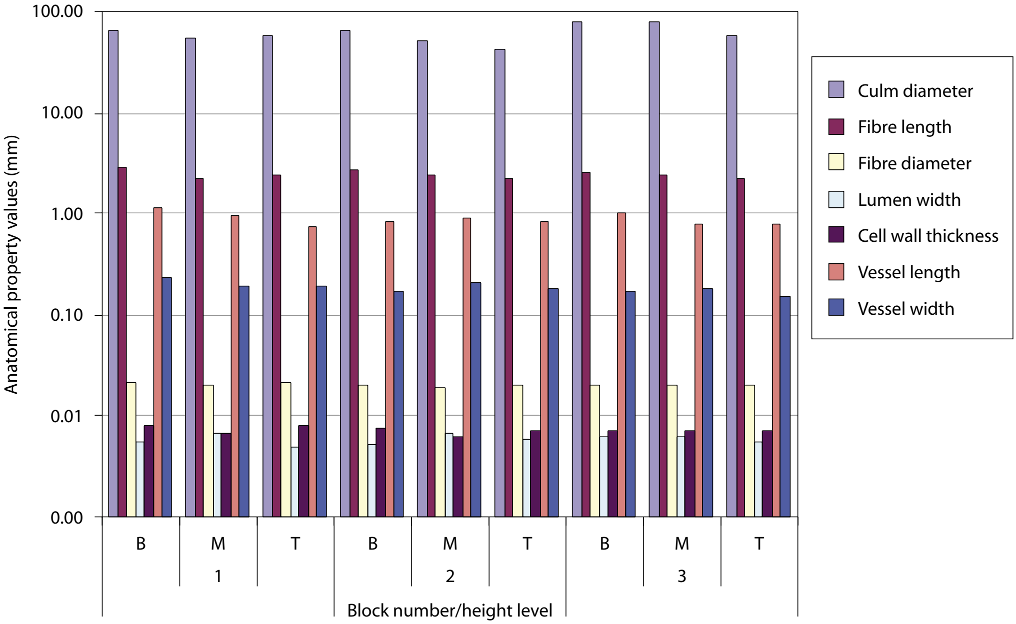

Figure 5. Anatomical properties of untreated 4–7-year-old *Bambusa blumeana* culms at different height levels. Note: B = butt (base); M = middle; T = top.

hot water and alcohol–benzene solubility is preferable. Likewise, high starch content is undesirable in the manufacture of cement-bonded particle board because the presence of hydroxyl groups in starch retards the setting time of the cement (Latif et al. 1993).

The starch content of culms from block 1 was much higher than those from blocks 2 and 3 at all height levels (Figure 6). This could be because blocks 2 and 3 were closer to the creek, with possibly greater access to water. The average ash content was slightly higher than the ranges reported by Espiloy et al. (1999) for six mature (but exact age unknown) Philippine bamboo species, 3-year-old *Gigantochloa atter* (kayali), *Bambusa* sp. 2 (laak) and 10 Chinese bamboo species. The ash content at the top portion was consistently higher than that in the butt and middle in all three blocks. Hot water extractability (HWE; measured as hot water solubility) and alcohol–benzene solubility showed no consistent trend of variation from butt to top.

Bambusa blumeana after treatment

Physical and mechanical properties

Relative density ranges in 1-, 2- and 3-year-old culms collected in 2005 were 0.40–0.50, 0.46–0.58 and 0.49–0.60, respectively. Relative density consistently increased from butt to top (data not shown).This property also increased from younger to older culms except in T3, T4, T7 and T11 where the 2-year-old culms had slightly higher values than the 3-year-old culms (Figure 7). Espiloy et al. (1986) and Liese (1998) reported that the fibrous wall of bamboo culms increased in density with age. The increase in culm wall thickness is caused by the deposition of additional lamellae, and may be reflected in an increase in relative density. Treatment differences were not marked and in T7, relative density was uniform across culm age.

According to Chaturvedi (1990), bamboo in its third year of growth is considered mature as it has already acquired full strength and density. However, Husan (1969) reported that a 3-year-old culm is still undergoing physiological activity in which both the rhizomes and culms continue to grow in weight and consequently increase in density. Hence, he suggests that 3 years old may not yet be the optimal culm age for pulping. Virtucio et al. (1990) reported that the maximum physico-mechanical properties and pulp yield of six bamboo species were attained in culms between 2 and 5 years of age.

The higher relative density values of some of the 4–7-year-old compared to 3-year-old culms that

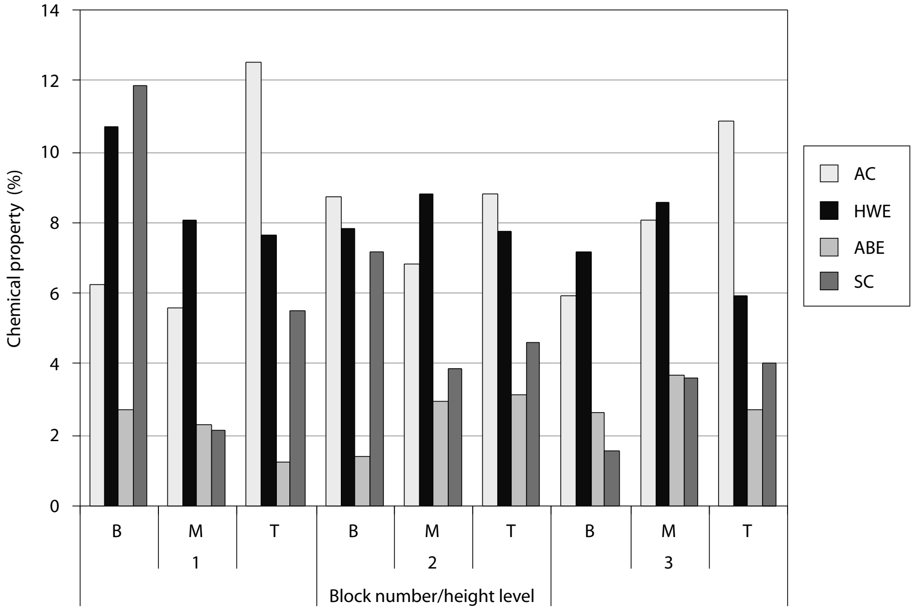

Figure 6. Chemical properties of untreated 4–7-year-old *Bambusa blumeana* culms at different height levels. Note: AC = ash content; HWE = hot water extractives; ABE = alcohol–benzene extractives; SC = starch content; B = butt (base); M = middle; T = top.

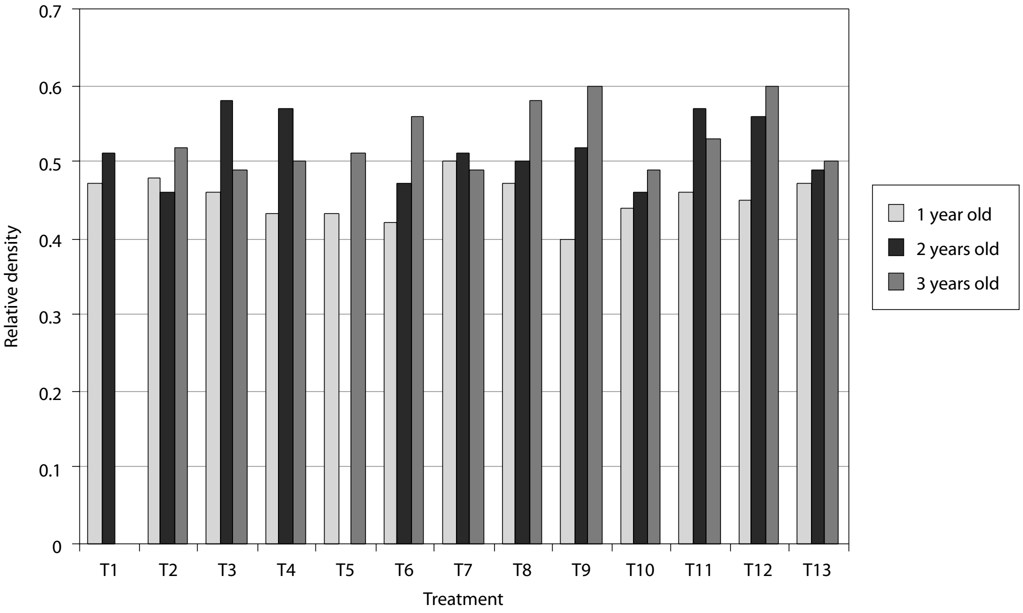

Figure 7. Average relative density of *Bambusa blumeana* culms at different ages that had been subjected to varying silvicultural treatment. Note: see Table 1 for treatment details; missing data due to bent or displaced culms.

received treatments may be due to the older ages of the former. Generally, 3 years old is considered the most appropriate age to harvest bamboo for maximum utilisation (Uriarte et al. 1988, as cited by Espiloy 1992) while according to Virtucio et al. (1990), 4 years old is the best age for harvest to generate more income and sustain the plantation.

The effect of treatments on shrinkage along the thickness and width was significant in the butt portion of 2-year-old culms. In the middle portion, treatment had significant effect on the shrinkage along the width and thickness of the 1- and 2-year-old culms, respectively. Treatment had no significant effect on shrinkage of the 3-year-old culms nor on shrinkage in the top culm portion. Treatments 1, 7 and 9 had significantly lower shrinkage along the thickness of butt portions of 2-year-old culms. On the other hand, T4 had significantly higher shrinkage along the width of 2-year-old culms, butt portion. In the middle portion of 1-year-old culms, T6 and T8 had significantly lower shrinkage along the width, while in 2-year-old culms of the same portion, T10 had significantly higher shrinkage along the thickness (Figure 8).

Fernandez (2005) reported that there were no significant differences in strength properties among fertiliser-treated and control culms. Moreover, Fernandez reported a negative/poor correlation between culm characteristics and relative density and mechanical properties.

The strength classification (see FPRDI 1980 for details) of 3-year-old culms harvested from clumps of *B. blumeana* that underwent 4 years of treatment at Ilocos Norte is shown in Table 3. Data regarding the top portion of the culms are not included because of the limited number of samples and the small diameter and thin culm wall in that section, which constrained its use for engineered products (floor tiles and lumber).

As per FPRDI's strength classification, culms from T2, T3, T5, T6, T7 and T8 are preferable for construction purposes or applications requiring medium to moderately high strength for all categories in Table 3. T1, T6 and T7 met the 1.5 cm culm wall thickness (data not shown) required in the bamboo floor tiles and laminate technology of the Mariano Marcos State University (MMSU) in Batac, Ilocos Norte (Zafaralla and Malab 2009). However, the strength properties were lower than in the other treatments, while T6 and T7 had fewer harvestable culms than T1. Although T8 had thinner culm wall than T1, T6 and T7 (data not presented), the higher strength properties of T8 could

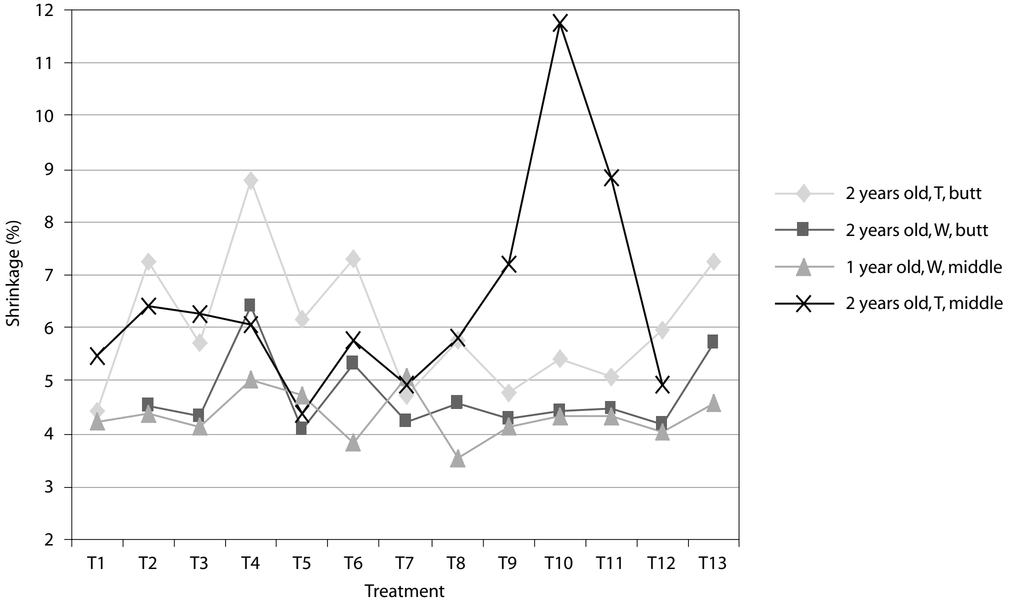

Figure 8. Shrinkage along the width (W) and thickness (T) of *Bambusa blumeana* culms of different ages that had been subjected to varying silvicultural treatment. Note: see Table 1 for treatment details.

compensate for the slight difference in the thickness of the end products.

The diameter ranges of culms at 3.5 m height used in this study were 38.88–89.59 mm, 32.17–82.47 mm and 41.15–89.57 mm for 1-, 2- and 3-year-old culms, respectively, while culm wall thickness ranges at the same height were 14.80–74.01 mm, 16.76–66.41 mm and 15.59–70.47 mm.

Only the butt and middle (3.5–4 and 4–8 m from the stump, respectively) were considered since these are the culm portions used for engineered products such as floor tiles and laminated lumber for construction.

Table 3. Strength property classification[a] of 3-year-old culms of *Bambusa blumeana* that had been subjected to varying silvicultural treatment

(a) Butt portion of the culm

Treatment[b]	Relative density	Static bending		Shearing stress	Maximum crushing strength
		Modulus of rupture	Modulus of elasticity		
T1	C5	C5	C4	C4	C3
T2	C4	C3	C2	C2	C2
T3	C4	C3	C2	C3	C2
T4	C5	C4	C2	C4	C4
T5	C4	C4	C3	C1	C2
T6	C4	C3	C2	C2	C3
T7	C4	C3	C1	C4	C2
T8	C4	C3	C1	C3	C1
T9	C4	C4	C2	C3	C2
T10	C4	C5	C2	C2	C2
T11	C4	C4	C3	C4	C2
T12	C3	C4	C1	C2	C2
T13	C4	C5	C3	C4	C2

(b) Middle portion of the culm

Treatment[b]	Relative density	Static bending		Shearing stress	Maximum crushing strength
		Modulus of rupture	Modulus of elasticity		
T1	C4	C3	C2	C4	C2
T2	C3	C4	C3	C1	C2
T3	C3	C5	C2	C2	C2
T4	C4	C5	C3	C4	C3
T5	C3	C3	C2	C1	C2
T6	C2	C5	C2	C2	C1
T7	C3	C4	C2	C2	C2
T8	C2	C3	C1	C2	C1
T9	C2	C5	C2	C3	C2
T10	C3	C3	C3	C1	C2
T11	C3	C4	C2	C2	C2
T12	C3	C5	C2	C2	C1
T13	C2	C5	C3	C3	C2

[a] Using the strength classification of the Forest Products Research and Development Institute (FPRDI 1980): C5 = low strength; C4 = moderately low strength; C3 = medium strength; C2 = moderately high strength; and C1 = high strength

[b] See Table 1 for treatment details

Although the top has higher relative density and strength properties than the middle and butt, the diameter and culm wall thickness of top sections are too small for making floor tiles and laminates.

Anatomical properties

As discussed above, fibre dimensions such as length and diameter, lumen width and cell wall thickness are useful indicators of wood quality. They have been known to affect many strength properties of paper. The effect of treatments on the anatomical properties of culms of different ages was not consistent. For instance, treatments significantly affected fibre length in 2-year-old culms (top only), fibre cell wall thickness in 3-year-old culms at (all height levels), vessel diameter in 1-year-old culms (butt only), and fibre lumen diameter in 1-year-old culms (butt and top), as detailed below.

Treatment 8 had the longest fibre length, significantly so compared to most other treatments (Figure 9). Fibre cell wall thickness generally increased from butt to top and T1, T5, T6 and T8 had significantly thicker cell walls than the other treatments (Figure 10). The diameter of vessel elements was significantly greater in T2 and T13 (Figure 11). For fibre lumen diameter: T2 had significantly wider lumen than most other treatments in the butt portion of the 2-year-old culms (Figure 12); T6, and T8 had wider lumen in the top portion of the 3-year-old culms (data not shown); and T1, T7 and T8 had significantly wider lumen width than other treatments in the top portion of the 1-year-old culms (Figure 12).

Based on the Runkel, Mulsteph and flexibility ratios as explained by Aday et al. (1980), the anatomical properties of harvested culms were unfavourable for pulp and paper making, regardless of treatment. However, the culms' long fibres, especially 2-year-old culms in T8 (over 3 mm; Figure 9), may be interesting to consider. In general, higher fibre length corresponds to a greater resistance to tearing.

Chemical properties

The effect of treatments on the chemical properties was not significant, nor was there an effect of position within the culm (data not presented).

Although the ash content of treated culms (T1–T12) and untreated culms (T13) did not significantly differ, it is noteworthy that the annual average values markedly decreased from 2002 to 2005 (Figure 13). This indicates that, as the clump age increases, the ash content decreases. This is advantageous as far as fibre conversion into pulp is concerned. As yet, no literature is available with which to compare these findings. Nonetheless, the trend may be attributed to the changes in soil composition and/or clump density.

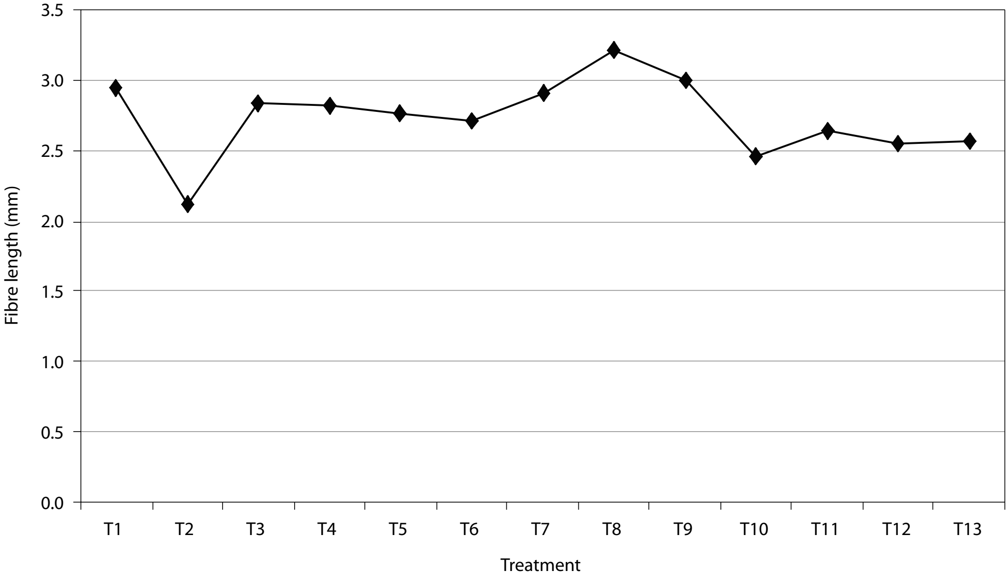

Figure 9. Effect of treatments on the fibre length in the top portion of 2-year-old culms of *Bambusa blumeana*. Note: see Table 1 for treatment details.

Dendrocalamus asper after treatment

Physical properties

Relative density. The effect of treatments on culm relative density was significant only for the butt portion of the culms in 2006 where T5, T7 and T8 were significantly lower than T10 (Figure 14). Given that higher relative density is a desirable quality for most applications, this indicates that treatments did not lead to improvements in this property. Although T3 had a higher value than T10, the difference was not significant (M.A. Alipon 2009, unpublished final report to ACIAR). Overall, there was no clear trend in relative density among treatments.

Moisture content (MC). This generally decreased from butt to top across treatments, but did not significantly differ between treatments. The butt portion in T8 (2005) and T7 (2006) had the highest

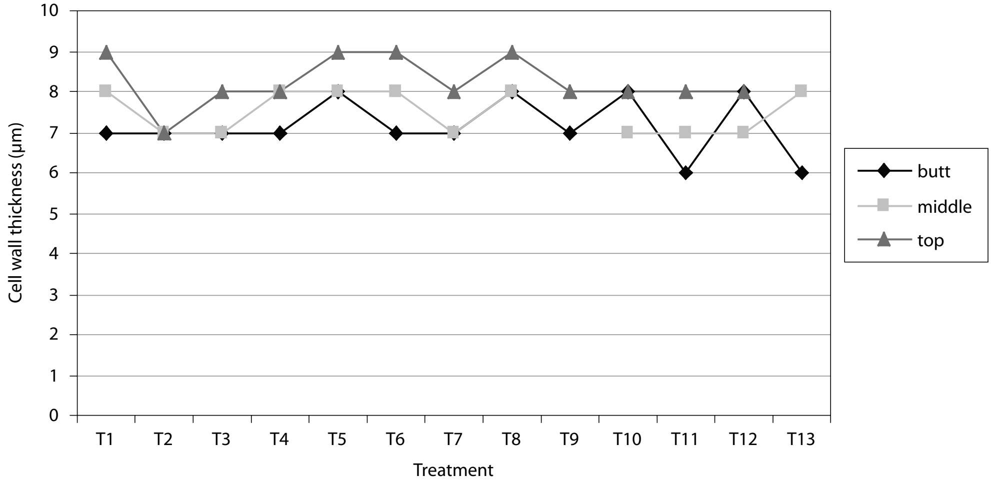

Figure 10. Effect of treatments on fibre cell wall thickness of 3-year-old culms of *Bambusa blumeana.* Note: see Table 1 for treatment details.

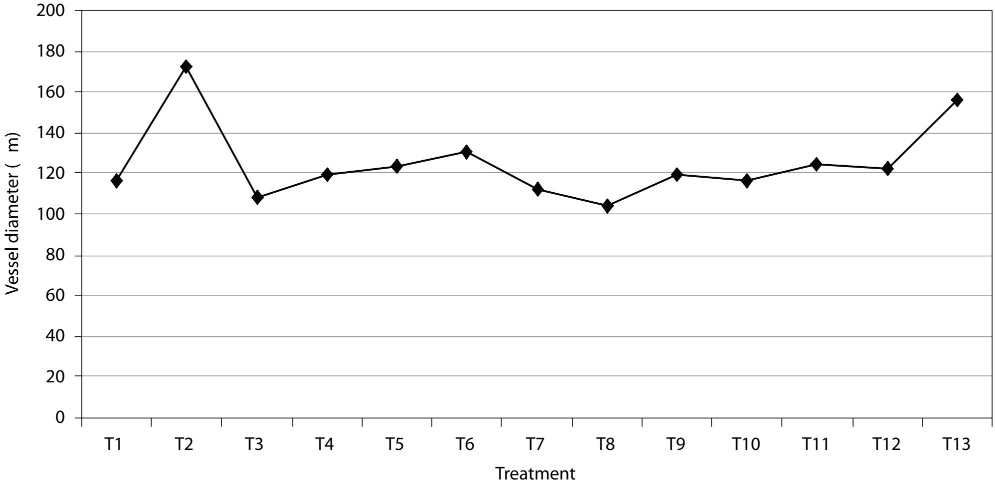

Figure 11. Effect of treatments on the vessel element diameter of the butt portion of 1-year-old culms of *Bambusa blumeana*. Note: see Table 1 for treatment details.

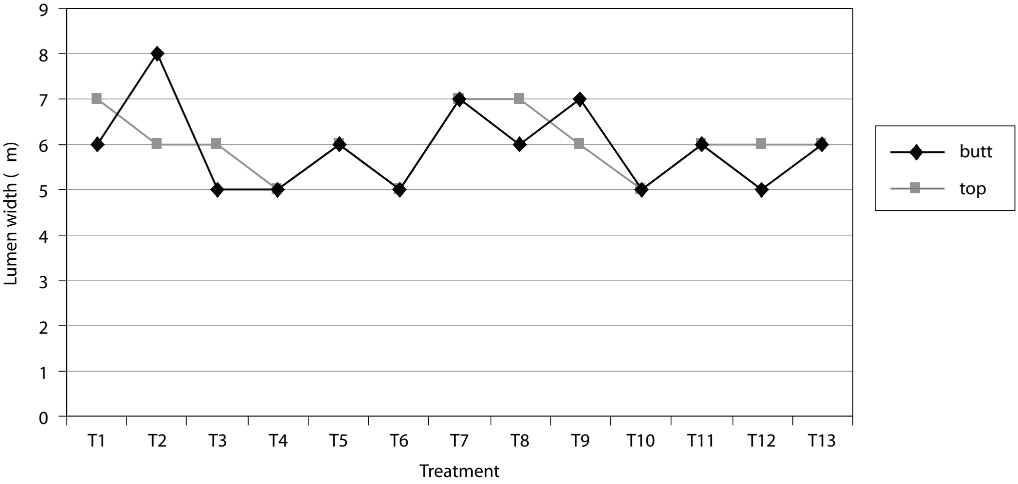

Figure 12. Effect of treatments on fibre lumen width of 1-year-old culms of *Bambusa blumeana*. Note: see Table 1 for treatment details.

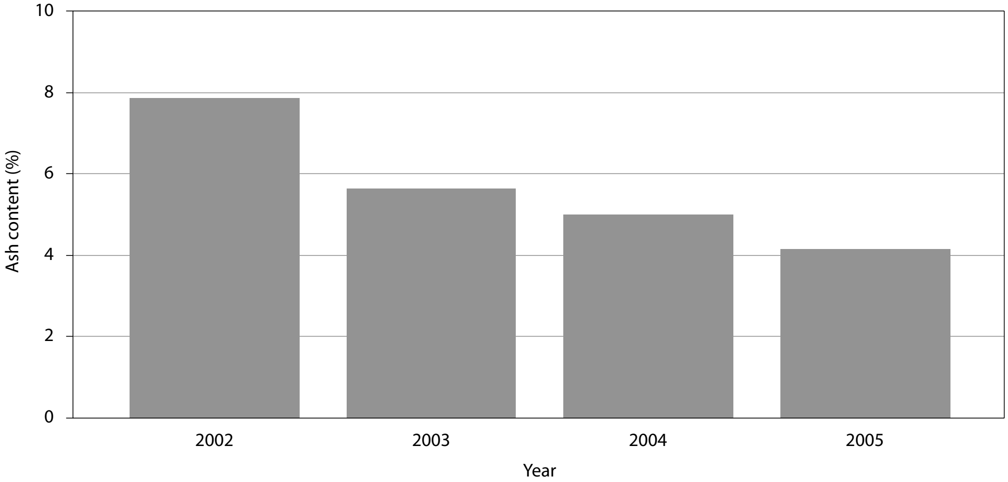

Figure 13. Average ash content of *Bambusa blumeana* culms from 2002 to 2005

MC in 2-year-old culms, however this was still lower than the top portion of T7 (1-year-old culms) (data not shown). Liese (1985) reported that MC was considerably lower in older culms than in younger ones. This may be attributed to the comparatively equal distribution of water in young culms. On the other hand, the higher MC at the butt was attributed to the presence of more parenchyma cells in this portion than the top. The decrease of MC with age and height of the culm has to be considered in determining the yield of material from fresh bamboo culms and for various aspects of wood processing (Latif et al. 1993).

Shrinkage. In 2005, 2-year-old culms from T1 had significantly higher shrinkage along the thickness of the culm middle portion than other treatments. In 2006, T2 and T8 had significantly higher shrinkage along the width of 1-year-old culm butt portions. Apart from these effects, there was no consistent trend of variation in shrinkage (thickness or width)

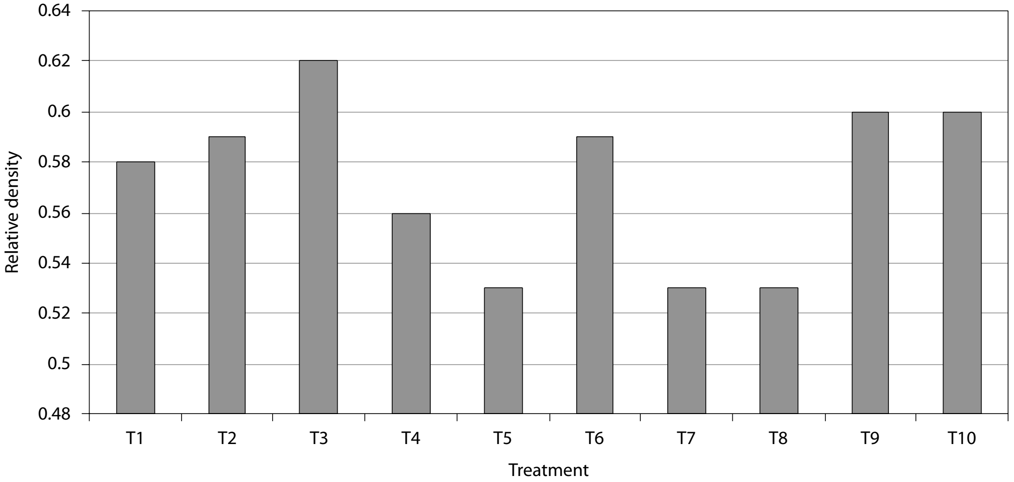

Figure 14. Effect of treatments on relative density of the butt portion of 2-year-old culms of *Dendrocalamus asper* measured in 2006. Note: see Table 2 for treatment details.

across treatments (Figure 15). The shrinkages were 50% less than those reported by Espiloy (1992). The difference may be due to differences in location and/or age of the culms.

Mechanical properties

Statistical analysis of the effects of treatments on the mechanical properties of *D. asper* is reported elsewhere (M.A. Alipon 2008, unpublished final report to ACIAR), and data are summarised in Figures 16–18.

Shearing stress (SS). The effect of treatment on 2-year-old culms harvested in 2005 was significant for SS at the internode (I) in the butt, middle and top culm portions, and at the node (N) in the middle and top portions. Overall, T5 at the top had significantly higher SS than the middle and butt portions (Figure 16a). In the 1-year-old culms collected in 2006, treatment differences in SS (I and N) were significant only in the top portion. Treatments 5 and 7 had significantly

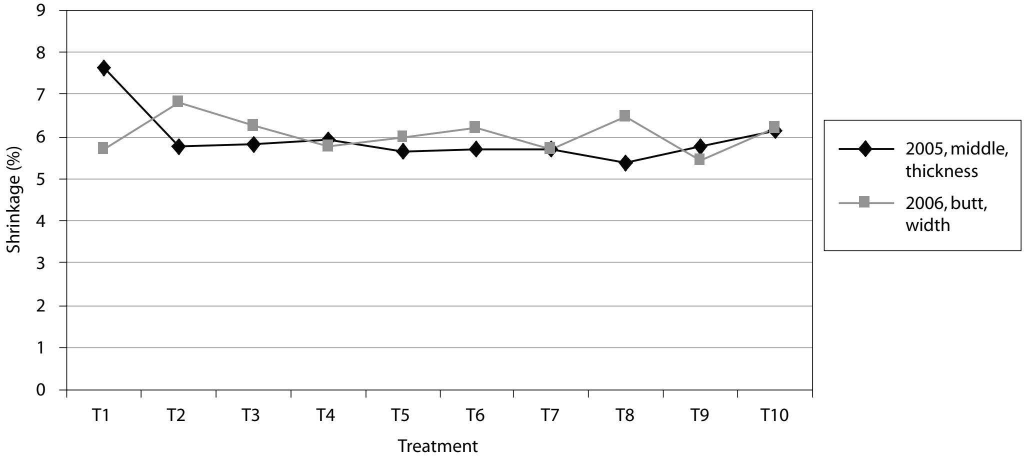

Figure 15. Shrinkage along the width (1-year-old) and thickness (2-year-old) culms of *Dendrocalamus asper* that had been subjected to various silvicultural treatments. Note: see Table 2 for treatment details.

lower SS at the nodes and internodes (Figure 17). In the 2-year-old culms harvested also in 2006, SS at the internodes showed significant differences only in the butt portion, while at the nodes in both at the butt and top portions at the nodes. In the butt portion, T5 and T7 had significantly lower SS at the nodes while at the top, T1, T3, T4, T6, T7 and T8 had significantly lower SS at the nodes (Figure 18a).

Stress at proportional limit (SPL). Except in T8, all treatment values increased from butt to top (data not shown). The effect of treatment was significant for T2 and T9 in the butt portion, and for T2 in the middle portion of 2-year-old culms tested in 2005. The middle portion of 2-year-old T2 culms had a significantly higher SPL value, as did those of T2 and T9 in the butt portion (Figure 16b). On the other

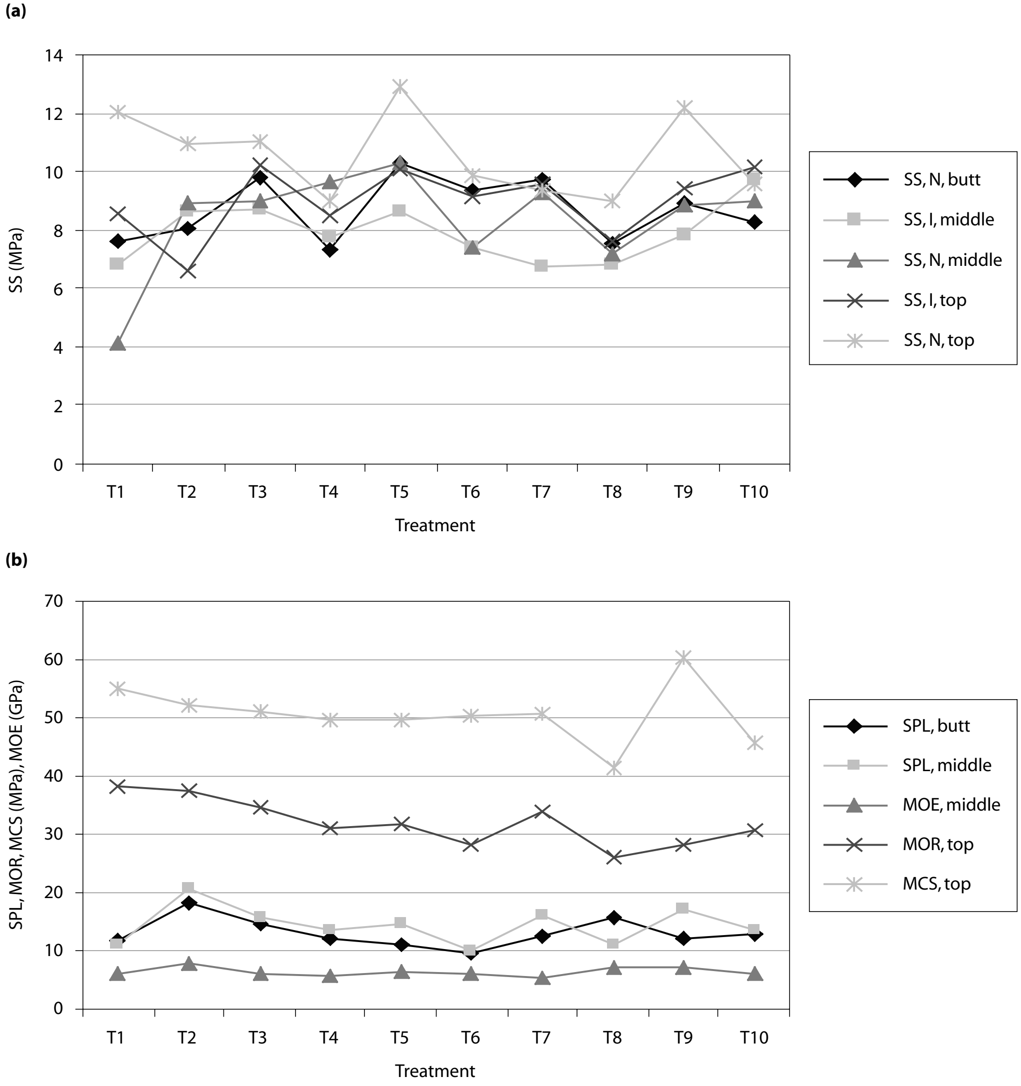

Figure 16. Strength properties of 2-year-old culms of *Dendrocalamus asper* at different height levels with significant effect of treatments, harvested in 2005. Note: see Table 2 for treatment details; SS = shearing stress; MCS = maximum crushing strength; SPL = stress at proportional limit; MOE = modulus of elasticity; MOR = modulus of rupture; N = node; I = internode.

hand, the middle portion of 2-year-old T3 and T9 culms tested in 2006 had significantly lower SPL values (Figure 18b).

Modulus of rupture (MOR). The butt portion had higher values than the middle and top (2005 and 2006; data not shown). In the top portion of 2-year-old culms in 2005, MOR was significantly highest in T1 (Figure 16b). The range of values between treatments was small and almost all treatments fell under C5 (low strength) regardless of the position in the culm (Table 4).

Modulus of elasticity (MOE). The effect of treatment was not significant except for T2, T8 and T9 in the middle portion of 2-year-old culms harvested in 2005 that were significantly higher (Figure 16b) and T7 in the middle portion of 2-year-old culms harvested in 2006 that were much lower (Figure 17).

Maximum crushing strength. For 2-year-old culms harvested in 2005, T9 had significantly higher MCS at the internodes (Figure 16b). In the butt portion of 2-year-old culms harvested in 2006, T1 and T7 had significantly lower MCS at the internodes while T3, T7 and T9 had significantly higher MCS at the nodes (Figure 18c). Treatment 7 had significantly lower MCS at the nodes in the middle portion and at the internodes of the top portion. The nodal MCS of T8 in the top portion was significantly lower than other treatments (Figure 18c).

The strength property classification (see FPRDI 1980 for details) of 2-year-old culms harvested from clumps of *D. asper* that underwent 4 years of treatment is presented in Table 4.

According to the strength classification, regardless of the treatment, *D. asper* had high (C1) MCS, moderately high (C2) to medium (C3) relative density and SS. However, the MOR and MOE fell in the moderately low (C4) and low (C5) groups.

The properties of culms with and without treatment were comparable. Of the 10 treatments, T3 (fertiliser applied but no mulch, six 1-year-old and six 2-year-old culms retained) showed the highest relative density (data not shown).

The properties of 1-year-old culms were comparable to 2-year-old culms. However, T6 (mulch and fertiliser applied, ten 1-year-old and 2-year-old culms) should provide more culms but this treatment did not succeed in attaining the desired number of culms due to mortality (Decipulo et al. 2009).

Anatomical properties

Statistical analyses on the effects of treatments on anatomical properties are presented elsewhere (M.A. Alipon 2008, unpublished final report to ACIAR). The effect of treatment on fibre cell wall thickness (CWT) was significant in 2005 in the butt and middle portions of 2-year-old culms and, in 2006, in the butt of 2-year-old and the top of 1-year-old culms (Figure 19). Among treatments in 2005, T3, T5, T6 and T8 had significantly higher CWT in the butt of 2-year-old culms. In the middle portion, the CWT in T3 and T5 was higher than the other treatments. Among treatments in 2006, T3, T6, T8 and T10 had significantly higher CWT in the butt portion than

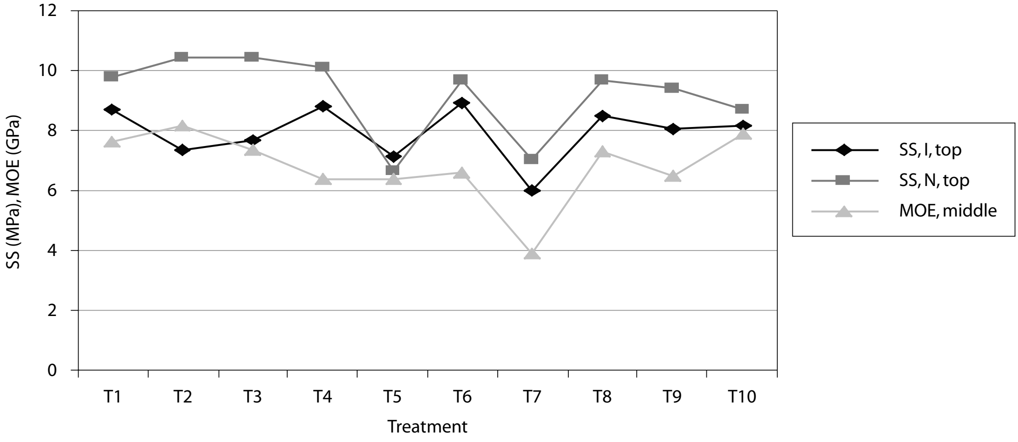

Figure 17. Strength properties of 1-year-old culms of *Dendrocalamus asper* at different height levels with significant effect of treatments, harvested in 2006. Note: see Table 2 for treatment details; SS = shearing stress; MOE = modulus of elasticity; N = node; I = internode.

other treatments, as did T5, T8 and T10 in the top portion. The thicker cell wall in some treatments indicates property improvement with treatment application. It is important to note that the thicker the cell wall, the higher the cellulose content and consequently, the higher the pulp yield.

Management treatments significantly affected the following anatomical properties: fibre length (2005, top portion, 2-year-old culms; 2006, butt, middle and top portions, 2-year-old culms; and 2006, top portion, 1-year-old culms); fibre width (2006, butt, middle and top portions, 2-year-old culms); vessel length (2006, top portion, 1- and 2-year-old culms); and fibre lumen diameter (2006, butt portion, 1-year-old culms—Figure 20).

Although the fibre length of treated culms was significantly shorter than untreated culms, it is noteworthy that the length was still long, with ranges of 3.183–3.762 mm (butt), 3.446–3.665 mm (middle), and 2.960–3.631 mm (top) (data not shown). The longest fibres were observed in T5 and T7 (3.762 and 3.513 mm, respectively, butt), T5 and T6 (3.665 and 3.663, respectively, middle), and T5 and T6 (3.463 and 3.631mm, respectively, top); quite close to those of the control (3.639–3.668 mm).

Table 4. Strength property classification[a] of 2-year-old culms of *Dendrocalamus asper* that had been subjected to varying silvicultural treatment

(a) Butt portion of the culm

Treatment[b]	Relative density	Static bending		Shearing stress	Maximum crushing strength
		Modulus of rupture	Modulus of elasticity		
T1	C2	C5	C5	C2	C1
T2	C2	C4	C5	C2	C1
T3	C2	C5	C5	C3	C1
T4	C2	C5	C5	C3	C1
T5	C3	C5	C5	C3	C1
T6	C2	C4	C5	C3	C1
T7	C3	C5	C5	C3	C1
T8	C3	C5	C5	C3	C1
T9	C2	C5	C4	C3	C1
T10	C2	C5	C5	C3	C1

(b) Middle portion of the culm

Treatment[b]	Relative density	Static bending		Shearing stress	Maximum crushing strength
		Modulus of rupture	Modulus of elasticity		
T1	C2	C5	C4	C2	C1
T2	C2	C5	C4	C2	C1
T3	C2	C5	C5	C3	C1
T4	C2	C5	C4	C2	C1
T5	C2	C5	C4	C3	C1
T6	C2	C5	C4	C3	C1
T7	C2	C5	C4	C3	C1
T8	C2	C5	C5	C3	C1
T9	C2	C5	C5	C3	C1
T10	C2	C5	C4	C3	C1

[a] Using the strength classification of the Forest Products Research and Development Institute (FPRDI 1980): C5 = low, C4 = moderately low, C3 = medium, C2 = moderately high and C1 = high strength

[b] See Table 1 for treatment details

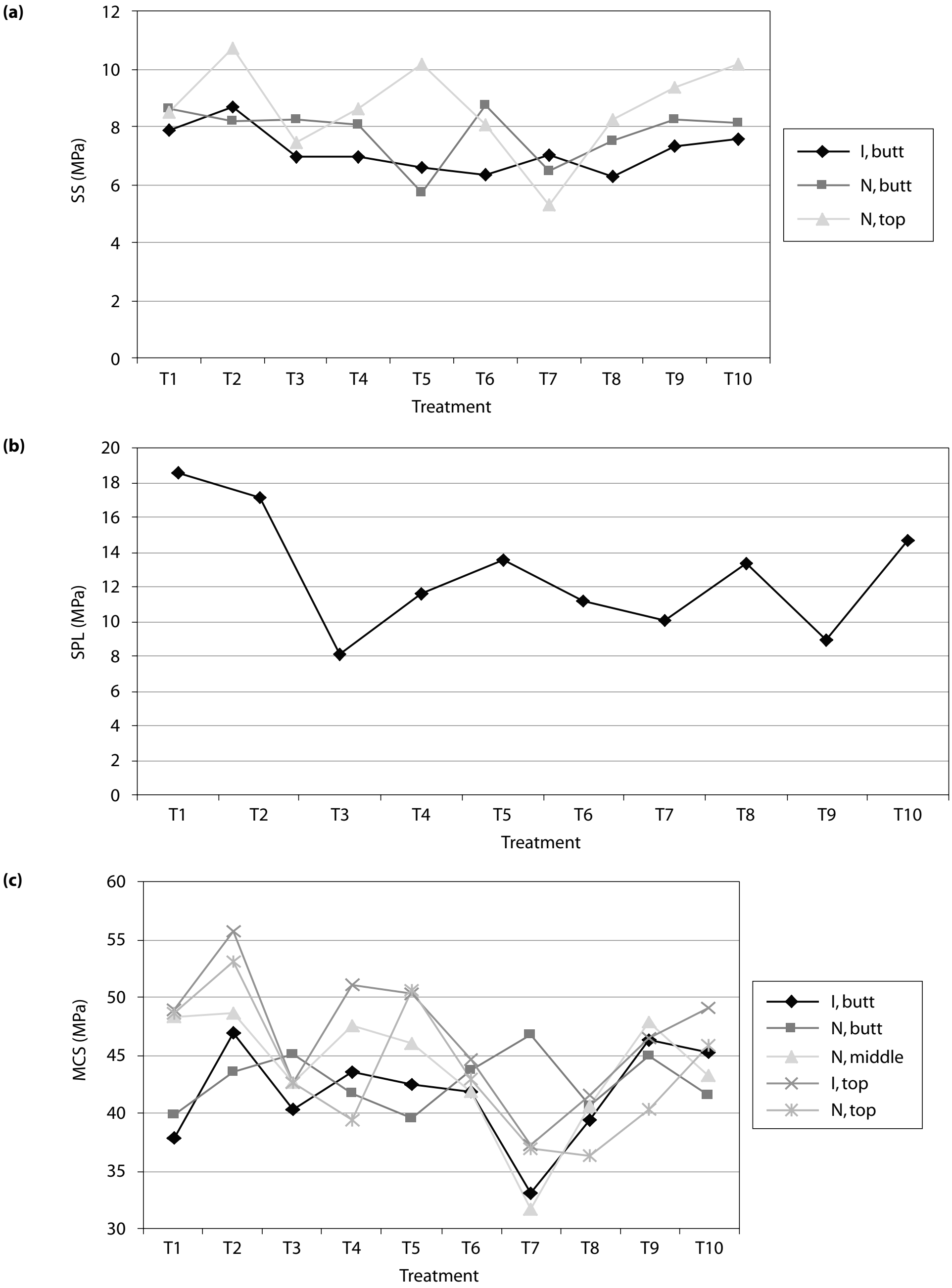

Figure 18. Strength properties of 2-year-old culms of *Dendrocalamus asper* at different height levels with significant effect of treatments, harvested in 2006 showing (a) shearing stress, (b) stress at proportional limit and (c) maximum crushing strength. Note: see Table 2 for treatment details; SS = shearing stress; MCS = maximum crushing strength; SPL = stress at proportional limit; N = node; I = internode.

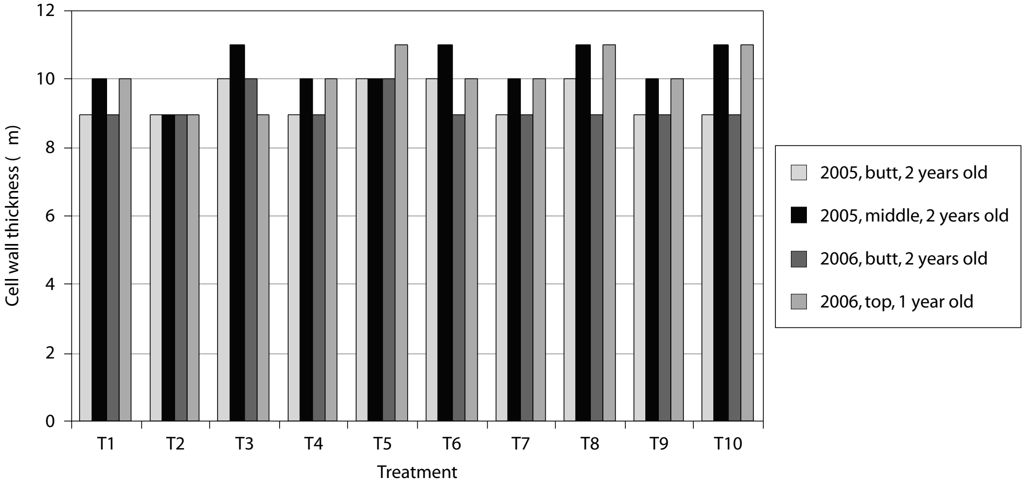

Figure 19. Effects of treatment on fibre cell wall thickness of *Dendrocalamus asper* culms at different height levels. Note: see Table 2 for treatment details.

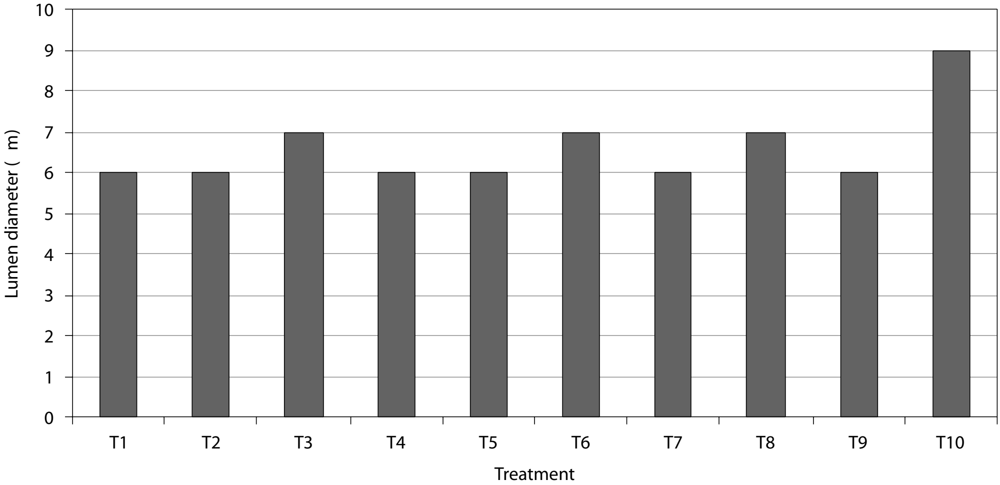

Figure 20. Effect of treatments on lumen diameter in the butt portion of 2-year-old *Dendrocalamus asper* culms harvested in 2006. Note: see Table 2 for treatment details.

According to Abasolo et al. (2005), the effect of fertiliser was not significant, but they did not quantify the impact of the fertiliser treatments on soil nutrient availability to see if there was indeed an effect.

Fibre length and cross-sectional dimensions (fibre width, lumen diameter and cell wall thickness) affect many strength properties of paper, as previously mentioned. Reports indicated that cross-sectional dimensions are closely related to paper strength (Aday et al. 1980). Indeed a 'minimum length' is required to provide sufficient bonding surface to spread the stresses over the entire area of the sheet and modify the advanced aspect of relatively thick-walled fibres (Panshin and de Zeeuw 1980). Therefore, the suitability of wood for pulp and paper depends to a great extent on the Runkel ratio (RR) which is the ratio of twice the cell wall thickness (CWT) to the diameter (width) of the lumen (LW) (RR = 2 CWT/LW).

Culms with a Runkel ratio greater than unity are not promising for pulp and paper making (Tamolang et al. 1968). However, it was also reported that although high fibre density (thick-walled fibres) produces sheets of low tensile strength, the maximum attainable tensile rupture line and maximum tear factor are considerably increased if the fibres are long. Thus, the length of the fibres may offset the detrimental effects of thick cell walls (America 1982).

In the current study, the Runkel ratios of treated and untreated samples were greater than 1.25, indicating their fibres are not promising for pulp and paper making. However, the fibres are extremely long (generally over 3 mm); consequently the tearing strength is proportionately high. Moreover, the fibre length and width (0.020–0.028 mm), regardless of the treatment, showed that it is possible to develop and apply fibre products for textile purposes. Wang and Jiang (2008) reported in detail the benefits of bamboo fibre application in China for production of textiles.

Chemical properties

The chemical properties of the culms showing significant difference between treated and untreated samples are presented in Figures 21 and 22.

Hot water extractives in T2 and T7 (butt), and T1 and T2 (middle) were significantly higher than that of T10. T2 had significantly higher HWE based on the average values of butt, middle and top portions. Other treated samples were comparable to untreated ones (Figure 21). All the samples contained large amounts of phenolic (alcohol–benzene) extractives (data not shown). Hot water extractives (HWEs) comprise tannins, gums, sugars, starches and colouring matters while phenolic extractives include only some HWE like tannin. However, both of them have been reported to lower pulp yield and chemical recovery (Hillis 1972).

The ash content of treated and untreated samples did not significantly vary except at the top where T7 (3.1%) was significantly higher than T10 (1.3%).

Results indicate that T1, T2 and T7 are the least preferable for converting culm fibres into various products such as pulp, paper and fibreboard.

Conclusions and recommendations

As indicated below for each species separately, the effects of treatment on the basic properties of culms were not consistent, although some general species-specific recommendations are made, particularly with respect to age of culms at harvest and suitability of culms for the production of engineered bamboo products. Greater differences were evident between species than between treatments, although the species effect was confounded with production sites.

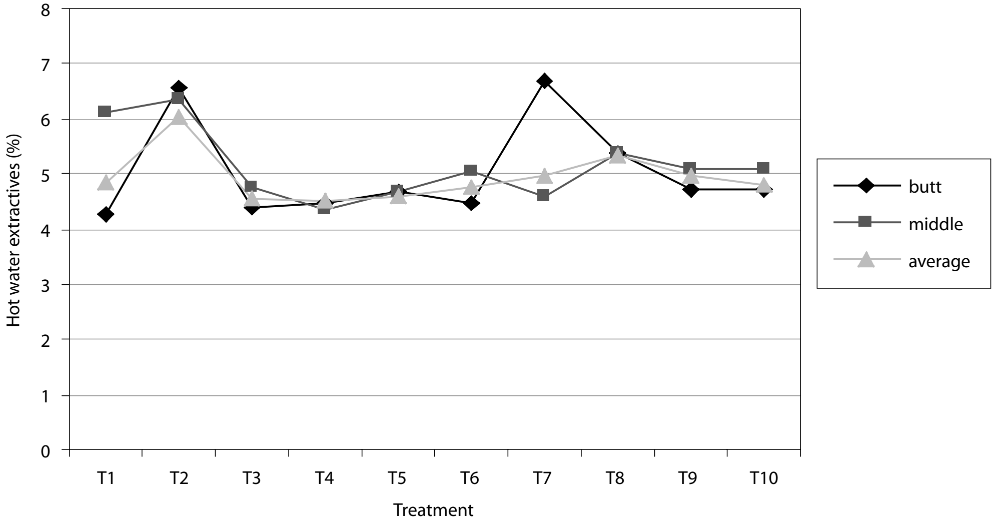

Figure 21. Effects of treatments on hot water solubility of 2-year-old *Dendrocalamus asper* culms at different height levels. Note: see Table 2 for treatment details.

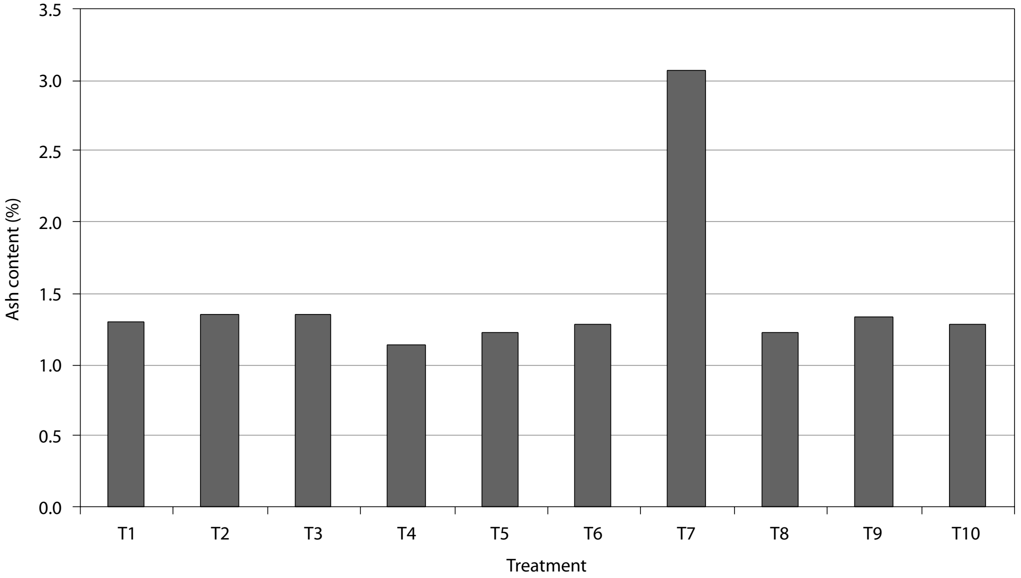

Figure 22. Effect of treatments on the ash content of the top portion of the culms of 2-year-old *Dendrocalamus asper*. Note: see Table 2 for treatment details.

Bambusa blumeana (kawayan tinik)

1. The effects of treatments on the physical, mechanical, chemical and anatomical properties were generally not significant.
2. T1 (with 4-4-4 standing culm density [SCD]—four 1-year-old, four 2-year-old and four 3-year-old culms are retained in each clump—continuous irrigation, mulch, organic matter and fertiliser) produced culms with the thickest walls (based on MMSU data 2005). However, based on the strength classification devised at FPRDI, the culms were inferior to those that received other treatments (T2–T12).
3. T8 (4-4-4-4 SCD, continuous irrigation, mulch, organic matter and fertiliser) generally exhibited the highest strength.
4. T12 (cleaning only, no irrigation but with mulch, organic matter and fertiliser) resulted in culms with comparable-to-better strength properties than T13 (‘do nothing’).
5. Culms that have been dislodged, bent or broken should be removed since their properties will no longer improve as they continue to age.
6. The usual practice is to cut the culm 2 m above the ground because of the thorny branches. However, with the right silvicultural treatment, the 2 m butt can be used for engineered products because of its favourable culm wall thickness, diameter, and physical and mechanical properties.
7. The strength properties of 4–7-year-old bamboo culms were better than those of 3-year-old culms. Hence, it is recommended to harvest culms older than 3 years old for housing construction and other structural uses where strength is a critical factor. However, the economics of harvesting at older ages need to be assessed.
8. Since T8 produced the highest number of culms with superior strength properties, it would be the best treatment to adopt to regenerate old stands of *B. blumeana* for sustainable and good-quality culms. However, irrigation as a management practice may be optional due to economic considerations.

Dendrocalamus asper (giant bamboo)

1. The effects of treatments on physical and mechanical properties were generally not significant. Hence, to produce culms for engineered products, any of the treatments could be adopted without any adverse effects on culm properties.
2. The effects of treatments on anatomical properties were generally significant, and were especially pronounced on fibre length and fibre cell wall

thickness. T3, T5, and T8 exhibited comparable cell wall thickness to T10. The application of any of these treatments to culms intended for pulping purposes might be beneficial, although T5 and T8 had low culm biomass yields (Decipulo et al. 2009).

3. T3 (6-6 SCD, with strategic irrigation and fertiliser but no mulch) gave the highest number of culms (Decipulo et al. 2009) with acceptable strength properties and comparable anatomical and chemical properties to untreated culms. Hence, it would be the best treatment for regenerating old clumps of *D. asper* for sustainable and good-quality culms.
4. In contrast to *B. blumeana*, where strength properties were still improving in culms older than 3 years old (regardless of the treatments), the strength properties of 1-year-old culms of *D. asper* were similar to those of 2-year-old culms. Hence, 1-year-old culms can already be harvested and used for various engineered products, i.e. housing and construction. Similarly, the economics of harvesting 1-year-old instead of 2-year-old culms should be assessed.

Other recommendations

1. Bamboo-processing equipment for *B. blumeana* and *D. asper* should have adjustable blades/gadgets that could accommodate a culm wall thickness of 1.5–1.2 cm. This would ensure a greater raw material supply for engineered products, particularly floor tiles and lumber.
2. While it is better to harvest 3-year-old culms, a younger culm that has been dislodged or damaged should be harvested and used for an application where strength is not a critical requirement.
3. The prospect of using *B. blumeana* and *D. asper* fibres for high-value-added products, such as textiles, should be explored.

Acknowledgments

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Economics and market potential of bamboo for shoots and engineered products in the Philippines

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Abstract

Bamboo has been widely used for traditional purposes. Bamboo products are also good substitutes for wood products but they have not been widely accepted. A study was undertaken to determine the potential demand for engineered bamboo and bamboo shoots and to compute the costs and returns of adopting various treatments implemented in the Ilocos Norte, Capiz and Bukidnon sites of the bamboo project funded by the Australian Centre for International Agricultural Research (ACIAR).

Bamboo shoot production is not pursued on a large-scale basis in the Philippines as there is no canning factory in the country that can absorb production of this perishable product. Furthermore, the pungent taste and odour of the shoots, availability of other vegetables and relatively low price of alternatives affect the acceptability of this product. Better technologies need to be developed to address the sensory issues if the production and utilisation of shoots are to be promoted. Awareness of the significance of bamboo shoots as an alternative or additional food source must be improved through information campaign drives such as cooking festivals and other extension strategies.

The high cost of production and transport impedes the adoption of relevant technologies in the engineered bamboo industry. In addition, competition from China limits local incentive to transform bamboo culms (poles) into engineered products. Nevertheless, potential exists for engineered bamboo products to be accepted in the foreign market. There needs to be an integrated approach to the utilisation of culms to minimise wastage, and linkages throughout the production–consumption chain must be enhanced.

Benefit–cost analyses showed that, in terms of optimising conditions for clump productivity over a prolonged period, mulching and fertiliser applications could be forgone, but irrigation provided good financial returns at sites where rainfall is a limiting factor. However, optimal management regimes are highly site-dependent.

To promote bamboo as a sustainable industry in the Philippines, several sectoral policies that constrain the use of bamboo need to be reviewed.

Introduction

The bamboo sector in the Philippines comprises various market participants performing different functions and roles (Rivera et al. 1996). There are those who plant and harvest the bamboo culms (poles), which are turned over to the traders or intermediaries who subsequently market the product. There are also semi-processors/processors who convert the raw materials into more useful, attractive and economically valuable finished products. However, most people who depend on bamboo for their livelihood, such as gatherers and weavers, are poor.

Bamboo plantations and natural stands exist all over the Philippines and are found on both government and private lands. These local sources, together with some imports, provide bamboo raw materials utilised in the manufacture of various traditional products such as furniture, handicrafts, baskets, fishing and agriculture implements, food, pulp and paper, and construction materials. Because of its inefficient use and poor management, bamboo is perceived to be of

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low value (Rivera et al. 1996). Some policymakers likewise overlook the importance and role of bamboo in society. As a general rule, undervalued resources tend to be over-exploited or abused by users because of the impression that they are neither scarce nor important. As a consequence, producers are less likely to invest in production technologies for less valuable resources. Thus, policymakers and forest managers tend to favour the development of resources considered to be more valuable (Pabuayon et al. 2001).

However, bamboo can now be turned into high-value products, known as 'engineered bamboo products', including laminated bamboo veneer for floor tiles, tabletops and panels. Hence, the potential exists to greatly expand the bamboo industry in the Philippines, and thus improve the livelihood of people working in the sector. But to achieve this, further research and development are needed. Some productivity-enhancing technologies for bamboo are already available, but the incentives for adoption, and consequent commercialisation, are usually not present, as producers cannot gain access to favourable markets. To improve this situation, the market potential of bamboo products should be analysed, including vital information about the demand for and supply of raw materials and finished products. This should be done in association with knowledge of the facilitating and constraining factors for growth and development, so that interventions to be promoted in the future will not be futile.

Despite changes in processing technologies, people in the Philippines have been relatively slow to adopt them. While it has already been established that bamboo products are good substitutes for wood products, the acceptance of such products has not been too enthusiastic. However, the reasons for this have not been fully established. Thus, the factors affecting availability and acceptability of the products are also important considerations in formulating workable and appropriate measures for future implementation. Furthermore, the costs and benefits of adopting new strategies or interventions need to be ascertained to allow monitoring of financial viability.

Study objectives

The objectives of this study were to:

1. determine the extent of bamboo plantations and natural stands and estimate the existing supply of bamboo raw materials in the Philippines
2. determine the existing and potential demand for engineered bamboo and bamboo shoots
3. determine the factors affecting the availability and acceptability of engineered bamboo and bamboo shoots
4. review the policies that govern the harvest and sale of bamboo
5. calculate the costs and returns of producing bamboo for shoots and engineered products
6. formulate recommendations in the light of the findings.

Methodology

Information sources

Primary and secondary data were gathered about the market potential of selected bamboo products. Relevant articles, reports and documents were reviewed.

The extent of the bamboo plantations and natural stands growing on government and private lands was estimated using data found in reports and other documents of local and national government and non-government agencies. Data from the Department of Environment and Natural Resources (DENR) were reviewed, primarily based on the Forest Management Bureau and plantation forest files. Key informants were interviewed to generate further information. Data were validated using pre-tested surveys of representatives from the various sectors, such as bamboo producers/harvesters, traders and manufacturers. Key informants from the DENR research sector were also interviewed to gain their views regarding the potential of bamboo for shoots and engineered products.

Data on bamboo imports were also reviewed. This information was retrieved from DENR, the Department of Trade and Industry (DTI), the Department of Science and Technology and National Statistical Coordinating Board databases.

Bamboo shoots

Estimation of the existing and potential demand for bamboo shoots was based on responses of representatives of bamboo shoot vendors and Department of Tourism (DOT) accredited hotel restaurants in Metro Manila. The cost of production was obtained from interviews with key informants. Information gathered included volume demanded, sources of shoots, markets for shoots, reasons why shoots are (or are not) processed or consumed, costs incurred and returns obtained in the production of shoots, and opportunities and constraints in the commercialisation of bamboo shoots. Market vendors were interviewed as key informants in different wet markets of four regions of the Philippines.

Engineered bamboo

For the existing and potential demand for engineered bamboo, respondents included furniture-manufacturing firms, engineers involved in the construction of residential buildings, designers, manufacturers and traders of engineered products (tiles, tabletops, floorboards etc.). Information gathered included end products manufactured, estimated volume demanded, wood product substitutes, current buying and selling prices, knowledge or awareness of engineered bamboo products, costs and returns of producing engineered bamboo, reasons why engineered bamboo is preferred or rejected over other wood products, and constraints and opportunities in utilising engineered bamboo.

Analysis

Descriptive analysis provided a representation of the existing situation and potential of the bamboo industry in terms of the selected bamboo products.

Status of bamboo shoots

Four regions where bamboo is widely found were visited—Region 1 (Ilocos Region), Region 6 (Western Visayas), Region 10 (Northern Mindanao) and Region 11 (Davao Region). These regions, with the exception of Region 11, include the sites of the project 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).

Species sold in the market

Table 1 shows the various species of bamboo shoots sold in the study regions. The buyers were restaurant owners/managers and households. *Bambusa blumeana* (kawayan tinik) was the main species sold in regions 1, 6 and 11, while *Dendrocalamus asper* (giant bamboo) was also sold as shoots in the markets of Region 10. Other species were sold in lesser quantities, but identified only by their common names—kawayan dalusan, botong and lunas.

Volumes of sales

The indicative average volumes of shoots sold in selected wet markets are shown in Table 2. The volume of shoots sold is partly dependent on availability. Sometimes there is a glut of bamboo shoots (peak season), while at other times they are not readily found in the market (lean season). The average volume of bamboo shoots sold in the selected wet markets during the lean months (September–November) was 535 kg/month. In contrast, 1,032 kg/month were sold during the peak season (April–August). Note that sources and volumes marketed are not well established for bamboo shoots compared to other forestry products or agricultural crops such as rice and corn.

There is no known bamboo shoot canning plant in the Philippines at present. The current small-scale nature of production, plus other factors—such as an unstable supply of bamboo shoots, increased production and maintenance costs, and unsure markets—deterred a Taiwanese businessman who scouted for an area in Northern Mindanao (Region 10) from establishing a bamboo shoot cannery.

Table 1. Species of bamboo shoots sold in selected wet markets

Site (city, province, region)	Species[a]	Local name
Batac, Ilocos Norte, Region 1	*Bambusa blumeana*	Kawayan tinik
Dumarao, Capiz, Region 6	*B. blumeana* –	Kawayan tinik Kawayan dalusan
Cagayan de Oro, Misamis Oriental, Region 10	*B. bambusa* *Dendrocalamus asper*	Kawayan tinik Giant bamboo
Davao City, Davao del Sur, Region 11	*B. blumeana* – –	Kawayan tinik Botong Lunas

[a] For some bamboos, no species name was available, only the local common name

Table 2. Average volume of bamboo shoots sold per month during lean and peak seasons in selected wet markets in 2005

Site (city, province, region)	Season	
	Lean (kg/month)	Peak (kg/month)
Batac, Ilocos Norte, Region 1	530	1,250
Dumarao, Capiz, Region 6	500	1,000
Cagayan de Oro, Misamis Oriental, Region 10	450	700
Davao City, Davao del Sur, Region 11	658	1,177
Average	535	1,032

Pricing

The price of bamboo shoots tended to increase during lean months when supply was lower. The average buying price of the market vendors from shoot growers/harvesters was PHP14.33/kg during lean months while only PHP9.73/kg during peak months (Table 3). Of the four regions visited, the Davao City wet market in Region 11 reported the lowest buying price at PHP9.30/kg (lean months) and PHP8.90/kg during peak months. In contrast, Batac wet market (Region 1) had a high buying price of PHP18.00/kg during lean months.

In these wet markets, bamboo shoots were sold at an average price of PHP19.88/kg during the lean season and PHP15.38/kg during the peak season. Davao City wet market respondents (Region 11) reported the lowest selling price of PHP17.00/kg during lean months, while Region 10 vendors reported the lowest selling price of PHP12.50/kg during the peak season. The highest selling price during both seasons was in the Batac wet markets (Region 1), with PHP25.00/kg during lean months and PHP20.00/kg during peak months.

Shelf life

Table 4 shows that with no treatment, the shelf life of bamboo shoots—sliced and without skin—is only a day. However, with water soaking and the addition of alum, bamboo shoots can remain fresh and edible for 3–7 days. When the shoots are soaked in water then washed in running water, they remain fresh and edible for 2–7 days.

Factors affecting availability

There are several factors that affect the availability or supply of bamboo shoots. These include the extent of bamboo-growing areas, presence of appropriate technology, perishability or shelf life of the product, preference of the growers to harvest culms instead of shoots, favourable environment for growing bamboo, season of the year, and the existence of local and national policies that either constrain or facilitate supply.

Factors affecting acceptability

The preference of consumers and the sustainability of supply affect the acceptability of bamboo shoots in the market. Local consumers tend to reject bamboo shoots in favour of other, cheaper vegetables (such as carrots and young coconut shoots).

Table 3. Average buying and selling prices of bamboo shoots during lean and peak seasons in selected wet markets, 2005

Site (city, province, region)	Buying price (PHP/kg)		Selling price (PHP/kg)	
	Lean	Peak	Lean	Peak
Batac, Ilocos Norte, Region 1	18.00	10.00	25.00	20.00
Dumarao, Capiz, Region 6	15.00	10.00	20.00	15.00
Cagayan de Oro, Misamis Oriental, Region 10	15.00	10.00	17.50	12.50
Davao City, Davao del Sur, Region 11	9.30	8.90	17.00	14.00
Average	14.33	9.73	19.88	15.38

Table 4. Shelf life of skinned bamboo shoots and those treated to prolong freshness

Treatment	Shelf life (days)
Soaked in water	3
Soaked with a daily change of water	2–7
Soaked in water with alum	3–7
No treatment	1

Demand in the restaurants of hotels

For the purpose of accreditation by the Manila Department of Tourism, hotels are classified into the following categories based on the quality of their services and facilities: economy (the lowest), standard, first class and deluxe (the highest). For each category, the following aspects were studied: whether or not bamboo shoots were included on the menu and preferred form; volume of use; characteristics of consumers; reasons for not using shoots; and the possibility of permanently including shoots in future menus.

In general, restaurant representatives of all hotel classes gave similar answers to the survey questions. Factors that varied between hotel classes are detailed in Table 5. Bamboo shoots were not often included in the standard restaurant menus, but only prepared upon request. People requesting dishes incorporating shoots were of middle- to high-income classes and mainly Filipino, Chinese and Japanese nationals. Most restaurants used canned shoots (imported, as there is no canning facility in the Philippines), but this was primarily a decision of the chef, mostly based on availability and whether they were familiar with preparation of fresh shoots.

The main reasons given for why bamboo shoots are not consumed more widely were: pungent odour and aftertaste; inconsistent supply and quality of fresh shoots; low client demand; lack of knowledge on preparation and use; and availability of cheaper alternatives. Introduction of bamboo shoots into the regular menu of restaurants of any hotel class seems unlikely unless these issues are addressed.

Status of engineered bamboo

Engineered bamboo is a relatively new product in the Philippines. Very few entities have embarked on its development. The survey gathered information from identified enterprises that have been in the past, or are presently, involved in engineered bamboo production, trading or utilisation. These are presented in the form of case studies of specific companies and their experiences and perceptions of the industry.

Jireh Industries: production and trade

Jireh Industries is located at Valencia City, Bukidnon (Region 10) and manufactures various engineered products from bamboo and wood harvested from plantations. It utilises equipment invented and fabricated by the owner himself. He has received several research and development awards because of his inventions. The company started its engineered bamboo processing operation in the summer of 2003. In 3 weeks, it produced sixty 2 m × 2 m and 2 m × 3 m bamboo boards. The boards made over 4 months were exported to Africa through negotiations made by an intermediary based in Manila.

The factory can potentially produce on a weekly basis 200 m^2 of floor tiles requiring 100 bamboo culms. One culm of 5 cm in diameter can be stretched to as much as 13 cm using their flattening machine. Buyers interested in buying bamboo floor tiles must place orders in advance to allow ample time to dry and process culms to meet the product quality standard. The presence of existing bamboo plantations and

Table 5. Characteristics of bamboo shoot utilisation in hotel restaurants

Factor	Hotel type			
	Economy	Standard	First class	Deluxe
No. restaurants surveyed	6	14	6	15
No. currently using shoots	2	6	3	10
Volume used (kg/month)[a]	1–3	6–15	38–44	3–70[b]
Preferred form of shoots	Canned	Mainly canned, some fresh	Mainly canned, one also used fresh	Canned and fresh
Planned future use in menu cycle?	No	Maybe	No	No

[a] Average amount used per month per restaurant that uses bamboo shoots

[b] Highly variable as they occasionally use bamboo shoots for special functions

natural stands ensures a good supply of culms for use as raw materials. In addition, as better protection measures continue to be adopted, more healthy, high-quality culms can be marketed and utilised for improved bamboo products. The owner argued that lifting the ban on the exportation of bamboo culms should not be pursued, as Filipino manufacturers would be disadvantaged because a higher percentage of the available bamboo would be sold to foreign markets where higher prices are offered.

The accepted moisture content of bamboo for processing is based on requirements set by the country of destination and is based on equilibrium with the ambient humidity in the importing country. In the United States of America (USA), the accepted range is 6–8%. In Japan, the accepted level is 10–12%. Local buyers, such as those in the furniture sector, require a range of moisture content of 12–18%. The moisture content of freshly cut *Bambusa* sp. 2 (laak) and *Gigantochloa atter* (kayali) is much higher (M.A. Alipon 2007, pers. comm.). Therefore, to lower the moisture content, bamboo is oven- or kiln-dried for about a week.

Factors limiting production include high production and shipping/transport costs and the many documents required by various checkpoints during transport. The high cost of raw material inputs was also mentioned as a limiting factor as far as engineered bamboo production is concerned.

Formaply Industries, Inc.: trade

Formaply imports engineered bamboo products such as panels and floorboards from China in shipments of approximately 22 m^3. These products are supplied to the construction and furniture sectors. The company manager told of a plan to construct a plant in the province of Cebu (Region 7) as part of their expansion activities. At present, they export to Europe some of the products they have imported from China. The company thus serves as a broker between China and the European market, just like the brokers of rattan products based in Singapore. Three-quarters of the volume consists of floorboards, while only one-quarter is panel boards. Laminated bamboo panels are sold at PHP1,400/m^2 while laminated floorboards are sold at PHP800–900 apiece.

Bamboo products are long-lasting and relatively easy to maintain. If these could be produced locally, the red tape involved in importation would be minimised and the cost of shipping reduced. Although bamboo raw materials are available, there is a lack of knowledge on how to utilise them properly. Some industries have experienced difficulties in developing new production techniques and processes for bamboo products. However, engineered bamboo products do have potential in the market due to their uniqueness, and consumers show much interest when they see these products. The respondent emphasised that the Philippines should be able to compete globally in the furniture and construction sectors.

Trayline Corporation: utlilisation

Trayline Corporation manufactures furniture made from leather, engineered bamboo and other combinations of local and imported materials. Laminated bamboo is used for tabletops and benches, which are considered very attractive and stylish. Bamboo comprises only 5–10% of the total furniture raw material inputs of this company. It is used only for designing/accenting purposes. The use of bamboo raw materials is limited due to the problems they have encountered in the production process. For example, a container of bamboo furniture was prevented from being shipped abroad due to the presence of powder-post beetles. It had to be opened, treated and repackaged before it was accepted by the foreign buyer, with concomitant delays and additional expense. Also, because of the natural oil present in the bamboo skin, paints, varnish and other finishing materials do not easily adhere to the surface. Thus, bamboo culms must be properly processed and prepared before application of finishing materials. In addition, some suppliers profess that the bamboo culms delivered have been kiln-dried when they have not and the quality of the finished products is thus negatively affected. The manufacturers felt that they were short-changed by the supplier, and would like quality assurance. The industry also experiences difficulty in transporting raw materials from harvest locations to manufacturing sites due to many checkpoints. The officials staffing these points make things difficult for them to pass, thus they resort to giving ‘grease money’.

Balbin’s Quality Furniture: production, utilisation and trade

Balbin’s respondent believes that bamboo has great potential in the market, particularly in novel products. A new design for bamboo trays, using laminated bamboo veneer, is being tested for sale in the export market. Problems with investments do not exist for this company as clients help financially to pursue the projects. Similar government support would be welcome, but is currently non-existent. To highlight how this could help—Vietnam used to rank way below the Philippines in the list of Association of Southeast Asian Nations (ASEAN) countries that export furniture and handicraft, but now because of government support, Vietnam has overtaken the Philippines in ranking based on recent trade figures.

The relatively large difference between the price of bamboo and narra (*Pterocarpus indicus*) tiles emphasises the undervaluation of engineered bamboo. At present, narra tiles sell for PHP1,200/m^2 while bamboo tiles are only PHP550/m^2 and the cost of producing bamboo tiles is PHP40/m^2. In veneering, only the stump (butt; lowest 30%) of the culm is used, from which 0.37 m^2 of tiles can be produced. Increasing the proportion of culm used, improving tile quality and promoting use of these products are all strategies that could benefit the engineered bamboo industry.

The company representative related that when the engineered bamboo products are exported, about 10% of the volume is rejected. When a sample is provided to the buyer, the 'second best' (according to the supplier's standard) is submitted rather than the 'best' to give some allowances for rejects. There are times when this strategy works to their advantage. But there are times when this does not work and becomes a hindrance. The taste and preference of the market is dynamic and is one of the bases for product success.

To prevent the occurrence of powderpost beetles, this company dips culms in agricultural insecticide rather than diesel since this was deemed too expensive. Afterwards, both ends of the culms are covered with cement.

Asia Rattan: production, utilisation and trade

Asia Rattan exports furniture made from materials such as wood, rattan, seagrass and bamboo. Its products are exported to the USA and elsewhere. A monthly order from foreign buyers of 75 corner tables is shipped regularly. The tables, measuring 46 cm × 46 cm × 91 cm, are made from a combination of wood and laminated bamboo. There is no problem with bamboo supply since there are many suppliers in the vicinity. The problem, however, is efficiency in the use of bamboo culms. Only 90–122 cm of the lowest portion of the culm can be used. Thus, to become more efficient, other uses for the remaining portion need to be found.

Two types of machine can be used in producing laminated bamboo. One, imported from the USA, is very expensive while the other is locally fabricated and currently used by the company. However, the local machine is limited in the size of laminates it can produce, so the manufacturer is challenged to develop novel designs within this constraint. Another problem is the deformity of some bamboo culms, which results in wastage during the processing stage. A lack of efficient and low-cost preservation treatment strategies also constrains the use of bamboo for engineered products. The competition offered by China in terms of price and volume is too severe; direct competition cannot be pursued.

Nevertheless, opportunities exist in the Philippine bamboo furniture industry because of the ingenuity and craftsmanship of local designers and workers. Bamboo is a cheaper substitute for wood, but currently bamboo comprises only 5–10% of the materials used in furniture made by Asia Rattan. Bamboo is only used as an accent or for decorative purposes.

At present, laminated bamboo is sold at PHP110–150/m^2; relatively higher than woody species of *Gmelina*, which is sold at PHP70/m^2, but lower than mahogany (*Swietenia* spp.) at PHP150/m^2 and very cheap compared to imported maple (*Acer* spp.) priced at PHP3,000/m^2.

The cost of equipment needed for a veneering/lamination plant is PHP600,000 for the veneering machine, PHP1.6 million for the presser and PHP500,000 for the roller. Three labourers are usually employed in the veneering/lamination plant during an 8-hour shift. Additional labourers are employed only when there are big orders.

Laminating involves gluing veneer onto a wooden base. Since the company makes use of a cold press, approximately PHP55/m^2 is spent in the gluing process. This expense is high compared to a hot compress, which costs only PHP7/m^2 of glued material. However, the investment needed for a hot press is prohibitive at PHP3 million.

Bamboo for conventional products

While interviewing key informants on engineered bamboo, other enterprises that utilise bamboo for more conventional products were also encountered. These are outlined below.

Kabagay Handicraft

Kabagay is located in Aringay, La Union (Region 1) and produces handicraft items made from various raw materials such as bamboo, rattan, nito (*Lygodium* spp.) and rono (a reputed native bamboo). It started its operations in 1981 when the supply of rattan was running out as a result of the export ban imposed by Indonesia. The company 'resorted to' bamboo as an alternative raw material. In the past, the company tried to manufacture bamboo boards but encountered problems, including difficulty in controlling insects and limitations in devising varied designs. The price of engineered bamboo as flooring was PHP200/m^2.

The firm now focuses on bamboo and makes products such as gazebos, mats, blinds, salad sets and rocking chairs, among others. They also designed 'knock down' nipa huts, gazebos and cabanas that are sold in the foreign market for US$900, US$450 and US$650, respectively. The company has no problem with the supply of bamboo because it has many suppliers in Aringay and neighbouring towns. Four truckloads of bamboo culms are supplied on a weekly basis.

Export of bamboo furniture to date has not been successful due to insect borers that were detected upon inspection once they reached the foreign buyers. The buyers demanded Kabagay Handicraft replace the furniture. Thus, high losses were incurred in terms of manufacturing and transport costs. After this experience, diesel was used to treat the culms, but that darkens their colour. Powderpost beetle is also a problem insect in the bamboo industry. Solignum, a chemical usually used to control termites, can be used to treat bamboo against the powderpost beetle, but the price is high at PHP154/L. Nevertheless, this company constructed a pit filled with solignum which is used to treat the finished product by full immersion before it is marketed.

A whole bamboo culm (8–9 m) costs PHP35–150, while a shorter one (1.5–1.8 m) is PHP24. The volume of bamboo raw material exports cannot be readily determined because it is most often reported as dollar value of the manufactured product rather than volume. However, based on the designs used by the respondent for Kabagay, for every US$10,000 worth of product, approximately 5% of the total value is spent on bamboo raw materials for high-end products while about 10% for low-end products. On average, bamboo raw materials account for only about 7% of the total product value.

Bamboo International

Bamboo International (formerly Elm and Oak) exports candleholders of varied designs made out of bamboo twigs. The company takes pride in the quality of its products and practice of zero waste in its production activities. Accordingly, 100% of its raw materials are used in product manufacture. Products are made exactly according to the numbers ordered and no spare stock is carried within the company.

As a small-scale company, the major concern of management in addressing exports is its limited capital and face-to-face access to buyers: the number of potential buyers visiting trade fairs and exhibits has been reduced by fears of terrorism and diseases such as severe acute respiratory syndrome (SARS) and avian influenza (bird flu). For example, very few buyers attended the international trade fair in 2003 due to travel bans imposed by their respective countries.

CM Bamboo Craft

CM Bamboo Craft is a company run and managed by Catholic nuns. It produces bamboo items including chairs, tables, kitchen utensils, Christmas decorations, pens, portraits, frames and key chains. The company exports to the United Kingdom and Taiwan and, during 1998–99, the demand for bamboo products was high. They used to earn millions of pesos in exports, but demand diminished dramatically after the 11 September 2001 attack in New York, USA and similar occurrences.

Bamboo exportation

Bamboo has traditionally been exported as finished products either as furniture or handicraft items. In 2000, the total exportation of bamboo furniture alone was valued at US$3.18 million (free on board; FOB). In 1991–2000, the bamboo furniture and handicraft industries generated average export revenues of US$1.9 million/year and US$436.94 million/year, respectively. Approximately 30% of the exported handicrafts were bamboo in origin (Virtucio and Roxas 2003). There were also exports of bamboo culms and hand-woven bamboo mats (sawali), but only in very limited volumes. Culm exports were limited by the government's policy of allowing culm exportation only for scientific or testing purposes. However, bamboo was reclassificed to 'regulated' rather than 'prohibited' in May 2005 to support the government's effort to promote the Philippine export industry. (Further information about government policy in relation to bamboo is provided later in this paper.)

Table 6 shows the quantity and value of bamboo culms exported in 1999–2003. The quantity exported in 2003 was lower than in 2002 but the value increased tremendously from the previous year. This may be due to an increase in the price of bamboo in the foreign market or the weakening of the peso in relation to the other foreign currencies.

Table 6. Bamboo exports, 1999–2003 (DENR 2003)

Year	Quantity ('000 kg)	Value[a] (US$'000)
1999	4	6
2000	19	39
2001	30	36
2002	65	28
2003	54	113

[a] Free on board (FOB) value

Bamboo importation

Bamboo has been imported into the Philippines from several counties including China, Hong Kong, Thailand and Vietnam. Table 7 shows that the highest bamboo importation occurred in 2002 with 237 t. However, the highest documented value of bamboo importation between 1999 and 2003 was in 2001 at US$212,000 (FOB) or US$227,000 (cost, insurance and freight; CIF). In 2002, several manufactured bamboo products were imported from China, Hong Kong and Taiwan. These products included bamboo sheets, flooring, culms, chopsticks and round sticks.

Table 7. Bamboo imports, 1999–2003 (DENR 2003)

Year	Quantity (tonnes)	Value[a] (FOB) (US$'000)	Value[a] (CIF) (US$'000)
1999	73	44	48
2000	143	85	93
2001	200	212	227
2002	237	206	218
2003	103	103	112

[a] FOB = free on board; CIF = cost, insurance and shipping

Projected demand and supply

The *Master plan for the development of bamboo as a renewable and sustainable resource* (OIDCI 1997) provided a 10-year projection of the demand and supply situation for bamboo for various traditional uses in the agriculture, fishing, furniture, handicraft and construction sectors that showed a supply deficit under all conditions. Without intervention, it was assumed that supply would be sourced from natural stands. Another assumption was that the moderate increase in demand through the years was based on population growth and furniture and handicraft exports.

The 'with intervention' scenarios (A and B; Table 8) were based on development of diversified products (pulp, 'plyboo', plyboard, laminated bamboo and mat board) that would be introduced in 2003. This was expected to lead to increased demand for bamboo culms. Scenarios A and B were similar in their assumptions about increased focus on market expansion and product diversification, but scenario B had higher export growth projections in furniture and handicrafts. Table 8 shows that there would be a supply deficit under all three conditions over the 10-year projection period. Hence, efforts to increase raw material production must be pursued at the same level as those for product development and diversification. To close the gap between supply and demand, more bamboo plantations must be developed and managed using the appropriate management practices.

Demand for engineered bamboo products

Bamboo is in high demand in the housing and construction sectors. Most of the demand comes from rural communities, where bamboo is used in combination with other construction materials. As reported by the DTI in 1997, if each household from the rural areas consumes at least five culms a year for maintenance, the total requirements nationwide will be approximately 7.3 million culms. At present, there is a limited market for engineered bamboo but this is seen as slowly growing (as discussed above). Engineered bamboo is distributed to both the domestic and export markets. The domestic market is segmented for furniture and handicraft. The high-quality products are directed to high-end markets, i.e. hotels, restaurants, condominiums and residential houses, while low-end ones are sold to low-end, medium-income consumers.

Table 8. Projected demand and deficit (in ’000 culms) with and without intervention (OIDCI 1997)

Year	Supply[b]	Without intervention		With intervention[a]			
		Demand	Deficit	Demand		Deficit	
				A	B	A	B
1998	38,009	52,247	14,238	52,247	52,247	14,238	14,238
1999	39,686	52,326	12,640	52,326	52,396	12,641	12,710
2000	41,120	52,411	11,291	52,411	62,563	11,291	11,443
2001	41,279	52,502	11,223	52,502	52,751	11,223	11,472
2002	41,279	52,601	11,322	52,601	52,982	11,322	11,703
2003	41,477	52,781	11,304	58,381	58,982	16,904	17,505
2004	41,673	52,982	11,309	58,842	59,717	17,169	18,044
2005	41,871	53,205	11,334	59,351	60,568	17,480	18,697
2006	42,068	53,455	11,387	59,916	61,558	17,848	19,490
2007	42,265	53,736	11,471	60,543	62,649	18,278	20,384

[a] Annual growth rates: scenario A = furniture—3% in 1999–2002 and 6% in 2003–07, and handicraft—15% in 1999–2002 and 20% in 2003–07; scenario B = furniture—6% in 1999–2002 and 12% in 2003–07, and handicraft—15% in 1999–2002 and 30% in 2003–07.

[b] Production in 1998 was sourced from natural stands, with additional production in 1999 from Department of Environment and Natural Resources (DENR) plantations, increased production in 2000–02 from mature plantations established earlier, and increased production in 2003–07 based on a 5% annual increase in plantation development since 1998.

If, for example, the construction sector considers bamboo in their design and plans and allows for bamboo to comprise at least 50% of its material requirements, then a sizeable demand for engineered bamboo will be created. The National Housing Authority estimated the housing needs for the bottom 40% of the total population for 1999–2004 to be 2.2 million housing units (2002 National Statistics Office Philippine Yearbook). However, with a backlog of 1.1 million more, this results in a total of 3.3 million housing units for the past 7 years as of 2006. Personal communication with a practising, licensed civil engineer suggests that a 24 m^2 single, detached, low-cost housing unit would need approximately 80 pieces of lumber measuring 5.1 × 7.6 × 30.5 cm, estimated to be 1.13 m^3 (Table 9). If 50% of the wood requirements for those 3.3 million housing units were substituted with bamboo tiles, then about 40 million 1 m^2 tiles would have to be produced (Table 9). This translates to a requirement for 158 million bamboo culms. Since wood in the local market is limited and relatively highly priced, the country resorts to importation, which drains the dollar reserves. Thus, if the use of alternative raw materials, such as bamboo, can be pursued, then the problem of high costs and limited supply of these materials could be addressed.

Policies affecting the Philippine bamboo sector

Harvest and transport policies

Collecting and harvesting bamboo in forestlands is governed by existing DENR policies and regulations that require the gatherers to secure a cutting permit as specified in the Revised Forestry Administrative Order No. 11, dated 14 September 1970. Bamboo is combined with the other non-wood (minor) forest products. Pursuant to DENR Department Administrative Order (DAO) 38 series of 1990 and in line with the DENR policy on decentralisation, permit issue has been delegated to the DENR regional offices. Applications for cutting permits are filed through the relevant Community Environment and Natural Resources Office (CENRO). Forest charges must be paid for harvesting bamboo on public land. Exempted from these charges for planted bamboos are industrial tree plantations and private lands that are covered by existing titles or tax declarations.

DENR also monitors the movement of bamboo by requiring a Certificate of Non-timber Forest Products Origin (CNFPO). This is specified in DAO 59, issued on 30 September 1993. Again, bamboo planted on titled and tax-declared alienable and disposable land is exempted, provided that certification by the CENRO is obtained.

Table 9. Estimated wood and bamboo requirements in the housing sector (for 3.3 million housing units)

Floor area of low-cost housing units (m^2)	Estimated volume of wood needed by floor area (m^3)	Estimated no. of bamboo tiles required (each 1 m^2)[a]	Total wood requirement (million m^3)	Total no. of 1 m^2 bamboo tiles required (million)	Total no. of culms required (million)
24	1.13	12	3.73	39.60	158
32	1.50	16	4.95	52.80	211
50	2.35	25	7.75	82.50	330

[a] If 50% of wood requirement is substituted with bamboo

Although forest charges and other fees are levied by the government for culms harvested on public land—for example, a fee of PHP0.10–0.60/m is meant to be paid as forest charges for bamboo harvested from natural stands (DAO 2000-63)—these are not always paid. Because it is difficult to establish where bamboo resources originated, people can avoid paying these charges by fraudulently stating that their culms were harvested from plantations or other private land. Furthermore, the amount of forest charge or government share charged for the resource seems to have been determined without a scientific and economic basis. Thus, the true value of the resource has not been properly considered in the value determination. In particular, if the resource is undervalued, then the development of better technologies for its utilisation may not be initiated.

It is recommended that more research be undertaken to generate appropriate information for better understanding and decision-making, with collaboration among research institutions, regulatory offices, private entities, community organisations and other concerned stakeholders. Appropriate policies must also be formulated for appropriate production, allocation and utilisation of bamboo.

Trade policies

Before 2005, based on the amended rules and regulations implementing Presidential Decree (PD) 930, bamboo culms could not be exported except for scientific or testing purposes for which an export clearance from the government was required. Exporters of manufactured bamboo products followed the general procedures required for exportation. Importation of bamboo culms for commercial purposes (e.g. for pearl farm fencing) was likewise allowed. However, it was recommended by concerned sectors that these policies be reviewed. Such studies would help formulate recommendations for favourable steps towards the development of bamboo plantations and sourcing of raw materials to support the expansion of bamboo-based industries.

Initial reviews by the DTI showed strong support from the private sector engaged in the export of bamboo and rattan products for the reclassification of bamboo and rattan from ‘prohibited’ to ‘regulated’ products by reason of abundance of supply in the Philippines. Subsequently, a study funded by the Food and Agriculture Organization of the United Nations (FAO) on Global Forest Resources Assessment (GBRA) Update on Bamboo Resources for 2005 reported that there were approximately 156,574 ha of bamboo in the country. This could supply around 4,059,087 harvestable culms per year against an average demand of 200,880 culms per year by the fishpen, construction and furniture industries. The GBRA 2005 data were derived from an assessment conducted in 2002–04. With the apparent huge supply of bamboo resources compared to the demand, in May 2005, bamboo was reclassified from ‘regulated’. This change supported the government’s effort to promote the Philippine export industry.

However, these data are at odds with the projections of OIDCI 1997 (Table 8); it is believed that the very small sample size of the FAO/GBRA study influenced their estimates downwards. As well as the demand in the housing and construction sectors (discussed above), the DTI in 1997 reported that the banana industry had a total bamboo culm requirement each year of about 36 million. In the fishing and mariculture industries, about 210,000 and 3 million culms, respectively, are needed annually to replace 50% of the bamboo fishpens. All these figures add up to more than the estimated number of culms that can be supplied by the existing natural stands and plantations based on the GBRA 2005 report. Given this, the reclassification of bamboo for export from ‘prohibited’ to ‘regulated’ status may have a detrimental impact on the handicraft, furniture and construction sectors as there is a possibility of creating a large gap between production and consumption, not only in the local but in the foreign market as well.

Reforestation and rehabilitation programs of DENR

Bamboo has been introduced and used in the Integrated Social Forestry (ISF) projects and the Community-Based Forest Management (CBFM) program as per the DAO No. 31 series of 1991. With the inclusion of bamboo species in the rehabilitation programs of the government, community-based and private entities have recognised the important role bamboo plays in attaining environmental stability. This policy encourages the planting of the bamboo species to provide vegetation to degraded areas over a shorter time frame than other reforestation species. It also provides the surrounding communities an additional source of income from the sale of culms and semi-processed or manufactured bamboo products. This strategy of the government is seen to support the livelihood of the upland communities and at the same time address the environmental problem of forest denudation and degradation.

Recommendations and policy implications

Increasing consumption of bamboo shoots

Many people dislike the pungent taste and odour of both fresh and canned shoots. It may be easier to promote increased shoot consumption if technology could be developed to overcome this problem. In addition, people who are currently unfamiliar with shoots as a vegetable do not know how to prepare them. Hence, awareness of the significance of bamboo shoots as an alternative or additional food source should be improved. This could be done through an information campaign including appropriate information materials or kits on the proper handling and pre-cooking procedures that eliminate the odour and bitter aftertaste. As part of this campaign, food exhibits, fairs and cooking competitions promoting shoot consumption and providing suitable recipes and cooking ideas could be held with support from the association of hotels and restaurants, the Department of Tourism, the DTI and other concerned government and non-government organisations.

Improving the engineered bamboo industry

One of the concerns raised by the manufacturers of engineered bamboo is the inefficient utilisation of bamboo culms, as only the butt portion is preferred for engineered bamboo manufacture. There should be an integrated approach to the utilisation of bamboo culms for all possible uses. Wastage must be reduced for efficiency and economic reasons. Links throughout the production–consumption chain must be enhanced. This could be done through identification of appropriate markets and products and complementary activities taking place in the chain. Furthermore, appropriate facilitating mechanisms such as policies and rules governing the production, marketing and utilisation of bamboo culms and manufactured products must be in place and in operation.

Profitability indicators for the ACIAR project sites

The sites discussed here were part of the ACIAR-funded project entitled *Improving and maintaining productivity of bamboo for quality timber and shoots in Australia and the Philippines* (ACIAR Project No. HORT/2000/127).

Capiz trial

Details of the trial in Dumarao, Capiz, are provided elsewhere in these proceedings (Marquez 2009). Based on the streams of benefits and costs of the treatments in the three project sites (data not presented), the net present value (NPV) estimated over a 6-year period for the various treatments in Capiz showed that treatment 6 (T6)—with continuous irrigation and application of fertiliser, organic matter and mulch, and retention of three 1-year-old and three 2-year-old culms per clump (3-3 standing culm density, or SCD)—had the highest NPV of PHP294,924/ha at the 12% discount rate (data not presented). The next two highest ranks were for T10 and T9. All three treatments were irrigated and supplied with fertiliser, mulch and organic matter, but differed in their SCD (which for T10 was 6-6, then harvest all 3-year-old culms; and for T9 was retain all shoots and harvest all 3-year-old culms). In treatments where shoots were harvested, this contributed to increased income, and could be attained by the adopter of the technology within the 6-year period.

While the NPV indicates how much the bamboo plantation is presently worth over a given number of years, the benefit:cost ratio (BCR) shows how much is realised in relation to the costs invested in the plantation. The results from the Capiz site indicate that one can forgo fertiliser application and mulching but not irrigation (as in T5) to be able to get a high BCR, especially when implementing a 4-4 SCD, as adopted in T5. It had a BCR of 6.3 and ranked highest among the Capiz treatments. This means that for every PHP1 put into the business, it gives back a benefit of PHP6 within the 6-year period of maintaining the plantation. Treatment 4 (with irrigation and mulch but no fertiliser, 4-4 SCD) also provided good results and obtained the second-highest ranking for BCR at 5. Treatment 6 (with irrigation, fertiliser and mulch, 3-3 SCD) ranked third in the BCR rating for the Capiz site if only the actual harvests were considered.

Ilocos Norte trial

Details of the Batac, Ilocos Norte, trial are provided in Malab et al. (2009). The three highest-ranked treatments for NPV and BCR results were very similar as those for Capiz. Treatment 5 ranked first for NPV and BCR (data not presented). The clumps in this treatment were not fertilised or mulched but were continuously irrigated. The SCD was 4-4-4. The NPVs estimated for this treatment were PHP219,227/ha at the 12% discount rate and PHP203,113/ha at 15%. The BCR was 5.9. However, there was a difference in the treatments that ranked second for these two profitability indicators. For NPV, T3 was ranked second while T1 ranked third. For BCR, T4 and T2 ranked second and third, respectively. Treatments in the top three for both measures all had 4-4-4 SCD and all except T2 used irrigation. With the dry weather conditions of Batac, bamboo seemed to react positively to irrigation. However, the relatively high rank of T2 (not irrigated) in the BCR ratings indicates that while irrigation is an important input for high productivity, it is also an expense that can be done away with and still be able to obtain good BCR results, which eventually makes the bamboo plantation profitable.

Bukidnon trial

Details of the Impalutao, Bukidnon, trial are provided in Decipulo et al. (2009). The amount of fertiliser applied and the numbers of culms retained and harvested differed from the treatments at Ilocos Norte and Capiz. The species differed too, with *Dendrocalamus asper* (giant bamboo) in Bukidnon rather than *Bambusa blumeana* (kawayan tinik) as in Ilocos Norte and Capiz. In addition, irrigation was not considered as a treatment for the Bukidnon site and there was no harvesting of the shoots for sale—thus the income from shoots was not included in the financial estimates.

Based on unpublished data, by far the highest NPV (PHP292,474/ha using the 12% discount rate) at the Bukidnon site was obtained for T6, where fertiliser and mulch were applied and the SCD was 10-10. The second highest NPV (PHP191,134/ha) was for T3 (fertiliser but no mulch, 6-6 SCD). The treatment with the third-highest NPV (PHP182,466/ha) was T4, which also was the highest in terms of BCR at 5.81. In this treatment, no fertiliser or mulch was applied to the clumps, which had a 6-6 SCD.

Interestingly, T10 ranked fourth in the NPV ratings at PHP175,662/ha and second in the BCR ratings at 5.6, even though it received no fertiliser or mulch. As a silvicutural strategy, all 3-year-old and above culms (but no younger ones) were harvested.

If no harvesting or maintenance activity (except weeding and culm marking) was done in the plantation (T9), a negative NPV was obtained. A negative NPV implies that the plantation is not financially sound.

Summarising NPV ranking by treatment

Use of irrigation was the common factor for the Capiz and Ilocos Norte sites for the three NPV top-ranking treatments. High culm retention featured in the highest NPV at the Bukidnon site. Mulch and fertiliser were applied in the three top-ranking treatments in Capiz, but not in the top-ranking treatment in Ilocos Norte. However, the second- and third-ranked treatments in Ilocos Norte did receive fertiliser, organic matter and mulch. This strategy was similar for the three top-ranking treatments in Bukidnon.

Summarising BCR ranking by treatment

Treatment 5 and T4 ranked first and second, respectively, for BCR for both the Capiz and Ilocos Norte sites (which had the same input regime, but different SCD—4-4 in Capiz and 4-4-4 in Ilocos Norte). However, T6 in Capiz was ranked third where a different silvicultural strategy (3-3 SCD) was adopted. On the other hand, Ilocos Norte had T2 as the third-ranked treatment, with no irrigation and 4-4-4 SCD. Incurring the least cost and at the same time obtaining the highest benefits is crucial in the

BCR analysis. The results indicate that one can forgo the expenses of fertiliser, mulch and organic matter but still get a high BCR. However, as manifested in the results obtained, irrigation cannot be sacrificed, as production or yield and consequently income will be adversely affected. Therefore, water is a deciding factor in the productivity, and consequently the yield, of bamboo plantations and natural stands.

The BCR result for Bukidnon indicates that the best approach is to adopt a 6-6 SCD, with no mulch or fertiliser applied. This treatment also ranked third in the NPV ratings. Even without the application of fertiliser and mulch, but with the appropriate silvicultural strategy, high financial returns seemed feasible on this fertile soil. Thus, the prevailing environmental conditions at each site influenced the management strategy that gave the highest financial returns.

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Cultivated bamboo in the Northern Territory of Australia

Mark Traynor[1] and David J. Midmore[2]

Abstract

Trials were conducted on established, yet young (3.5–4.5-year-old), stands of *Dendrocalamus asper* and *D. latiflorus* on three properties in the Northern Territory, Australia; one managed to organic standards. Imposed treatments involved fertiliser rates, irrigation regimes and standing culm numbers. In essence, fertiliser application was effective in hastening shoot appearance and increasing their numbers, especially in wetter years, but culm yield was not markedly affected in these young plantations by fertiliser. Dry (winter) season irrigation was apparently not necessary for shoot production; heavy irrigation just before the beginning and during the shoot season was all that was required. In contrast, culm dry weights were responsive to dry-season irrigation. Maintaining a higher standing culm density, with a greater proportion of 1- and 2-year-old culms enhanced shoot numbers, and an annual strategy of leaving four shoots per clump to develop into culms (to be harvested when just over 3 years of age) was most suitable for shoot and culm production.

Introduction

The Northern Territory (NT) is home to the sole endemic clumping bamboo species of Australia, *Bambusa arnhemica*. Culms of this species have traditionally been harvested in the wild by Indigenous peoples for water containers and didgeridoos. More recently, the shoots have been harvested by Asian immigrants to the area, for both personal but increasingly more importantly for commercial purposes, with seasonal exports to southern states of Australia. The natural resource, which is generally found close to major river systems in the region (Franklin and Bowman 2004), is controlled by the Northern Territory Government—over-exploitation has become of concern as conservation measures fail to stem indiscriminate harvesting (PWCNT 1995; Franklin 2006).

Given that the environment of the NT is conducive to the growth of bamboo, and that the harvest of *B. arnhemica* is limited, a number of entrepreneurs have established bamboo in plantations ranging from 2 to 10 ha, with the view to supplying bamboo shoots for both domestic and export markets. The species planted include vegetatively propagated *Dendrocalamus asper*, *D. latiflorus*, *D. brandisii* and *Bambusa oldhamii*. Given a recent flowering event in *B. arnhemica*, this species has also been propagated from seed by some growers.

Since all of these species are new to plantation-style cultivation in the NT, growers are keen to acquire information on the agronomic/silvicultural management specific to the region, with particular emphasis on mineral nutrition, irrigation and thinning regimes and how they influence the number and size distribution of bamboo shoots and culms. Several trials were set up in the early 2000s, following on from earlier research undertaken by the then NT Department

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of Primary Industries and Fisheries and Central Queensland University (Kleinhenz and Midmore 2002). That research showed that shoot emergence coincided with peaks of rainfall in the NT (i.e. during January to March), and it was hypothesised that irrigation before the natural onset of the rainy season could bring forward shoot harvest dates. The impact of nitrogen (N) nutrition on leaf N for optimum yield was highlighted in the earlier research in Queensland (Kleinhenz and Midmore 2002) and the current trials aimed to determine whether the same was true in the NT, although for different species. Likewise, earlier studies showing that younger culms provided greater shoot yields than did older culms were of interest to NT growers keen to enter early into the seasonal market, and this was included in the present study.

The trials, in three sites, therefore studied the effects of irrigation, N nutrition and management of culm number on shoot and culm yields of *D. asper* and *D. latiflorus*.

Materials and methods

Experimental sites

Three sites were chosen for experimentation, within a 60 km radius from Darwin, NT.

Site 1 (Berry Springs)

This site utilised a 4.5-year-old planting of *Dendrocalamus asper*, established from tissue-cultured plantlets and spaced at 6 m between clumps within a row and 12 m between rows. A natural grass stand was periodically mown between rows and used to mulch the bamboo clumps. The farm was managed organically.

Irrigation was provided through a mini-sprinkler system, with the capacity to irrigate a 20 m^2 area for each clump and to supply 80 L/hour/clump. The trial comprised a factorial design with two irrigation × three fertiliser × three thinning treatments, in a randomised complete block set-up with three replications. Plot size comprised nine plants (i.e. clumps).

Site 2 (Middle Point)

This trial utilised a 3.5-year-old planting of *D. latiflorus* established from cuttings at spacing of 7 m × 8 m between clumps. Irrigation was provided by mini sprinklers. The trial investigated the effects of three irrigation treatments and two fertiliser treatments, in a randomised complete block design with three replications. This site is at the NT Government horticultural research farm.

All clumps were subjected to a 4-4-4 thinning schedule, i.e. at any one time there were four 0–1-year-old-culms, four 1–2-year-old culms and four 2–3-year-old culms. Harvesting of culms took place in the dry season, following the shoot season, and the four culms older than 3 years were removed at ground level. Plot size was four plants.

Site 3 (Old Bynoe Road)

The third trial utilised a 4-year-old planting of *D. latiflorus* grown from cuttings and planted 6 m apart within a single windbreak row. The trial compared two irrigation and three fertiliser treatments plus three thinning treatments, replicated three times in a randomised complete block design. Plot size was nine plants and irrigation was provided by mini sprinklers.

At both sites 1 and 3, some seedlings of *B. arhemica* were also planted, for general observation, but data are not presented herein.

Treatments

Fertiliser

Earlier research (Kleinhenz and Midmore 2002) indicated that 3% leaf nitrogen (N) concentration was linked with optimal yields across a number of bamboo species, and they established a quadratic relationship between % leaf N and fertiliser application rates, such that, for a given deficiency in % leaf N, a determined fertiliser rate would bring % leaf N to 3%. One fertiliser treatment, the 100% N, was determined by the N rate required to bring actual % leaf N to 3%, based upon leaf N analysis before fertiliser application, in the 100% irrigation treatment. Percentage leaf N was again measured soon (within 3–4 weeks) after application to determine the response. The other two fertiliser treatments comprised 25% of the fertiliser input dictated by the 100% treatment, and double the prescribed amount of N, i.e. the 200% treatment.

At site 1, the fertiliser was applied as an organic product with 5:3:1.5 N:P:K (ratio of nitrogen to phosphorus to potassium). At sites 2 and 3, it was applied as a mineral blend of 15:4:11 N:P:K. All treatments were applied to a 20 m^2 area around each clump.

Irrigation

The 100% irrigation treatment was scheduled to provide 100% of the monthly average daily evaporation values, irrigated twice daily. The 50% irrigation treatment provided one-half of the 100%

treatment, again irrigated twice daily, and the drought treatment did not provide irrigation during the dry season months of April to September, with irrigation at 100% commencing October of each year. The irrigated area around each clump was 20 m^2. The irrigation quantities applied at site 2 according to treatment are provided in Table 1. Similar amounts were applied according to treatment at the other sites, because October–March rainfall was also similar across sites (Table 2).

Table 1. Irrigation quantities (L/month) at site 2 according to treatment

Month	Treatment[a]		
	100%	50%	Drought
Jan	6,820	3,410	6,820
Feb	5,600	2,800	5,600
Mar	6,200	3,100	6,200
Apr	6,900	3,450	0
May	7,440	3,720	0
Jun	7,200	3,600	0
Jul	7,440	3,720	0
Aug	7,750	3,875	0
Sep	8,400	4,200	0
Oct	8,990	4,495	8,990
Nov	8,100	4,050	8,100
Dec	7,440	3,720	7,440
Totals	88,280	44,140	43,150
ML/ha/year	15.8	7.9	7.7

[a] 100% = scheduled to provide 100% of the monthly average daily evaporation values; 50% = one-half of the 100% treatment; drought = no irrigation from April to September, otherwise as for 100%

Table 2. Total October–March rainfall (mm) at sites 2 and 3

Date	Site 2	Site 3
2002–03	1,396	1,460
2003–04	1,728	1,924
2004–05	950	1,079

Thinning

Three thinning treatments were imposed at sites 1 and 3. The 4-4-4 standing culm density (SCD) was as described for site 2. The 4-2-2 SCD comprised four 0–1-year-old culms, two 1–2-year old culms and two 2–3-year-old culms. The 2-2-2 SCD was as for the 4-4-4 SCD, but with only two culms of each age class. During the wet season, the designated number of shoots was left in each clump to grow into culms and each was given an identification marking for that year. Other shoots were harvested fresh. During the following dry season, the designated number of the oldest culms was removed, leaving each clump with the required SCD for each treatment. This resulted in three generations of experimental culms in each thinning treatment with their own colour identification marking. The thinning of treatments was conducted in July each year.

All treatments were established before the start of the 2002 dry season, although the initial thinning of all treatments was done in late 2001 so that each clump had a specific culm population according to its designated treatment.

Data collection

Shoot and culm harvest

Shoots were manually harvested on a twice or three-times weekly schedule, to ensure that shoots were within the accepted height-to-base diameter ratios of 2:1 and 3:1, separated into various size classes, counted and weighed. Untrimmed shoots greater than 0.35 kg were generally classed as marketable. Shoots were then trimmed ready for market before each shoot was weighed, measured and recorded.

Culms were harvested in July of each year and in 2004 and 2005 (some treatments only) they were measured for determination of culm biomass, as described by Zhu et al. (2009).

Soil water content

All treatments were monitored once a week with a Diviner moisture probe to a depth of 1 m. Monitoring with tensiometers was conducted during the first year but did not produce useful data and was not continued after the 2002 dry season. Tensiometers measure the soil water potential and could not be maintained within their working range of 0–80 centibars. The Diviner moisture probe measures volumetric soil water content at 10 cm increments and monitoring sites require no maintenance.

Leaf nitrogen concentration

Youngest fully expanded leaves from at least 10 branches were collected from 1-year-old culms from each plot, dried, ground and subjected to Kjeldahl analysis for total % N. Samples were collected just before anticipated timing of fertiliser applications (generally in October and April) and 3–4 weeks later.

On a number of occasions, the nitrate concentration in juice expressed from harvested shoots was quantified using the Reflectoquant test system and related to % leaf N.

Data analysis

Analyses of shoot yield data were done for each site as repeated measures models that accounted for the three shoot seasons in one model, using the software Statistical. Analyses presented are for average marketable shoot number per clump—to test for treatment effect on shoot yield, and average individual marketable shoot weight per clump—to test any treatment effect on shoot size. Significant interactions between treatments and seasons across sites 2 and 3 were most likely caused by the comparatively low rainfall of the 2004–05 wet season, which was also responsible for the yield reduction in some.

Results

Fertiliser treatments

Application rates and monitoring of leaf N

At site 1, the organic input site, even with large quantities of N application, % leaf N did not reach 3% (Figure 1). Indeed, the grower, after year 1 of the project, decided that he could not justify the costs associated with the prescribed application rates, and he pulled out of the trial.

At sites 2 and 3, % leaf N was more responsive to N applications, although rarely did % leaf N reach 3% (Figure 2 and Figure 3, respectively). The total amounts of N applied in each year are presented in Table 3 and the % leaf N before the shoot season in Table 4. Carryover effects of N treatments were evident; higher rates of N application resulted in higher pre-application % N in leaves, but the rates of application to achieve this were considerable, reaching over 1,000 kg N/ha in 2 of the 4 years.

Since phosphorus and potassium were applied in proportions following the N rates (for the N:P:K ratio of the compound fertiliser was 4:1:3), it is instructive to review the data on leaf K (Table 4). The data show no effect of rate of K application on leaf K, although there was an indication that the leaf concentration declined after the first year.

Shoot and culm yields

Despite there having been negligible effect of fertiliser on % leaf N at site 1—the organic site—shoot number, albeit very low, showed a positive response (Figure 4) in the first (and only) season's harvest. At site 2, where only 25% and 100% fertiliser were compared, the higher rate led to more shoots in the first two seasons (Figure 5), but averaged over the three seasons the effect was not significant.

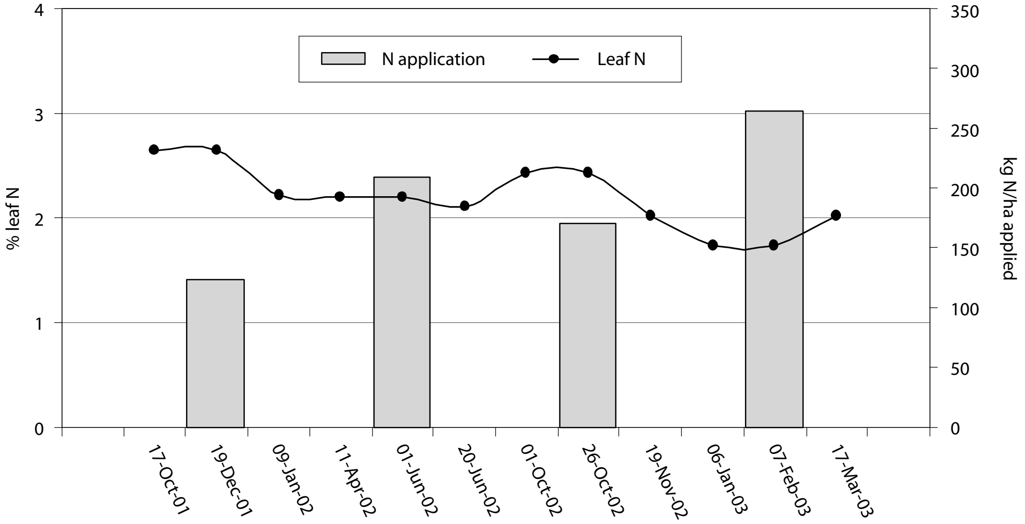

Figure 1. Nitrogen application (100% treatment) and response in leaf N at site 1. Note: 100% treatment = amount of fertiliser calculated to bring leaf N to 3%.

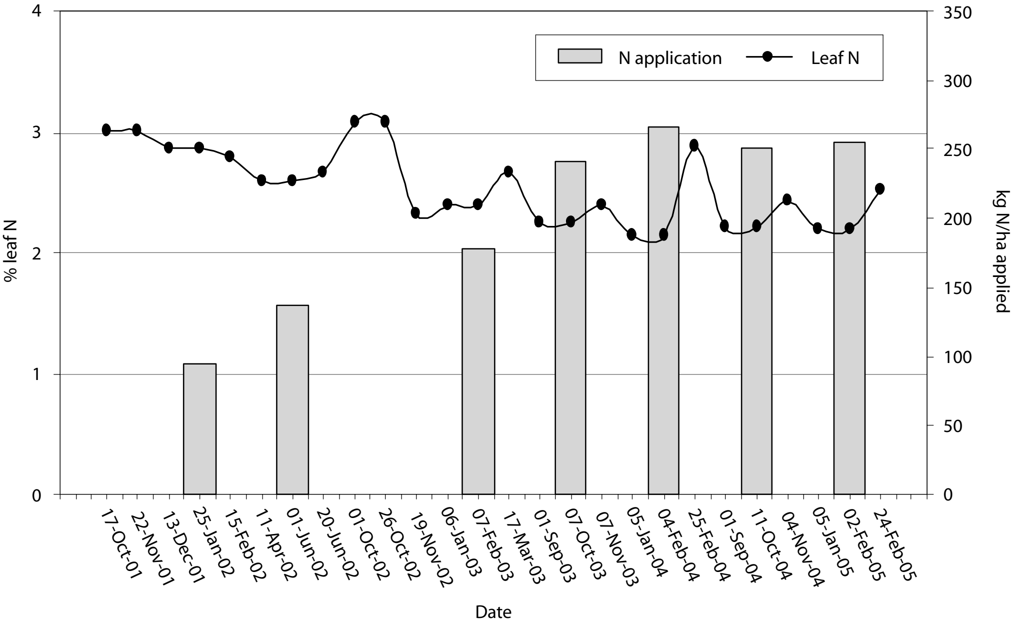

Figure 2. Nitrogen application (100% treatment) and response in leaf N at site 2. Note: 100% treatment = amount of fertiliser calculated to bring leaf N to 3%.

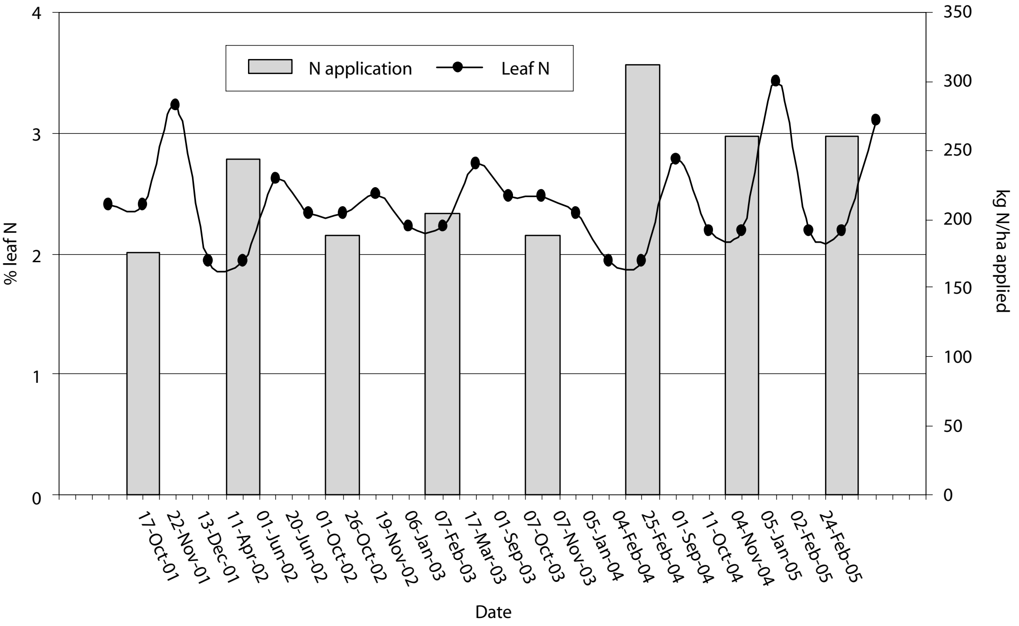

Figure 3. Nitrogen application (100% treatment) and response in leaf N at site 3. Note: 100% treatment = amount of fertiliser calculated to bring leaf N to 3%.

Table 3. Annual totals (kg/ha) of applied nitrogen (N) and potassium (K) at sites 2 and 3

Year	Site 3 treatments[a]						Site 2 treatments[a]			
	25%		100%		200%		25%		100%	
	N	K	N	K	N	K	N	K	N	K
2001–02	105	74	419	297	838	594	58	42	231	168
2002–03	98	72	393	287	786	574	45	33	178	132
2003–04	125	91	500	363	1,000	726	127	92	507	369
2004–05	130	94	520	374	1,040	748	127	93	506	369

[a] 100% = amount of fertiliser calculated to bring leaf N to 3%; 25% = one-quarter of the amount dictated by the 100% treatment; 200% = double the 100% input

Table 4. Leaf nutrient levels before pre-shooting fertiliser application for each year of the project for sites 2 and 3

Sampling date	Site 3 treatments[a]						Site 2 treatments[a]			
	25%		100%		200%		25%		100%	
	Leaf N	Leaf K	Leaf N	Leaf K	Leaf N	Leaf K	Leaf N	Leaf K	Leaf N	Leaf K
26 Oct 2002	2.23	2.05	2.33	2.05	2.71	1.92	2.99	1.68	3.09	1.69
07 Oct 2003	2.27	1.75	2.47	1.59	2.69	1.59	2.16	1.43	2.26	1.38
11 Oct 2004	1.92	1.73	2.18	1.64	2.47	1.65	2.13	1.66	2.22	1.37

[a] 100% = amount of fertiliser calculated to bring leaf N to 3%; 25% = one-quarter of the amount dictated by the 100% treatment; 200% = double the 100% input

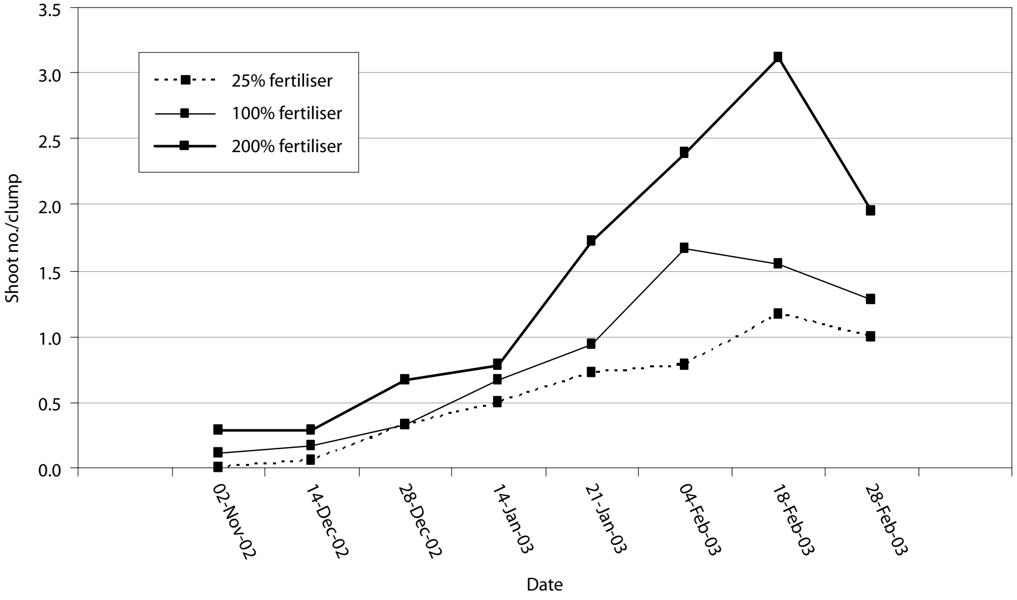

Figure 4. Average shoot number per clump for the 2002–03 season at site 1 as affected by fertiliser treatments. Note: 100% fertiliser = amount of fertiliser calculated to bring leaf N to 3%; 25% = one-quarter of the amount dictated by the 100% treatment; 200% = double the 100% input.

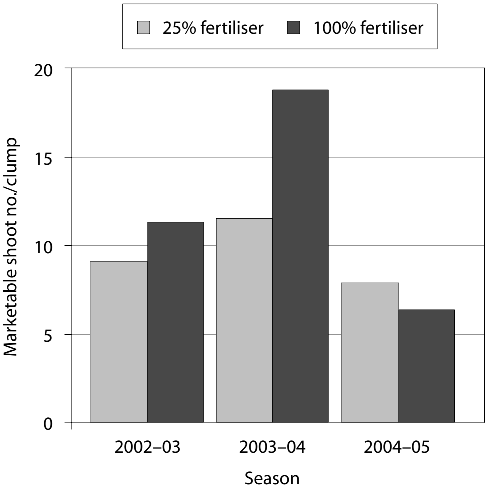

Figure 5. Average marketable shoot number per clump over the three shoot seasons at site 2 as affected by fertiliser treatments. Note: 100% fertiliser = amount of fertiliser calculated to bring leaf N to 3%; 25% = one-quarter of the amount dictated by the 100% treatment

Higher fertiliser rates at site 3 resulted in more shoots in association with an earlier harvest (Figure 6). As clumps aged, the shoot size distribution tended towards larger shoots (Figure 7) and, at site 3, average marketable shoot number per clump ranged from 3.1 in the 25% fertiliser treatment, 5.3 in the 100% treatment, to 8.2 in the 200% treatment (data not shown).

Weight per shoot did not differ between fertiliser treatments at site 1 (0.10 kg at 25% N, 0.10 kg at 100% N and 0.09 kg at 200% N; data not shown). Likewise, at neither site 2 nor site 3 was weight per shoot affected by fertiliser treatment (on average 0.48 kg at 25% N and 0.48 kg at 100% N at site 2, and 0.38 kg at 25% N, 0.39 kg at 100% N and 0.40 kg at 200% N at site 3; data not shown). Therefore, the response of total shoot yield in the fertiliser treatments followed the pattern of shoot numbers.

Culms were weighed as harvested only at sites 2 and 3 in 2004 and at site 2 in 2005. At neither site in 2004 was culm weight affected by fertiliser treatment, with culms in the range of 5.0–6.0 t/ha at site 2 and 6.9–7.3 t/ha at site 3 (detailed data not shown). This was about one-half of the total above-ground biomass produced. Leaf and branches comprised c. 52% and culms c. 48% of the total biomass at

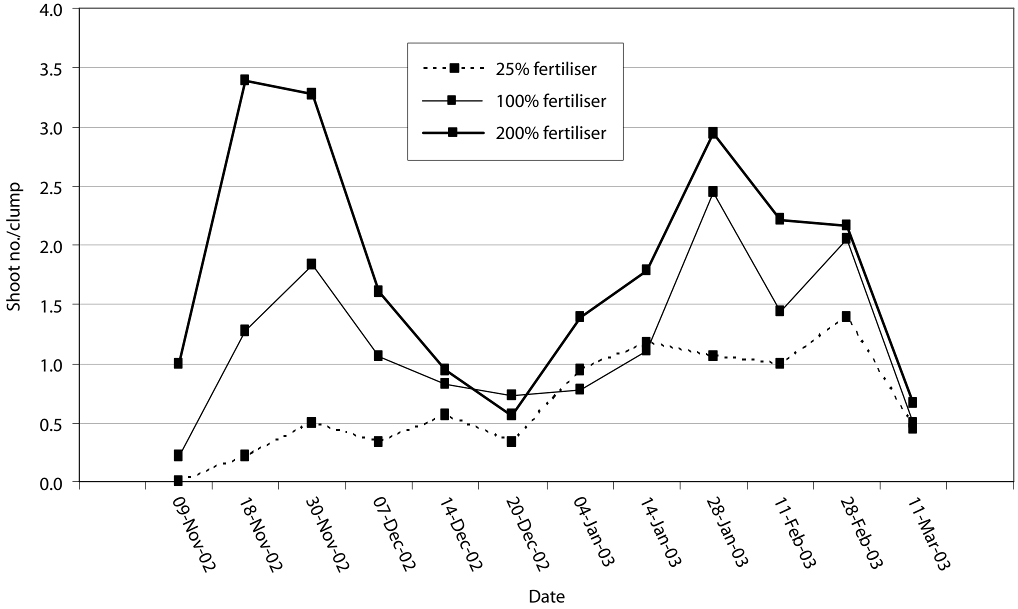

Figure 6. Average shoot number per clump for the 2002–03 season at site 3 as affected by fertiliser treatments. Note: 100% fertiliser = amount of fertiliser calculated to bring leaf N to 3%; 25% = one-quarter of the amount dictated by the 100% treatment; 200% = double the 100% input.

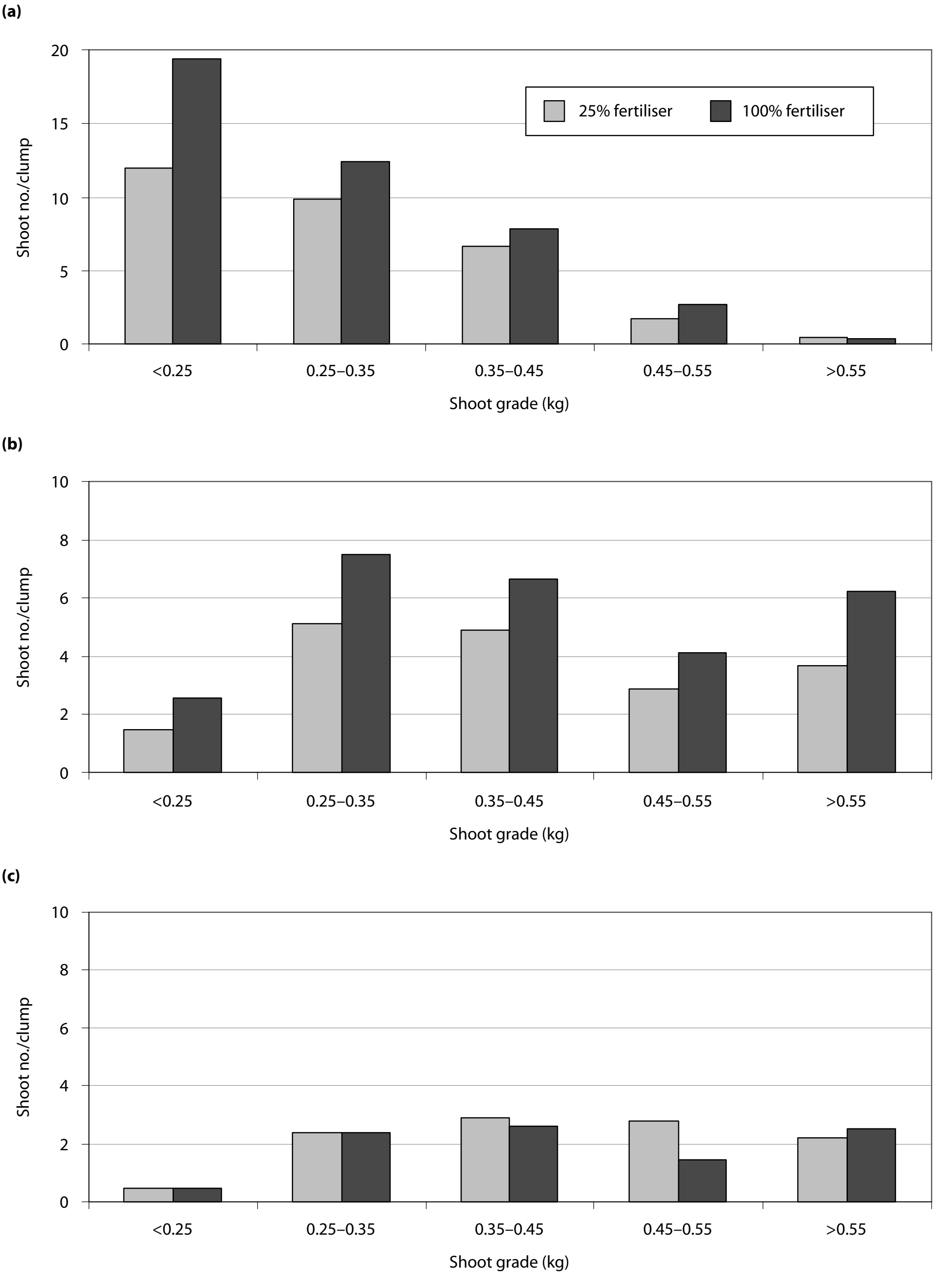

Figure 7. Shoot size distribution (average shoot number per clump) over three seasons at site 2 as affected by treatments: (a) 2002–03; (b) 2003–04; and (c) 2004–05. Note: 100% fertiliser = amount of fertiliser calculated to bring leaf N to 3%; 25% = one-quarter of the amount dictated by the 100% treatment.

site 2 with *D. latiflorus*, and at site 3 for *D. latiflorus*, values were c. 45% and c. 55%, respectively. There was a tendency for higher N to increase culm over branch-plus-leaf biomass and in site 2 in 2005, culms in the 100% N treatment were 13% heavier.

Irrigation treatments

Application rates and soil moisture content

Average application amounts (Table 1) show small variation between months, with September and October receiving greatest amounts and February (due to cloudy wet days with lower evaporation) the least. Seasonal rainfall for sites 2 and 3 is presented in Table 2 and it is evident that there was a near twofold difference between 2003–04 and 2004–05.

At site 1, soil water monitoring continued only until early 2003, and showed greater availability of water in the 100% than the 50% treatment (data not presented), with the exception of December through to March 2003 when the two treatments did not differ.

At site 2, the volumetric soil water content (VSWC) for the drought and 50% treatments was very similar throughout the three dry seasons and the timing of recommencement in October of full irrigation in the drought treatment is quite clear (Figure 8). The drought treatment thereafter received the 100% rate and the soil moisture for that treatment then remained quite similar to that of the 100% treatment. For this site, the 100% irrigation treatment reached field capacity (128–146 mm over 0–50 cm soil depth) in only the 2003–04 wet season when considerably more rainfall was received than in the other 2 years. The VSWC of the 100% inputs in the upper profile were considerably higher than the 50% and drought treatments, and remained above wilting point (45–46 mm over 0–50 cm soil depth). The VSWC of the three treatments was quite similar in the lower compared to the upper soil profile, with less fluctuation in weekly records (data not presented). The VSWC of the 100% treatment remained below 80 mm in the lower profile, indicating that very little applied water reached below 50 cm soil depth. These monitoring data combined with shoot yield data suggest that the evaporation replacement treatment (100%) was insufficient in quantity to markedly affect plant performance.

At site 3, although the VSWC in the upper soil profile of the 100% treatment remained slightly higher than the 50% inputs over the three dry seasons, both treatments were very similar (Figure 9). This indicates the free drainage of the soil and contrasts with site 2

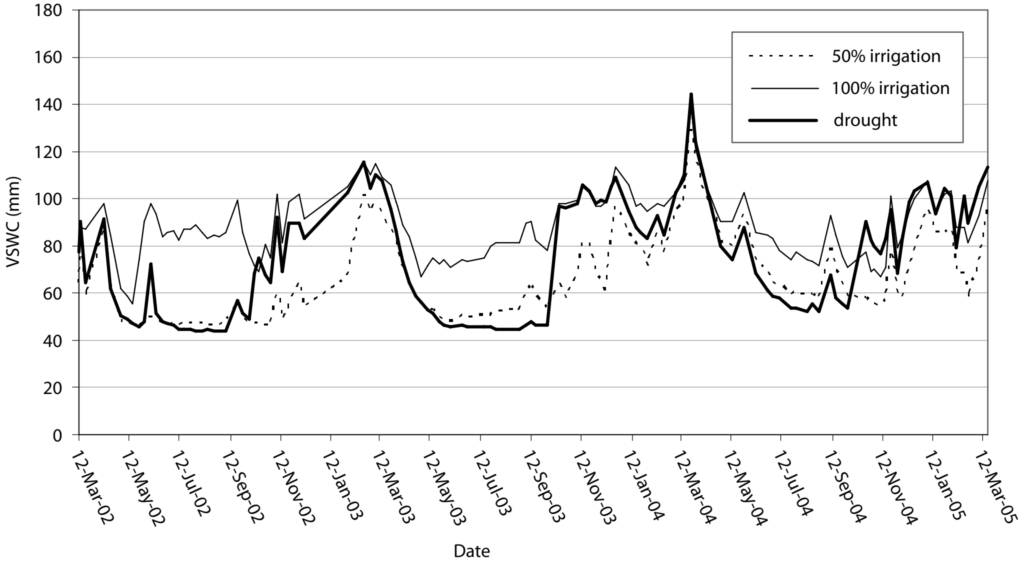

Figure 8. Volumetric soil water content (VSWC) of the upper soil profile (0–50 cm) for irrigation treatments at site 2. Note: 100% irrigation = scheduled to provide 100% of the monthly average daily evaporation values; 50% = one-half of the 100% treatment; drought = no irrigation from April to September, otherwise as for 100%.

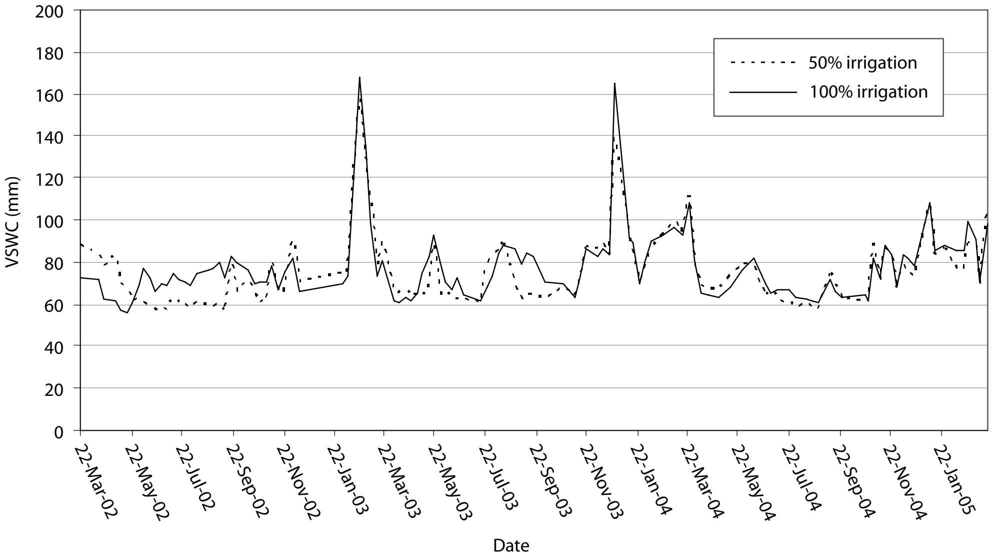

Figure 9. Volumetric soil water content (VSWC) of the upper soil profile (0–50 cm) for irrigation treatments at site 3. Note: 100% irrigation = scheduled to provide 100% of the monthly average daily evaporation values; 50% = one-half of the 100% treatment.

where the soil had a greater water-holding capacity and was able to retain more of the water applied in the 100% treatment. More water was held in the lower soil profile in the 100% treatment compared to the 50% inputs (Figure 10) which may also indicate that the additional water of the 100% treatment drained through the soil profile. As with site 2, it seems that the evaporation replacement treatment (100%) was insufficient in volume to satisfy plant demand.

Although site 3 received more total rainfall in each of the three wet seasons, data for VSWC indicate that the peaks of the three wet seasons are compressed compared with those of site 2. This is further indication of the lower water-holding capacity of the soil at site 3.

Shoot and culm yields

The onset of the shoot season was earlier with the 100% compared to the 50% irrigation treatments at site 1, but overall number did not differ, and weight per shoot and size grade distribution also did not differ between irrigation treatments (data not presented).

The winter drought treatment at site 2 resulted in a consistent increase in the number of marketable shoots per clump (Figure 11), the effect being greater in 2003–04, the year with the greatest rainfall, and in combination with the 100% fertiliser treatment compared to the 25% fertiliser treatment (data not presented). At site 3, averaged over the three seasons, irrigation had no effect on shoot number (although the tendency was for shoot number to be greater for the 50% irrigation treatments; $P = 0.07$), nor weight per shoot. At site 2, weight per shoot was also not affected by irrigation treatment, hence total yield per clump responded in the same manner to irrigation as did number of shoots per clump.

In contrast to these data showing benefits of drought on shoot numbers, 100% irrigation at site 2 led to calculated culm dry-weight yields of 6.5 t/ha in 2004 and 7.5 t/ha in 2005 compared to 5.4 and 6.5 t/ha for 50% irrigation and 4.9 and 5.1 t/ha for the winter season drought treatment, respectively. At site 3, there was no effect of irrigation on culm dry weight (detailed data not presented).

Thinning treatments

Thinning treatments were imposed only at sites 1 and 3.

At site 1, where monitoring was for the first season only, there was a marked (but in absolute terms small) increase in shoot number with the 2-2-2 treatment compared to the others, but no effect on size-grade distribution (data not presented).

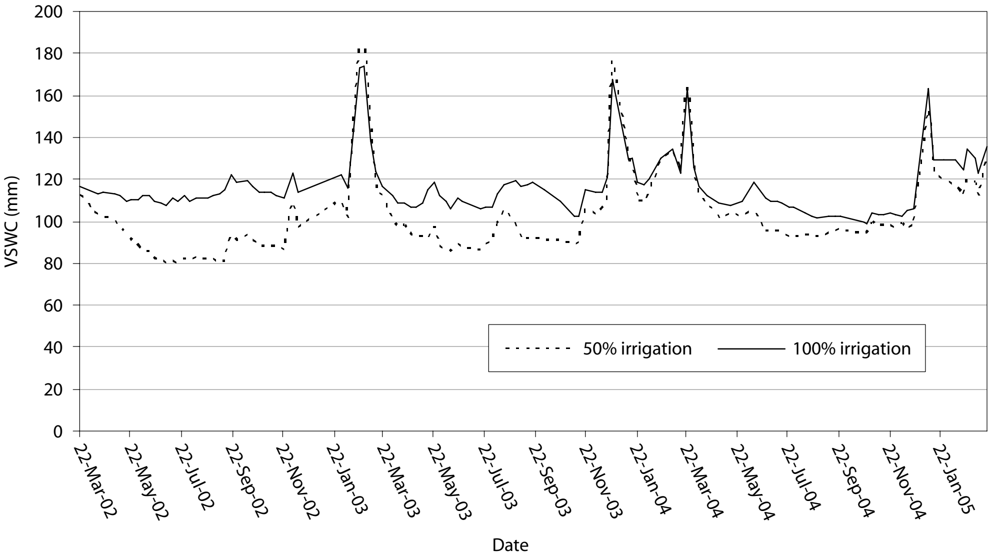

Figure 10. Volumetric soil water content (VSWC) of the lower soil profile (50–100 cm) for irrigation treatments at site 3. Note: 100% irrigation = scheduled to provide 100% of the monthly average daily evaporation values; 50% = one-half of the 100% treatment.

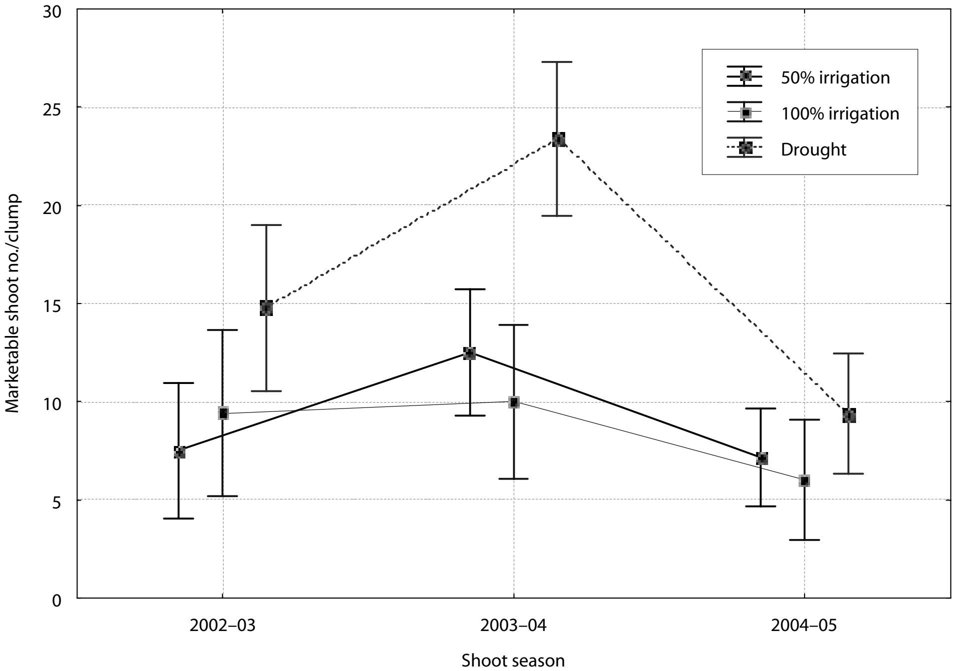

Figure 11. Average marketable shoot number per clump for the irrigation treatments over three shoot seasons at site 2 (vertical bars denote ± 95% confidence limits)

Both number and individual weight of shoots were influenced by thinning treatments at site 3. Averaged over the three seasons, shoot number per clump and weight per shoot were similar for 4-4-4 and 4-2-2 treatments, and both were greater by a factor of two than the number for 2-2-2, although the effect on number was not notable in the first year after the treatment was imposed (Figure 12) and the effect on weight per shoot was evident in only the third year (data not presented).

Individual culm dry weights at site 3 in the 2004 harvest were not markedly affected by thinning treatments, but because the 4-2-2 and 2-2-2 treatments had only half the number of culms harvested compared to the 4-4-4, their yields (c. 3.6–3.7 t/ha) were only 50% those of 4-4-4 (6.8 t/ha).

Discussion

Fertiliser

The higher fertiliser rates almost invariably resulted in a higher shoot yield and more shoots early in the season. This effect was strongest when combined with a good wet season. Illustrative data from 2002–03, presented in Figure 13, show the cumulative number of marketable shoots harvested from the start of harvest through to the end of December for the fertiliser treatments at site 3. The higher rates of fertiliser application consistently resulted in more harvested shoots during the early stages of the three shooting seasons. This trend was evident for the two fertiliser treatments at site 2 for the first two seasons but not in 2004–05 (data not presented). The use of strategic applications of fertiliser in the management of bamboo for shoot production may provide an economic advantage in the market. Indeed, high nitrogen supply has enhancing effects in terms of earliness and numbers of tillers in other members of the grass family (see e.g. Salvagiotti and Miralles 2007).

While the response to increased nitrogen and potassium fertiliser was strongly reflected in shoot yield, the response in leaf nutrient levels was surprisingly small. The objective to achieve 3% nitrogen in the leaves of 1-year-old culms using the calculated diagnosis and recommendation integrated system (DRIS) fertiliser application rate (Kleinhenz and Midmore 2002), although based on a number of bamboo species, was generally not successful and would need updating to suit NT conditions.

An alternative fertiliser strategy for local growers might be based on the correlation of experimental yields with fertiliser inputs, supported by leaf nutrient concentration ranges developed from project data.

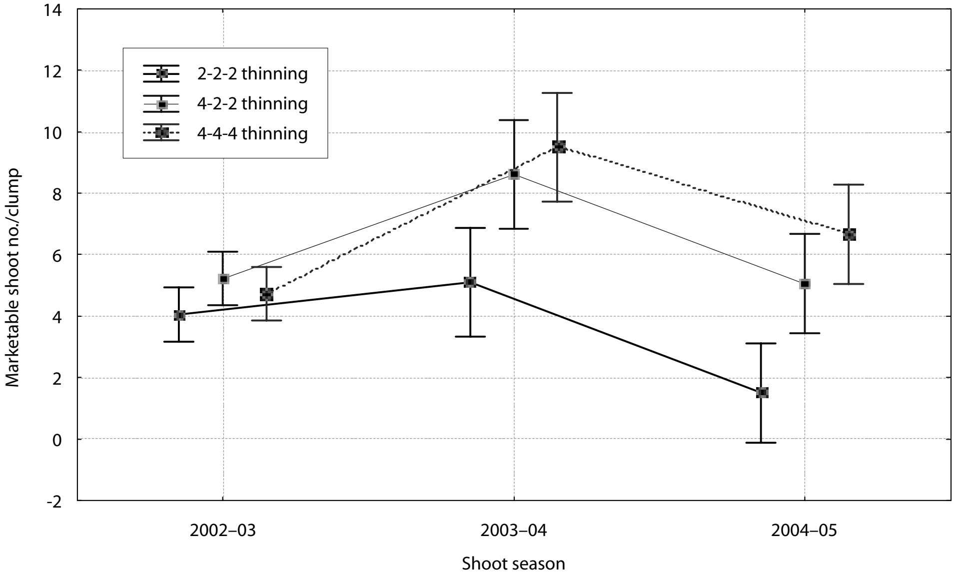

Figure 12. Average marketable shoot number per clump for the thinning treatments over the three shoot seasons at site 3 (vertical bars denote ± 95% confidence limits)

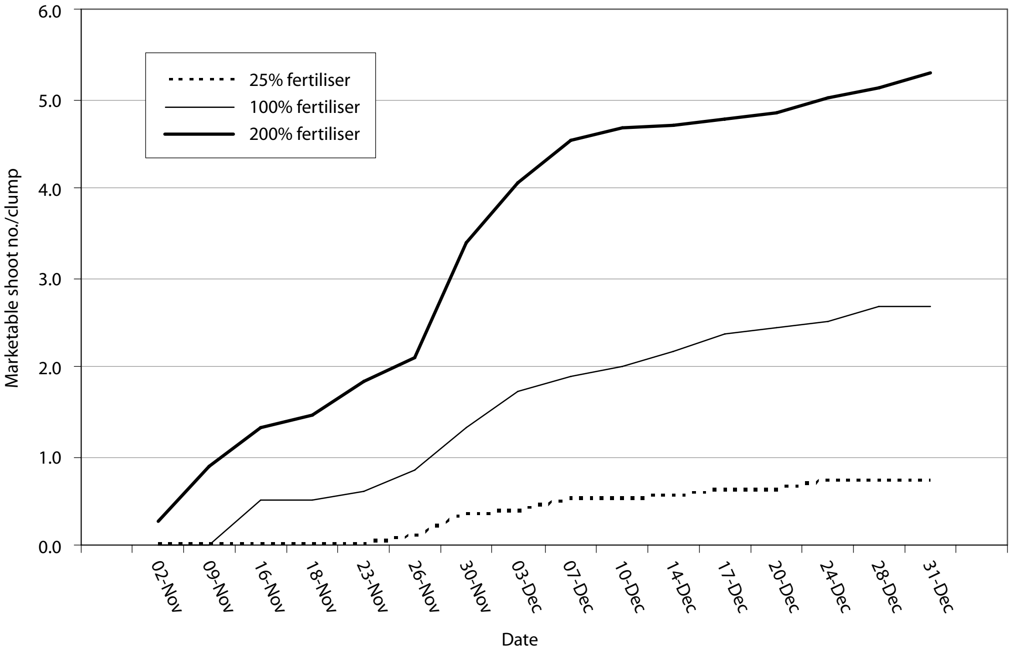

Figure 13. Early marketable shoot numbers per clump as affected by fertiliser treatments for site 3 in 2002

Although not tested in this project, it is considered that the strategic fertigation of nitrogen and potassium would have benefits over the application of solid fertilisers. High daily rates could be applied over a week or more directly into the surface roots. This would minimise leaching caused by monsoonal rainfall, which may occur with single applications of solid fertiliser.

Culm yields in 2004 were not influenced by fertiliser treatments, but were to a small degree in 2005, perhaps a further indication (see below) that growth of the bamboo clumps was constrained by water shortage, even at the highest irrigation rate.

Irrigation

Watering as we trialled during 5 months (May–September) of the 6-month dry season (April–September) may not be necessary. An irrigation strategy of supplying high-volume irrigation to mature clumps only before and during the shoot season appeared to have the same effect on shoot yield as irrigation throughout the dry season, and saved on irrigation costs. There was indeed a close relationship between the propensity of clumps to shoot and both rainfall and VSWC. Figure 14 indicates the strong correlation between rainfall and significant increases in VSWC. The commencement and continuation of shoot emergence during this project was strongly reliant on monsoonal rainfall. The shooting periods at sites 2 and 3 appear to be initiated by significant increases in VSWC within the upper soil profile (e.g. Figure 15), which contains most of the clump roots (Kleinhenz and Midmore 2001). These data indicate that shooting began when the upper profile reached 100 mm water content per 50 cm profile at site 2 and at around 80 mm at the site 3. If a high-volume irrigation strategy were trialled to initiate early or out-of-season shooting, then frequent monitoring of VSWC would be required. Data from southern Queensland (Kleinhenz et al. 2003) do show that imposed early irrigation before natural summer rainfall can bring forward shoot appearance.

Although the 100% daily irrigation inputs used in the project are similar to those applied to various tropical tree crops (Diczbalis and Wicks 2002), they appear to be insufficient to have a significant effect on bamboo shoot production and failed to sustain the VSWC that was anticipated.

Only monsoonal rainfall achieved the required wetted soil profile to trigger shoot emergence; evaporation replacement irrigation inputs were not sufficient.

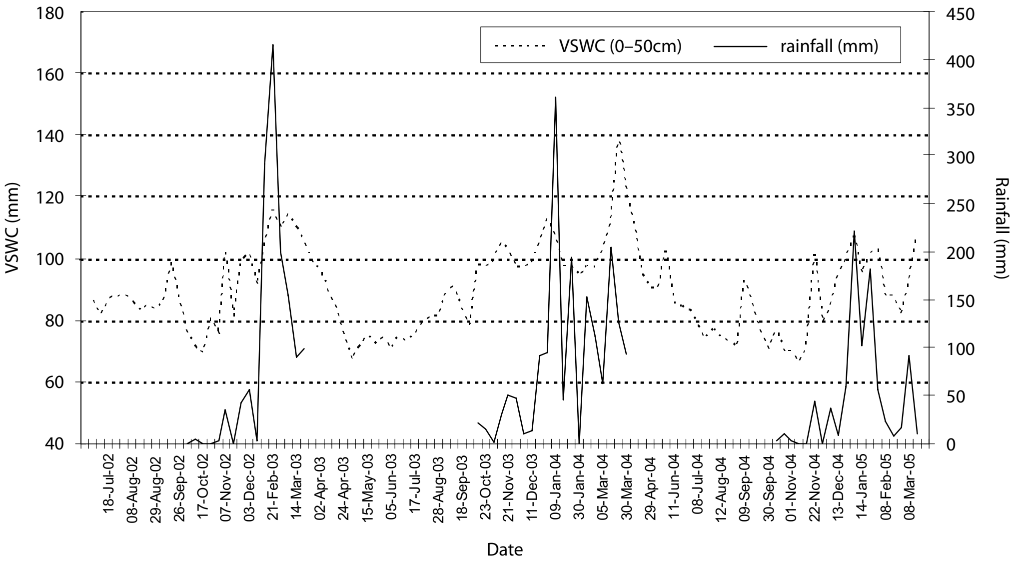

Figure 14. Rainfall and volumetric soil water content (VSWC) of the upper soil profile (0–50 cm) for the 100% irrigation treatment at site 2 over three seasons. Note: 100% irrigation = scheduled to provide 100% of the monthly mean daily evaporation values.

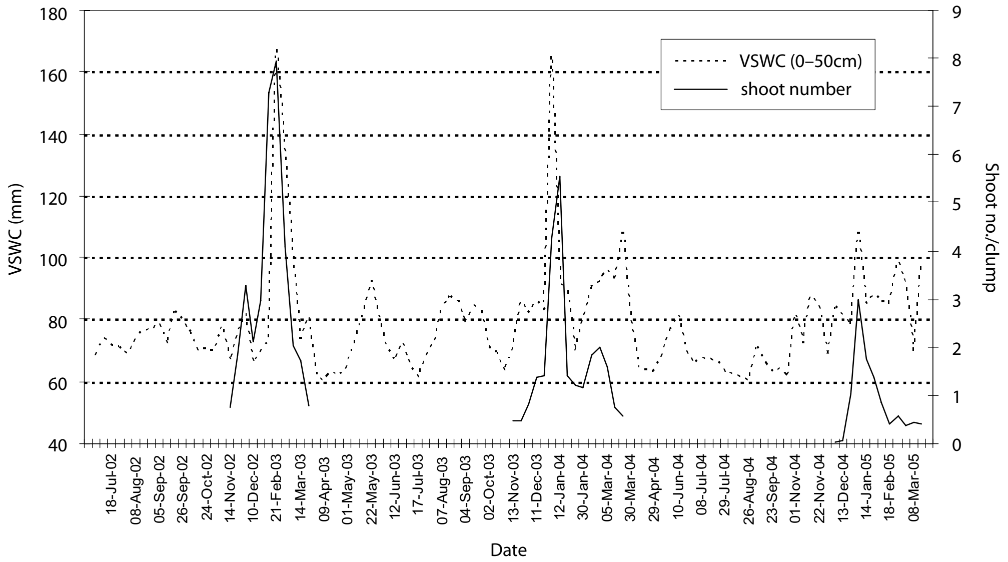

Figure 15. Volumetric soil water content (VSWC) of the upper soil profile (0–50 cm) and average shoot number per clump for the 100% irrigation treatment at site 3 over three seasons. Note: 100% irrigation = scheduled to provide 100% of the monthly mean daily evaporation values.

Most likely, a large volume of dormant root mass would need to be 'activated' by high-volume irrigation to induce shooting before the wet season. Seasonal monsoon rainfall is high volume, continuous over an extended period and falls on the total plantation area. To achieve this with irrigation may prove difficult and expensive but would be worth investigation in an attempt to achieve earlier or out-of-season shooting.

Weight of culms at harvest (in 2004) was affected by irrigation treatment. At site 2, the site with the heavier soil type, drought (irrigation only for 5 months during the dry season) reduced culm weight compared to full 100% irrigation (by 24% in 2004 and 33% in 2005) and 50% irrigation also reduced culm yield (by 15% in 2004 and 13% in 2005). At site 3, with a lighter soil and less notable difference between soil depths in VSWC (Figures 9 and 10), irrigation rates (50% or 100%) did not affect culm weights.

Thinning

The marketable shoot yield increased with higher standing culm density (SCD) and with a higher percentage of 1- and 2-year-old culms across treatments. Higher SCD may result in the development of more rhizome axes and a greater shoot yield potential from the growing points of these axes. Project research in the Philippines has shown that 1- and 2-year-old culms can produce 90% of new shoots (Malab et al. 2009) and the data from the current thinning treatments support that finding.

A productive thinning strategy for shoot production would maintain only (or a high percentage of) 1- and 2-year-old culms and apply a SCD that encourages strong rhizome development. Possible thinning schedules focusing on shoot production might be 4-4-2 or 4-4. If both shoots and mature 3-year-old timber culms are to be harvested, then 4-4-4 would be a better schedule. Before the first thinning operation of young bamboo plants, it is important to encourage a well-developed and branching rhizome (M. Traynor, personal observation).

There are some important considerations in the selection of shoots to grow into culms. Shoots selected early in the season will have the full benefit of favourable wet-season conditions to become established culms, while shoots selected late in the season may have their development restricted by the onset of the dry season. Selected shoots should be of good size and evenly spaced around the clump. Some form of yearly identification marking of new culms will assist at thinning time.

Thinning treatments did not affect the individual weight of culms, most likely because clumps were widely spaced and still without canopy overlap and hence did not impose severe within-clump competition, and culm yield per unit area was directly proportional to the number of culms harvested.

In summary, fertiliser application was effective in hastening timing of shoot appearance and their numbers, especially in wetter years, but culm yield was not affected by fertiliser. Dry-season (winter) irrigation was not, apparently, necessary for shoot production; heavy irrigation just before the beginning and during the shoot season was all that was required. In contrast, culm dry weights were responsive to dry-season irrigation. Maintaining a higher standing culm density, with a greater proportion of 1- and 2-year-old culms enhanced shoot numbers, and an annual strategy of leaving four shoots per clump to develop into culms, to be harvested when just over 3 years of age, was most suitable for shoot and culm production.

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Identifying agricultural practices to sustain bamboo production in Queensland, Australia

Grant X. Zhu, Steve Ockerby, Daniel T. White and David J. Midmore[1]

Abstract

Bamboo, as a relatively new plantation crop in Australia, requires an integrated agricultural strategy as a benchmark against which improvements to optimise productivity and maximise growers' gross margin can be assessed. An important aspect of bamboo production is how to balance the productivity and returns from edible shoots and/or culms for timber. A 6-year trial was set up on an existing clumping bamboo (*Bambusa oldhamii*) grove at Eumundi, Queensland, Australia, from 2001 to 2006. Using conventional best management as a control (T1—fertilised, irrigated, early-season selection of shoots for timber culms, and designed wide clump space), five other treatment variations (T2—no irrigation during dry season, T3—late-season selection, T4—narrow spacing, T5—late-season selection, and harvesting excess shoots only as early thinning, and T6—non-irrigation, non-fertilisation, early-season selection) were imposed. Shoots and culms in each treatment were seasonally harvested during 2003–05, and the total production, i.e. fresh weight (FW) for shoots and dry weight (DW) and volume for culms, were summed for each treatment. Water-use efficiency for dry culms at c. 1.0 g/kg (total applied water plus precipitation) was not dissimilar to other species. There was a trade-off between shoot and culm production when the harvest of shoots as a vegetable was excessive. To compare bamboo productivity between treatments, a productivity index (PI) was calculated to convert the value of culm DW to relative market value of edible shoot FW using a range of ratios from 0.0–1.0 such that the value of 1 kg of culm was adjusted as a ratio of the value of 1 kg of edible shoot. We concluded that T3 was the best strategy for producing shoots only, T5 was the best for culms only, and T2 was the best for dual production of shoots and culms because it increased average relative water-use efficiency by 28%. However, the case study indicated that T3 was a financially sustainable management for growers in Australia regardless of the fluctuation in shoot and culm market prices. Additionally, a leaf chlorophyll meter proved to be reliable in estimating bamboo leaf nitrogen concentration as a guide to nitrogen fertiliser decisions.

Introduction

The first broadacre commercial bamboo farm in Australia was established in 1989 and a handbook for bamboo selection, establishment and utilisation was published 10 years later (Dart 1999). Research by Kleinhenz et al. (2003) at the same location showed that growth and yield of the running bamboo *Phyllostachys pubescens* responded strongly to increased water supply and marginally to increasing rates of fertilisation. The study showed that concentration of leaf nitrogen (N) was an early and better indicator of yield response to fertiliser than was soil N. Kleinhenz and Midmore (2002) showed that bamboo leaf N level was more responsive to N fertiliser application when the leaf N concentration was below 3%.

Frequent sampling of bamboo leaves and analysis of leaf N with wet chemistry is laborious and costly. Alternatively, soil plant analysis development (SPAD) is widely used for measuring plant total chlorophyll (TCHL) concentration, and SPAD readings have positive and linear correlations with TCHL in several crops and weeds (Turner and Jund 1991; Monje and Bugbee 1992) and are closely related to plant leaf N

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concentration in temperate grasses (Gáborccaroník 2003), rice (Peng et al.1996) and wheat (Debaeke et al. 2006). SPAD may be useful for measuring bamboo leaf N concentration for fertiliser decision-making.

To promote bamboo shoot and culm (pole) production, irrigation is required when rainfall is insufficient (Lin 1996). In a clay soil with well-watered condition, Kleinhenz and Midmore (2002) suggested that approximately 3,300 mm annual rainfall equivalent water can be transpired by bamboo in Queensland, Australia, but for high shoot yield, it is important to ensure that 2,000 mm water is provided 1–2 months before, and during, the shoot season.

In addition to N, potassium (K) is crucial for bamboo leaf and stem development (Kleinhenz and Midmore 2002), particularly for timber production. Kleinhenz and Midmore (2001) summarised existing reports on bamboo agronomy and silviculture and determined that average application of N, phosphorus (P), and K were 318, 149 and 126 kg/ha/year, respectively, and higher amounts (523, 226 and 228 kg/ha/year) were applied for shoot-only production than for shoot and timber (315, 97 and 142 kg/ha/year) or timber-only (225, 135 and 89 kg/ha/year).

Clump population and culm number per clump also affect harvested quantities of shoots or timber or both. Kleinhenz and Midmore (2002) specified that for *Bambusa oldhamii* the optimal culm population was c. 3,600/ha for shoots and timber, based on a strategy of retaining three 1-year-old, three 2-year-old and three 3-year-old culms (denoted as a 3-3-3 standing culm density) in a stand of 400 clumps/ha.

For optimal and sustainable shoot and timber production, it is imperative to establish a benchmark for agricultural management that includes irrigation, fertilisation and thinning regimes. Based on that benchmark, new management practices can be identified to facilitate the production goals of growers (such as shoots only or timber only or both) while sustaining productivity. Water use and nutrient (particularly nitrogen) use efficiencies are major concerns of growers intent on increasing their gross margin with either similar or increased production, and we aimed to quantify those variables.

Materials and methods

Site selection and experimental design

A bamboo (*Bambusa oldhamii*) plantation established in 1991 at Belli Park, Eumundi (26°28'S, 152°56'E, 120 km north of Brisbane) in Queensland, Australia, was selected for the experiment. Clumps were growing in rows 5 m apart and with 5 m between clumps within the row (400 clumps/ha). The experiment was established on 11 September 2001 by overlaying the experimental design within the plantation, thinning the existing clumps to reduce culm numbers to the desired value and according to treatment, separate versus close spacing between culms within a clump, and installing facilities for irrigation and related soil-moisture measurement. A randomised complete block design with four replicates was used for the experiment with treatments as detailed in Table 1. Plot size comprised three clumps, the middle of which was reserved for most data collections.

The average annual rainfall at the site for 1995–2005 was about 1,466 mm, of which about 68% (1,045 mm) occurred just before and within the shoot and wet season (November–April) (see Figure 1 for 2002–05).

Table 1. Treatment details of the experimental design at Belli Park, Eumundi, Queensland, Australia

Treatment		Treatment details				
Code	Name	Irrigation	Fertiliser	Selection of shoot for timber	Designed clump space	Edible shoots harvested
T1	Control	Yes	Yes	Early-season	Wide	Yes
T2	Dry-season[a] stress	Not during dry season	Yes	Early-season	Wide	Yes
T3	Late-season selection	Yes	Yes	Late-season	Wide	Yes
T4	Narrow Spacing	Yes	Yes	Early-season	Narrow	Yes
T5	Rhizome stress	Yes	Yes	Late-season	Wide	No[b]
T6	Unmanaged clump	No	No	Early-season	Wide	Yes

[a] Dry season for purposes of this treatment was defined as the beginning of May to the end of August

[b] In excess of the five required per year for the treatment were removed just before next shoot season to keep the wide spacing

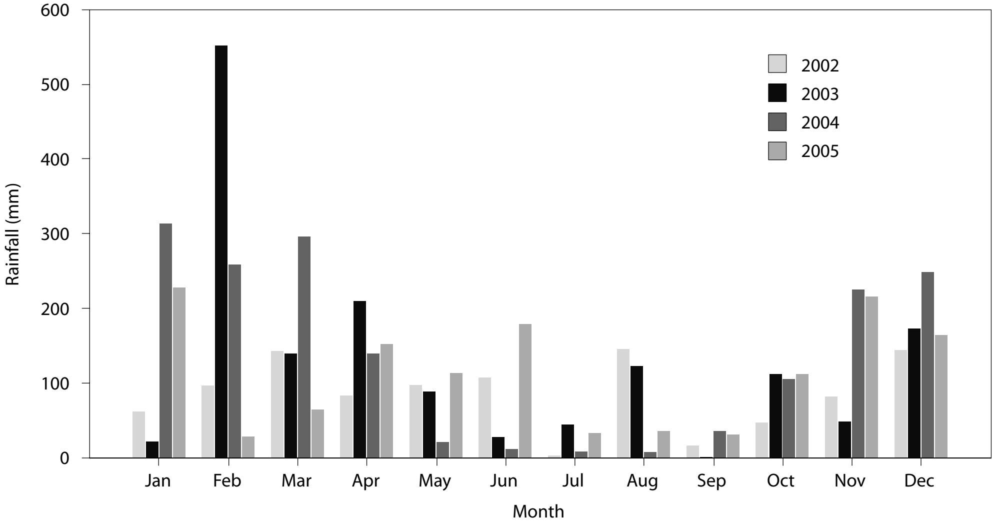

Figure 1. Monthly rainfall for 2002–05 at Eumundi, Queensland, Australia

According to Kleinhenz et al. (2003), the soil at the site is an acidic clay (pH < 6.0) with low availability of N, P, K and organic carbon (C), and high levels of manganese and aluminium.

Details of the treatments

The trial used a 5-5 standing culm density, such that each year, five 1-year-old and five 2-year-old culms were retained in the clump, and 5 new shoots were grown each year to develop into culms. The five 2-year-old culms were harvested before the next shoot season (at an average age of 2.5–2.8 years).

Irrigation was applied to only the clump area (3.5 m maximum diameter) to replace pan evaporation validated by use of tensiometers (three/plot) installed in the control treatment (T1) and unmanaged clumps (T6) at depths of 15, 30 and 50 cm to monitor soil moisture. Before irrigation began, soil samples were taken at 0–5 cm and 12.5–17.5 cm to determine soil gravimetric water content (%), and tensiometer readings at the corresponding sites were recorded. Linear regression analysis confirmed that the mean soil moisture content at 0–17.5 cm was closely related to the tensiometer readings averaged at 15, 30 and 50 cm (Figure 2a). Tensiometer readings at 50 cm were positively correlated with those at 30 cm (Figure 2b). Therefore, the decision was made to irrigate when the average readings in the control treatment exceeded 60 centibars, at which soil gravimetric water content was below 18%. However, due to water restrictions, this was not always possible.

Before applying fertiliser, bamboo leaves (youngest fully expanded leaves from the youngest culms) were sampled for N concentration (Figure 3a) to determine the amount of N required to raise leaf N to 3% (Kleinhenz and Midmore 2002). Mineral fertiliser (N:P:K at approximately 4:1:4 – 4:1:3) was applied to match nutrient requirements as prescribed by the total N levels in leaf samples from the 1-year-old culms.

Fertiliser was applied to a 20 m^2 area centred on each clump. On several occasions, non-destructive measurements were also undertaken with a leaf chlorophyll meter (Minolta SPAD-502) to develop a relationship between SPAD readings and bamboo leaf N concentration (Figure 3b).

The schedule of the N fertiliser timing and rate is indicated in Figure 3a.

Leaf N concentrations differed slightly between clumps before the fertiliser application so the absolute amount of N applied to raise leaf N concentration to 3% differed slightly between treatments.

Clump light interception was measured on some occasions with a line radiometer (AccuPAR Decagon Devices Inc., United States of America). Ten measurements were taken per clump, three each to the north and south of each clump and two to the east and west, between 11:00 and 13:00 h, and the average of readings was related to a concurrent reading with an exposed radiometer.

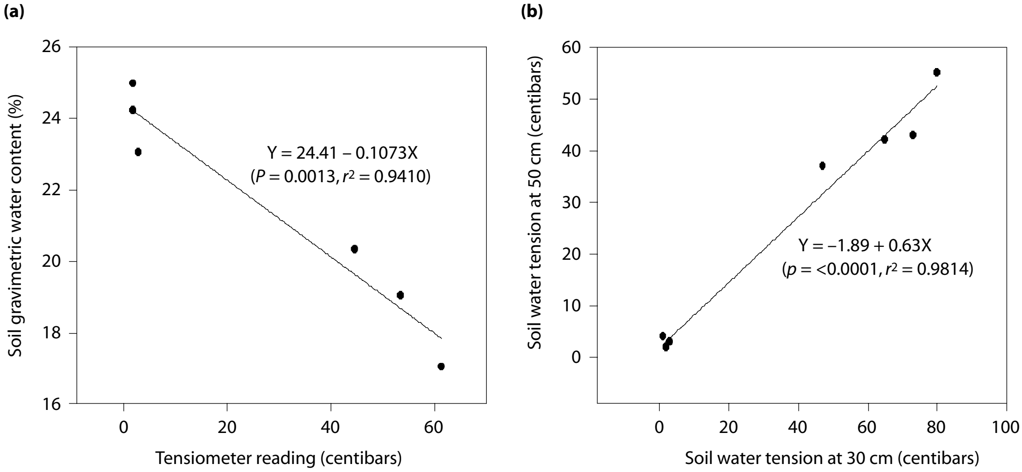

Figure 2. Relationship (a) between soil gravimetric water content and tensiometer readings and (b) between tensiometer readings at 30 cm and 50 cm depth

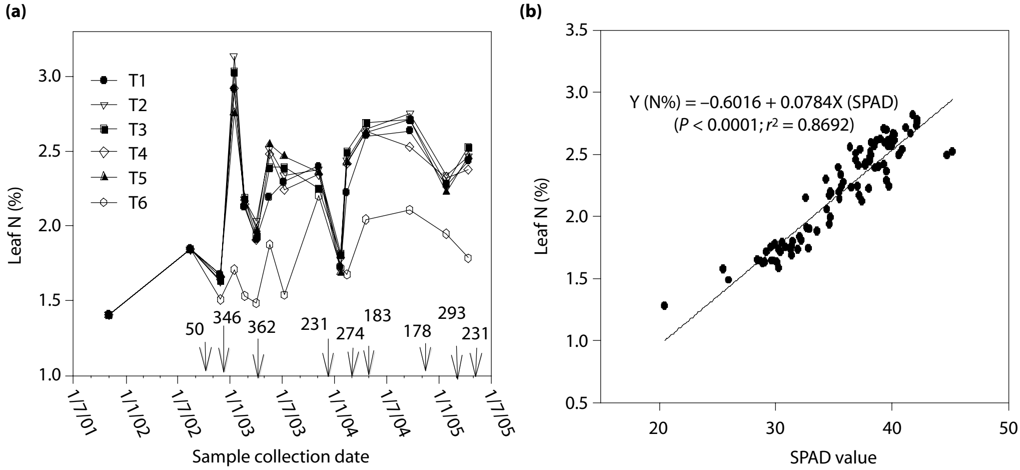

Figure 3. Bamboo leaf N concentration during 2002–05 (a) with related timing (with arrow down) and quantity (kg N/ha) of fertilisation, and (b) the relationship between leaf N concentration and soil plant analysis development (SPAD)

Shoots were harvested from January to March each year from 2003–05; total shoot numbers (including marketable, non-marketable and shoots for timber), and shoot marketable fresh weight (MFW) were recorded. Culms designated for harvest (i.e. those greater than 2 years old) were harvested in July 2003, August 2004 and October 2005. Numbers of culms and culm length from the base were recorded at culm harvest. Culm volumes (V) were calculated as shown in equation (1), according to the typical shape of the culm that is represented by a cylinder (cl) plus a cone (cn) (Figure 4) with the height of the cylinder (h_1) being two-thirds and that of the circular cone one-third (h_2) of the total height; and that the radius of the circular cone (r) two-thirds of basal radius (R) of the cylinder. This representation applies only to *Bambusa oldhamii* in the current experiment.

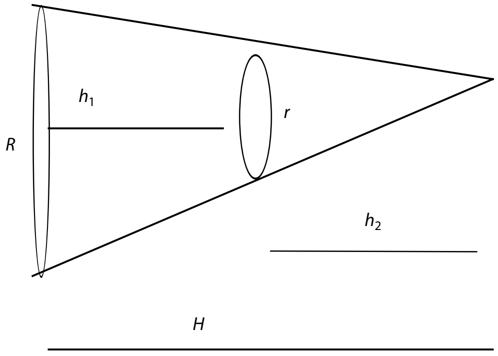

Figure 4. Estimation of bamboo culm general shape (see text for details)

In addition, to estimate total culm dry weight (DW), culms were sampled and sectioned to calculate the average apparent density according to the volumes (including the cylinder hole) and DW of each sample for each harvest/year (equation 2).

Data analysis and presentation

Water-use efficiency (WUE) was calculated based on total harvested fresh shoot or dry culm weights divided by the volume of water irrigated to each clump (water meters were inserted in-line to measure the amount of water applied to each treatment, and catch cans at the beginning of the experiment measured the volume applied to each clump) from the beginning of irrigation to the last irrigation, plus the amount of rain falling equally on each treatment during the same period, and assuming these amounts of water were fully available to plants. No account was made for run-off or drainage. Dry-season stress (T2) received less irrigation than T1 and T3–T5, and T6 (no irrigation) received rainfall only.

Nitrogen-fertiliser-use efficiencies (NFUEs) were calculated according to the total shoot and culm weights for each of five treatments (T1–T5) minus the total shoot and culm weights produced by T6 (unmanaged clump, not fertilised); with the differences divided by the N applied to each of the five treatments, respectively.

Analysis of variance with multiple comparisons (Systat Software, Inc. 2005, San Jose, California, United States of America) was used to determine significant differences among the treatments at $P = 0.05$. The analyses focused on differences between a specified treatment and the control with an orthogonal contrast test. When $0.05 < P < 0.1$, the differences between two treatments were discussed. Simple linear regressions were employed to define relationship between parameter pairs (e.g. culm and shoot production, WUE and NFUE).

The comparisons that showed trends between treatments and the differences between treatments within a season and across seasons are presented in Figures 5–13.

Converting shoot and culm production into a unified indicator for comparison

The aim of the experiment was to identify the best management practice to maximise edible shoot or timber production, or both. For the last, some treatments may produce more shoots, but fewer culms, creating difficulties for dual-purpose growers to identify the best treatment to maximise the gross margin. To address this problem, we introduced the productivity index (PI). The PI converts the DW of culms into shoot MFW equivalency, assuming the unit values of culm DW vary, ranging from one-tenth to unity of the value of shoot MFW (equation 3).

Assuming $K = 1$, and $n = 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9$ and 1, respectively, PI can be calculated according to each n value based on the shoot MFW and culm DW harvested, and the differences between treatments can be compared according to the differences between the unified PI. This equation can be applied to bamboo growers for any of the three defined purposes: for shoot-only, n should be equal to or greater than 0, so the value of culm DW is negligible; and for culm-only, n can be still equal to, or smaller than K, since the production of MFW is negligible.

The differences of WUE and NFUE for shoot and culm production can similarly be compared between treatments by converting WUE and NFUE to the related PI, i.e. PI-WUE and PI-NFUE (equations 4 and 5).

Validation

To verify comparisons of PIs between treatments, real prices of shoots and culms from the experimental site were adopted. Bamboo shoot prices (D.L. Dart, Sole Director, Bamboo Australia Pty Ltd, pers. comm. 2006) varied from A$8.50/kg in November–December to A$3.50/kg in February–March of the following year and averaged A$6.00/kg; and the price of natural poles (culms) was roughly $2.76/kg (Bamboo Australia 2007). We used a value of $90.00/t ($n < 0.1$) payable for bamboo use for sequestering C or for pulp in calculations and comparisons of gross margins between treatments.

Results

Growth status and related water and nitrogen supply

Ground cover

Changes of groundcover over time, represented by light interception, reflected imposed treatments and culm harvesting (Figure 5). Following culm harvest on the afternoon of 8 July 2003, light interception was reduced in all treatments except for the unmanaged clump (T6). It was further reduced in T1, T2 and T3 between July 2003 and January 2004, whereas it increased over the same period in T4 and T5. Over the next 7 months, it increased to approximately the same value as in July 2003, and the treatments' values remained in the same order.

Soil water

Soil water was monitored with tensiometers in the control (T1) and the unmanaged clump (T6) treatments, and soil water content averaged for 15, 30 and

$$
\begin{aligned}
V &= vcl + vcn \\
vcl &= 1/3\pi\,(r^2 + rR + R^2)\,h_1 \\
vcn &= 1/3h_2r^2\,\pi \\
V &= 1/3\pi\,(r^2 + rR + R^2)\,h_1 + 1/3h_2r^2\,\pi \\
&= 1/3\pi\,[(r^2 + rR + R^2)\,h_1 + h_2r^2] \qquad (1) \\
\text{As } r &= 2/3R;\ \text{and } h_1 = 2/3H;\ \text{and } h_2 = 1/3H,\ \text{Therefore:} \\
V &= 1/3\pi\,[((4/9R^2 + 2/3R^2 + R^2)*2/3H) + 1/3H*4/9R^2] \\
&= 1/3\pi\,[(19/9R^2*2/3H) + (1/3H*4/9R^2)] = 14/27*H*R^2*\pi
\end{aligned}
$$

DW (kg/clump) = Volume of culms harvested (m^3/clump)
× apparent density of sampled culm (kg/m^3) (2)

PI (A\$/clump) = K * shoot MFW + n * culm DW
where the K is the value of unit shoot MFW and n is value of culm unit DW. (3)

PI-WUE (\$/kg/mm) = K * WUE for shoot MFW + n * WUE for culm DW (4)

PI-NFUE (\$/kg/kg) = K * NFUE for shoot MFW + n * NFUE for culm DW (5)

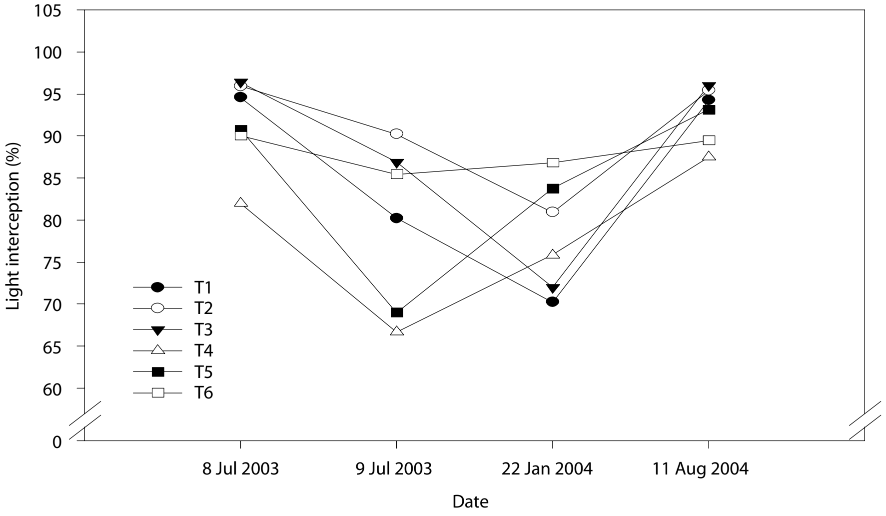

Figure 5. Light interception by bamboo clumps during the treatment period of 2003–04. Note: see Table 1 for treatment details.

50 cm (Figure 6) showed that the unmanaged clump (without irrigation) suffered water stress compared to the control (with irrigation) in 2002 when irrigation was available. In subsequent years drought prevented full application of irrigation water. Even with irrigation, plants suffered water stress at times in November and January due to high temperatures that led to high evapotranspiration. This was more apparent in 2002 and 2003 (Figure 6a and b) when the rainfall was very low (Figure 1) and relative humidity low. Control clumps also had very limited soil moisture during the dry season in 2004 and 2005 (Figure 6c and d) when irrigation was not sufficient due to water restrictions.

Leaf nitrogen concentration

The leaf nitrogen (N) concentration of the unmanaged clump (T6) was lower than that of other treatments on most occasions (Figure 3a). For all treatments the N concentration was relatively low during January–March compared to other periods probably due to the dilution effect of culm and leaf expansion, although this response was less apparent in 2005 (Figure 3a). Fertiliser application clearly increased leaf N concentration; for example, the leaf N concentration for the fertilised treatments reached 3% in January 2003 following application of 346 kg N/ha in late December 2002, but the N level dropped to below 2% in early January 2004 even after application of 231 kg N/ha in December 2003, most likely due to the exceedingly dry conditions, for we have shown (Kleinhenz et al. 2003) that for bamboo to respond to N fertiliser, supply of water—whether from irrigation or rainfall—is essential.

The leaf N concentration was closely related to measures of leaf chlorophyll concentration indicated by the readings of SPAD (Figure 3b), and the latter is simple and cheaper than wet chemistry determinations and, at least in the 1.5–3% N concentration range critical to plant N nutrition, can act as a surrogate for leaf N when determining the timing and quantity of N fertiliser.

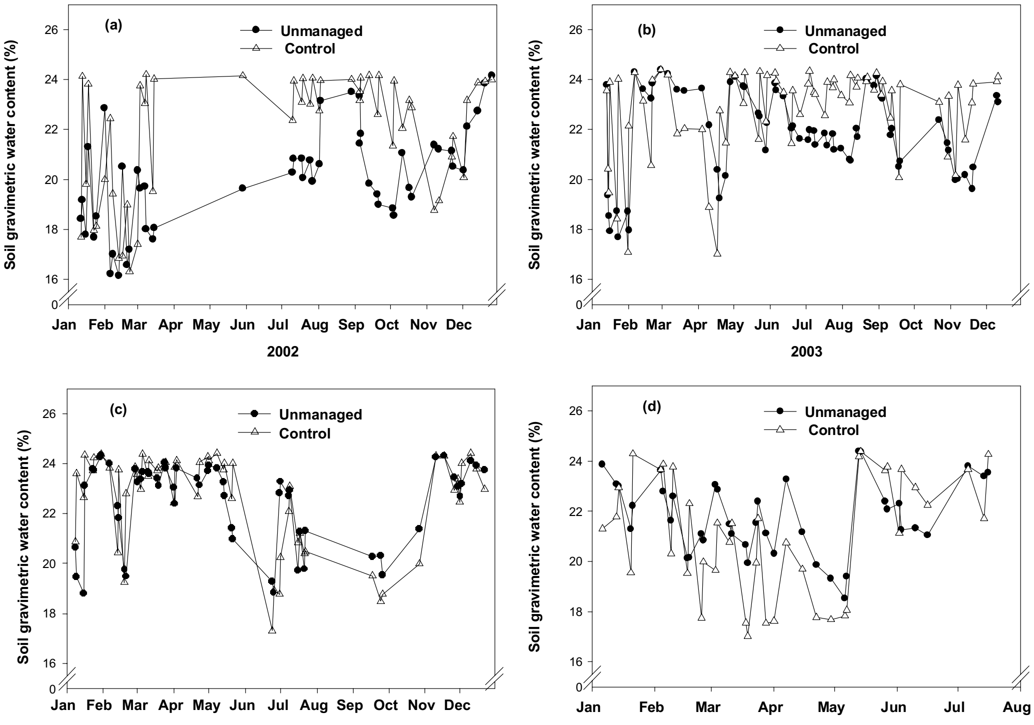

Figure 6. Average soil water status (0–50 cm) monitored by tensiometers for two selected treatments during 2002–05

Comparisons of bamboo shoot production

Shoot production within a season

As the period November–April is normally the rainy summer season in Queensland, bamboo shoots can be harvested from untreated clumps starting from January. Following 1 year of imposed treatments, the bamboo shoots were harvested from January 2003, and again in 2004 and 2005 over the same period. Within the harvest season in 2003, treatments T1, T2 and T4, i.e. those in which shoots were left for culm production early in the shoot season, produced more early shoots per clump than those of T3, T5 and T6 (Figure 7a). However, T3 became more productive later in the season, but both T5 and T6, i.e. those with rhizome stress or unmanaged, consistently produced fewer shoots (Figure 7a).

For marketable fresh weight (MFW), there was a greater proportional difference between treatments than for shoot number, with T3 constantly superior to other treatments (Figure 7b), reflecting greater individual shoot weight for that treatment.

The advantages of T3 were still evident in 2004 for both shoot number and weight per clump (Figure 8). It is interesting to note that the unmanaged treatment (T6) produced many shoots from February 2005 onwards (Figure 9a), but their size was not marketable (Figure 9b). In addition, T1, the control, caught up with, and surpassed, other treatments in shoot number and shoot MFW (Figure 9) from February 2005 onwards.

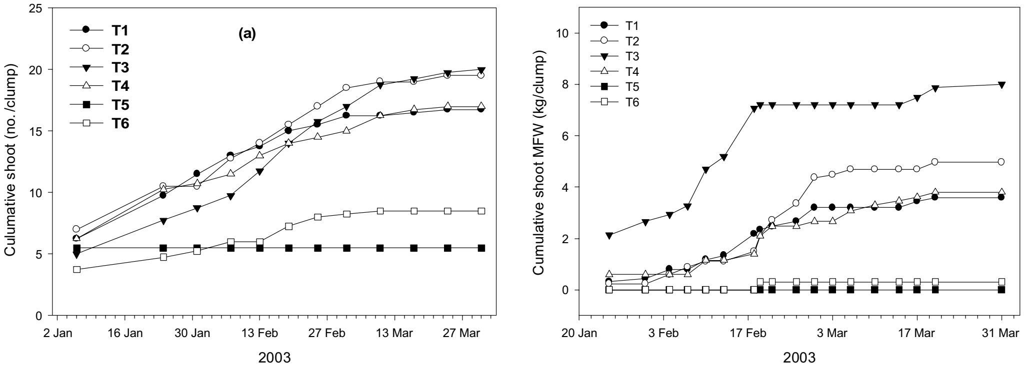

Figure 7. Seasonal cumulative bamboo shoot production in (a) number and (b) marketable fresh weight (MFW) in 2003. Note: see Table 1 for treatment details.

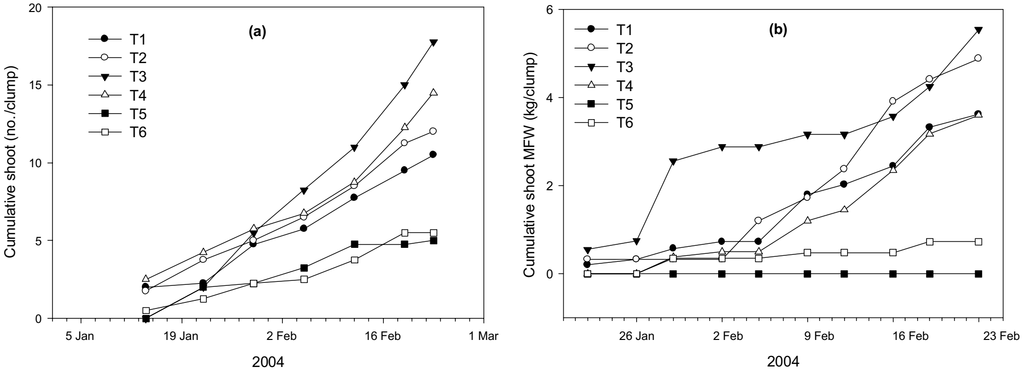

Figure 8. Seasonal cumulative bamboo shoot production in (a) number and (b) marketable fresh weight (MFW) in 2004. Note: see Table 1 for treatment details.

Shoot production across seasons

The annual shoot number for T3, the late-season selection of shoots for culms, was quite steady across the three harvest seasons (Figure 10a), but its ability to produce marketable shoots declined with each year (Figure 10b). There was a great increase in shoot numbers produced by T5 and T6 in 2005, but T6 did not produce many marketable shoots across the 3 years, and T5 produced a similar quantity of marketable shoots compared to T1, T2, T3 and T4 only in 2005 (Figure 10b).

Analysis of the cumulative shoot production, whether number or MFW across the 3 years, showed that T3 was superior to other treatments, particularly to T5 and T6 (Figure 11).

In summary, the best treatment for bamboo shoot production was the late-season selection (T3), and the worst treatments were rhizome stress (T5) and unmanaged clumps (T6). Other treatments, such as dry-season stress (T2) and narrow spacing (T4) were similar to the control in shoot production. Compared to T1 (control), the superiority of the T3 was verified through statistical analysis (Table 2) for both shoot number and shoot MFW.

Comparisons of bamboo culm production

Compared to the control and other treatments, the rhizome-stress treatment (T5) showed the greatest culm number in the first 2 years (Figure 12). This reflected that in T5, a number of culms less than

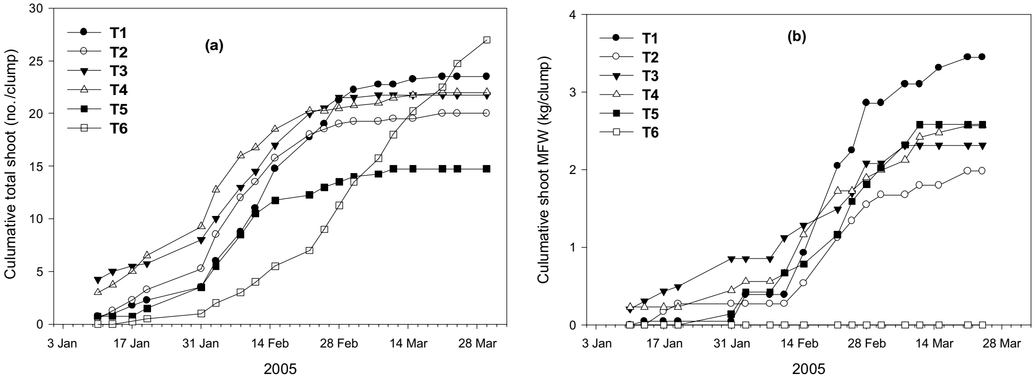

Figure 9. Seasonal cumulative bamboo shoot production in (a) number and (b) marketable fresh weight (MFW) in 2005. Note: see Table 1 for treatment details.

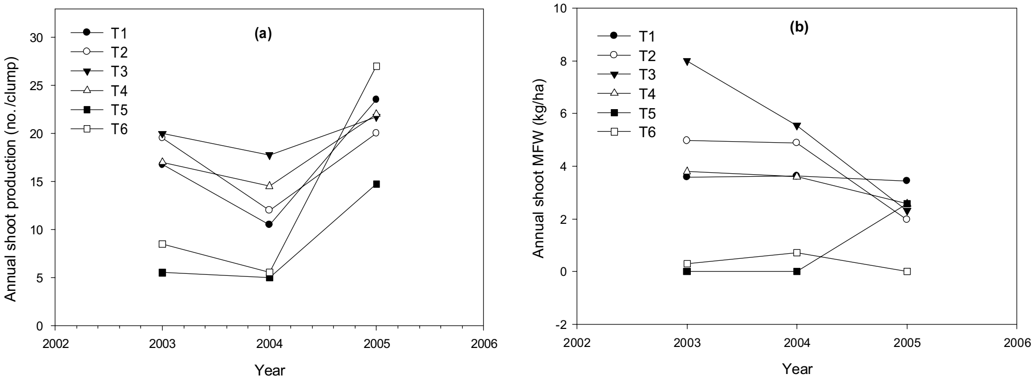

Figure 10. Annual bamboo shoot production in (a) number and (b) marketable fresh weight across 2003–05. Note: see Table 1 for treatment details.

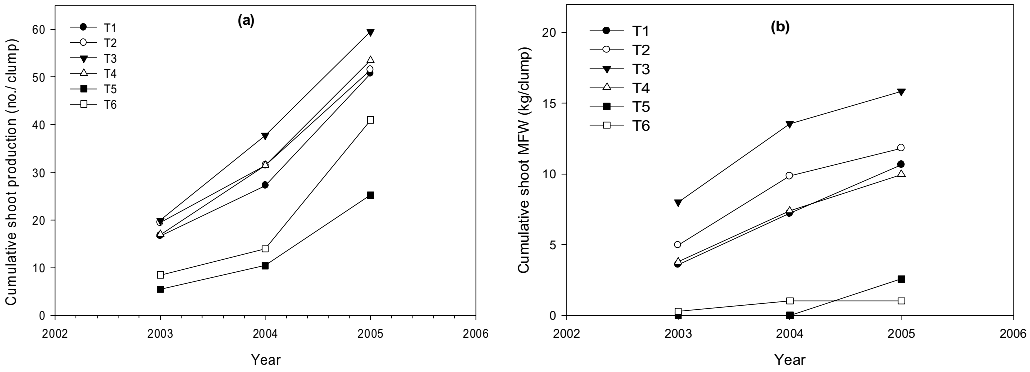

Figure 11. Cumulative bamboo shoot production in (a) number and (b) marketable fresh weight (MFW) across 2003–05. Note: see Table 1 for treatment details.

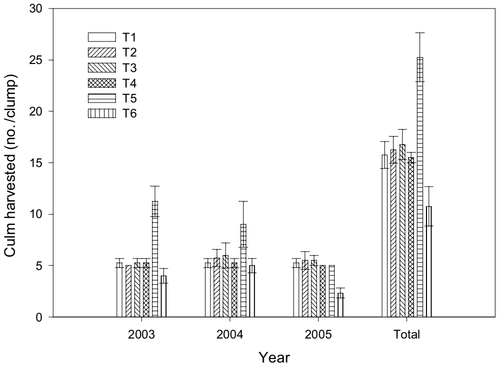

Figure 12. Yearly (2003, 2004 and 2005) and total culm number harvested. Note: see Table 1 for treatment details.

Table 2. Comparison of bamboo shoot production between the late-season selection (T3) and control (T1) across 2003–05

Treatment	Shoot number[a] (no./clump)				Marketable fresh weight (kg/clump)			
	2003	2004	2005	Total	2003	2004	2005	Total
Control	13.7	6.0	6.8	26.5	3.59	3.63	2.17	9.39
Late-season selection	15.4	15.7	12.8	43.9	8.00	5.55	2.31	15.86
P	0.400	**<0.0001**	**0.0712**	**0.0092**	**0.0031**	0.1571	0.8777	**0.0003**

[a] Shoot number includes marketable and non-marketable shoots, excluding shoots left to develop into culms

1 year old were also harvested—those culms being the ones left on the clump to 'stress' the rhizome. In the third year, edible shoots were harvested (to see if the rhizome had been 'stressed'), and therefore only five 3-year-old culms were harvested for biomass. Culm DW and volume per clump were also the greatest for T5 and, on average, least for T6 (Table 3). Compared to the control, T5 had 43.2% more culm dry matter in 2003, 98.3% in 2004, and 46.0% in total, and culm volume was greater by 43.2%, 98.3% and 47.2%, respectively (Table 3).

Table 3. Comparison of dry weight (DW; t/ha) and volume (m^3/ha) of bamboo culms harvested in July 2003, August 2004 and October 2005, and total, among the treatments

Treatment	2003		2004		2005		Total	
	DW	Volume	DW	Volume	DW	Volume	DW	Volume
T1	**24.15**	**61.52**	**23.70**	**55.28**	**25.57**	**55.00**	**73.42**	**171.80**
T2	19.95	50.84	24.84	57.96	30.78	66.20	75.57	175.00
T3	20.72	52.80	26.27	61.28	20.50	44.12	67.49	158.20
T4	19.18	48.88	28.32	66.04	24.05	51.72	71.55	166.64
T5	**34.59****	**88.12****	**46.99****	**109.60****	25.64	55.16	**107.22***	**252.88***
T6	**16.17****	49.40	26.24	61.20	**6.36****	**13.68****	**48.77***	**124.28+**
P	**0.0002**	**0.0009**	**0.0016**	**0.0016**	**0.0059**	**0.0059**	**0.0069**	**0.0120**

Note: + = $0.1 > P > 0.05$; * = $0.05 > P > 0.01$; ** = $0.01 > P > 0.001$, compared to the control; see Table 1 for treatment details

Relationships between shoot and culm production

No clear relationship was detected between the number of shoots produced and the shoot MFW either within a year or across the 3-year shoot production period. This is understandable as some shoots harvested were not marketable (particularly in T6), and some shoots were counted but retained for culm production.

Similarly, on a per clump basis, no relationship was found between shoot MFW and culm production (neither culm dry matter nor volume), indicating that limited shoot harvest for consumption may have minimal impact on culm production. However, the relationship between shoot number and culm volume was negative (culm volume = 0.5538 – [0.0028 × shoot number harvested]), but barely significant ($P = 0.053$) and only explained 15% for the variation in culm volume. Therefore, excessive shoot harvest in terms of number may have some negative, but small effects on culm production.

WUE, NFUE and their relationships

Consideration of the efficiency in using soil water (from rainfall and irrigation) for shoot production showed that T2 (dry-season stress—no irrigation in the dry season) and T6 (unmanaged clump—no irrigation) had higher WUE than the control when based upon the total number of shoots produced (Table 4). The higher WUE for T6 was due to the sharp increase

Table 4. Comparisons of water-use efficiency (WUE) for both shoot and culm production between the control (T1) and other treatments during 2003–05

Treatment[a]	Total shoots produced[b] (no./mm/ha)	Shoots harvested[c] (no./mm/ha)	Shoot fresh weight[d] (kg/mm/ha)	Culm dry weight (kg/mm/ha)	Culm volume (cm^3/mm/ha)
T1	**2.28**	**1.13**	**0.37**	**8.48**	**19,828**
T2	**2.85+**	1.45	**0.58****	10.64	24,672
T3	2.74	**1.88***	**0.68****	7.80	18,256
T4	2.40	1.28	**0.46+**	7.64	17,788
T5	**1.11****	**0.46***	**0.12****	**11.48***	**27,056***
T6	**3.26***	**0.42***	**0.08****	9.20	23,500
P	**0.0049**	**0.0002**	**<0.0001**	**0.0671**	**0.0640**

[a] See Table 1 for treatment details

[b] Including shoots for culm production

[c] Including marketable and non-marketable shoots

[d] Marketable shoots only

Notes: 1 mm/ha = 10 m^3 and represents the amount of water received from rain and irrigation; + = $0.1 > P > 0.05$; * = $0.05 > P > 0.01$; ** = $0.01 > P > 0.001$, compared to the control (T1) of shoot number produced in 2005 (see Figure 10a). However, based upon the marketable shoot weight, T2 (dry-season stress) and T3 (late-season selection) had higher WUE than the control, and T5 and T6 were lower than the control. No significant difference was detected between T2 and T3 ($P = 0.1005$). Although T5 (rhizome stress) had lower WUE than the control in shoot production, it had the highest WUE in culm production (dry weight and volume), and was the only treatment that differed significantly from the control in culm WUE.

As for WUE based upon shoot fresh weight, compared to the control, T2 and T3 had greater NFUE for shoot production (particularly in shoot MFW), and T5 had the lowest NFUE in shoot production, but the highest NFUE in culm production (Table 5).

A positive and linear regression was identified between WUE and NFUE for both shoot (Figure 13a) and culm (Figure 13b) production; an increase of WUE could lead to an increase of NFUE in bamboo production.

Identifying the best treatments according to the productivity index (PI)

According to the data, the late-season culm selection (T3), when compared to the control, produced more shoots in number and MFW (Figure 11, Table 2) without compromising culm production (Table 3). The rhizome-stress treatment (T5) produced more culm in terms of total volume and dry weight, but its production of marketable shoots was negligible compared to the control.

Table 5. Absolute differences between treatments T1–T5 and T6 (unmanaged clump as a contrast using t-test) for the calculations of nitrogen-fertiliser-use efficiency (NFUE) for shoot and clump production[a]

Treatment[b]	Total shoots produced[c] (no./kg)	Shoots harvested[d] (no./kg)	Shoot fresh weight[e] (kg/kg)	Culm dry weight (kg/kg)	Culm volume (cm^3/g)
T1	**1.98**	**4.42**	**1.65**	**14.95**	**29.0**
T2	2.26	4.83	**2.22+**	16.61	31.60
T3	**4.25+**	**8.21***	**3.16****	11.53	21.1
T4	2.38	4.81	1.93	9.99	17.4
T5	**–3.99****	**1.06***	**0.37****	**30.24***	**65.9***

[a] All values are given per weight of fertiliser N

[b] See Table 1 for treatment details

[c] Including shoots for culm production

[d] Including marketable and non-marketable shoots

[e] Marketable shoots only

Note: + = $0.1 > P > 0.05$; * = $0.05 > P > 0.01$; ** = $0.01 > P > 0.001$, compared to the control (T1)

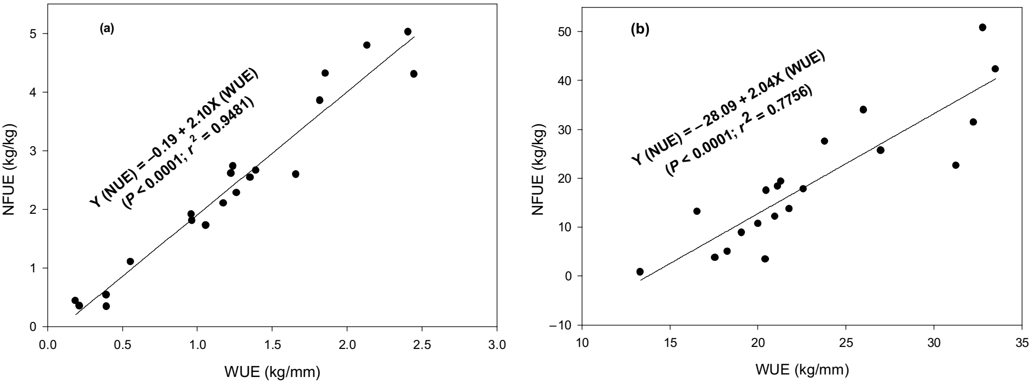

Figure 13. Regression analyses between nitrogen-fertiliser-use efficiency (NFUE) and water-use efficiency (WUE) for (a) shoot and (b) culm production

Using equation (3), the productivity index (PI) was calculated according to each *n* value (0.1–1.0) based on the total harvested shoot MFW and culm DW (Table 6). Recommendations can be made to bamboo growers that when the unit value of culm DW is one-tenth or less ($n \leq 0.1$) that of shoot FW (e.g. at a market price of $6.00/kg for shoots, the price of culms would be ≤ $0.60/kg), T3 (late-season selection of shoots) is recommended for maximum gross margin; when the unit value of culm DW is the same as, or higher ($n \geq 1$) than that of shoot FW, T5 (rhizome stress) is recommended; when $1 > n > 0.1$, all treatments excluding T6 have similar economic impact; and under any circumstance, the T6 (unmanaged clump) is the worst treatment (Table 6).

However, if growers are constrained by water availability for shoot and culm production, the treatment that maximises the WUE and consequently gross margin is of interest to growers. Hence, according to equation (4), PI-WUE was calculated and compared between treatments (Table 7). According to the PI-WUE, when the culm value was one-tenth of shoot value, both T2 and T3 generated higher gross margin than the control (T1); however, T2 would be a preferred option for growers because it was less affected by changes of relative market values of shoot and culms, unless the value of culm was the same as the shoot ($n = 1$) when T5 showed the greatest advantage in gross margin (Table 7).

The same principle for PI-NFUE (equation 5) was also applied and compared among treatments. No significant difference in PI-NFUE was detected between treatments and the control unless the market value of unit culm DW was the same as that of shoot

Table 6. Comparisons of the productivity index[a] between treatments for the total harvested bamboo shoot and culm production (2003–05)

n	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
T1[b]	**25.03**	**26.93**	**33.60**	**36.88**	**41.25**	**47.37**	**56.54**	**71.84**	**102.43**	**194.20**
T2	27.11	28.99	35.45	38.82	43.32	49.62	59.07	74.81	106.30	200.76
T3	**32.74***	34.61	36.96	39.97	43.99	49.61	58.05	72.11	100.24	184.62
T4	26.51	28.35	30.65	33.60	37.54	43.06	51.33	65.12	92.70	175.42
T5	27.41	30.16	33.61	38.05	43.96	52.23	64.65	85.33	126.71	**250.84***
T6	**12.98****	**14.30****	**15.96****	**18.09****	**20.93****	**24.90****	**30.86****	**40.80****	**60.68***	**120.30***
df	13	13	15	15	15	15	15	15	15	15
P	**0.0003**	**0.0004**	**0.0056**	**0.0067**	**0.0080**	**0.0093**	**0.0104**	**0.0109**	**0.0105**	**0.0091**

[a] See text for details of how the productivity index was calculated

[b] See Table 1 for treatment details

Note: * = 0.05 > *P* > 0.01; ** = 0.01 > *P* > 0.001, compared to the control (T1); df = degrees of freedom

Table 7. Comparisons of the productivity index related to water-use efficiency (PI-WUE)[a] between treatments for bamboo shoot and culm production

n	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
T1[b]	**2.87**	**3.58**	**3.88**	**4.26**	**4.76**	**5.47**	**6.53**	**8.29**	**11.82**	**22.41**
T2	**3.83***	**4.63+**	**5.00+**	**5.47+**	**6.11+**	**7.00***	**8.33+**	10.55	14.99	28.31
T3	**3.78***	3.99	4.27	4.61	5.08	5.73	6.70	8.32	11.57	21.31
T4	3.06	3.27	3.54	3.88	4.33	4.97	5.92	7.52	10.70	20.25
T5	3.16	3.48	3.88	4.39	5.07	6.03	7.46	9.85	14.62	**28.95+**
T6	2.49	2.75	3.07	3.48	4.03	4.79	5.94	7.85	11.68	23.17
df	13	15	15	15	15	15	15	15	15	15
P	**0.0272**	**0.0735**	**0.0967**	0.1249	0.1557	0.1836	0.1999	0.1949	0.1646	0.1163

[a] Calculation was based on the WUE for shoot marketable fresh weight, plus WUE for culm dry weight at different *n* values (see text for further details)

[b] See Table 1 for treatment details

Note: * = 0.05 > *P* > 0.01; ** = 0.01 > *P* > 0.001, compared to the control (T1); df = degrees of freedom

FW, in which case T5 (rhizome stress) was the best treatment for maximal NFUE (data not presented), which is similar to the findings for WUE (Table 7).

Validation of the proposed PI models

The above models can be verified by entering the real prices of bamboo shoots and culms at the experimental site. For bamboo shoots, high (A$8.50/kg), low (A$3.50/kg) and medium prices (A$6.00/kg) were used for calculations, respectively; whereas for culms, two average prices were used (A$2.76/kg culm DW for high-value culms and A$90.00/t or A$0.09/kg if the culms were simply sold for C sequestration value or for pulp or energy generation), and the total gross revenues were calculated accordingly (Tables 8 and 9). The data in Table 8 including high-value culms fit the hypothesised PI model (Table 6) well, for the price ratios between culm DW and shoot FW were within the range of 0.1–1.0, and were 0.32, 0.46 and 0.79 at the given culm DW price of A$2.76/kg, when the shoot prices (A$/kg) were 8.5, 6.0, and 3.5, respectively. T5 always performed well, and better than T1 ($P = 0.07$), when the shoot price was low, whereas T4 performed poorly with the low shoot price. T6 performed poorly at any given price, and achieved only one-half of the gross margin of T5. However, statistically, T1, T2 and T3 were equally as good as T5 at any given shoot price.

When the lower price for bamboo culms ($0.09/kg, or $n = 0.03$ compared to the low shoot price, which is out of the predefined n range of 0.1–1.0) was used (Table 9), T3 was always superior to T4, T5 and T6 at any given shoot price, and outperformed T1 and T2 as well at high shoot price. This is the extreme case when bamboo growers cannot sell the culms for better prices.

The economic implications of Tables 8 and 9 are that when culms can be sold as a timber with an average price of A$2.76/kg, T1, T2, T3 and T5 are equally good and better than T6 at any given shoot price; whereas when the culms are sold for other uses with a low price, T3 showed the greatest advantage for any given shoot price.

Discussion

Bamboo is a perennial horticultural crop for shoot production, a timber source, an effective medium for C sequestration, and an energy source. Therefore,

Table 8. Calculation of gross margin (A$/clump) during 2003–05 based on shoot fresh weight with high (A$8.50/kg), medium (A$6.00/kg) and low (A$3.50/kg) prices, and culm dry weight at the average price of A$2.76/kg

Treatment	Shoot price	T1[A]	T2	T3	T4	T5	T6	df	*P*
Gross margin (A$/clump)	High	596.0 ab	620.3 ab	600.7 ab	541.5 ab	700.0 a	341.0 c	15	0.0107
	Medium	569.4 a	590.8 a	561.0 a	516.6 a	693.5 a	338.4 b	15	0.0106
	Low	542.8 ab	561.2 ab	521.4 ab	491.7 b	687.1 a	335.8 c	15	0.0095

[A] See Table 1 for treatment details

Note: Values followed by the same letter within a row are not significantly different at $P = 0.05$ according to Duncan's multiple range test; df = degrees of freedom

Table 9. Calculation of gross margin (A$/clump) during 2003–05 based on shoot fresh weight with high (A$8.50/kg), medium (A$6.00/kg) and low (A$3.50/kg) prices, and culm dry weight at the low price of $0.09/kg

Treatment	Shoot price	T1[A]	T2	T3	T4	T5	T6	df	*P*
Gross margin (A$/clump)	High	107.1 b	117.6 b	150.0 a	99.6 b	44.3 c	19.4 c	15	<0.0001
	Medium	80.5 ab	88.0 ab	110.4 a	74.7 b	37.8 c	16.9 c	15	<0.0001
	Low	53.8 ab	58.4 ab	70.7 a	49.8 b	31.4 c	14.3 c	15	<0.0001

[A] See Table 1 for treatment details

Note: Values followed by the same letter within a row are not significantly different at $P = 0.05$ according to Duncan's multiple range test; df = degrees of freedom bamboo should be managed with an integrated approach, both seasonally and yearly, for sustainable production. Accordingly, evaluation and comparison of the management effects should in part be based on the summed results across years.

The use of PI to unify the values of culm DW and shoot FW made it possible to compare the differences between treatments. Mathematically, the price ratios (*n*) between culm DW and shoot FW are not confined, but the hypothesised *n* range (0.1–1.0) is realistic, and provides the base on which growers can use the calculated PI table as a quick reference for their management decisions. When growers cannot sell their culms as timber at a good price, comparisons of gross margins between treatments were also made when culms were sold for other uses at a considerably lower price ($n < 0.1$).

When compared to the control treatment (i.e. designed with wide clump space, early selection of shoot for timber production, and with irrigation and fertilisation) which represents a conventional management practice for bamboo production, improved management practices can increase bamboo productivity, WUE and NFUE. Based on the current trials, the ideal improved treatments were T2 (dry-season stress), T3 (late-season selection) and T5 (rhizome stress), depending on the bamboo growers' intentions to maximise their gross margin. If a grower focuses on shoot production (or if the market value of culm per unit DW is much smaller than that of shoot per unit FW, e.g. $n \leq 0.1$) then T3 is the preferred choice; if the focus is on culm production, T5 is the preferred choice; and in most other instances, T2 is the preferred choice as it greatly increased WUE without compromising the combined values of shoot and culm production. The values for WUE (Table 4) at c. 10 kg/m^3 (or 1.0 g/kg) are intermediate to the range of values presented by Trebejo and Midmore (1990) for total dry weight of potato plants, but considerably lower than the 5.3 g/kg reported for willow by Linderson et al. (2007), although the latter values were based upon transpirational-use efficiency, not on total water-use efficiency.

If water were a limited resource and/or a paid-for commodity, T2 would be of particular interest. Declining agricultural supply of water necessitates the development of methods for efficient irrigation. In our research, bamboo with dry-season stress resulted in an average PI-WUE 29% higher than the control (Table 7). From a practical perspective, the management of dry-season stress in the present experiment is similar to that in rice production where alternate wetting and drying cycles, albeit on a much shorter time frame, in trials conducted in China and the Philippines, reported water savings of 13–30%, with no significant reduction in yield (Cabangon et al. 2001; Belder et al. 2002; Virk et al. 2004). Similar irrigation strategies, but again on a much shorter time frame, have been widely implemented in horticultural industries; for example, by adopting partial root drying which increases fruit quality and water-use efficiency by 50% (Stoll et al. 2000) to 80% (dos Santos et al. 2003) compared to full irrigation.

The physiological mechanism for the superiority of shoot production in T3 (late-season selection of shoots for timber production) is not clear; it may be that leaving early shoots for culm production inhibits further shoot production but this was not so in the NT (Traynor et al. 2009), or it may be that younger culms in the following season are more likely to support more shoots in that season.

The treatment T5, where essentially no shoots were removed as a vegetable, and culms less than 1 year of age and additional in number to the five to keep were harvested, had the highest timber production. The annual biomass removed (on average c. 20–45 t/ha) was comparable to other reports (Kleinhenz and Midmore 2001).

Nevertheless, in terms of financial suitability for growers, T3 may be the best option for generating stable income for growers regardless of fluctuations in the shoot and culm markets. These results are for *B. oldhamii* growing in southern Queensland. Recommendations should be considered and adapted according to different bamboo species and their growing conditions.

When the marketing value of the culm is low, the production of shoots is very important. To ensure sustainable bamboo growth status for shoot production, leaf N concentration should be monitored periodically to guide decisions for fertiliser application. However, growers cannot afford to have frequent chemical analysis of bamboo leaves upon which to base fertiliser decisions. Fortunately, our research showed that the use of a SPAD chlorophyll meter is a cheap and reliable surrogate to estimate leaf N concentration. However, meter measurements should be calibrated to leaf N concentration for each species and growing situation.

As the bamboo industry is still relatively new to Australia, economic analysis should be undertaken to assist growers to determine break-even prices for culms and shoots. This analysis will take into account the costs of irrigation, fertilisation and harvest, with or without hired labour. In this regard, this newly completed bamboo experiment can be subjected to further economic analysis.

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