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THESIS

LIGHT ACCLIMATIZATION ABILITY OF SOME SPECIES OF *BAMBUSEAE*

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A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
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Harry Graybill Simmons IV 2008: Light Acclimatization Ability of Some Species of *Bambuseae*. Master of Science (Tropical Agriculture), Major Field: Tropical Agriculture, Interdisciplinary Graduate Program. Thesis Advisor: Associate Professor Surawit Wannakrairoj, Ph.D. 102 pages.

Light acclimatization ability of the *Bambuseae* tribe was evaluated for possible indoor use. Twenty greenhouse grown accessions from the *Bambusa, Cephalostachyum, Dendrocalamus, Gigantochloa, Schizostachyum, Thyrsostachys* and *Vietnamosasa* genera were investigated. *Bambusa nana*, *Bambusa vulgaris* 'Wamin,' *Thyrsostachys siamensis* and *Vietnamosasa ciliata* had the highest average quality grade. Nineteen accessions were then subjected to 10% sunlight levels for 6 weeks whereupon plant health was evaluated using SPAD Chlorophyll Meter. SPAD readings showed an increase in chlorophyll when grown under 10% sunlight for *V. ciliata* and *B. vulgaris* 'Wamin.' They were the only species with high average quality grades to show this increase. A light response curve of *B. vulgaris* 'Wamin' leaves showed a light saturation point at levels >1000 μmol m^{-2} s^{-1},where P_{max} equaled an average 9.31 μmol CO_2 m^{-2} s^{-1}. Regression analysis indicated a light compensation point of a very low 17.7 μmol m^{-2} s^{-1}. When drenched with 1000 ml per pot of 225 and 450 ppm paclobutrazol, *B. vulgaris* 'Wamin' showed no change in chlorophyll or P_{max}. At higher concentrations of 1,800; 3,600 and 10,000 ppm paclobutrazol, increases in chlorophyll were recorded while P_{max} was significantly reduced. *B. nana*, *B. vulgaris* 'Wamin,' *T. siamensis* and *V. ciliata* were placed in 10, 35, 50 or 100% light levels for 6 weeks before being evaluated for changes in chlorophyll and P_{max}. Chlorophyll and P_{max} in *V. ciliata* were inversely related to light levels while chlorophyll and P_{max} in *B. nana* and *T. siamensis* increased with light levels. *B. vulgaris* 'Wamin' had mixed results. *B. vulgaris* 'Wamin' treated with 0, 225 and 450 ppm paclobutrazol and exposed to 10% light for 6 weeks showed no statistically significant differences in chlorophyll levels.

Student's signature　　　　Thesis Advisor's signature　　　　3 / 6 / 08

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Harry Graybill Simmons IV

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LIST OF SYMBOLS AND ABBREVIATIONS

μmol $m^{-2}s^{-1}$	=	micromoles per square meter per second
a	=	LCP at PAR measured in μmol CO_2 m^{-2} s^{-1}
A	=	net photosynthesis measured in μmol CO_2 m^{-2} s^{-1}
ABS	=	American Bamboo Society
AQG	=	average quality grade
A_{SAT}	=	saturation vale of the photosynthetic curve
A_{SAT} - E	=	gross maximum photosynthetic rate
b_c	=	a constant number
b	=	slope of the regression line
c.v.	=	coefficient of variance
c_c	=	mole fraction of CO_2 in the leaf chamber, μmol CO_2 mol air $^{-1}$
c_e	=	mole fraction of CO_2 entering the leaf chamber, μmol CO_2 mol air $^{-1}$
CRD	=	completely randomized design
E	=	transpiration of the leaf, mol H_2O m^{-2} s^{-1}
LCP	=	light compensation point
LRC	=	light response curve
LSP	=	light saturation point
LSD	=	least significant difference
m	=	slope of the regression line
n	=	number of recorded units
PFD	=	Photon Flux Density, μmol m^{-2} s^{-1}
P_{max}	=	photosynthetic rate at LSP
P_n	=	photosynthetic rate
PPFD	=	photosynthetic photon flux density
R2	=	coefficient of determination
s	=	leaf area in cm^2
SPAD	=	single photo avalanche diode

LIST OF SYMBOLS AND ABBREVIATIONS (Continued)

u_e	=	mole flow rate of air entering the leaf chamber, µmol s^{-1}
USDA	=	United States Department of Agriculture
w_c	=	mole fraction of water vapor in the leaf chamber,mmol H_2O mol air $^{-1}$
w_e	=	mole fraction of water vapor entering the leaf chamber, mmol H_2O mol air $^{-1}$
x	=	independent PAR values measured in µmol CO^2 m^{-2} s^{-1}
$\overline{X}$	=	average of known independent x values
y	=	a function of the independent value x
$\overline{Y}$	=	average of known dependent y values
θ	=	convex value of the model curve, calculated based on amount of CO_2 trapped in Calvin-Benson cycle
ϕ	=	initial slope of the curve under low incident levels

LIGHT ACCLIMATIZATION ABILITY OF SOME SPECIES OF *BAMBUSEAE*

INTRODUCTION

Although *Bambuseae*, more commonly referred to as woody bamboos, have been propagated by man for over 5000 years, we have only recently begun to tap their economical potential (Liese, 2003). The Bambusoideae sub-family has garnered much attention in recent years as a very important cash commodity throughout the world. International trade in bamboo and its products in 2003 exceeded a value of 2.5 billion US dollars. When local consumption is included (the majority of value from bamboo), experts estimate the financial impact of bamboo in excess of 7.2 billion US dollars (Bystriakova *et al.*, 2003). Bamboo has become so profitable that in many communities, other rare or endangered plant species are being crowded out in preference of the more economically productive species. Natural stands are being exploited to the point that many profitable species are being destroyed. Many species of shade tolerant bamboo are also seeing their native habitats destroyed along with the surrounding forests (Crompton, 2006). An estimated 400 species, approximately one-fourth of the known bamboo species, are potentially threatened by the loss of forest cover area (Bystriakova *et al.*, 2003). In addition bamboo experts predict there are still dozens of species yet to be discovered by science (Dransfield, 1991).

Understanding the adaptability of bamboo to areas of limited light is an important concern for all of the most important economical uses of bamboo. However, very little research on this topic has been performed. A call for increased research has repeatedly been made but unanswered (Subansenee, 1994). Perhaps the greatest and most economically valuable use of this knowledge would be in the production of ornamental bamboo for use in areas of limited light, such as interior and exterior landscaping. Because of its beauty, versatility and durability, bamboo is becoming an increasingly popular choice for both exterior and interior landscapes (Henly and Poole, 1987). Bamboo has been used for many centuries as an ornamental plant decorating homes, gardens, palaces and temples for both public and private enjoyment (Okamura *et al.*, 1986). Recently, many researchers have begun to realize the economic potential of ornamental varieties of bamboo (Zhang and Chen, 1995). A better understanding of the species and cultivars suited for indoor use as well as their light requirements is important to increasing its use as an indoor ornamental and realizing bamboo's economic potential.

OBJECTIVES

1. Determine the *Bambuseae* species with the highest horticultural potential when grown under greenhouse conditions.

2. Determine best performing species under low light levels.

3. Calculate a light response curve for tropical *Bambuseae*.

4. Determine relationship between chlorophyll content and photosynthesis after chemical acclimatization in some species of *Bambuseae.*

5. Determine relationship between chlorophyll content and photosynthesis after physical acclimatization in some species of *Bambuseae.*

6. Examine possible combined effect of both chemical and physical light acclimatization techniques.

LITERATURE REVIEW

1. Botany and Morphology of *Bambuseae*

Bamboos are members of the Poacea (Graminea) family (Dahlgren, 1985). They can be distinguished from other grasses by unusual flowering patterns, woody culms, underground and aerial branching systems and distinct leaf structures (Zhang and Clark, 2000). The subfamilial rank of *Bambusoideae* contains both the herbaceous and woody bamboos. The woody bamboos are found in the single tribe of *Bambuseae* and can be distinguished from herbaceous bamboos by their lignified stems (culms) (Crompton, 2006). Because of difficulties in classifying *Bambuseae,* there is some contention as to how many genera and species taxonomists have identified. There are between 90 and 115 genera and between 1200 and 1575 species with new species identified every year (Ohrnberger, 1999).

Bambusea can be found naturally on all continents excluding Antarctica and Europe. *Bambuseae* are found as far north as 46º North Latitude and as far south as 47º South Latitude in South America. They can be found at elevations from sea-level to more than 4200 meters (Bystriakova *et al.*, 2003). However, the largest concentrations of *Bambuseae* occur in tropical areas of Asia and Central and South America (Judziewicz *et. al.*, 1999). Correspondingly, the centers of genetic diversity among the *Bambuseae* are located along the northwestern, coastal regions of South America and southern China extending into tropical South-East Asia (Ohrnberger, 1999).

Bamboo taxonomy is complex. Identifying species is difficult due to the small size and similarity of the florescence (Bedell, 1997). This difficulty is compounded by the sometimes extremely long intervals between flowerings. Early scientists used many vegetative structures other than flowers to identify and classify bamboos (Gamble, 1896; Holttum, 1958; Kurtz, 1876, Munro, 1868; Riviere and Riviere, 1878).

The flowers of bamboos are called florets. Each floret consists of a lemma, a palea, 3 lodicules, 3 or 6 stamens and an ovary with 3 stigmas (McClure, 1966). McClure described the 2 structures of flowering as semelaucant and iteraucant. The semelaucant type is determinant with spikelets formed in a raceme which die shortly after opening. The iteraucant type is indeterminant with pseudospikelets bearing a spikelet on the distal end and buds at the base, which form additional pseudospikelets. The iteraucant type usually continues until culm reserves are exhausted.

There are 3 types of flowering intervals exhibited by bamboos. The most familiar is gregarious flowering where the whole species flowers over a 2 or 3 year interval and dies (Wong, 1995). The second type is sporadic flowering. Individual clumps or culms flower and die but non-flowering specimens survive (Dransfield, 1992). The third type is continuous flowering. In continuous flowering, individual culms in a clump flower and die but are replaced by new culms (Holttum, 1958).

There is great diversity in culm habit and structure. Culms may be erect, apically arching, arching, scandent (clambering) or decumbent (Clark, 2008). Culm diameter is determined upon shoot emergence (Dransfield, 1992) and may exceed 30 cm (Seethalakshmi and Kumar, 1998). Internodes may be solid, hollow or both (Kurtz, 1876). Culm height may exceed 30 meters and generally decreases in diameter as it approaches the apex (Wong, 1995). Nodes may be flush or swollen and may contain root-like or thorn-like appendages (Clark, 2008). Young culms may contain a white, waxy layer called bloom. Some species exhibit a sulcus above branching structures (McClure, 1966). Culm walls may be thick or thin and are comprised of microbundles of several different arrangements (Liese, 1998).

Early scientists recognized the importance of rhizomes in distinguishing bamboos from other grasses (Riviere and Riviere, 1878). Sympodial and monopodial are terms that distinguish the 2 forms of rhizome branching rather than rhizome structure (Stapleton, 1997). True morphological structure of rhizomes can be divided into 4 groups. Short-necked pachymorph refers to swollen, curving rhizomes giving rise to one, slightly smaller diametered culms within a short distance of each other.

Long-neck pachymorph is similar but with long necks distancing culms from each other. Leptomorph rhizomes are of uniform diameter and run parallel to ground surface with an occasional culm of greater or equal size. The fourth structure is called tillering leptomorph and combines leptomorph rhizomes with sympodial branching (Clark, 2008). A fifth form called Amphimorph has recently been described but has yet to be widely accepted by taxonomists (Judziewicz *et.al*, 2002).

Branching is another characteristic used in bamboo taxonomy. Important is the number of buds per mid-culm node (0, 1, 2 or more) and whether multiple buds are sub-equal or 1 bud dominant (Dransfield, 2002). Node compression at the base of the primary or sole branch is also important. Primary branch size relative to culm size as well as secondary branch complement size can also be distinctive (Wong, 1995). Branching may be intravaginal, extravaginal and infravaginal as well (Judziewicz *et. al.*, 1999).

Culm leaves are modified leaves used to protect the young shoots. The abaixial surface may be covered with stiff hairs, soft hairs, glaborous or scabrous. The hairs may be black, brown, golden or white and are very useful in distinguishing species in the same genus (Dransfield, 1992). The culm leaf girdle may be absent, faintly present or prominent. Culm leaf blade shape and position are also useful in distinguishing species of the same genus. Culm leaf auricles are important characteristics as well. They may be uniform or unequal, erect, reflexed, glaborous, ciliate or fimbriate (Clark, 2008). Culm leaf ligules are also used in bamboo taxonomic classification. The ligule may be absent, faintly present or prominent. It may also be fringed or not (Wong, 1995).

As with culm leaves, foliar leaves have many morphological characteristics useful in identification (Ellis, 1976; Fujimoto, 1966). Bamboo foliar leaves have fusoid cells below the epidermis, distinguishing it from other grasses. These cells are believed to be instrumental in bamboo’s ability to adapt to difficult habitats (GPWG, 2001). Foliar leaves may also have an abaixially marginal green stripe. Auricles may be present or absent, abset, ciliate or fimbriate. Oral Setae and outer ligule may be present or absent (McClure, 1966). The sheath summit may also be absent or present. The sheath summit indumenta may be glaborous, ciliate or fimbriate. A pseudopetial may be present or absent. The leaf midrib may be centrally aligned or acentral, entirely distinct or partially distinct and protrude adaxially, abaxially or both (Clark, 2008).

Bamboo fruit is rarely observed but is an important part of bamboo morphology. There are 2 types of bamboo fruit. The most common is the caryopsis which is similar to grains produced in other grasses. The caryopsis consists of a dry, hard or papery pericarp which may be strongly attached or easily removed. The second form of bamboo fruit consists of a fleshy pericarp and is found only in some tropical species (Clark, 2008).

2. International Importance

Bamboo has been used as an ornamental plant of grace and beauty for many centuries. Beautiful specimens have been placed in palaces, temples, public and private institutions, homes and gardens throughout the world. Ornamental bamboo is valued for a number of traits. Several varieties exhibit culms with beautiful and interesting shapes and sizes (Meredith, 2001). Others species are treasured for the vast spectrum of stripes, speckles and solid culm colors; yellow, orange, red, brown, black, white and innumerable shades of green (Bell, 2000). *Bambuseae* are also valued for their leaves which, although not as diverse as the culms, come in a large variety of lengths, widths, shades and variegations (Zhang and Chen, 1995). Perhaps its most valued trait is that the *Bambuseae* tribe has adapted to almost every extreme of climate and difficult habitat (Liese, 2003).

Bambuseae as an ornamental plant may have been first cultivated and used in Japan (Okamura *et al.*, 1986). Because of its relatively harsh, temperate environment, most *Bambuseae* native to Japan are very durable and make excellent plants for ornamental landscaping (Fairchild, 1903). Years of evolution and selection have produced some of the most beautiful ornamental varieties (Okamura *et al.*, 1986).

Most of the ornamental bamboos used in the islands of Japan are resistant to frost and some freezing (Farrelly, 1984). Many of the varieties adapted from understory species, are well suited to low irradiance experienced indoors (Noguchi and Yoshida, 2004).

Europe has used bamboo as an ornamental plant since the eighteenth century (Soderstrom, 1985). The only occupied continent to have no native species (Meredith, 2001), bamboo was imported in the 1700's specifically for use as an ornamental (Soderstrom, 1985). Some nurseries in Europe offer more than 150 ornamental species (EBS- British Bamboo Nurseries, 2004). Ohrnberger (1999) references the horticultural use in Europe of more than 200 species and varieties of *Bambuseae* growing in almost every condition. Research on ornamental grasses and bamboos in Europe has shown that at least 4 species have adapted and performed well even in the cold, northern climate of Denmark (Clausen, 1979). European researchers have actively pursued tissue culture experiments genetically improving ornamental bamboos (Gielis and Oprins, 2002). Some labs have commercial production of more than 60 species for both ornamental and agricultural use (Gielis *et al.*, 2002).

Currently the largest market for ornamental bamboo is in the United States. With only 1 genus and 3 species of *Bambuseae* native to the country (Judziewicz, 1999), there are now over 450 species and cultivars available for ornamental use (American Bamboo Society – Species Source List, 2004). The United States Department of Agriculture (USDA) has promoted the use of ornamental bamboo since the early 1900's (Fairchild, 1903). In 1924, the USDA published an informational booklet promoting bamboo use in home and garden. Later, the USDA (1961) published an even more informative pamphlet specifically encouraging, explaining, and supporting the use of ornamental bamboo. This message apparently was well received. In 2004, the American Bamboo Society (ABS) claims in its membership over 100 commercial nurseries and growers that specialize in growing bamboo for ornamental purposes (ABS– Plant and Product Resources, USA, 2004). It is estimated, however, that the largest proportion of ornamental bamboos in the U.S. are produced and sold by large nurseries not affiliated with the ABS (Hotchkiss, 2004). While actual sales are difficult to calculate, both the USDA and ABS agree annual sales of bamboo is a multi-million dollar industry. Most ornamental bamboos in the United States sell for between $30 and $100 dollars per specimen based on size, availability and ornamental characteristics (Evans, 2004). When demand is high, prices for a single specimen can exceed $1000 (ABS, 2004). Use of *Bambuseae* as an ornamental plant in the United States is both popular and profitable.

Many other countries in Asia and South-East Asia also use bamboo quite extensively as an ornamental plant. Dransfield and Widjaja (1995) describe many species with economical importance in South-East Asia, including several with ornamental value. Many other researchers have also recognized the importance and potential of ornamental bamboo in Asia (Zhang and Ma, 1996). In 1994, Yanchuan and Ailin suggested that the development and sale of ornamental bamboos in the coastal regions would significantly increase average income and prosperity in those regions. Several plant nurseries in Southern China now export ornamental bamboos worldwide (China Bamboo Centre – Bamboo List, 2004 and Zhejiang Yunfeng Wholesale Nursery, 2004). In research performed by Lan and Mao (1987), *Phyllostachys pubescence* was shown to be easily reshaped into interesting, sometimes grotesque, shapes increasing the ornamental value of this already valuable ornamental bamboo. In the Philippines, Gigare (1997) recommended growing bamboos with interesting or "deformed" culm characteristics. Other Philippine researchers outlined the importance and potential opportunities for rural farmers in growing ornamental bamboos (Tangan, 1997). The Ecosystems Research and Development Bureau recommended several ornamental bamboos to be used in the urban parks and gardens in the Philippines (Roxas, 2000). The Nagaland Forest Department in Kohima, India recently recognized the usefulness and importance of ornamental bamboo use in India (Shashidar and Arunkumar, 1999). In Thailand, many native species of bamboo are used in landscaping, some of which have been exported and used in many other countries (Chen, 1986; Ohrnberger, 1999; Bennet, 1988). No specific economic data is available with regard to annual sales of ornamental bamboo in Asia.

3. Interior Landscaping of *Bambuseae*

Little scientific research has been recorded on the requirements and difficulties of using *Bambuseae* indoors. Species native to the tropics are preferred for use as indoor plants for several reasons. Most tropical species have sympodial (pachymorph) rhizome systems which adapt more easily to confined spaces (Cusack, 1999). Tropical species do not require a dormant season nor do they experience seasonal leaf drop as do most temperate species. The tropical species also prefer the constant temperature and day length experienced in the interior setting, thus reducing trauma and easing acclimatization (Laughlin, 1997). In 1987, Henley and Poole performed experiments evaluating sixteen species and cultivars of *Bambuseae* for potential use in interior landscapes. Four species were found to have great potential. Since that time, several experts have recommended between 20 and 30 species of *Bambuseae* that can be grown in interior spaces. (Alderman, 2004; Bamboo Sorcery, 2004; Janquith *et al*., 2004; Lucas. 2001; Meredith, 2001) However, no references to scientifically reviewable research are mentioned to substantiate the claims.

Several factors must be considered for growing *Bambuseae* indoors. The most important is extremely reduced light levels in interior settings (Welsh and Cotner, 1998). The amount of daily light received in the area of the planting must be determined before selecting a suitably conforming species (Alderman, 2004). Proper humidity levels are also crucial in maintaining the health and beauty of indoor bamboo as interiors are often very dry (Bamboo Sorcery: Bamboos for Indoors, 2004). Watering also can be problematic as lower light levels decrease plant water requirements (Janquith *et al.*, 2004). *Bambuseae* can be easily damaged by waterlogged roots. Fertilizer must also be carefully used as increases in fertilizer may have dangerous effects on leaves and roots (Conover and Poole, 1978). *Bambuseae* grown in the low light conditions usually found indoors will normally have slowed or reduced growth (Saitoh *et al.*, 2002). Some species will require pruning, which may increases shoots and foliage (Yokoyama and Shibata, 1997). Pruning will also decrease height, leaf size, overall size, and increase attractiveness of the specimens

(Helliwell, 1997). Some experts have also suggested air movement as beneficial, but this claim is unsubstantiated (Wright and Alvarez, 2004).

4. Low-Light Adaptation in *Bambuseae*

Because many bamboos have evolved as understory plants in forest settings with limited light resources (Saitoh *et al.*, 2002), many exhibit the growth characteristics and low light compensation point (LCP) associated with shade plants when grown in reduced light levels (Lei and Koike, 1998). As in most understory plants, light becomes the limiting resource in understory bamboo (Chazdon, 1988). Widmer (1998) observed a morphological difference among naturally occurring *Chusquea* species growing in full sun and those growing in shaded areas. Culm number and diameter, clump density, and biomass were significantly larger among every *Chusquea* specimen growing in full sun; while specimens of the same species growing under limited light were smaller but occurred more frequently in the area measured. Not only can species in the same genus vary dramatically as to their shade and light tolerance levels, but individual plants of the same species as well. Research performed by Saitoh *et al.* (2002) on *Sasa palmata* showed that the specific leaf area in shade grown specimens was greater than specimens growing in full sun, indicating a morphological plasticity which enabled individual bamboo plants to adapt to areas of low light levels. However, plants in low light conditions had a greatly reduced biomass, more so above than below ground, when compared to light grown specimens. This may be a plant response to conserve energy by reducing the excess respiration in above ground biomass which exceeds respiration of biomass below ground (Kramer and Kozlowski, 1979).

Xu *et al*. (1991) observed total Photosynthetic rate (P_n) decreasing as temperatures decreased and humidity decreased in *Phyllostachys pubescence*. Other researchers have observed differences in P_n at different levels in the canopy of *Phyllostachys pubescence* (Yang *et al.*, 1991). These experiments measured the LCP of *P. pubescence* growing in full sun to be an average of 50 µmol m^{-2} s^{-1} for all levels of the canopy. No measurements were made for changes to LCP while light levels changed during production. They also found that leaves in the lower third of the canopy had much lower Light Response Curves (LRC) when compared to the upper third of the canopy. *Phyllostachys pubescens* leaves in the lower shaded tier reached a light saturation point at a level between 200-400 µmol m^{-2} s^{-1}. This value represents an overall negative P_n value. The finding is most likely due to the reduced light levels reaching the lower tier. Another possible factor may be the reduced CO_2 content found in the understory of the *Phyllostachys pubescence* research area. Sternberg and DeAngelis (2002) found decreased levels of CO_2 in the understory of forest canopies in the natural setting reduced P_n values as well as LCP. CO_2 levels are reduced as the upper canopy, with full exposure to light resources, respires most available CO_2 leaving greatly reduced levels for understory use (Xu *et al*., 1991).

5. Acclimatization for Low-Light Conditions

Bambuseae, like many plants, require light acclimatization before being grown in areas of low irradiance. In some of the earliest light acclimatization experiments on plants used solely for ornamental purposes, Conover and Poole (1973 and 1975) showed that lowering light levels from full sun to varying degrees of shade for several weeks during production of *Ficus benjamina* plants increased performance in simulated interior settings. Joiner *et al.* (1977) also showed that the light compensation point (LCP) could be lowered by lowering the light levels used during production of *Ficus benjamina*. Plants with low LCP generally perform better under low light conditions than plants with higher LCP (Kubiske and Pregitzer, 1996). Shade plants also exhibit changes in leaf structure as adaptations to low light levels including darker color, change in leaf area, change in leaf shape and a singular, thin layer of palisade cells (Fails *et al.*, 1982; Turner *et al.,* 1987).

Chemical acclimatization has also been used to lower LCP and increase plant health under low light levels. Paclobutrazol, a triazole, was first used as a growth regulator in 1985 (Goulston and Shearing, 1985). It was found that plants treated with paclobutrazol had several morphological changes which decreased the LCP and increased the ability to adapt to lower light levels (Sankhla *et al.*, 1985). Leaves of plants treated with paclobutrazol exhibit the same morphological changes as those seen in physically acclimatized plants such as darker color, increase in chlorophyll, increased chloroplast size and number of thylakoid per granum stack (Fletcher *et al.*, 2000). It was also found that paclobutrazol can be used as either a foliar spray or as a soil drench to treat plants (Goulston and Shearing, 1985).

MATERIALS AND METHODS

Twenty species and cultivars of the *Bambuseae* tribe from seven genera were obtained from several different locations in Thailand. This collection represented approximate 25% of the total number of species found in Thailand.

Experiment 1: Evaluating commercial quality of 17 *Bambuseae* species.

Twenty accessions from the *Bambuseae* tribe were collected for this experiment (Table 1). All plants were collected over a 2-month period between February and April, 2005 and kept at the Horticultural Research Center at Bangkhen campus, Kasetsart University, Bangkok, Thailand (13°50'59N, 100°33'50E). This time period coincided with the end of the dry season and the best time to propagate and purchase bamboos. *Vietnamosasa ciliata* and *Vietnamosasa pusilla* were grown from rootstock collected from natural stands. Mature specimens of *Bambusa multiplex* 'Riviereorum' were purchased and divided at the greenhouse. Both varieties of *Dendrocalamus asper* were 6 months old branch cuttings. The remaining accessions evaluated were culm cuttings less than 3 months old. Fifteen replications from each accession were collected with three exceptions based on availability (12 specimens of *Bambusa multiplex* 'Riviereorum', 14 specimens of *Vietnamosasa ciliata* and 9 specimens of *Vietnamosasa pusilla)*. All plants were removed from their original containers and repotted in 11 liter pots with a mixture of 50% leaf-mold and 50% topsoil. Between 3 and 4 cm gravel was added to the bottom of each container to ensure proper drainage. Each plant was then given a single application of 5 grams of 14-14-14 control-release fertilizer (3 month formula, Osmocote©) and watered 3 times weekly.

Table 1 *Bambuseae* accessions evaluated in experiment 1

	Scientific Name	Thai Name
1	*Bambusa bambos* (L.) Voss	Phai nam
		Phai ba
2	*Bambusa blumeana* Schult.f.	Mai si suk
		Phai si suk
3	*Bambusa glaucophylla* 'Malay Dwarf' Wong	Phai ngen
4	*Bambusa multiplex* (Lour.) Raeusch.	Phai liang
		Phai yok
5	*Bambusa multiplex* 'Riviereorum' (Lour.) Raeusch.	Phai seshuan
6	*Bambusa nana* Roxb.	Phai liang
7	*Bambusa nutans* Wall.	Phai bong
8	*Bambusa tuldoides* Munro	Phai gae
		Phai nam tao
9	*Bambusa vulgaris* 'Vitatta' Gamble	Phai luang
10	*Bambusa vulgaris* 'Wamin' Schrad. Ex Wendl.	Phai nam tao
11	*Cephalostachyum pergracile* Munro	Mai paeng
		Phai kao laam
12	*Dendrocalamus asper* 'Dam'(Roem. & Schult.) Backer ex K. Heyne	Phai tong dam
13	*Dendrocalamus asper* 'Thai Green' Backer ex K. Heyne	Phai tong khiaw
14	*Dendrocalamus membranacea* Munro	Mai nuan
		Mai sang
		Phai lai lo
		Phai nuan
		Phai sang doi
		Phai sang nuan
15	*Gigantochloa albociliata* (Munro)Ngyuen	Phai phak kham
		Phai rai
		Phak kham
16	*Gigantochloa ligulata* Gamble	Phai ne
		Phai kai
17	*Schizostachyum brachycladum* (Munro) Kurz	Khriap
		Pai bo
		Phai si tong
		Phai khriap
18	*Thyrsostachys siamensis* Gamble	Mai ruak
		Phai ruak
19	*Vietnamosasa ciliate* (Camus) Nguyen	Chot
		Phai chot
20	*Vietnamosasa pusilla* (Camus&Chevalier)Nguyen	Phai phek
		Phek
		Pek

Source: Pattanawiboon *et al.* (2001); Smitinand (2001); Cousens, (2001).

All specimens were arranged following the Completely Randomized Design (CRD) statistical method with 5 plantsin each of 3 replications(Hoshmand, 2001). Specimens were grown under the above conditions and watered thrice weekly. After the 6-week period grown under full sunlight, the plants were evaluated for commercial quality using a grading system frequently used by plant breeders and scientists (Henny and Chen, 2003; Conolly and Poole, 1975, Heuvelink *et al.*, 2001). Each specimen was graded in 3 different categories: the attractiveness of foliage, culms and plant form. These three scores were then combined to reach a total Averaged Quality Grade (AQG). All 20 accessions were graded with 1 being unsatisfactory quality and 5 being superior quality.

Leaves of each specimen were ranked between 1 and 5, with 1 being poorest quality and 5 being superior quality (Figure 1). Foliage scores were assessed based on the following criteria (Henely and Poole, 1987):

AQG leaf score 1: Extensive damage to majority of the leaves, many leaves brown and/or dieing, sparse positioning in canopy usually with large, coarse leaves.

AQG leaf score 2: Damage to most leaves, tips and edges of leaves brown, some dead leaves, leaves sparse, large and coarse.

AQG leaf score 3: Some leaf damage usually on tips or edges, occasional dead or dieing leaf, canopy has greater number of leaves and partially full, leaves often less coarse.

AQG leaf score 4: Small amount of leaf damage not readily noticeable, may or may not be fine textured, variegation less prominent or non existent, many leaves but not full.

AQG leaf score 5: No observable damage or blemish, fine textured, may or may not be variegated, leaves numerous and full.

Figure 1 Leaf average quality grade scores of 1(a), 2(b), 3(c), 4(d) and 5 (e,f).

Culms were also given an AQG score between 1 and 5 (Figure 2, 3). Culm AQG scores were assessed based on the following criteria (Henley and Poole, 1987):

AQG culm score 1: Culms may have persistent culm leaf remnants, extensive damage, scarring, fading color, branch scars at nodes, rapidly declining quality and/or unattractive branches, nodes and internodes.

AQG culm score 2: Culms may have persistent culm leaf remnants, obvious damage, scarring and blemishes, fading color, branch scars and/or unattractive branches, nodes and internodes.

AQG culm score 3: Infrequent culm leaf remnants; some noticeable damage to culms; attractive striations, colors and shapes of nodes/internodes; may or may not have unattractive branching/branch scars.

AQG culm score 4: Culms without culm leaf remnants; noticeable damage only upon close inspection; attractive colors, striations and shapes of nodes/internodes; may or may not have unattractive branching/branch scars.

AQG culm score 5: No noticeable damage or blemishes, culm leaves not present, superior quality, very attractive colors, striations or node/internode shapes.

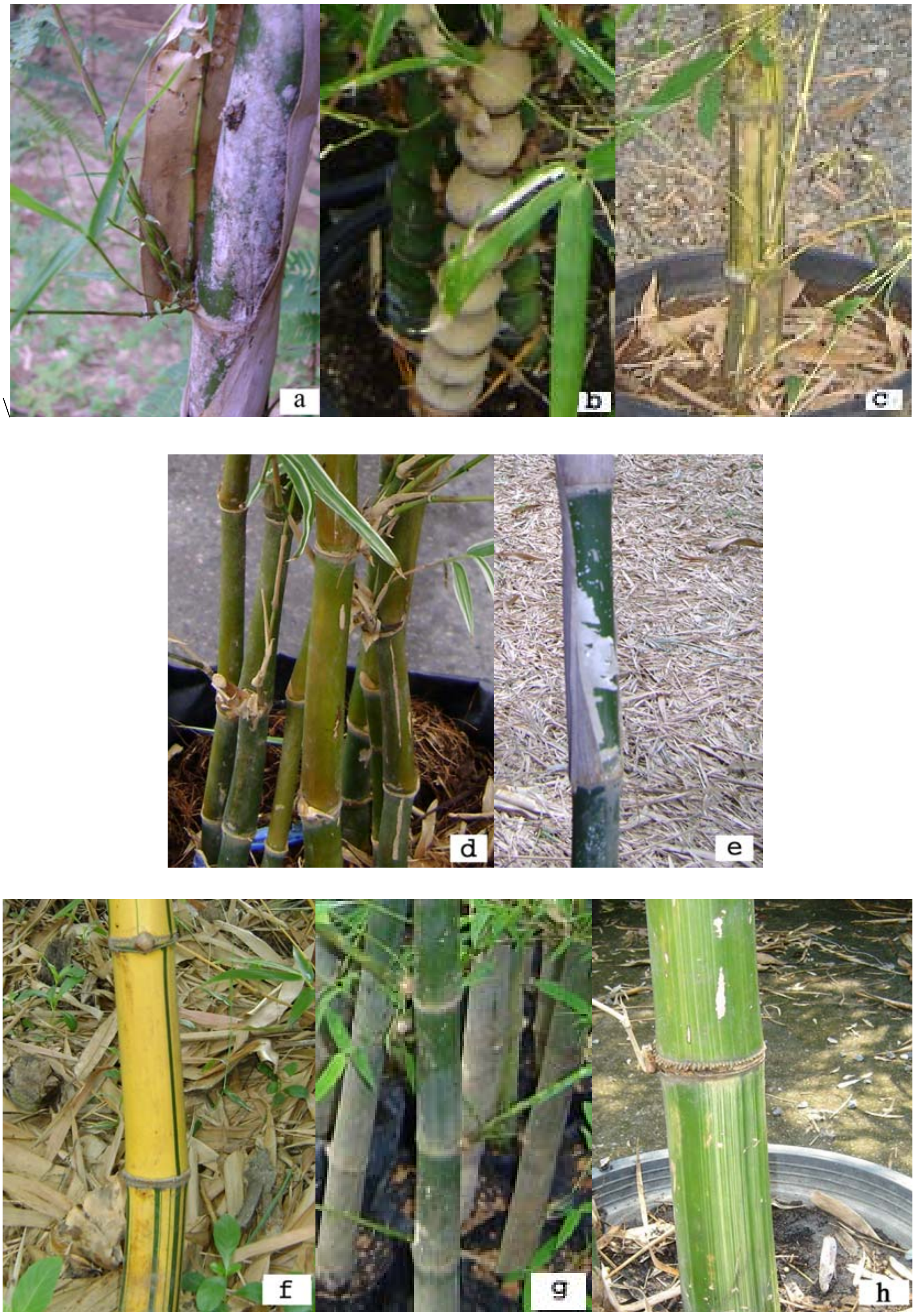

Figure 2 Culm average quality grade scores of 1(a, b), 2(c, d) and 3(f, g, h).

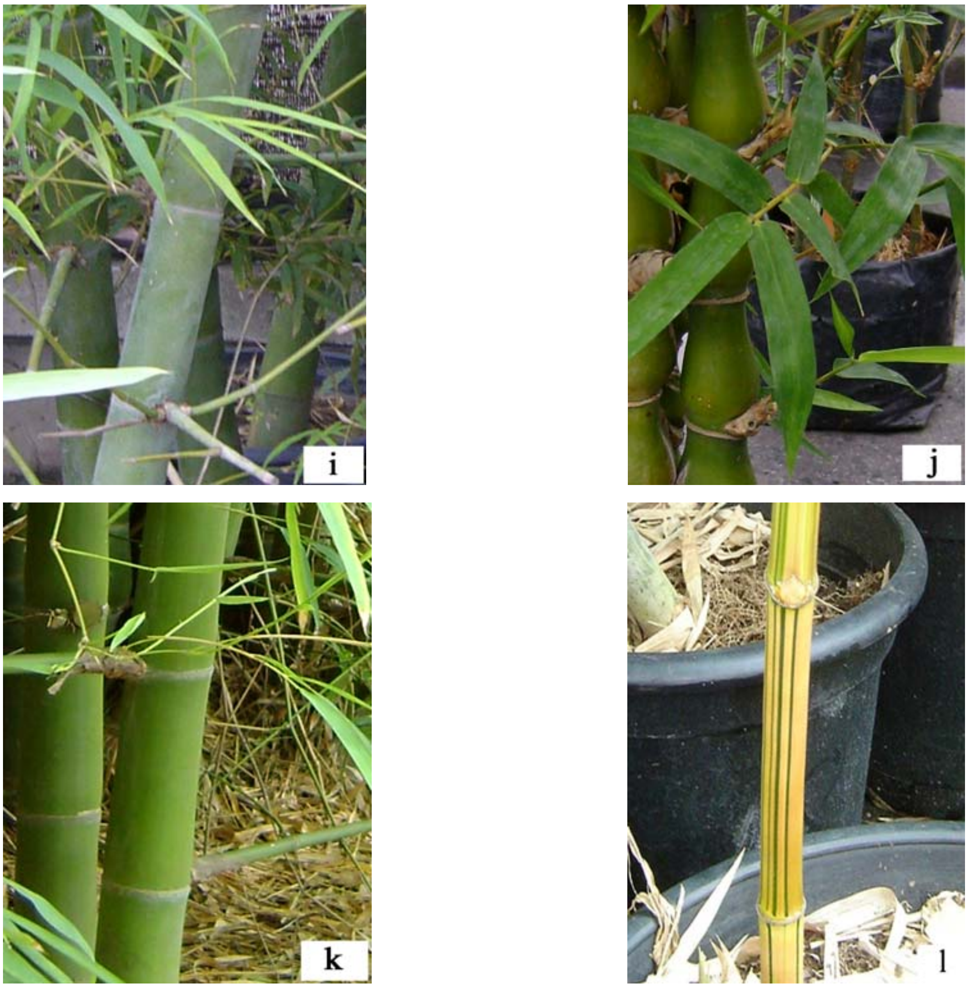

Figure 3 Culm average quality grade scores of 4(i, j) and 5(k, l).

Plant form was also given an AQG score between 1 and 5 (Figure 4). Plant form AQG scores were assessed based on the following criteria (Henley and Poole, 1987):

AQG form score 1: Plant form very coarse, branching long, dispersed, scandent or decumbent, protruding and open with no order.

AQG form score 2: Plant form coarse, branching less dispersed with open canopy and large, numerous gaps.

AQG form score 3: Plant form medium/not coarse, branching more compact and organized with fewer protruding branches and fewer gaps in canopy, increased symetry.

AQG form score 4: Full form with infrequent gaps in canopy or protruding branches, mostly symetrical.

AQG form score 5: Plant form full, canopy has no gaps or protruding branches, very symetrical shape.

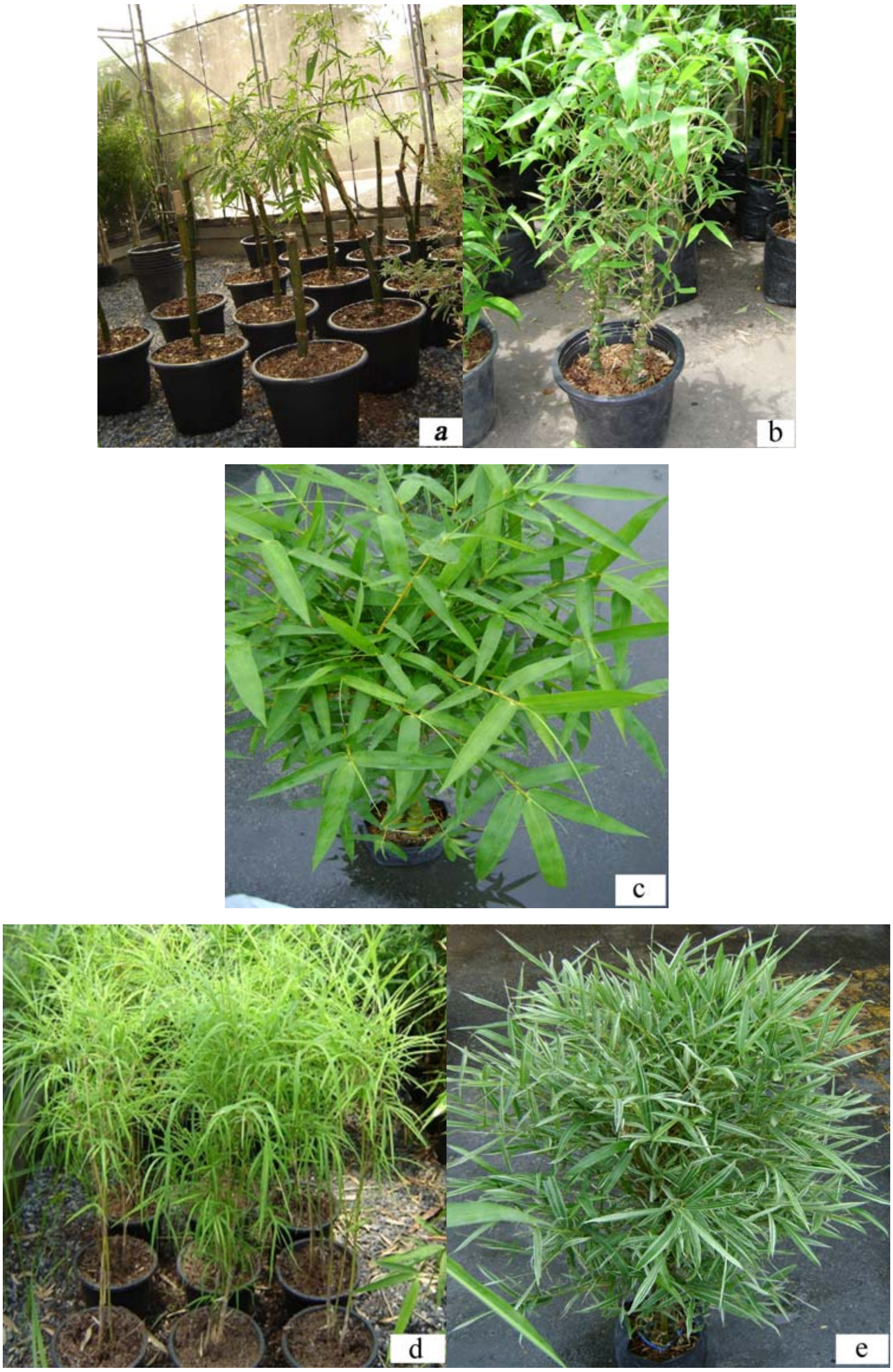

Figure 4 Plant form average quality grade score of 1(a), 2(b), 3(c), 4(d) and 5(e).

Experiment 2: Changes in chlorophyll content and commercial quality under low light levels in 16 *Bambuseae* species.

In this experiment, 19 accessions of bamboo (from the experiment 1, except *Bambusa tuldoides*) were collected and cultivated at the same greenhouse used in experiment 1. Fifteen specimens from each species were collected with 3 exceptions based on scarcity (12 specimens of *Bambusa multiplex* 'Riviereorum', 14 specimens of *Vietnamosasa ciliata* and 9 specimens of *Vietnamosasa pusilla*.

Leaf chlorophyll content was measured in all specimens. Chlorophyll content was evaluated with the SPAD 502 Chlorophyll Meter. The SPAD measures the leaf transmittance of light at 650 nm and 940 nm (Mass and Dunlap, 1989). Chlorophyll absorbs light from each of these spectra at different rates. The variance in the rate of absorption at these 2 different levels allows the chlorophyll content to be accurately measured.

Leaves were chosen which had emerged while in cultivation at the research center, which had no physical damage or blemishes and which were between 3 and 4 months old. Leaves were marked after first week of emergence with plastic markers. Each specimen also received an AQG score based on overall horticultural value of leaves, horticultural value of culms and commercial value of the specimen. The entire area was then limited to 10% full sunlight, as determined by the 3-Sensor Quantum Light Meter Model BQM (Spectrum Technologies, Inc) for a six week period. Light amounts were limited by covering all replications using black, polyurethane shade cloth. The specimen plants used in this experiment were the same plants that had been previously grown and evaluated in experiment 1. This experiment occurred from May to June, 2005. All specimens were grown for 3 months under full sunlight prior to the experiment.

The plants were watered thrice weekly. Marked leaves of each plant were reassessed to record any change in the chlorophyll content. The plants were reevaluated using the AQG system used in experiment 1 to identify species that acclimatized well under 10% full light. The specimens were arranged following the CRD statistical method with 3 replications of 5 plants per replication.

Experiment 3: Photosynthetic changes in *Bambusa vulgaris* 'Wamin' after chemical acclimatization.

In September of 2005, 42 pots with 3 culm divisions per pot of *Bambusa vulgaris* 'Wamin' were purched. All culm divisions ranged between 40-60 cm in height and between 2-4 cm in diameter. All plants were potted with a soil mixture of 50% topsoil and 50% coconut coir. Three to 4 cm of gravel was placed in the bottom of each 11 liter, black, plastic pot to insure proper drainage. Each plant was fertilized with 5 grams of 14-14-14 controlled-release fertilizer once at the time of potting and watered thrice weekly. The culm divisions were cultivated under similar conditions as in experiment 2 until December to insure uniformity among the samples. Culm division diameter, height and number did not change. In January, 2006 a leaf was selected from each plant as in experiment 2. A light response curve (LRC) was calculated from 18 specimens using the LI-6400 system (LI-COR, Inc). The chlorophyll content of each plant was then evaluated using the Minolta SPAD 502 (Minolta, Inc.). The maximum P_n of the same leaf at a daily photosynthetic photon flux density (PPFD) of 1500 micromoles per square meter per second ($\mu mol\ m^{-2}s^{-1}$) was then analyzed using the LI-6400 system. Plants were then treated with paclobutrazol (Predict®, ai:14%, Dynamic Agro Services, Ltd., Bangkok, Thailand). The paclobutrazol was applied using the soil drench method with 1,000 ml of 0, 225, 450, 900, 1,800, 3,600 or 10,000 ppm solution. The treatments were administered to the plants and arranged according to CRD statistical design with 7 replications of 6 pots per replication. All plants were evaluated six weeks after chemical application.

Healthy leaves of 3 to 4 months old which had emerged after plant acquisition were chosen for uniformity. Leaves were measured while temperatures ranged between 25°C and 31°C to minimize leaf fluctuations due to extreme temperature differences.

All measurements of P_n used during this research were recorded using the LI-6400 system. The Blackman Model uses CO_2 and H_2O retained and released in the electron transport system during leaf respiration to measure P_n (Takahiro *et al.*, 2000). Using this model, P_n is calculated thusly:

$$A = \frac{\phi PFD + (A_{SAT} - E) - \sqrt{(\phi PFD + (A_{SAT} - E))^2 - 4(A_{SAT} - E)\phi PFD}}{2\theta} - E \text{ .}$$

Where: A = net photosynthesis (maximum assimilation rate) measured in µmol CO_2 m^{-2} s^{-1}; also called P_n.

A_{SAT} = saturation vale of the photosynthetic curve.

E = transpiration of the leaf, mol H_2O m^{-2} s^{-1}.

PFD = Photon Flux Density, µmol CO_2 m^{-2} s^{-1}.

(A_{SAT}-E) = gross maximum photosynthetic rate.

θ = convex value of the model curve, calculated based on amount of CO_2 trapped in Calvin-Benson cycle.

ϕ = initial slope of the curve under low incident levels.

Using readings from the LI-6400 system, the previous formula can be rearranged into the following:

$$A = \frac{u_e(c_e - c_c)}{100s} - c_c E \text{ .}$$

Where: A = net photosynthesis measured in µmol CO_2 m^{-2} s^{-1}.

c_c = mole fraction of CO_2 in the leaf chamber, µmol CO_2 mol air $^{-1}$.

c_e = mole fraction of CO_2 entering the leaf chamber, µmol CO_2 mol air $^{-1}$.

E = transpiration, mol H_2O m^{-2} s^{-1}.

s = leaf area, cm^2.

u_e = mole flow rate of air entering the leaf chamber, µmol s^{-1}.

The formula can be further simplified by substituting the formula for transpiration $a = \overline{Y}$ (E in the formula). The formula for transpiration is as follows:

$$E = \frac{u_e(w_c - we)}{s \bullet 10^5 \left(1 - \frac{w_c}{1000}\right)}.$$

Where: w_c = mole fraction of water vapor in the leaf chamber, mmol H_2O mol air $^{-1}$.

w_e = mole fraction of water vapor entering the leaf chamber, mmol H_2O mol air $^{-1}$.

LCP was calculated once the LRC was known. The LCP equals the point at which the amount of O_2 produced equals (or exactly compensates) the amount used in the photosynthetic process. In calculating LRC, the LCP equals the least squares regression line intercept of the X axis. This process was calculated thusly:

$$a = \overline{Y} - b\overline{X}$$

Where: a = LCP P_n at light level measured in µmol CO_2 m^{-2} s^{-1}.

b = slope of the regression line.

$\overline{Y}$ = average of known dependent y values.

$\overline{X}$ = average of known independent x values.

n = number of units recorded.

And where:

$$b = \frac{n\left(\sum xy\right) - \left(\sum x\right)\left(\sum y\right)}{n\left(\sum x^2\right) - \left(\sum x\right)^2}.$$

The light saturation point (LSP) of leaves was calculated also by using the data recorded in the LRC. The LSP equals the point at which additional light gives no increase in the total photosynthetic rate. This value is found when the slope of the regression line equals 0. This is calculated with the following formula:

$$y = mx + b$$

Where: y = a function of the independent value x.
m = slope of the regression line.
x = independent PAR values measured in μmol CO_2 m^{-2} s^{-1}
b = a constant number.

Experiment 4: Photosynthetic changes in 4 species of *Bambuseae* under different light levels.

Based on results from the previous 2 experiments, *Bambusa nana, Bambusa vulgaris* 'Wamin', *Thyrsostachys siamensis* and *Vietnamosasa ciliata* were chosen for evaluation for change in P_{max} when different light levels were used. Experiment was performed from March through April 2006. Twenty four plants of each species were acquired locally in December, 2005. *Vietnamosasa ciliata* plants were established from rootstock collected from natural stands. Each plant had 4-7 culms per pot with a diameter of 0.3 – 1 cm and a height of 40 – 60 cm. The remaining species were single culm divisions 2-4 cm in diameter and 40 – 60 cm in height. All plants were repotted in a mixture of 50% topsoil and 50% coconut coir. Between 3 and 4 centimeters of gravel were placed in the bottom of each 11 liter plastic pot to improve drainage. Each plant was fertilized with 5 grams of 14-14-14 control-release fertilizer once at time of potting and watered thrice weekly. All specimens were grown under full light for 3 months prior to treatment.

The greenhouse was divided into 4 sections of different levels of irradiance: 10, 35, 50 or 100% full sun as determined by the 3-Sensor Quantum Light Meter Model BQM (Minolta, Inc.). For each of the 4 species, 6 replications were randomly placed in each of the four greenhouse shade levels. A CRD statistical design was used. Leaves for analysis were selected under the same guidelines as in experiment 2 and 3. The chlorophyll levels of the leaves were measured using the Minolta SPAD-502. The P_{max} of the same leaf at a daily PPFD of 1,500 µmol $m^{-2}s^{-1}$ was then analyzed using the LI-6400 system.

After a 6-week period, chlorophyll levels were again measured. P_{max} was also measured and compared to the previous measurements.

Experiment 5: Photosynthetic changes in *Bambusa vulgaris* 'Wamin' after chemical acclimatization.

Bambusa vulgaris 'Wamin' was selected for this experiment based on results of the previous four experiments and the popular use of this species as an ornamental plant. Thirty pots with 3 culm divisions per pot were acquired in June, 2006 from a local nursery. All culm divisions measured between 2-4 cm in diameter and 40 – 60 cm in height. All plants were repotted in a mixture of 50% topsoil and 50% coconut coir. Between 3 and 4 centimeters of gravel were placed in the bottom of each 11 liter, black, plastic pot to improve drainage. Each plant was fertilized once at the time of potting with 5 grams of 14-14-14 controlled-release fertilizer and watered thrice weekly. All specimens were grown under full light for 3 months prior to experiment.

Twenty pots were treated using the drench method with 1,000 ml of paclobutrazol solution at the concentration of either 225 or 450 ppm. Ten plants were used as the control. Plants were arranged in compliance with the CRD statistical design. The greenhouse light levels were reduced to 10% full sunlight. The chlorophyll levels of selected leaves, chosen as in previous experiments, were measured using the Minolta SPAD-502. The chlorophyll measurements were recorded at 2-week intervals over a 10-week period from September 1st until November 10th, 2006. Measurements were then compared for changes.

RESULTS AND DISCUSSION

Experiment 1: Evaluating commercial quality of 17 *Bambuseae* species.

Of the 20 accessions of *Bambuseae* grown under full sunlight, AQG's ranged between 2.47 and 4.12 with 1 being unsatisfactory quality and 5 being superior quality. AQG was derived by calculating an equally weighted average of leaf, culm and plant quality scores. Each trait is different and important to the overall quality. Evaluations occurred in June 2005. Results are found in Table 3 and Figure 1.

Leaf quality was the most immediately recognizable trait. Small, dense, fine textured leaves looked more attractive than large, coarse leaves. The loss of several leaves has no negative impact on plant quality if the pant has many small leaves. This is not the case in larger leaf specimens. Some leaves also exhibit attractive striations of white and green. However, the color and shape of bamboo leaves are not as colorful or varied as the culms.

Culm shape, size and color vary greatly. Culms exhibiting attractive features such as bright colors, striations or swollen internodes received higher quality scores. Persistent culm leaves looked worn and detracted from culm appearance. It is difficult to change culm appearance.

Plant form is also important when determining overall quality. Size and shape can vary greatly. Species with short, full, compact forms are more versatile and desirable for horticultural purposes than large, scraggly or scandent species. Plant shape is easily manipulated in some species by pruning and growing techniques. This ability to change plant form easily makes this trait important for horticultural purposes.

Table 2 Average quality grade of 20 *Bambuseae* accessions after 6 weeks grown under full sunlight.

	Scientific Name	Average Quality Grade				
		Foliage	**Culms**	**Plant**	**Average**	**±SE**
1	*Bambusa bambos*	3.09	3.05	3.55	3.23	0.46
2	*Bambusa blumeana*	3.66	3.21	4.1	3.66	0.89
3	*Bambusa glaucophylla* 'Malay Dwarf'	4.22	2.51	4.05	3.59	1.02
4	*Bambusa multiplex*	3.5	3.3	3.91	3.57	0.61
5	*Bambusa multiplex* 'Riviereorum'	4.28	3.26	3.23	3.59	0.87
6	*Bambusa nana*	4.34	4.01	4.02	4.12	0.32
7	*Bambusa nutans*	3.01	2.72	2.8	2.84	0.21
8	*Bambusa tuldoides*	2.55	4.44	3.63	3.54	0.81
9	*Bambusa vulgaris* 'Vitatta'	3.12	3.85	3.58	3.52	0.47
10	*Bambusa vulgaris* 'Wamin'	3.14	4.89	3.27	3.77	0.86
11	*Cephalostachyum pergacile*	2.13	3.87	2.74	2.91	0.78
12	*Dendrocalamus asper* 'Dam'	2.77	2.36	2.28	2.47	0.39
13	*Dendrocalamus asper* 'Thai Green'	2.98	2.17	2.56	2.57	0.40
14	*Dendrocalamus membranacea*	3.41	3.88	3.32	3.54	0.56
15	*Gigantlochloa ligulata*	3.15	3.6	3.4	3.38	0.63
16	*Gigantochloa albociliata*	2.89	3.74	3.26	3.30	0.88
17	*Schizostachyum brachycladum*	3.16	4.43	3.17	3.59	0.92
18	*Thyrsostachys siamensis*	4.37	3.36	4.29	4.01	0.77
19	*Vietnamosasa ciliata*	4.62	3.12	3.42	3.72	1.04
20	*Vietnamosasa pusilla*	2.73	2.16	3.33	2.74	1.23

Plant form was also given an AQG score between 1 and 5 (Figure 4). Plant form AQG scores were assessed based on the following criteria (Henley and Poole, 1987):

AQG form score 1: Plant form very coarse, branching long, dispersed, scandent or decumbent, protruding and open with no order.
AQG form score 2: Plant form coarse, branching less dispersed with open canopy and large, numerous gaps.
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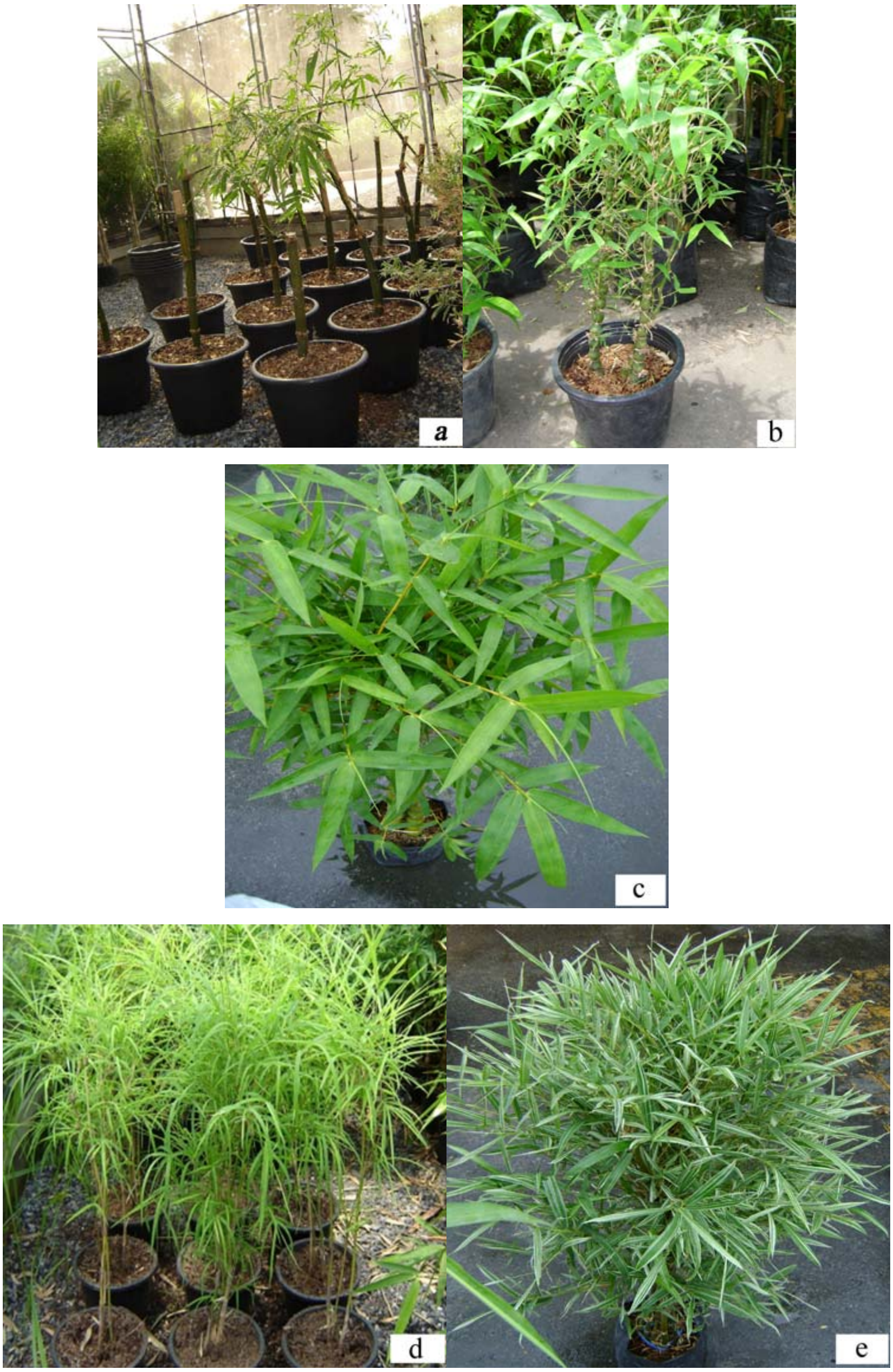

Figure 4 Plant form average quality grade score of 1(a), 2(b), 3(c), 4(d) and 5(e).

Experiment 2: Changes in chlorophyll content and commercial quality under low light levels in 16 *Bambuseae* species.

In this experiment, 19 accessions of bamboo (from the experiment 1, except *Bambusa tuldoides*) were collected and cultivated at the same greenhouse used in experiment 1. Fifteen specimens from each species were collected with 3 exceptions based on scarcity (12 specimens of *Bambusa multiplex* 'Riviereorum', 14 specimens of *Vietnamosasa ciliata* and 9 specimens of *Vietnamosasa pusilla*.

Leaf chlorophyll content was measured in all specimens. Chlorophyll content was evaluated with the SPAD 502 Chlorophyll Meter. The SPAD measures the leaf transmittance of light at 650 nm and 940 nm (Mass and Dunlap, 1989). Chlorophyll absorbs light from each of these spectra at different rates. The variance in the rate of absorption at these 2 different levels allows the chlorophyll content to be accurately measured.

Leaves were chosen which had emerged while in cultivation at the research center, which had no physical damage or blemishes and which were between 3 and 4 months old. Leaves were marked after first week of emergence with plastic markers. Each specimen also received an AQG score based on overall horticultural value of leaves, horticultural value of culms and commercial value of the specimen. The entire area was then limited to 10% full sunlight, as determined by the 3-Sensor Quantum Light Meter Model BQM (Spectrum Technologies, Inc) for a six week period. Light amounts were limited by covering all replications using black, polyurethane shade cloth. The specimen plants used in this experiment were the same plants that had been previously grown and evaluated in experiment 1. This experiment occurred from May to June, 2005. All specimens were grown for 3 months under full sunlight prior to the experiment.

The plants were watered thrice weekly. Marked leaves of each plant were reassessed to record any change in the chlorophyll content. The plants were reevaluated using the AQG system used in experiment 1 to identify species that acclimatized well under 10% full light. The specimens were arranged following the CRD statistical method with 3 replications of 5 plants per replication.

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Where: A = net photosynthesis (maximum assimilation rate) measured in µmol CO_2 m^{-2} s^{-1}; also called P_n.

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E = transpiration of the leaf, mol H_2O m^{-2} s^{-1}.

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The formula can be further simplified by substituting the formula for transpiration $a = \overline{Y}$ (E in the formula). The formula for transpiration is as follows:

$$E = \frac{u_e(w_c - w_e)}{s \bullet 10^5 \left(1 - \frac{w_c}{1000}\right)}.$$

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$$a = \overline{Y} - b\overline{X}$$

Where: a = LCP P_n at light level measured in µmol CO_2 m^{-2} s^{-1}.

b = slope of the regression line.

$\overline{Y}$ = average of known dependent y values.

$\overline{X}$ = average of known independent x values.

n = number of units recorded.

And where:

$$b = \frac{n\left(\sum xy\right) - \left(\sum x\right)\left(\sum y\right)}{n\left(\sum x^2\right) - \left(\sum x\right)^2}.$$

The light saturation point (LSP) of leaves was calculated also by using the data recorded in the LRC. The LSP equals the point at which additional light gives no increase in the total photosynthetic rate. This value is found when the slope of the regression line equals 0. This is calculated with the following formula:

$$y = mx + b$$

Where: y = a function of the independent value x.

m = slope of the regression line.

x = independent PAR values measured in µmol CO_2 m^{-2} s^{-1}

b = a constant number.

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The greenhouse was divided into 4 sections of different levels of irradiance: 10, 35, 50 or 100% full sun as determined by the 3-Sensor Quantum Light Meter Model BQM (Minolta, Inc.). For each of the 4 species, 6 replications were randomly placed in each of the four greenhouse shade levels. A CRD statistical design was used. Leaves for analysis were selected under the same guidelines as in experiment 2 and 3. The chlorophyll levels of the leaves were measured using the Minolta SPAD-502. The P_{max} of the same leaf at a daily PPFD of 1,500 µmol $m^{-2}s^{-1}$ was then analyzed using the LI-6400 system.

After a 6-week period, chlorophyll levels were again measured. P_{max} was also measured and compared to the previous measurements.

Experiment 5: Photosynthetic changes in *Bambusa vulgaris* 'Wamin' after chemical acclimatization.

Bambusa vulgaris 'Wamin' was selected for this experiment based on results of the previous four experiments and the popular use of this species as an ornamental plant. Thirty pots with 3 culm divisions per pot were acquired in June, 2006 from a local nursery. All culm divisions measured between 2-4 cm in diameter and 40 – 60 cm in height. All plants were repotted in a mixture of 50% topsoil and 50% coconut coir. Between 3 and 4 centimeters of gravel were placed in the bottom of each 11 liter, black, plastic pot to improve drainage. Each plant was fertilized once at the time of potting with 5 grams of 14-14-14 controlled-release fertilizer and watered thrice weekly. All specimens were grown under full light for 3 months prior to experiment.

Twenty pots were treated using the drench method with 1,000 ml of paclobutrazol solution at the concentration of either 225 or 450 ppm. Ten plants were used as the control. Plants were arranged in compliance with the CRD statistical design. The greenhouse light levels were reduced to 10% full sunlight. The chlorophyll levels of selected leaves, chosen as in previous experiments, were measured using the Minolta SPAD-502. The chlorophyll measurements were recorded at 2-week intervals over a 10-week period from September 1st until November 10th, 2006. Measurements were then compared for changes.

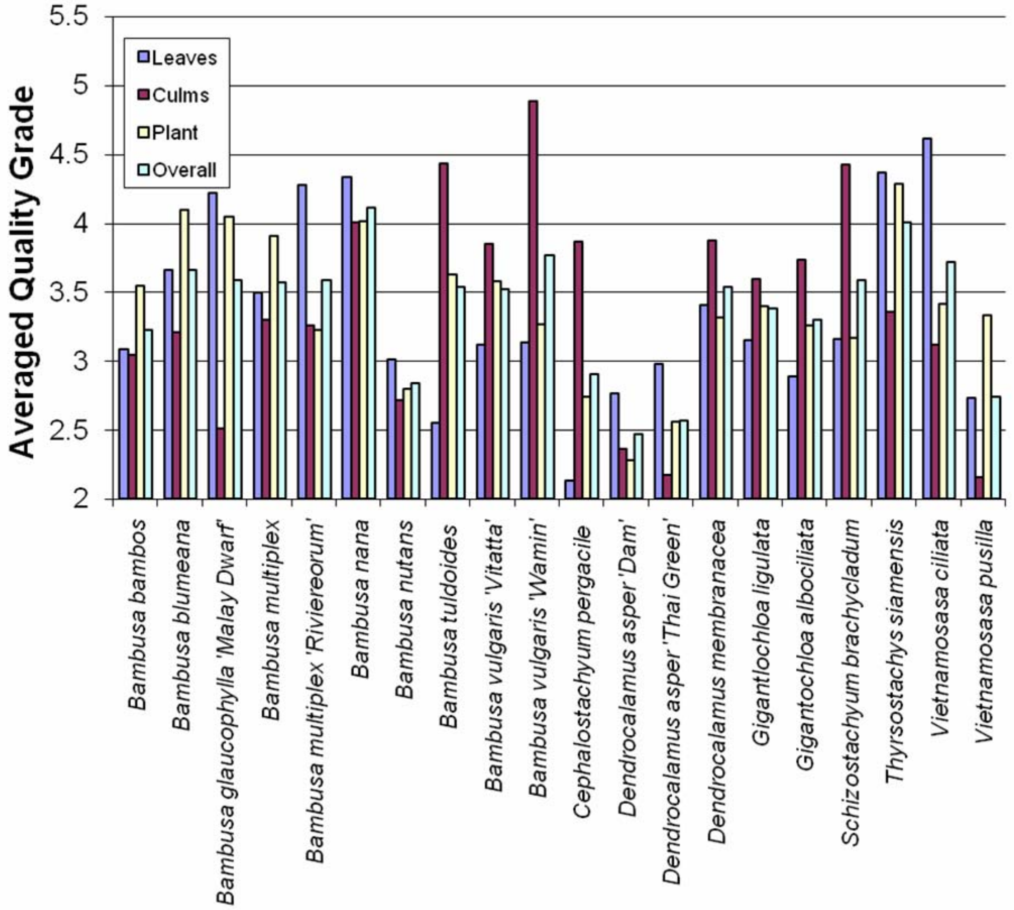


Figure 5 Average Quality Grade of 20 *Bambuseae* accessions.

Five accessions tested received an AQG foliage score of greater than 4.0. All of these exhibited fine textured foliage and full canopies. *V. ciliata* received the highest ranking of 4.62 due to its numerous thin, long leaves. *B. multiplex* 'Riviereorum' (4.28), *B. nana* (4.37) and *T. siamensis* (4.34) all had fine textured leaves slightly shorter and wider than *V. ciliata. B. glaucophylla* 'Malay Dwarf' scored 5th with an AQG foliage score of 4.28 due to its attractive, variegated leaves. Its leaves are slightly coarser than the higher ranking species.

The 3 highest AQG scores for culm quality were *B. vulgaris* 'Wamin' (4.89), *S. Brachycladum* (4.43) and *B. tuldoides* (4.44). Culms are very different on all three of these species. *B. vulgaris* 'Wamin' scored highest due to its unusually swollen internodes. This species is widely propagated for this feature. *S. brachycladum* scored high due to its golden culms with long, smooth internodes. *B. tuldoides* had strong, smooth dark green culms with very few blemishes.

Four accessions scored an AQG above 4.0. *T. siamensis* scored highest (4.29) due to its uniform culms, thick round canopy and tendency of leaves and branching to be close to the plant top and sparse on the lower culm. *B. nana* and *B. glaucophylla* (4.01 and 4.02 respectively) also exhibited branches and leaves close to the culm top forming a thick and compact plant. *B. blumeana* (4.1) exhibited bushy growth as well with a solid culm at the base. All of these forms seemed to have been influenced by pruning and cultivation techniques used prior to acquisition of the plants. These results emphasize the importance of proper pruning and care to maintain plant quality over the long term.

Five accessions tested received a total AQG below 3.0. An AQG rating below 3.0 indicates the plant does not have sufficient qualities to make it suitable for ornamental purposes. *Dendrocalamus asper* 'Dam' and *Dendrocalamus asper* 'Thai Green' scored the lowest at AQG's of 2.47 and 2.57 respectively. Coarse leaves and dull, unattractive culms did not improve when grown under greenhouse conditions. These two cultivars' poor performance is most likely due to the limited space allowed in each pot under the experiment parameters. As a large bamboo, rhizomes require a greater area for healthy growth. These results reflect the findings of Dransfield and Widjaja (1995) who explained that mature *D. asper* needs a minimum spacing of 5 meters between plants for proper growth. *Vietnamosasa pusilla* ranked 18th with an AQG of 2.74. This species shed leaves frequently and produced no new shoots. Dransfield (2000a) described this species as having an exceptionally deep rooting system. This allows it to survive drought and fire (Dransfield, 1997). However, the depth of the root system is limited by pot depth in this experiment. *Bambusa nutans* was 17th with an AQG of 2.84. This species had large, coarse leaves and unattractive culms. *Cephalostachyum pergracile* ranked 16th with 2.91. Although *Cephalostachyum pergracile* showed attractive culms, the persistent culm leaves and large coarse foliage caused it to receive a low mark.

The majority of tested accessions received a moderate AQG between 3.0 and 3.7. Several of these medium quality species; *Bambusa glaucophylla* 'Malay Dwarf', *Bambusa multiplex, Bambusa multiplex* 'Riviereorum', *Bambusa vulgaris* 'Wamin', *Bambusa vulgaris* 'Vittata' and *Schizostachyum brachycladum*; are internationally available and grown for ornamental purposes (Dart, 1997). *Bambusa bambos, Bambusa tuldoides, Dendrocalamus membranacea, Gigantochloa albociliata,* and *Gigantochloa ligulata* are primarily grown for shoot and culm production (Dransfield and Widjaja, 1995).

Four of the tested accessions received AQG's greater than 3.7. *Bambusa nana* received the highest AQG of 4.12 due to its fine foliage and smooth, attractive culms. *Thyrsostachys siamensis* received the second highest AQG of 4.01. It also exhibited fine foliage but received lower marks based on unattractive, persistant culm leaves. *Bambusa vulgaris* 'Wamin' received the third highest AQG of 3.77. 'Wamin' received this high grade in spite of its rather large, coarse leaves due to its attractive and unusually swollen culm internodes. *Vietnamosasa ciliata* received the fourth highest AQG of 3.72 due in large part to its fine, weeping foliage.

Bambusa nana, *Thyrsostachys siamensis* and *Vietnamosasa ciliata* are endemic to Thailand (Dransfield and Widjaja, 1995). *Bambusa nana* and *Thyrsostachys siamensis* are known and used as ornamentals locally (Pattanawiboon *et al*., 2001). They are not, however, widely known outside the country. *Bambusa vulgaris* 'Wamin' is an ornamental endemic to China and grown throughout America, Asia, and Europe as an ornamental (Ohrnberger, 1999). *Vietnamosasa ciliata* is not currently being used as an ornamental.

In Henley and Poole's 1987 assessment of bamboos for interior use, only 1 species, *Bambusa vulgaris* 'Vittata' was common to our experiment. They found that the accessions tested of the *Bambusa* genus were able to survive hot conditions better (more vigor) than the other accessions tested. They also found no statistically significant difference in the quality grade scores between plants grown in full sun and those grown under 47% full sun.

Several factors determine which plants can be used as ornamentals indoors. One of the greatest limiting factors for indoor use is light. Light conditions indoors usually fall below PAR values of 25 $\mu mol\ m^{-2}\ s^{-1}$ or less than 1% full sunlight. All accessions were also graded based on potential maximum height at maturity (Table 3, Figure 6). Although the plants in this experiment had heights that did not change, long-term height may be important in choosing bamboo plants most desirable for varying growth areas (Henley and Poole, 1987). Height is one of the major deciding factors when determining horticultural value for indoor plants (Rice and Rice, 2003).

Table 3 Average maximum height (cm) at maturity of 20 *Bambuseae* accessions**.**

	Scientific Name	Minimum	Maximum
1	*Bambusa bambos*	2000	3000
2	*Bambusa blumeana*	1500	2000
3	*Bambusa glaucophylla* 'Malay Dwarf'	300	500
4	*Bambusa multiplex*	200	400
6	*Bambusa multiplex* 'Riviereorum'	100	250
5	*Bambusa nana*	800	1800
7	*Bambusa nutans*	600	1200
8	*Bambusa tuldoides*	700	1500
9	*Bambusa vulgaris* 'Vitatta'	1000	1500
10	*Bambusa vulgaris* 'Wamin'	200	500
11	*Cephalostachyum pergracile*	1000	1200
12	*Dendrocalamus asper* 'Dam'	2000	3000
13	*Dendrocalamus asper* 'Thai Green'	2000	3000
14	*Dendrocalamus membranacea*	2000	2500
15	*Gigantochloa albociliata*	600	1000
16	*Gigantochloa ligulata*	600	900
17	*Schizostachyum brachycladum*	1000	1500
18	*Thyrsostachys siamensis*	800	1400
19	*Vietnamosasa ciliata*	100	250
20	*Vietnamosasa pusilla*	50	150

Source: Ohrnberger (1999).

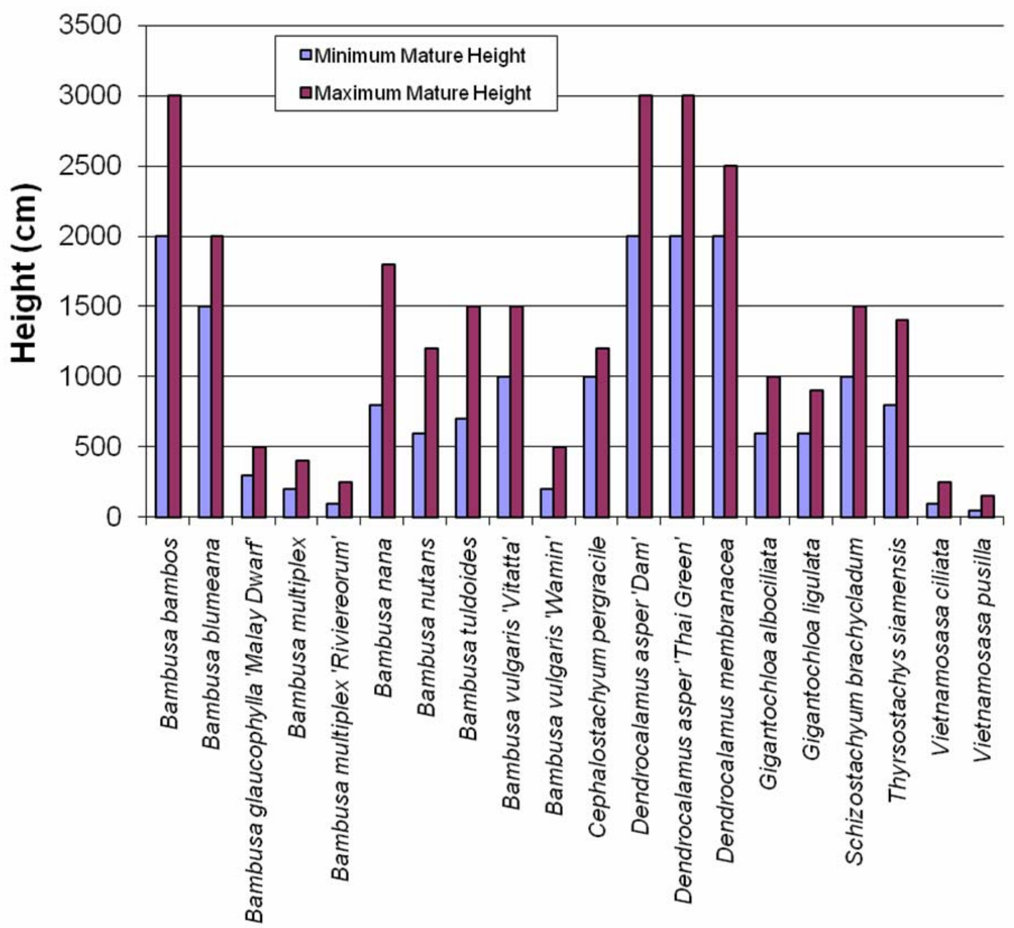


Figure 6 Average minimum and maximum heights of *Bamuseae* species tested (Ohrnberger 1999).

Experiment 2: Changes in chlorophyll content and commercial quality under low light levels in 16 *Bambuseae* species.

Chlorophyll content can effectively be used to measure plant health and quality. Changes in chlorophyll content can be used to determine overall plant health (Piekielek *et al*., 1995) as well as measure environmental stress (Vallardares and Pearcy, 1997). Chlorophyll content has been shown to be an accurate measure of plant response to the stress of decreased light levels (Martinez and Guimet, 2003). Chlorophyll content has been found to positively correspond with several other factors. The most significant of these factors are respiration (Earl and Tollenaar, 1997) and nitrogen content (Vidal *et al.,* 1999). To reduce any chlorophyll measurement variance due to these factors, all plants were grown in the same greenhouse with controlled release fertilizer and potted in the same soil mixture. However, Martinez and Guiamet (2003) found that chlorophyll measurements using the SPAD may have some small variance due to leaf water content and water stress. To negate variance due to water stress, all plants were watered during early morning hours and SPAD measurements were taken between 9:00am and 12:00pm. To further minimize variance, leaves between 3 and 4 months old for each replication were marked, chlorophyll content measured 5 times and the average reading was taken.

Changes in chlorophyll content can be used to determine overall plant health (Piekielek *et al*., 1995) as well as to indicate environmental stress (Vallardares and Pearcy, 1997). Most of the 19 accessions of *Bambuseae* showed no significant change in the average chlorophyll content during the 6 weeks while under reduced light levels (Table 4). Eleven accessions were found to show no significant change in chlorophyll content (*Vietnamosasa pusilla* (0.93), *Dendrocalamus membranacea* (0.42), *Bambusa multiplex* 'Riviereorum' (0.05), *Thyrsostachys siamensis* (-0.02), *Schizostachyum brachycladum* (-0.06), *Bambusa multiplex* (-0.20), *Gigantochloa albociliata* (-0.34), *Bambusa vulgaris* 'Vittata’ (-0.59), *Bambusa blumeana* (-0.74), *Dendrocalamus asper* 'Thai Green' (-0.76) and *Gigantochloa ligulata* (-1.31) (Table 5). This was expected as it is believed that *Bambuseae* evolved as a forest grass able to tolerate both partial and full light levels (Bystriakova *et al.,* 2003).

Three accessions showed a significant decrease in chlorophyll content after a 6 week period under the 10% sunlight (Table 5). *Bambusa nana* showed the greatest decrease in chlorophyll with a decrease of 3.34 SPAD units. *B. nana* in native to Thailand and grows in areas where it often receives full sunlight. This species is often confused with *B. multiplex* due to its fine leaves and ease of propagation. The chlorophyll content of *Bambusa nutans* decreased 2.79 SPAD units. *B. nutans* is a medium size bamboo often found in light gaps in the forest (Pattanawiboon, 2001). The chlorophyll content of *Dendrocalamus asper* 'Dam' decreased 2.54 SPAD units. *D. asper* 'Dam' is known only in cultivation where it is grown in full sun. This decrease in chlorophyll is a typical response of plants adapted to full sunlight. Lower chlorophyll in sun loving plants reflects a decrease in plant health and photosynthesis in response to decreased light levels.

Vietnamosasa ciliata was the only species to show a highly significant increase in chlorophyll at 10% light levels with an average chlorophyll content increase of 9.48 SPAD units. This increase in chlorophyll indicates an overall increase in plant health and ability for P_n at lower light levels. While *V. ciliata* can sometimes be found growing in the open (Hacker *et al.*, 1996), it is most commonly found as an understory plant in dipterocarp forests (Dransfield, 1997). Its ability to adapt to low light levels is a characteristic most likely evolved for survival in this low light level environment. This result has been seen in other small bamboos (height < 3 meters) which survive in a forest understory (Saitoh *et al.*, 2002).

Four accessions showed a significant (95% confidence) increase in chlorophyll after the 6 week treatment of 10% light with a calculated t-test greater than the tabular t-test of 1.701. *Cephalostachyum pergracile* showed a significant increase of 5.02 in SPAD measured chlorophyll. As a medium sized species, it is often found in mixed and deciduous forests with limited light (Duriyaprapan and Jansen, 1997). Chlorophyll in *Bambusa glaucophylla* 'Malay Dwarf' significantly increased 4.15 points. 'Malay Dwarf' is a small, variegated species only known in cultivation and commonly grown as an ornamental (Ohrnberger, 1999). Chlorophyll content of *Bambusa vulgaris* 'Wamin' increased 3.26 SPAD units and *Bambusa bambos* increased 2.70 SPAD units respectively. *B. vulgaris* 'Wamin' is only known in cultivation and is often grown in low light conditions as an ornamental (Dransfield and Widjaja, 1995). *B. bambos* was the only large species (25m+) that chlorophyll increased under the treatment. It is typically a dominant plant in the landscape and not usually found under low light conditions. This increase in chlorophyll may indicate an ability to adapt to a wide range of light conditions. This might partially explain why *B. bambos* is one of the most widely distributed species in the world (Ohrnberger, 1999). These results are summarized in Table 5 and Figure 7.

Table 4 Chlorophyll levels of *Bambuseae* species after 6 weeks at 10% light levels.

Scientific Name		Average SPAD Units			
		Before	After	Change	t-test
1	*Bambusa bambos*	38.78	41.48	2.70	*
2	*Bambusa blumeana*	39.64	38.90	-0.74	ns
3	*Bambusa glaucophylla* 'Malay Dwarf'	25.88	30.03	4.15	*
4	*Bambusa multiplex*	39.66	39.46	-0.20	ns
5	*Bambusa multiplex* 'Riviereorum'	42.23	42.28	0.05	ns
6	*Bambusa nutans*	38.01	35.22	-2.79	*
7	*Bambusa nana*	41.94	38.60	-3.34	*
8	*Bambusa vulgaris* 'Vittata'	41.97	41.38	-0.59	ns
9	*Bambusa vulgaris* 'Wamin'	39.27	42.53	3.26	*
10	*Cephalostachyum pergacile*	30.41	35.43	5.02	*
11	*Dendrocalamus asper* 'Dam'	42.13	39.68	-2.45	*
12	*Dendrocalamus asper* 'Thai Green'	43.19	42.43	-0.76	ns
13	*Dendrocalamus membranacea*	38.83	39.25	0.42	ns
14	*Gigantochloa albociliata*	32.24	31.90	-0.34	ns
15	*Gigantochloa ligulata*	35.76	34.45	-1.31	ns
16	*Schizostachyum brachycladum*	45.54	45.48	-0.06	ns
17	*Thyrsostachys siamensis*	36.66	36.64	-0.02	ns
18	*Vietnamosasa ciliata*	27.65	37.13	9.48	**
19	*Vietnamosasa pusilla*	35.02	35.95	0.93	ns

* = Significant at the 95th percentile; ** = Significant at the 99th percentile

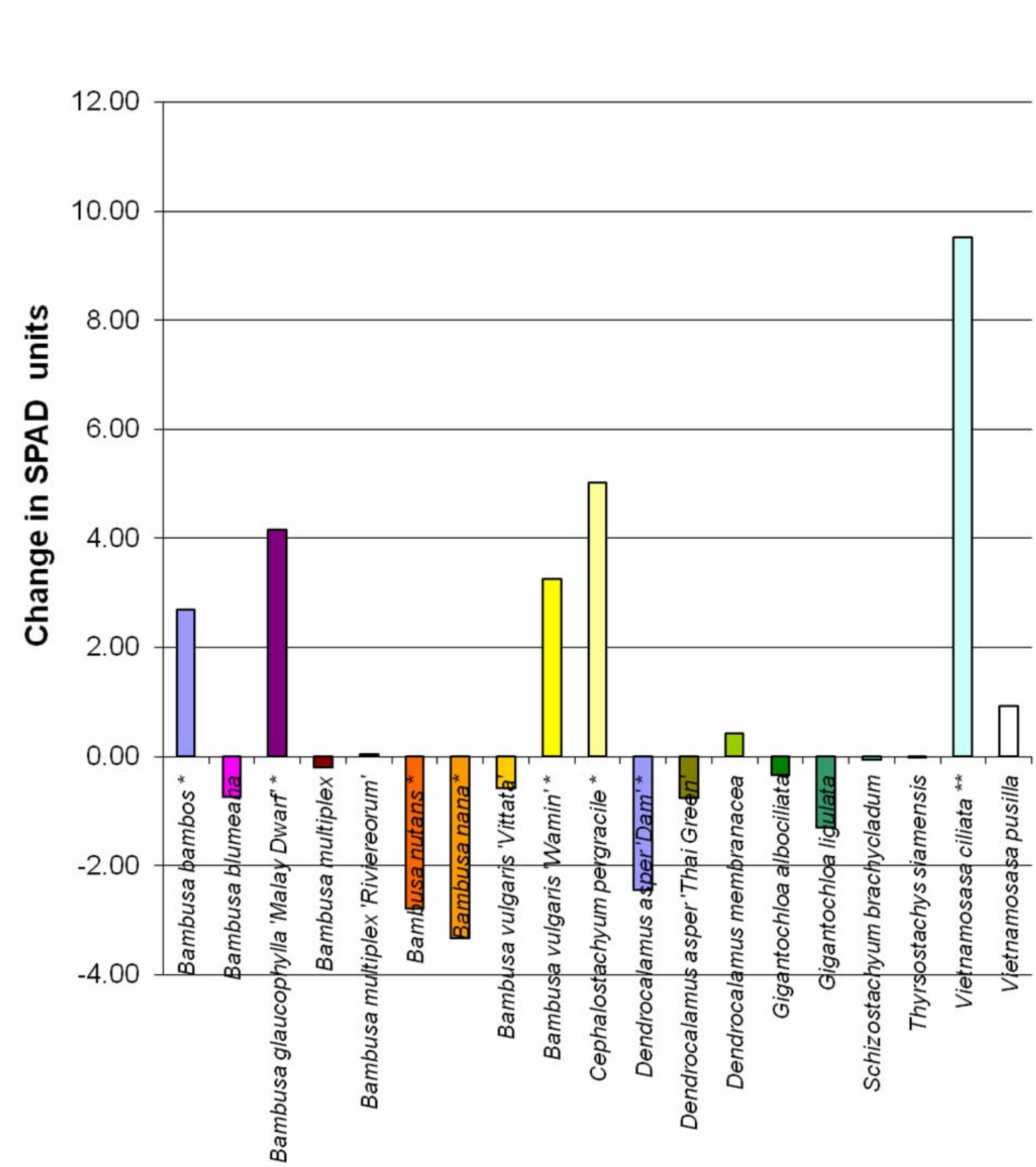


Figure 7 Change in chlorophyll content in 19 accessions of *Bamuseae* after 6 weeks under 10% sunlight.

The specimens were also rated on commercial quality (Table 6). These observations generally paralleled with the SPAD findings taken at the same time. The sole exception to the parallel findings was *Bambusa nana*. Although *B. nana* scored the lowest in chlorophyll change under the low light treatment, it ranked 4th in commercial quality. This may indicate the 6 week interval is not long enough to visually measure decreased plant health in *B. nana*. The highest quality was found in *Vietnamosasa ciliata*. Six other accessions showed an AQG greater than 3.0 after the 6 week treatment (*Dendrocalamus membranacea* 2nd, *Bambusa multiplex* 'Riviereorum' 3rd, *Thyrsostachys siamensis* 4th, *Bambusa vulgaris* 'Wamin' 5th and *Schizostachyum brachycladum* 6th). The remaining 13 accessions received AQG lower than 3.0 (Figure 8).

While all three plant qualities were weighted equally in this experiment, leaf quality is the quickest to deteriorate or improve when conditions change. It should be noted that culm quality in this experiment was similar for each species tested in the experiment 1. Culm quality can not be influenced by changing light levels over a short time period. Henley and Poole also found that culm quality remained largely unchanged over a short period of time (1987). It should also be noted that genotype can affect the ability to adapt to low light levels since the different accession of the same species performed differntly. Nutritional stress can also influence quality grade. Although all specimens were fertilized 3 months before the experiment with 3-month slow release fertilizer, additional fertilizer may insure that nutritional stress is not a factor.

Table 5 Average quality grade of *Bambuseae* species after 6 weeks at 10% light levels.

	Scientific Name	Average Qualities Grade			
		Foliage	**Culm**	**Plant**	**Average**
1	*Bambusa bambos*	3.00	2.46	2.69	2.72
2	*Bambusa blumeana*	2.50	2.29	2.43	2.41
3	*Bambusa glaucophylla 'Malay Dwarf'*	2.87	2.07	2.47	2.47
4	*Bambusa multiplex*	2.92	2.83	2.92	2.89
5	*Bambusa multiplex* 'Riviereorum'	3.50	3.57	3.43	3.50
6	*Bambusa nutans*	3.47	1.93	2.47	2.62
7	*Bambusa nana*	3.40	3.67	3.20	3.42
8	*Bambusa vulgaris 'Vittata'*	3.13	2.80	2.93	2.96
9	*Bambusa vulgaris* 'Wamin'	3.33	3.13	3.00	3.16
10	*Cephalostachyum pergracile*	1.93	1.93	1.89	1.92
11	*Dendrocalamus asper* 'Dam'	1.93	1.73	1.73	1.80
12	*Dendrocalamus asper* 'Thai Green'	2.80	2.20	2.33	2.44
13	*Dendrocalamus membranacea*	3.62	3.46	3.46	3.51
14	*Gigantochloa albociliata*	1.64	1.21	1.29	1.38
15	*Gigantochloa ligulata*	3.33	2.67	2.80	2.93
16	*Schizostachyum brachycladum*	3.25	3.23	2.92	3.13
17	*Thyrsostachys siamensis*	3.93	2.53	3.20	3.22
18	*Vietnamosasa ciliata*	4.11	3.33	3.89	3.78
19	*Vietnamosasa pusilla*	1.00	1.00	1.00	1.00

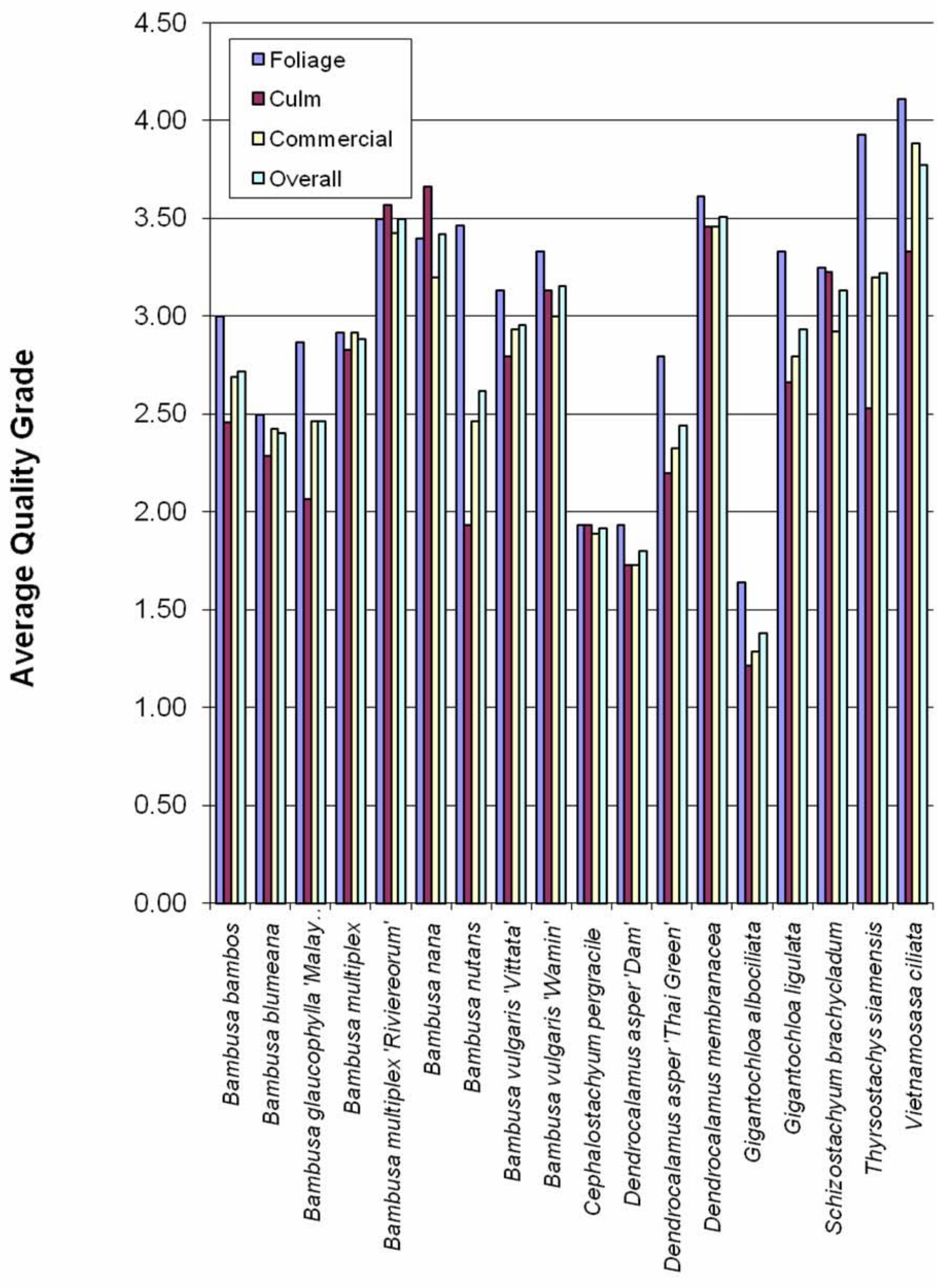


Figure 8 Average quality grade scores of 19 accessions of *Bamuseae* after 6 weeks under 10% sunlight.

Experiment 3: Photosynthetic changes in *Bambusa vulgaris* 'Wamin' after chemical acclimatization.

Young leaves of *Bambusa vulgaris* "Wamin" were analyzed for P_n at varying degrees of irradiance and a light response curve (LRC) was created. *Bambusa vulgaris* 'Wamin' was selected because it was in the top 5 AQG ranking in experiments 1 and 2, was in the top 5 chlorophyll increase under shade in experiment 2 and because of its wide use as an ornamental plant. The light saturation point (LSP), previously calculated while forming the LRC, was used to calculate changes to P_n before and after paclobutrazol treatment. Changes in chlorophyll content were also recorded.

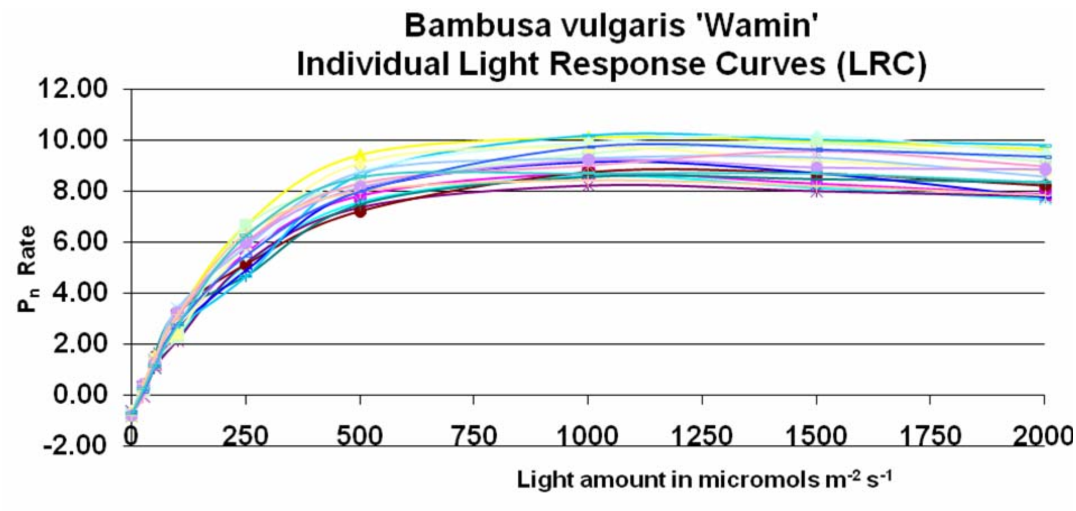
This experiment first required calculating P_n and leaf respiration. Calculating P_n of a leaf is a difficult task (Zeinalov, 2005). Humidity, temperature, season, leaf age, nitrogen levels and atmospheric change of CO can affect results make extrapolating information from other experiments difficult (Smirniotaki, 2006). Kikuzawa *et al.* (2004) found that several additional factors affect the total daily photosynthesis: Diel Effect (changes in clear-day solar radiation), Depression Effect (daily plant flux in photosynthesis), Shading Effect (light limited by other leaves and structures), Cloudy Effect (changes in solar radiation due to varying cloud coverage) and Inclination Effect (leaf angle and position in canopy).

Several measures were taken in order to limit these factors. All specimens received a single application of a 3 month controlled release fertilizer and were potted in the same soil mixture 4 months prior to the experiment. Plants were watered early morning, 1 hour before measurements were taken to prevent erroneous readings due to water stress. Measurements were taken daily from 9:00 am and 12:00 pm before temperature and irradiance peaked. The LI- 6400 system was calibrated daily, CO_2 and H_2O were scrubbed with soda lime and Dry Rite and measurements were matched frequently to adjust for changes.

The analyzed leaves were also selected to limit factors influencing P_n. Kitajima *et al.* (1997) showed that P_n in tropical plants declined significantly with age. Research published in 1986 by Huang, however, showed that *Bambuseae* leaves under 1 year old had a much higher P_n than leaves older than 1 year. Qui (1992) later confirmed that younger *Bambuseae* leaves had up to 3 times P_n than that of older leaves. These results were attributed to both a higher nutrient and higher metabolic rate in the younger leaves.

An LRC for tropical bamboo was first established by using 3-4 month old leaves of 18 replications of *Bambusa vulgaris* 'Wamin.' PAR values were recorded at 0, 25, 50, 100, 250, 500, 1000, 1500, 2000 μmol m^{-2} s^{-1} using the LI-6400 system. These results were analyzed and P_n at light level values were plotted to reveal the shape of the average LRC. The LRC exhibited the expected trajectory of a typical C-3 plant curve with a steep, linear increase at lower light levels followed by a gradual decrease in photosynthesis per μmol m^{-2} s^{-1} until LSP is reached. Average and individual results are shown in Figure 9.

Early research has shown that under low irradiance, the LRC is linear (Pessarakli, 2005). Furthermore Zeinalov (2005) explained that, while there are some exceptions, the regression line was most accurate at interpreting the x value at the y intercept when only the lowest measurements are analyzed. The results from all replications were analyzed to find the X-axis intecerpt or LCP (Figure 10). P_n was always positive when PAR equaled 50μmol m^{-2} s^{-1}. The average P_n when PAR equaled 25μmol m^{-2} s^{-1} was 0.27μmol CO_2 m^{-2} s^{-1}. The P_n when PAR equaled 0.00 μmol m^{-2} s^{-1} averaged a -0.71 μmol CO_2 m^{-2} s^{-1}. When the regression line was calculated, the y intercept (the point of 0 irradiance) showed -0.64μmol CO_2 m^{-2} s^{-1} with a positive slope of 0.0361(Figure 10). The regression line value for the LCP calculated to 17.7 μmol m^{-2} s^{-1} which is remarkably low and reflects the ability of *Bambuisa vulgaris* 'Wamin' to survive in very low light levels. The regression line equation for PAR values between 0 and 100 μmol m^{-2} s^{-1} is $y= -0.6396 + 0.0361x$ (Appendix Table 1). According to Conover *et al* (1989) this range is well within the range of most indoor, foliage plants.



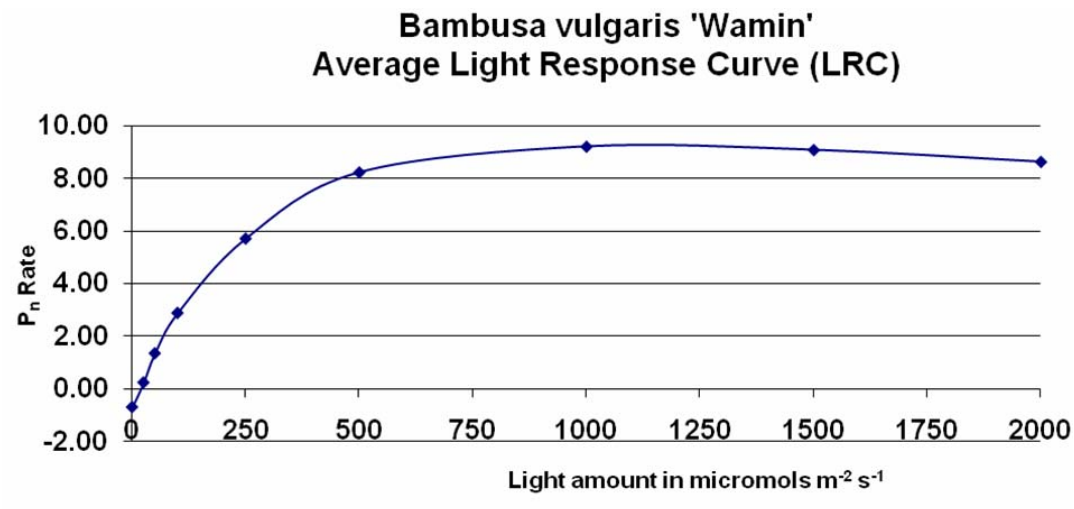


Figure 9 Individual and average light response curves of *Bambusa vulgaris* 'Wamin'.

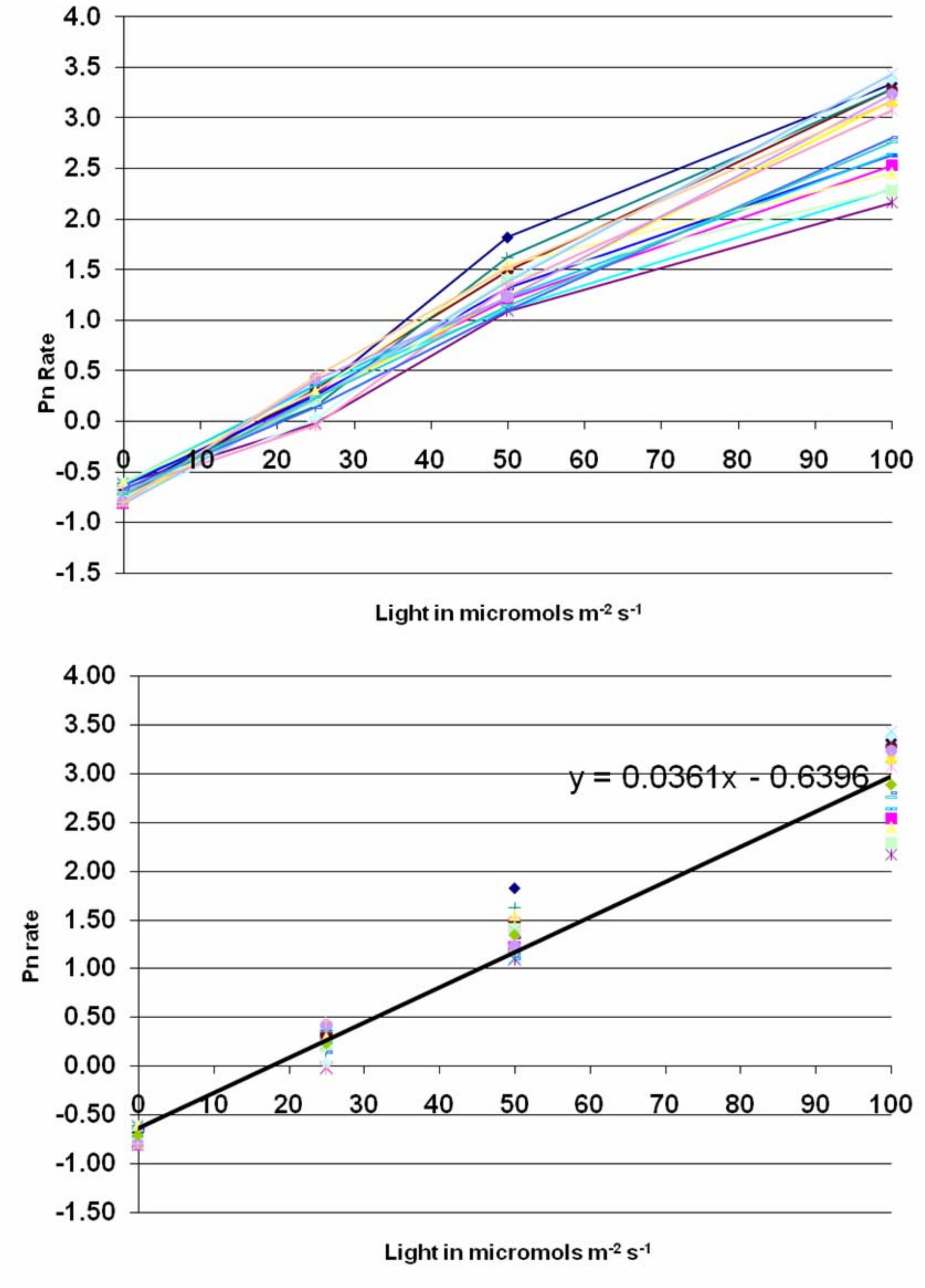
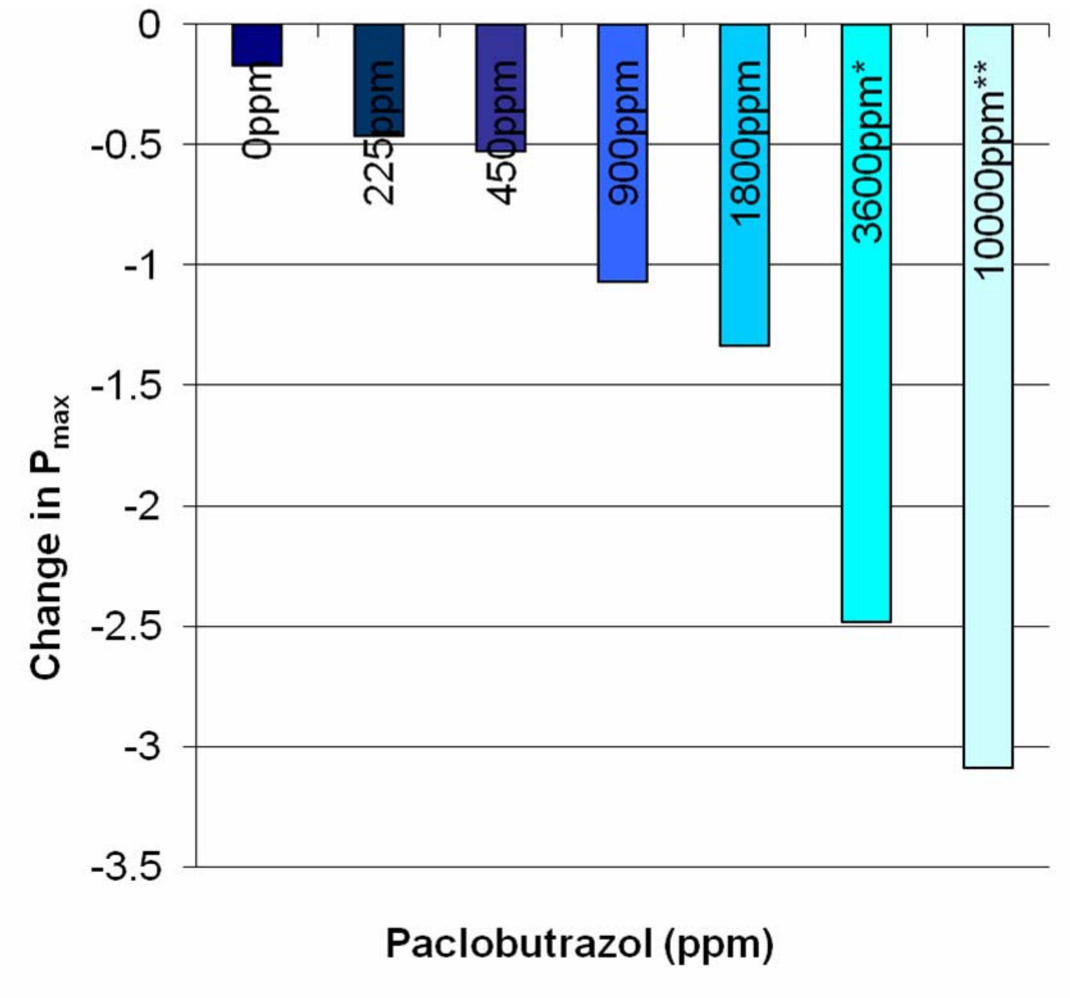


Figure 10 Actual and regression line readings for P_n at low light levels in *Bambusa vulgaris* 'Wamin'.

The results from calculating LSP showed that 3 to 4-month old leaves of *Bambusa vulgaris* 'Wamin' reached maximum utilization of irradiance after 1000µmol m^{-2} s^{-1} and remained unchanged at 1500µmol m^{-2} s^{-1} (Table 7). The average P_n at the LSP was 9.31 µmol CO_2 m^{-2} s^{-1}. It was interesting to note that at the highest level tested, 2000µmol m^{-2} s^{-1}, there was a drop in P_n rates. This was most likely caused by photoinhibition from the excess irradiance at high levels.

An LSP of 1200µmol m^{-2} s^{-1} was experienced by Kleinhenz and Midmore (2001) in similar tests on some temperate, monopodial *Bambuseae* species. However, the leaves of most temperate monopodial species have a 2 year life cycle while leaves of tropical sympodial species have an average life cycle of 6 years or more (Shammughavel *et al*, 1997; Kleinhenz and Midmore, 2001). This difference in lifecycles lead Kleinhenz and Midmore to predict that P_n rates in leaves of tropical sympodial bamboos would exceed their results as well as the similar results obtained by Koyama and Uchimura (1995) on temperate, monopodial *Phyllostachys bambusoides*. This experiment showed that P_n rates in 3 to 4 month old leaves of tropical sympodial bamboos equaled that of temperate monopodial bamboos. Further research is needed to see if P_n rates in leaves of tropical sympodial bamboos exceed those in temperate monopodial bamboos over the lifetime of the leaf.

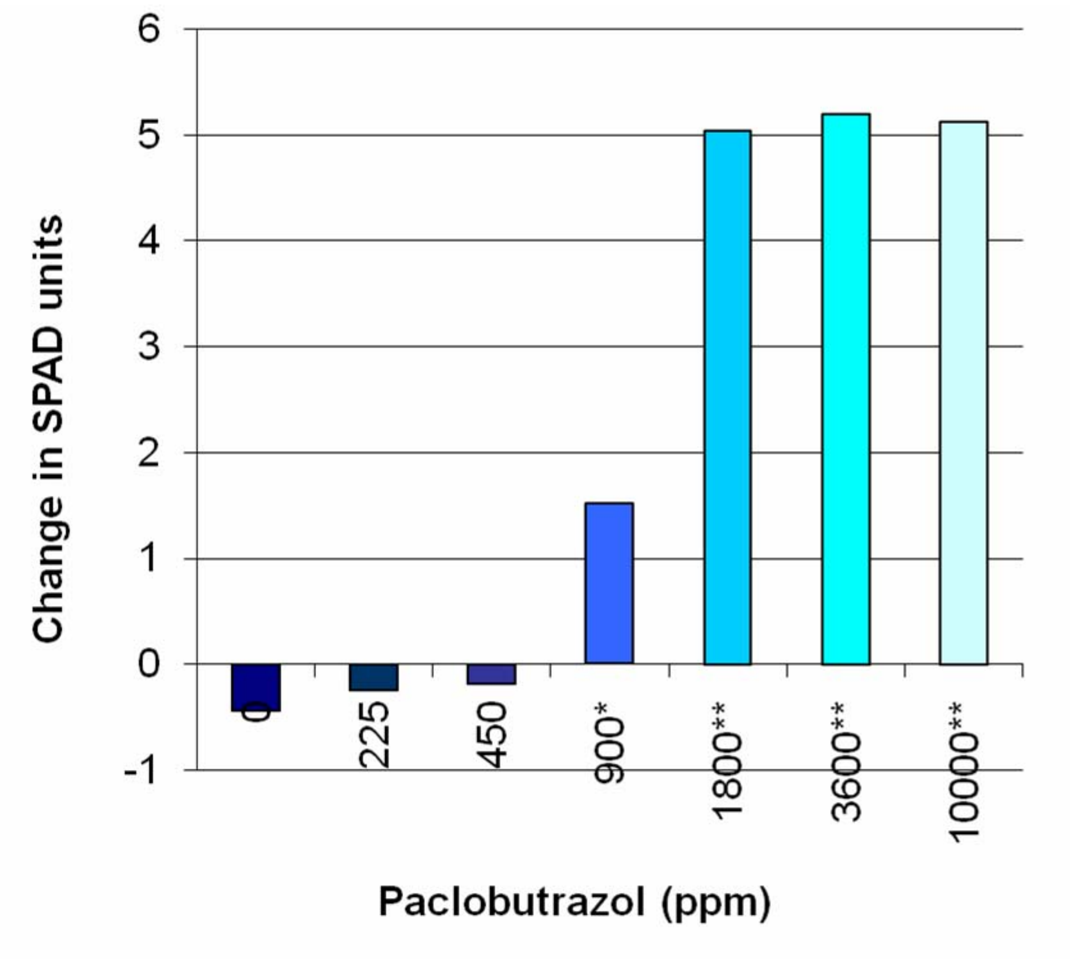
After measurements were taken for P_{max} at the LSP of 1500 µmol m^{-2} s^{-1} and for leaf chlorophyll content, the specimens were then placed randomly in the test plot and treated with paclobutrazol. Six weeks after the paclobutrazol drench, P_{max} and chlorophyll content were reevaluated. Statistical analysis revealed highly significant changes in P_{max}. A highly significant drop in P_{max} of 47% was measured from the treatment of 10,000ppm. A 37% decrease in P_{max} was recorded for treatment of 3,600 ppm which was significant. Treatment levels of 900 and 1,800 ppm paclobutrazol showed non-significant drops in P_{max} levels of 16% and 20% respectively. There were non-significant changes to the treatment levels of 225 and 450 ppm. Results are shown in Table 7 and Figure 11.



* = Significant at the 95th percentile; ** = Significant at the 99th percentile

Figure 11 Change in P_{max} in *Bambusa vulgaris* 'Wamin' 6 weeks after paclobutrazol treatment (1 liter per pot drench).

Changes in chlorophyll content were also recorded and compared. At the completion of 6 weeks there were no significant changes to chlorophyll content at the 225 and 450 ppm treatment levels. At 900 ppm there was a significant increase in chlorophyll levels. There were, however, highly significant increases at chlorophyll levels of 1,800, 3,600 and 10,000 ppm which showed increases of 5.033 (12.9%), 5.2 (13.8%) and 5.117 (13.2%) respectively (Table 7, Figure 12). The increase in chlorophyll levels at higher treatment levels was expected. Medina and Buenrostro (1995) showed that Paclobutrazol, while commonly used as a growth regulator, also increases chlorophyll content in leaves. However, this increase in chlorophyll is often accompanied by smaller leaves, decrease in vegetative growth and shoot elongation (Sankhla *et al.*, 1985; Zhou and Chi, 1993). Even so, the coefficient of variance was very high (49.3%) indicating these results are less reliable. Measuring results after a shorter interval (3 or 4 weeks) after treatment or increasing number of replications may reduce variance and give better results.



Note: c.v. = 48.9%; * = significant at the 95% level, ** = significant at 99% level.

Figure 12 Change in chlorophyll content in *Bambusa vulgaris* 'Wamin' 6 weeks after paclobutrazol treatment (1 liter per pot drench).

Table 7 *Bambusa vulgaris* 'Wamin' change in P_{max} and chlorophyll 6 weeks after paclobutrazol treatment.

Paclobutrazol (ppm)	0	225	450	900	1,800	3,600	10,000	F-test
P_{max}	-0.32[a]	-0.4[a]	-0.52[a]	-1.07[a]	-1.34[a]	-2.43[b]	-3.09[b]	*
Chlorophyll	-0.43[a]	-0.25[a]	-0.18[a]	1.52[b]	5.03[c]	5.2[c]	5.12[c]	**

*= significant at 95%, ** = significant at 99%

[a], [b], [c] = groups with no significant differences using the Duncan Multiple Range Test

Experiment 4: Photosynthetic changes in 4 species of *Bambuseae* under different light levels.

Bambusa vulgaris 'Wamin,' *Bambusa nana, Thyrsostachys siamensis* and *Vietnamosasa ciliata* were evaluated for ability to acclimatize to varying light levels. These 4 species were selected based on AQG scores as found in experiments 1 and 2. All replications were grown under full sun for 3 months prior to the experiment. Both P_{max} and chlorophyll content were then measured for all 24 replications from each species. Six replications of each species were placed in each of 4 light levels of 10, 35, 50 or 100% sunlight and randomly arranged in each treatment. After 6 weeks, P_{max} and chlorophyll content were re-evaluated and changes were recorded and analyzed using regression analysis.

Acclimatization to low light levels can occur when plants are cultivated under varying degrees of light. In 1975, Conover and Poole showed that *Ficus benjamina* plants cultivated under 60% to 80% light levels performed better under low light levels than like plants with no acclimatization. Joiner *et al*. (1977) later discovered that LCPs decrease as plants are cultivated under low light levels. Lower LCPs indicate a greater ability to survive under limited light (Steinkamp *et al*., 1991). It is also indicative of more efficient light-to-energy conversion.

However, LCP is not as reliable an indicator of plant health as other measures (Conover and Poole, 1989). As discussed in experiment 2, Piekielek *et al*. showed in 1995 that changes in chlorophyll content can be used accurately under controlled conditions to measure plant health. Both chlorophyll content and P_{max} were used to measure changes in all 4 species of *Bambuseae* used in this experiment.

Regression analysis showed a positive correlation between light levels and P_{max} changes for *B. nana, B. vulgaris* 'Wamin' and *T. siamensis*. *B. nana* showed a least squares regression line of $Y= -1.767 + 0.0181(x)$ with a Coefficient of Determination (r^2) of 0.789 (Figure 13). *B. vulgaris* 'Wamin' had a least squares regression line of $Y=-0.9727 + 0.015(x)$ with an r^2 of 0.562 (Figure 14). The regression line for *T. siamensis* was Y= -1.778 + 0.0188(x) with an r^2 of 0.412 (Figure 15).

P_{max} in *B. nana, B. vulgaris* 'Wamin' and *T. siamensis* were low under low light levels and increased as light levels increased. Decreases of 11.7% (-1.098 points), 13% (-1.227 points) and 15.8% (-1.483 points) respectively were found at the 10% light level. At the 35% light level, *B. nana* decreased 10.8% (-1.013 points), *B. vulgaris* 'Wamin' decreased only 1.8% (0.174 points) while *T. siamensis* decreased 16.9% (-1.592 points). P_{max} was mixed at 50% light with *B. nana* and *B. vulgaris* 'Wamin' increasing 5.6% (0.53 points) and 1.6% (0.152 points) respectively. *T. siamensis* still decreased slightly at 4.6% (-0.42 points). All 3 species had a slightly positive increase in the change in P_{max} of 4% (0.414 points), 3.1% (0.288 points) and 0.5% (0.045 points) at the 100% light level respectively.

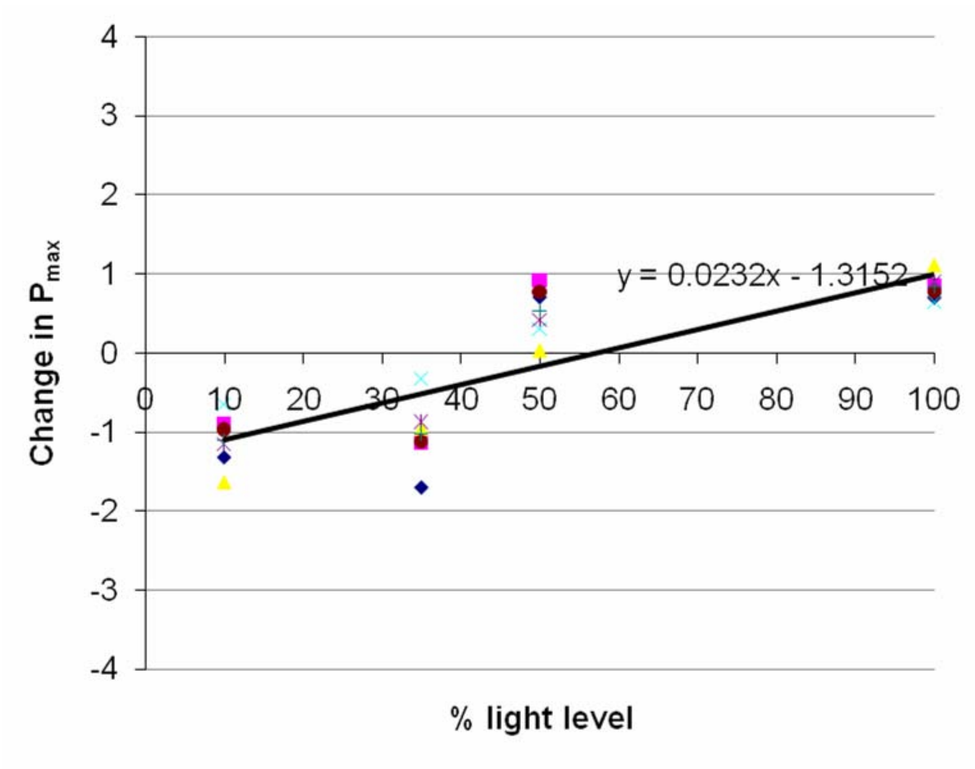


Figure 13 Regression line for change in P_{max} at increasing light levels for *Bambusa nana.*

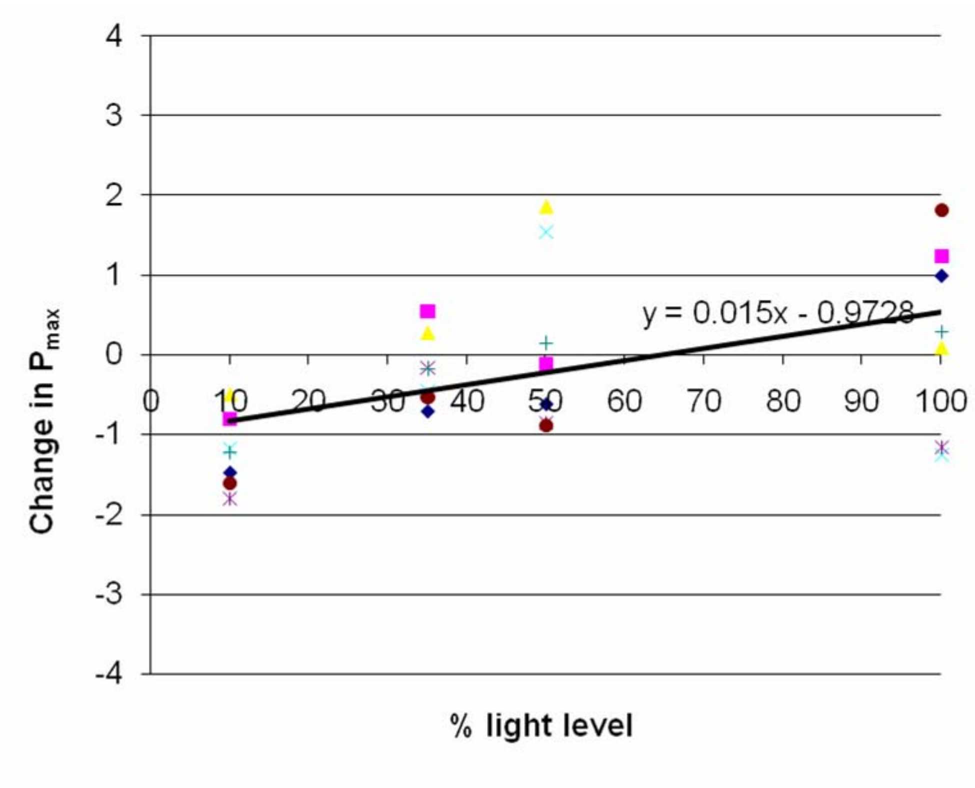


Figure 14 Regression line for change in P_{max} at increasing light levels for *Bambusa vulgaris* 'Wamin'.

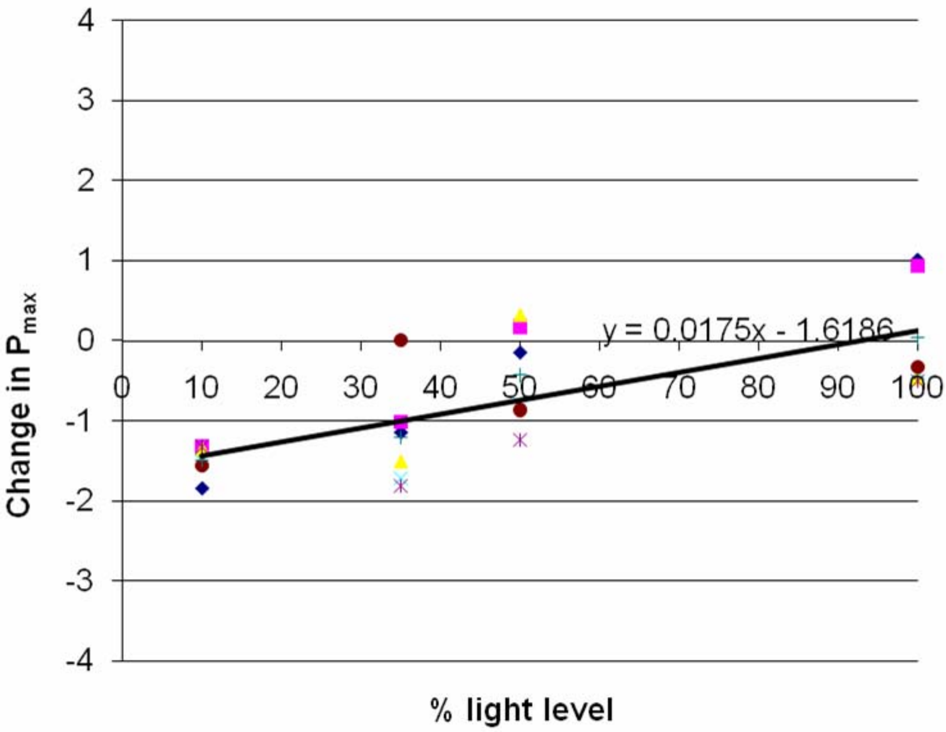


Figure 15 Regression line for change in P_{max} at increasing light levels for *Thyrsostachys siamensis.*

V. ciliata was the only species to exhibit a negative correlation between light amounts and changes in P_{max}. Regression analysis of changes in P_{max} produced a least squares regression line of Y= 3.440 - 0.0362(x) with an r^2 of 0.849 (Figure 16). At 10% light, *V. ciliata* showed an increase in P_{max} of 14% (1.323 points). An 8.6% (0.808points) increase was recorded at 35% light. A very small decrease of 0.7% (-0.065 points) was found at the 50% level. However, a large decrease in P_{max} of 20.4% (-1.92 points) was observed at the 100% light level. P_{max} results for all 4 species are found in Appendix Table 2 and summarized in Figure 17.

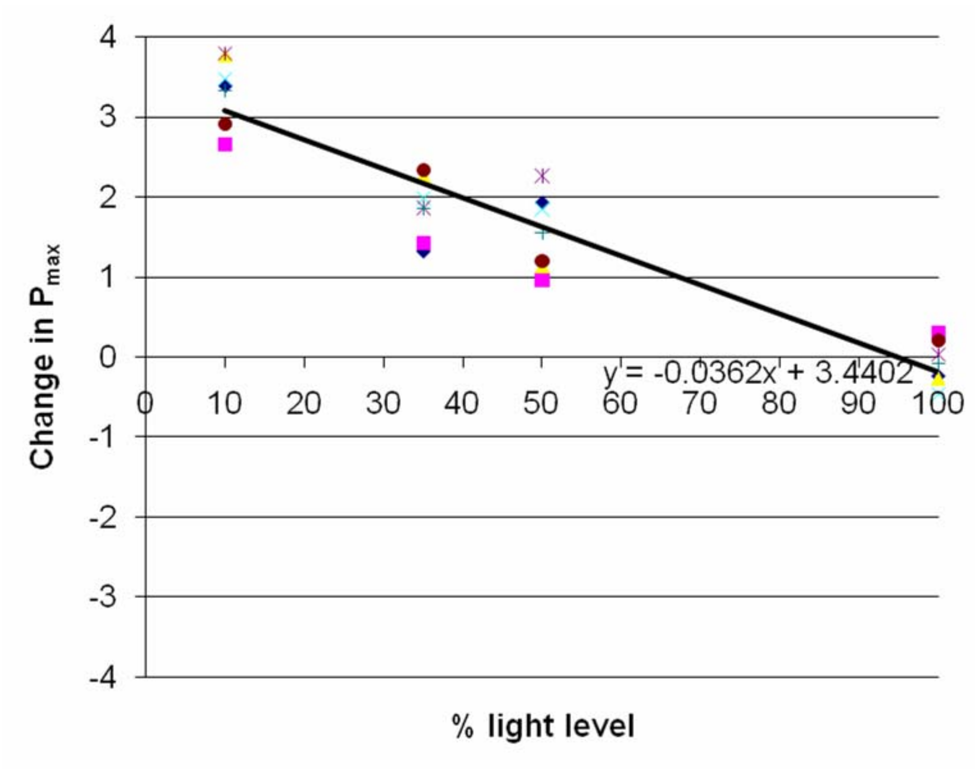


Figure 16 Regression line for change in P_{max} at increasing light levels for *Vietnamosasa ciliata.*

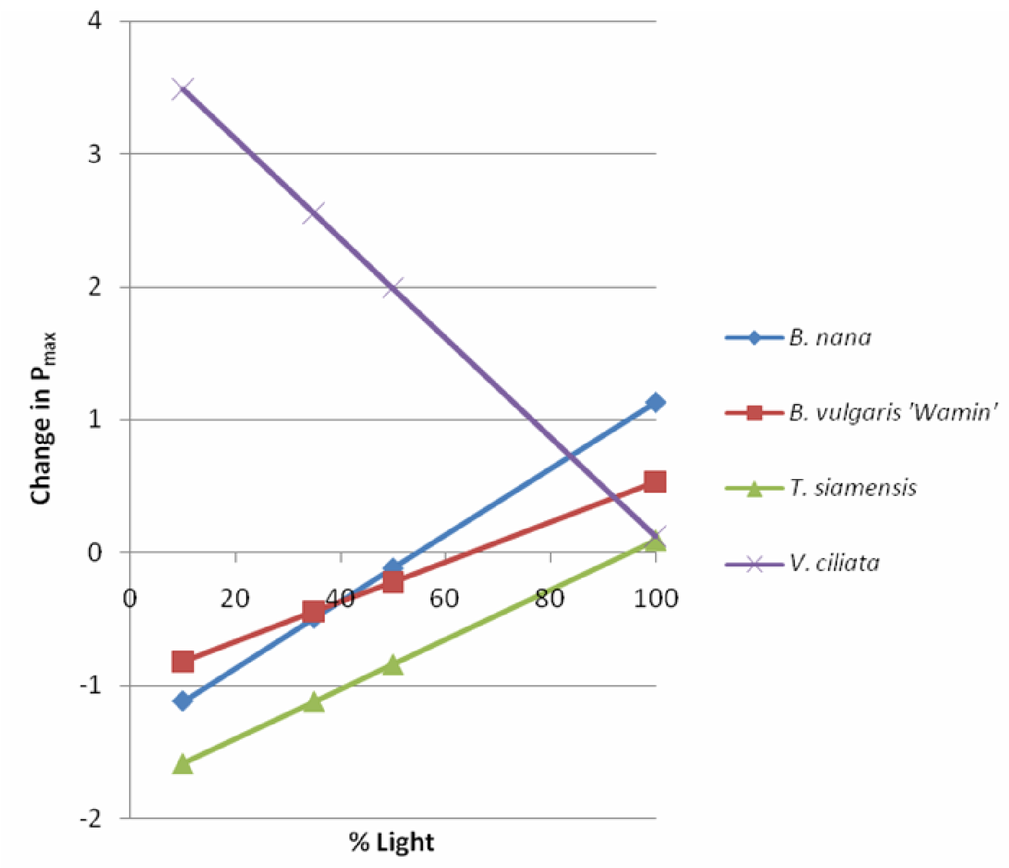


Figure 17 Comparison of regression lines for change in P_{max} at increasing light levels for 4 species of *Bambuseae.*

At 100% sunlight, P_{max} for all 4 species had very little change. Because all replications were grown for 3 months in full light levels prior to the experiment, it is expected that P_{max} would remain constant during the 6 weeks treatment for replications remaining at full light levels. *V. ciliata* showed a statistically significant, negative correlation between light amounts and chlorophyll levels. Regression analysis of chlorophyll amounts produced a least squares regression line of Y= 11.333 - 0.1191(x) with an r^2 of 0.767 (Figure 18). It exhibited a 14.8% (5.567 points) increase in chlorophyll at 10% light levels, a 0.5% (0.197 points) increase at 35% light levels, a 3.9% (-1.45 points) decrease at 50% and an 11.9% (-4.27) decrease at 100% (Appendix Table 3). Also showing a statistically significant decrease in chlorophyll as light levels increased was *B. vulgaris* 'Wamin.' It showed a least squares regression line of Y= 13.0601 - 0.1515(x) with an r^2 of 0.813 (Figure 19). At

10% light, it showed an average increase of 3.95 points or 10.5%. At 35% light it had a nominal, average increase of 1.133 points or 3%. At 50% and 100% light levels it showed a decreased chlorophyll content of -4.4% (-0.167) and -23% (-8.767) respectively (Appendix Table 3).

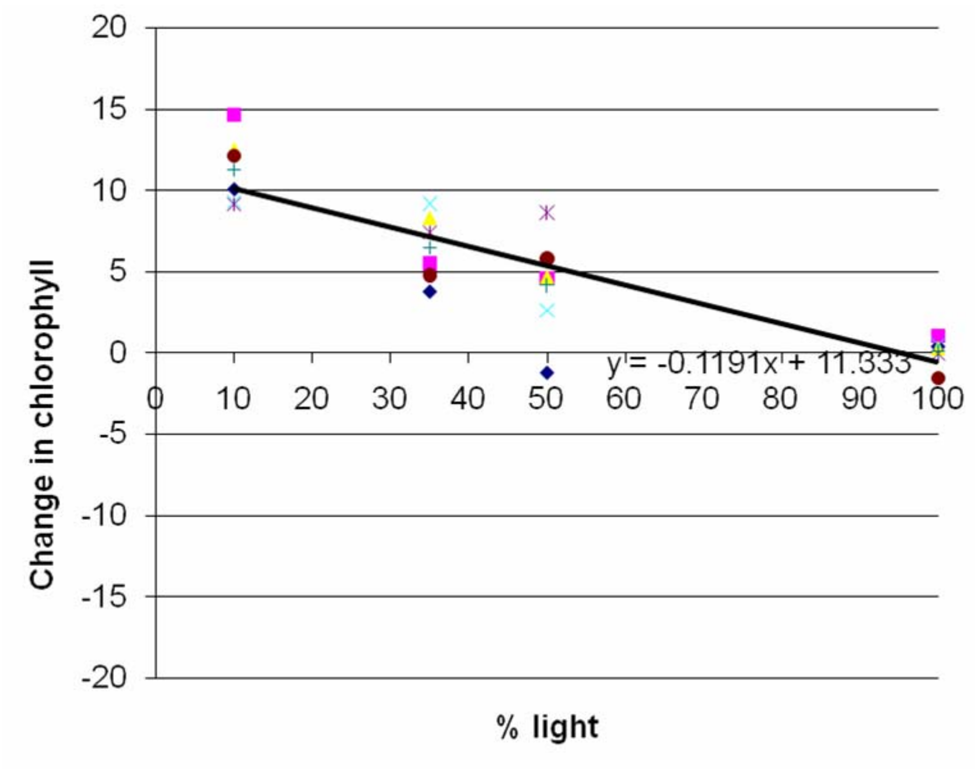


Figure 18 Regression line for change in chlorophyll content at increasing light levels for *Vietnamosasa ciliata***.**

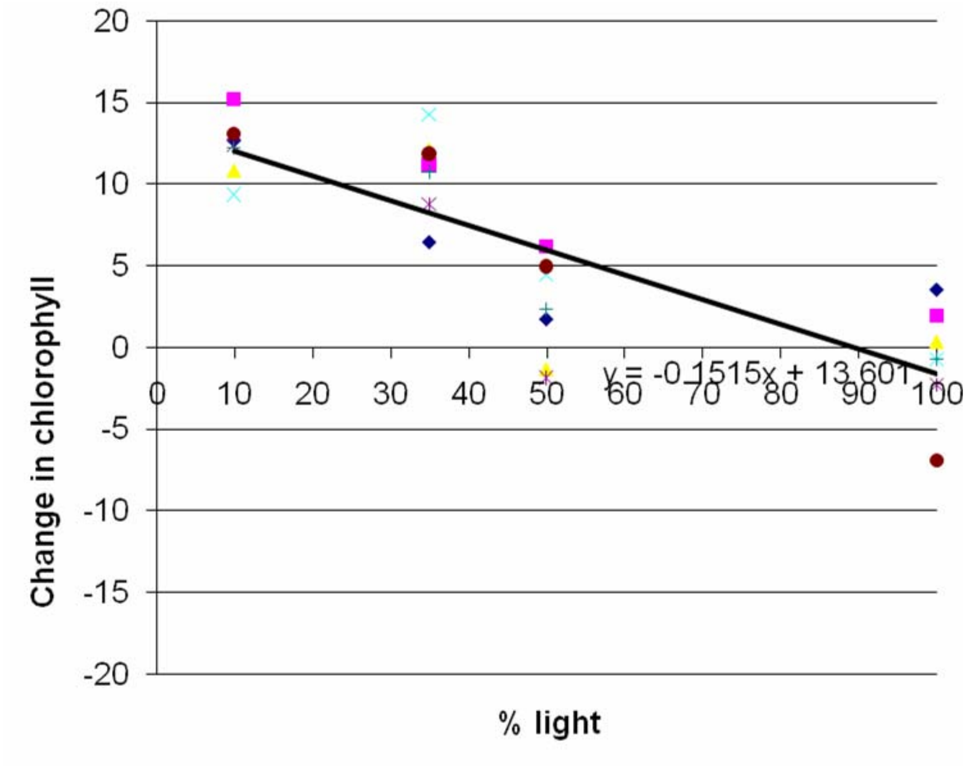


Figure 19 Regression line for change in chlorophyll content at increasing light levels for *Bambusa vulgaris* 'Wamin'.

The evaluation of the change in chlorophyll content after 6 weeks of light acclimatization in *B. nana* and *T. siamensis* followed the same pattern as seen previously in the analysis of P_{max}. *B. nana* showed a least squares regression line of Y= -11.679 + 0.1394(x) with an r^2 of 0.813 (Figure 20). The regression line for *T. siamensis* was Y= -11.873 + 0.1319(x) with an r^2 of 0.694 (Figure 21).

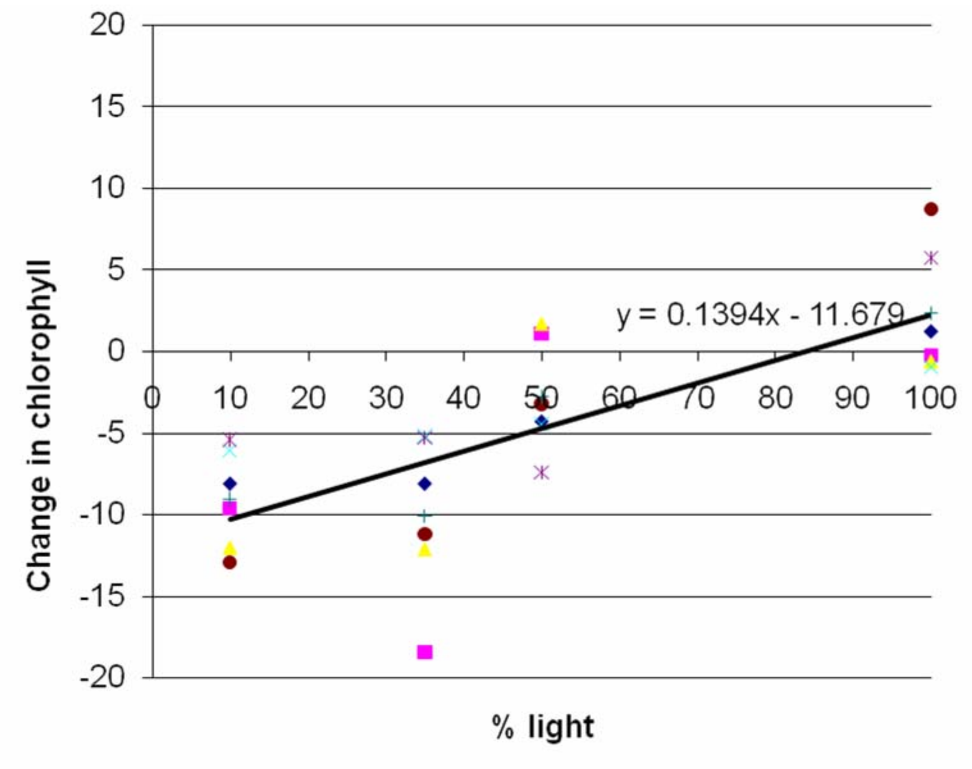


Figure 20 Regression line for change in chlorophyll content at increasing light levels for *Bambusa nana*.

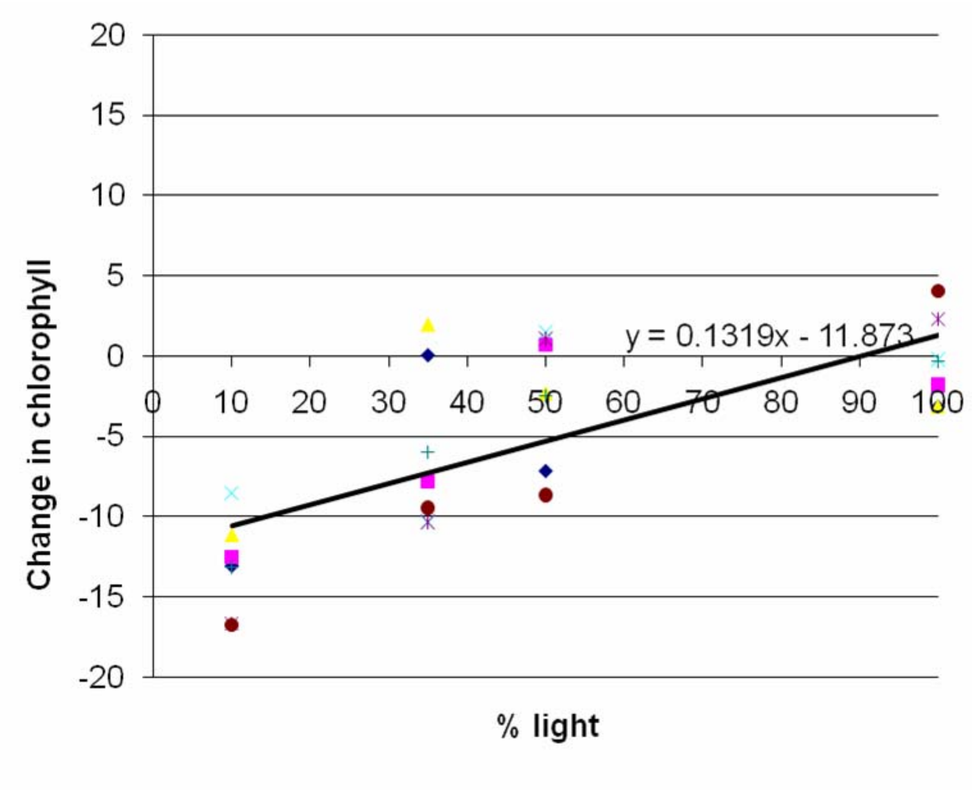


Figure 21 Regression line for change in chlorophyll content at increasing light levels for *Thyrsostachys siamensis*.

B. nana and *T. siamensis* had decreased chlorophyll content of 24.4% (-9.017 points) and 34.4% (-13.067 points) respectively under 10% light. At 35% light levels *B. nana* decreased in chlorophyll content 26.8% (10.05 points) while *T. siamensis* recorded a decrease of 15.4% (5.783 points). Both species also decreased in chlorophyll at the 50% light level treatment with 7.4% (2.767 points) and 12.75% (4.75 points) respectively. As expected, the chlorophyll content of *B. nana* increased under full sun with a rise of 6.1% (2.3 points). *T. siamensis* had a marginal decrease in chlorophyll content at full light of 0.8% (0.3 points). Appendix Table 3 and Figure 22 detail the changes in chlorophyll as light levels increase for all 4 species.

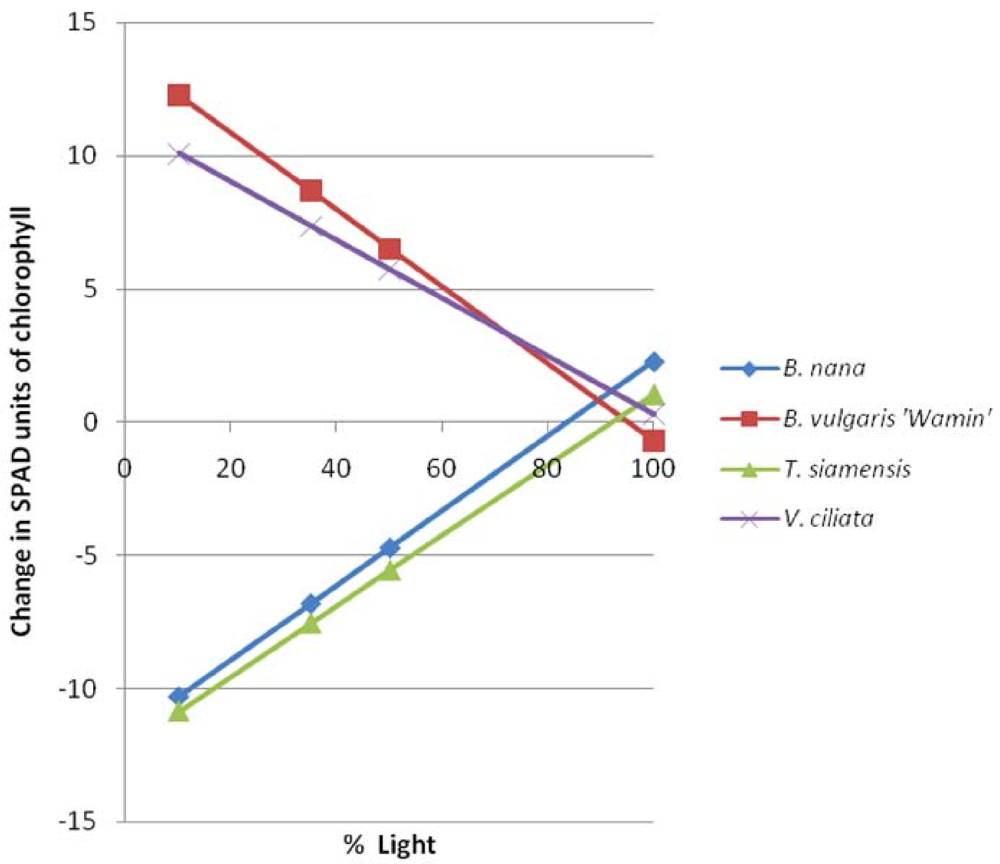


Figure 22 Comparison of regression lines for change in chlorophyll content at increasing light levels for 4 species of *Bambuseae.*

The majority of the results reflect expected outcomes. As with P_{max}, very little change occurred in chlorophyll content at full light levels. This lack of change reflects the stability reached by all replications by having been grown in full light for 3 months prior to the experiment. Decreases in P_{max} corresponded with a decrease in light availability for *B. nana* and *T. siamensis*. These two species also experienced significant reductions in chlorophyll as light levels decreased. Both species experienced maximum health (chlorophyll levels) and photosynthesis (P_{max}) at full light levels. These results are indicative of plants not well adapted for limited light conditions but rather full sunlight levels. Both species can attain heights of between 12 and 18 meters (Lin, 1968) and are often the dominant plant in its ecosystem. Pattanawiboon *et al*. noted in 2001 that each of these species is often found growing under full light conditions. *T. siamensis* is particularly vigorous in natural stands under full light conditions in Thailand (Dransfield and Widjaja, 1995).

V. ciliata was the only species to exhibit an inverse relationship between light levels and both chlorophyll content and P_{max}. Only recently classified by Ngyuen in 1990, little is known about this species. *V. ciliata* obtains a maximum height of between 1 and 2.5 meters (Ohrnberger, 1999). *V. ciliata* is endemic to the understory of dipterocarp forests (Dransfield, 2000a) where, because of its limited height, light levels are greatly reduced. However, *V. ciliata* can also be found in large savannahs where it is exposed to full sunlight (Hacker, 1997). The results of experiment 4 reflect *V. ciliata's* successful adaptation to these limited light levels. The adaptation of survival in environs of severely restricted light levels can be found in other small, *Bambuseae* genera (Dransfield, 2000b; Dransfield, 1992; Yokoyama and Shibata, 1997; Noguchi and Yoshida, 2004). Decreases recorded in both chlorophyll and P_{max} at high light levels, not often experienced in its native environment, indicate a decrease in plant health and photosynthesis at the 50% and 100% sunlight levels. Moderate changes at the 35% level reflect increasing plant health as *V. ciliata* approaches light levels closer to its optimum range. Further experiments should be performed at ranges below 10% sunlight to calculate the optimum light level and adaptability of this species.

B. vulgaris 'Wamin' showed mixed results. As light levels increased, chlorophyll content and plant health decreased. However, P_{max} increased correspondingly with light levels. Increased plant health at lower light levels may be a direct result of human intervention. Unlike the species type, which may attain heights of 20 meters, *B. vulgaris* 'Wamin' is a small cultivar usually only obtaining heights of 2 - 4 meters (Ohrnberger, 1999). This limited height requires plants to adapt to lower light more commonly experienced by shorter plants. This, coupled with human selection of healthy, shade loving plants, favors plants which perform better in areas of lower light. P_{max} levels in *B. vulgaris* 'Wamin' increased as light levels increase are similar to those found in light loving *B. nana* and *T. siamensis.* With regard to P_{max}, *B. vulgaris* 'Wamin' reacts as would a light loving, dominant species rather than the shade loving cultivar. This trait may be less easily influenced by selection and remains as in the type species before cultivar selection occured. Measuring and contrasting P_{max} and chlorophyll results between *B. vulgaris* 'Wamin' and *B. vulgaris* var. vulgaris would be useful in determining whether or not this is the case.

Alternatively, these mixed results could be a due to factors not limited by this experimental design. Of the 4 species tested, *B. vulgaris* 'Wamin' has a much larger leaves and a greater surface leaf area/leaf. While calculating total leaf surface area/plant was outside the scope of this experiment, greater surface area can allow for greater water loss. Water and nitrogen stress could account for the decrease in chlorophyll while photosynthesis levels increased under full sunlight (Martinez and Guiamet, 2003; Pessarakli, 2005). Although all plants were watered 3 times each week, this may have not been sufficient for this species during the traditional dry season. Nutrition levels were not tested but may also have some influence on results.

The regression line slopes calculated in this experiment and shown in Figures 16 and 21 show the ability of each of these species to adapt to changing light levels. Steeper slopes indicate a greater difference in chlorophyll and P_{max} between light levels and a larger preference for a particular light level. A more gradual slope indicates a small change between different light levels and an ability to tolerate a greater range of light levels. Actual values before and after treatments for each accession can be found in Appendix Table 4.

Experiment 5: Photosynthetic changes in *Bambusa vulgaris* 'Wamin' after chemical and physical acclimatization.

Thirty plants of *B. vulgaris* 'Wamin' were treated with both chemical and physical acclimatization treatments and analyzed for changes. All thirty replications were first grown for 4 weeks under greenhouse conditions. Both P_{max} and chlorophyll levels were measured and recorded. After which, 10 replications were each treated with1000ml solution of 225 or 450 ppm paclobutrazol using the soil drench method of application. The remaining 10 replications were not treated and used as a control. Chlorophyll content was measured over a 10 week period and recorded.

Previously, the experiment 3 did not show any significant changes in chlorophyll content when *B. vulgaris* 'Wamin' was grown under full sunlight and treated with 0, 225 and 450 ppm paclobutrazol using the soil drench method of application. However, as El Hodairi and Canham showed in 1990, in some instances there can be increasing effects on chlorophyll and photosynthesis in plants grown under low light levels when paclobutrazol is applied using the soil drench method. This accumulative effect was greater than either the chemical or light level treatments alone. Conversely, more recent studies by Kamoutsis *et al*. in 1999 found that effects on some plants treated with paclobutrazol using soil drench method decreased as shade levels increased. Gilley and Fletcher (2001) showed that paclobutrazol can decrease reaction to environmental stresses among some grasses. They did not, however, use limited light as one of their stress treatments.

In this experiment, there were no significant differences in chlorophyll levels between the 0, 225 and 450 ppm paclobutrazol treatments when grown under 10% sunlight. The difference in the increase in chlorophyll content between the control and 225 ppm was less than 0.2% while the difference between the control and 450 ppm was less than 0.8% (Table 8). The results show no significant differences between the control and either of the 2 treatments. No cumulative effect between low light levels and 225 or 450 ppm paclobutrazol when applied to *B. vulgaris* 'Wamin' could be found. The results are found in Figure 23.

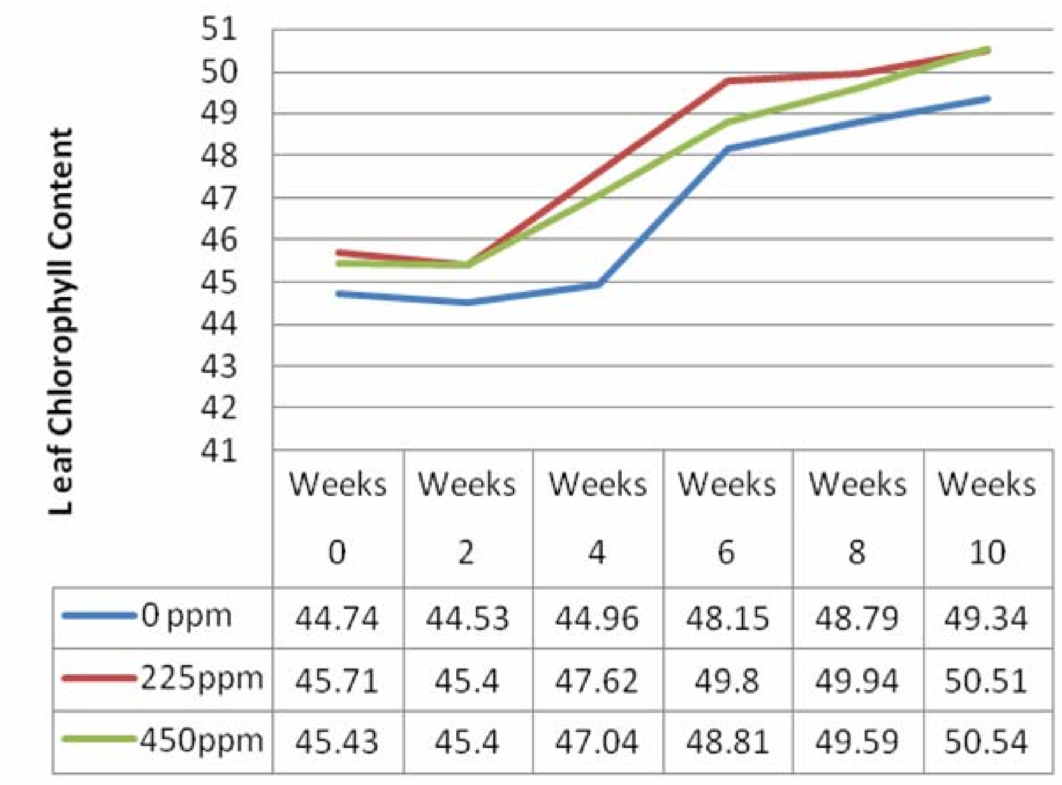


Figure 23 Chlorophyll content totals in *Bambusa vulgaris* 'Wamin' over 10 week period after paclobutrazol treatments are applied under 10% irradiance.

Table 8 Changes in chlorophyll levels in *Bambusa vulgaris* 'Wamin' 10 weeks after application of paclobutrazol treatments under 10% irradiance

	Treatment Mean Values		Difference from Control	
Treatment	**0 Weeks**	**10 Weeks**	**0 Weeks**	**10 Weeks**
0 ppm (Control)	44.74	49.34	-	-
225 ppm	45.71	50.51	0.97	1.17^{ns}
450 ppm	45.43	50.54	0.69	1.21^{ns}

F - test = 4.63.

^{ns} = not significant.

Chlorophyll content of the control, 225 and 450ppm treatments increased slightly in all three treatments over the 10 week period to a total average increase of 9.32%, 9.50% and 10.11% respectively. There was no increase during the first 2 weeks. Between 2 and 6 weeks all 3 treatments increased slightly This overall increase among all three levels is most likely a result of increasing plant health while grown under low light levels under greenhouse conditions. This slight increase also agrees with results found in both experiment 2 and 4 which showed that *B. vulgaris* 'Wamin' does better in decreased light levels than in full sunlight.

CONCLUSION

Of the 20 accessions of *Bambuseae* examined in this research, several received high rankings of horticultuiral value. Several species also showed the ability to adapt to low light levels. *B.bambos*, *B. glaucophylla, B. vulgaris* 'Wamin', *C. pergracile,* and *V. ciliata* all showed significant increases in chlorophyll, a reliable measure of plant health, when grown under 10% light. An increase in chlorophyll of 9.51 points or 36% at 10% light for *V. ciliata* was particularly high. *V. ciliata* also ranked as one of the most attractive species.

The LCP of *B. vulgaris* 'Wamin' was very low at an average of 18.3 and a regression line value of 17.7 µmol m^{-2} s^{-1} indicating an increased ability to acclimatize to low light levels. However, drenching with 225 or 450 mg per pot of paclobutrazol failed to significantly increase chlorophyll content in this species. Drenching with 900 – 10,000 mg per pot with paclobutrazol increased chlorophyll but greatly damaged plants, significantly reducing P_{max}. When the 4 most attractive species were placed in 4 light levels, results were mixed. *V. ciliata* experienced significant increases in both chlorophyll and P_{max} under decreasing light levels. *B. nana* and *T. siamensis* had positive correlations with regard to light versus P_{max} and chlorophyll. *B. vulgaris* ‘Wamin’ had mixed results.

Both *B. vulgaris* ‘Wamin’ and *V. ciliata* performed well under low light levels. They also both ranked in the top 4 species for AQG’s. While *B. vulgaris* ‘Wamin’ is often grown as an ornamental under low light conditions, *V. ciliata* is relatively unknown. *B. vulgaris* ‘Wamin’ exhibited an extremely low light compensation point that was less than 1% full sunlight and within light levels found in some interior spaces. Although LCP was not calculated for *V. ciliata*, it should perform as well or better than *B. vulgaris* ‘Wamin’ based on its photosynthesis and chlorophyll level results in experiment 4. These results showed that some *Bamuseae* species can acclimatize to low light levels. More research should be completed to verify the LCP for *V. ciliata.* Because of the vast diversity of the *Bambuseae*, additional species with economical and horticultural potential when acclimatized to areas of low light.

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APPENDIX

Appendix Table 1 Calculations for regression line used in determining LCP of *Bambusa vulgaris* 'Wamin' using low irradiance levels

				Confidence interval	
x	**y**	**Y**	**Standard of Error**	**95%**	**99%**
0	-0.71	-0.6396	0.1495	Yi=±0.436	Yi=±1.041
25	0.23	0.2629			
50	1.34	1.1654			
100	2.88	2.9704			

* = 95% confidence that Y*i* includes the true P_n

y = average actual found value of P_n

x = level of irradiance

Y = estimated regression value of P_n

Y*i* = confidence interval

Appendix Table 2 Actual values, regression values, confidence interval and coefficient of determination for changes in P_{max} in 4 accessions of *Bambuseae* after 6 week treatment of 10, 35, 50 or 100% sunlight.

	x	y	Y	r^2	Confidence interval at 95%
B. nana	10	-1.098	-5.669	0.789	5.869
-1.3152 +.0232x	35	-1.013	-1.620		
	50	0.530	-1.134		
	100	0.836	-0.567		
B. vulgaris	10	-1.227	6.485	0.562	9.283
'Wamin'	35	-0.174	1.853		
-0.9728 +.015x	50	0.152	1.297		
	100	0.288	0.649		
T. siamensis	10	-1.483	9.457	0.461	13.828
-1.778 +.0188x	35	-1.592	2.702		
	50	-0.420	1.891		
	100	0.045	0.946		
V.ciliata	10	3.335	-4.965	0.849	10.702
3.4402 +.0362x	35	1.872	-1.419		
	50	1.560	-0.993		
	100	-0.065	-0.497		

x = % light

y = Change in P_{max} (P_n at LSP of 1500µmoles CO_2 $m^{-2}s^{-1}$)

Y = Regression value of y at x

r^2 = Coefficient of Determination

Appendix Table 3 Actual values, regression values, confidence interval and coefficient of determination for changes in chlorophyll content in 4 accessions of *Bambuseae* after 6 week treatment of 10, 35, 50 or 100% sunlight.

	x	y	Y	r^2	Confidence interval at 95%
B. nana	10	-9.017	-8.378	0.598	9.636219
	35	-10.050	-2.394		
	50	-2.767	-1.676		
	100	2.300	-0.838		
B. vulgaris 'Wamin'	10	12.283	8.978	0.813	10.40753
	35	10.817	2.565		
	50	2.400	1.796		
	100	-0.633	0.898		
T. siamensis	10	-13.067	-9.002	0.694	6.169536
	35	-5.950	-2.572		
	50	-2.450	-1.800		
	100	-0.300	-0.900		
V.ciliata	10	11.283	9.497	0.767	5.569971
	35	6.500	2.713		
	50	4.183	1.899		
	100	0.135	0.950		

x = % light

y = Change in chlorophyll content

Y = Regression value of y at x

r^2 = Coefficient of Determination

Appendix Table 4 Actual values for P_{max} and SPAD measurements for 4 accessions of *Bambuseae* before and after 6 week treatment of 10, 35, 50 or 100% sunlight

	P_{max}							
	Before				After			
% sunlight	10	35	50	100	10	35	50	100
B. nana	10.02	9.87	9.39	9.56	8.90	9.37	9.27	10.69
B. vulgaris 'Wamin'	9.03	9.47	9.28	9.36	8.21	9.02	9.06	9.89
T. siamensis	10.79	11.04	10.68	10.45	9.20	9.92	9.84	10.55
V. ciliata	8.76	9.12	8.91	8.62	12.25	11.67	10.90	8.74

	SPAD							
	Before				After			
% sunlight	10	35	50	100	10	35	50	100
B. nana	37.64	38.50	37.79	38.33	27.35	31.70	33.09	40.62
B. vulgaris 'Wamin'	40.22	39.87	41.06	40.59	52.48	48.53	47.56	39.89
T. siamensis	41.12	40.95	41.00	39.94	30.26	33.40	35.44	40.99
V. ciliata	36.64	37.12	38.17	36.93	46.72	44.49	43.91	37.24

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	:American Society for Horticultural Science		2004 – present
	:International Society for Horticultural Science		2004 – present
	:Texas Organic Farmers and Growers Association		2008 – present
Awards			
	:Outstanding Student in Horticulture, ASHS,		1995
	:Who's Who among American Law Students		1996-1998
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