Bamboo Windbreak for Agriculture in Hawaii

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Introduction

The most widely used plant for agricultural windbreak was the "tall wiliwili" (*Erythrina variegata*, Tropic Coral) with its desired tall, columnar form. The "tall wiliwili" was easy to grow from cuttings, grew rapidly, stayed in a narrow columnar form and was non-invasive. In 2005, a new insect pest, the erythrina gall wasp (*Quadrastichus erythrinae* Kim), was found attacking all *Erythrina variegata* cultivars. By 2006, this pest had spread throughout the State of Hawaii. Complete destruction of wiliwili windbreaks occurred rapidly especially in drier, irrigated farms. Parasitic wasps have been introduced to provide biological control of the gall wasp, but alternative plants for windbreaks are urgently needed until the parasitic wasp population is sufficient to allow wiliwili again.

Bamboo is envisioned as a possible replacement for wiliwili as a windbreak while having other uses such as for landscaping, food and building materials. Bamboo is usually found in the wild in forest areas with annual rainfall usually exceeding 80 inches in Hawaii. Bamboo is also found in residential backyards in dry areas indicating that it will grow on leeward farms with irrigation. Nurseries and experts in Hawaii were contacted to assist in the selection of species best adapted to our environment and with the following windbreak properties: non-invasive, rapid growing, and tall with sufficient width to provide optimum windbreak effect. It cannot be too wide and reduce the area to farm nor having a root system that negatively impacts surrounding crops.

Materials and Methods

Bamboo Species

The following bunching bamboo species were selected for comparison at three farms sites on Oahu:

- *Thyrsotachys siamensis* – 25 to 30 ft tall with 3-inch canes. It has construction grade canes and edible shoots. It is used as an ornamental in landscape.
- *Bambusa oliveriana* – 30 to 40 ft with 2-inch canes. It is wind tolerant, has wood of good quality, edible shoots and currently used as windbreak and privacy hedge.
- *Bambusa heterostachya* – 25 to 35 ft. It is well adapted to most conditions in Hawaii and forms a dense hedge.
- *Bambusa pervariabilis* – over 40 ft tall. It is used for construction, weaving, ornamental and has edible shoots.
- *Bambusa ventricosa* – about 40 ft tall with 2-inch canes. Very attractive ornamental with striped canes.

- *Bambusa tuldoides* – 25 to 40 ft tall with 2-inch canes. It's able to withstand heavy winds and is attractive.
- *Bambusa oldhamii* – 40 to 50 ft tall with 4- to 5-inch canes. It is impervious to the wind, edible shoots and good wood. Used extensively as windbreak in New Zealand.
- *Bambusa textilis* – about 40 ft tall with 2- to 3-inch canes. It is an attractive ornamental and used for hedges and windbreak. The fibrous canes are used for weaving.
- *Bambusa lako* – 40 to 50 ft tall with 4-inch canes. It is an outstanding ornamental, which is adapted to dry, windy locations.

Majority of the plants were obtained from Quindembo Nursery located at Kamuela, Hawaii. The descriptions above were obtained from Quindembo. Pictures of mature plants are posted on their website. Some plants were purchased from several windward Oahu nurseries. The plants were in one- to three-gallon pots with heights from 1 to 5 ft tall. The plant size at transplanting was uniform for a given species but different among the species.

Trial Sites

Three sites with different environments were selected on Oahu. The average annual rainfall totals were 25, 40 and 70 inches at Waipahu (HARC Kunia Experiment Substation – leeward southern site), Waialua (Pioneer Seed Company – leeward northern site) and Maunawili (HARC Maunawili Experiment Substation – windward eastern site), respectively. The respective soil series were Molokai silty clay loam, Waipahu silty clay and Kaneohe silty clay loam. The experimental design and species were similar for the three sites to enable statistical comparison of the location effects on bamboo. The Waipahu site had four additional species.

The Waipahu site was transplanted on November 29, 2007 with all nine species. Five species (first five of the above list) were completely replicated in five blocks in a randomized complete block design, *Bambusa oldhamii* and *Bambusa tuldoides* had three replicates in blocks 1, 2 and 3, and *Bambusa teftilis* and *Bambusa lako* were unreplicated and attached to block 2. A replicate of each species consisted of one plant at all sites. The Waipahu site was drip-irrigated with two one-gallon per hour emitters per plant. The plants were spaced 15 ft apart within a row with two rows spaced 25 ft apart. Gypsum was applied in each planting hole (one hand full or 0.2 lb per plant), and one hand full of 16-16-16 was placed around each plant soon after transplanting. Three additional applications of 16-16-16 were made at one-month intervals with the last application after 90 days after transplanting (DAT).

The Maunawili site was transplanted on December 13, 2007 with the same fertilization practices and spacings as the Waipahu site except the plants were planted in a single row. The five species were arranged in a completely randomized block design. This site is at a higher cooler elevation in a windward climate with no irrigated.

The Waialua trial site was transplanted on January 28, 2008 with the same five species, fertilization and design as the Maunawili site. This site was drip-irrigated by Pioneer Seed Company. All of the sites were kept weed-free by hand weeding and the use of careful spot application of glyphosate. No other pesticides were used at all of the trial sites.

Measurements

Weather data were collected electronically from automated weather stations installed at each site. The trial sites were within 1000 ft of a weather station. Data are available for air temperature, precipitation, relative humidity and wind speed. Solar radiation data are available at Waipahu and Waialua but not at Maunawili due to a defective sensor (sensor was replaced on September 3, 2008). The temperature and rainfall data will be used to compare the environmental conditions affecting growth among the sites.

The growth measurements consisted of shoot counts per plant, height of tallest shoot from the ground and the average shoot diameter. Each plant was rated on a relative scale of 1 to 9 where 1 was no windbreak potential and 9 was the best. In addition, the maximum width of each plant was measured to calculate the plant volume (using a cone volume) to estimate the windbreak potential. In some species, the shoot counts were inaccurate because it was difficult to distinguish the primary cane from the side branches, especially for *Thyrsotachys siamensis*. The cane diameter was later discontinued because of highly variable results for the same plant and had little correlation to growth or to evaluate the windbreak potential. The diameter measurements will resume once the plants approach their mature height.

Monthly growth measurements were taken at all three sites along with digital photographs of all plants. Growth measurements at transplanting were obtained for only the Waialua site. The measurements for this report were obtained from December 24, 2007 to August 19, 2008. Measurements will continue for about five years but at less frequent intervals until the plants are mature.

Table 1. Transplant and growth measurement dates and relative to days after transplanting (DAT) for the three sites.

	Transplant Date	1	DAT	2	DAT	3	DAT	4	DAT
Kunia	11/29/07	12/24/07	25	01/29/08	61	02/27/08	90	03/28/08	120
Maunawili	12/13/07	01/09/08	27	02/11/08	60	03/11/08	89	04/11/08	120
Waialua	01/24/08	01/24/08	0	02/25/08	32	03/25/08	61	04/23/08	90

	5	DAT	6	DAT	7	DAT	8	DAT
Kunia	04/28/08	151	05/27/08	180	06/26/08	210	08/19/08	264
Maunawili	05/12/08	151	06/10/08	180	07/10/08	210	08/20/08	251
Waialua	05/23/08	120	06/23/08	151	07/22/08	180	08/21/08	210

Results and Discussions

Comparison of Weather Data

A summary of the temperature and rainfall are presented in Table 2 for Waipahu, Maunawili and Waialua. The Waipahu site had the warmest average maximum temperatures at 82.8°F and the least amount of rainfall total at 10 inches. Waialua had slightly lower average maximum temperatures at 82.1°F and significantly more rainfall at 24 inches. The higher rainfall suggests more cloud cover and less solar radiation for plant growth. The Maunawili site had the lowest average maximum temperature at 78.1°F, the highest average minimum temperature at 68.0°F and the highest rainfall total at 38 inches. The higher monthly minimum temperatures at Maunawili indicate a greenhouse effect due to low clouds.

The growth potential at each site can be compared using the calculated degree-days at 65°F, which is part of the calculation in the weather stations software (Weathernews Winds version 3.21). The higher degree-days total at Waipahu implies better growing conditions. Waialua totals were slightly less than Waipahu and the lowest at Maunawili. Hence we expect the best growth at Waipahu with adequate irrigation and the poorest growth at Maunawili. The 8-month rainfall is too low to grow bamboo without irrigation at Waipahu; bamboo growth will be marginal at Waialua without irrigation from March through September. Rainfall was low and inadequate only in March at Maunawili, the unirrigated site.

Table 2. Average monthly maximum and minimum air temperatures and rainfall totals during the trial period for the three sites.

Waipahu

	Air Temp. (°F)		Degree	Total
Month	**Max**	**Min**	**Days 65°F**	**Precip (in.)**
Dec-07	80.2	67.6	276	5.31
Jan-08	78.9	63.6	194	0.66
Feb-08	80.8	63.7	211	1.05
Mar-08	83.4	65.6	294	0.05
Apr-08	82.1	65.9	271	0.99
May-08	84.1	67.3	331	0.92
Jun-08	85.5	68.7	363	0.42
Jul-08	87.1	69.8	416	0.67
Avg/Total	**82.8**	**66.5**	**2356**	**10.07**

Maunawili

	Air Temp. (°F)		Degree	Total
Month	**Max**	**Min**	**Days 65°F**	**Precip (in.)**
Dec-07	75.8	68.3	218	16.89
Jan-08	74.6	65.0	149	5.28
Feb-08	77.2	65.7	188	3.06

Mar-08	78.5	67.8	254	0.52
Apr-08	77.5	66.6	212	2.99
May-08	80.4	69.3	305	2.52
Jun-08	80.1	70.0	303	3.52
Jul-08	80.9	71.2	342	3.33
Avg/Total	**78.1**	**68.0**	**1971**	**38.11**

Waialua

	Air Temp. (°F)		Degree	Total
Month	**Max**	**Min**	**Days 65°F**	**Precip (in.)**
Dec-07	78.8	66.3	235	7.9
Jan-08	77.0	62.0	141	1.12
Feb-08	79.3	62.5	166	11.93
Mar-08	82.9	65.3	264	0.24
Apr-08	81.5	65.6	257	0.38
May-08	85.3	68.6	362	0.99
Jun-08	85.3	68.8	362	0.99
Jul-08	86.5	70.1	413	0.88
Avg/Total	**82.1**	**66.2**	**2200**	**24.43**

Growth Measurements

The cane count and diameter measurements were too inaccurate to provide meaningful or significant differences. Therefore, the latter measurements will not be presented nor discussed in this report. These measurements will resume when the plants are more mature.

Height was the best measurement to characterize growth. The visual rating was also good and strongly correlated the plant volume (volume = $1/3\pi r^2 h$), which utilized the width (r = radius) and height (h) measurements. The height, rating and volume results will be presented and discussed. Statistics were preformed on all of the data collected, but only the results for the last measurements made on August 19 to 20, 2008 for height, rating and volume will be presented.

The tallest of the five species planted at Waipahu and Maunawili was *Bambusa heterostachya* after 208 to 264 days after transplanting but not significantly different from *Bambusa oliveriana* and *Bambusa ventricosa* (Table 3). *Bambusa heterostachya* and *Bambusa lako* had the most rapid growth at 158 and 123 cm at Waipahu (Table 4). *Bambusa oliveriana* was the best at Waialua with a growth of 57 cm. Thyrsotachys siamenisis performed well and had the third best growth at the three sites.

By plotting height to dates for each site, we find the *Bambusa heterostachya* had the best growth rate (curve with the steepest slope) and *Bambusa oliveriana* next. The growth of *Bambusa ventricosa* was poor as indicated by a flat curve in Figure 1 for the Waipahu site. The other sites followed similar trends as the Waipahu site.

Table 3. Plant height (cm) relative to days after transplanting (DAT) at Waipahu, Maunawili and Waialua. Statistical comparisons of last measurements were performed using ANOVA and the means were compared using the least square difference method. Means with the same letters are not significantly different at the 0.05 level.

Waipahu	**Plant Height (cm)**								
DAT	**25**	**61**	**90**	**119**	**159**	**194**	**209**	**264**	
T. siamensis	32	30	27	31	61	89	92	127	ab
B. oliveriana	92	89	90	103	162	183	217	215	a
B. heterostachya	94	95	92	174	175	269	267	252	a
B. pervariabilis	110	110	101	95	89	112	105	106	c
B. ventricosa	170	177	169	160	148	154	155	188	ab
B. tuldoides	243	237	254	251	251	290	286	273	a
B. oldhamii	266	264	267	258	273	299	302	306	a
B. textilis	280	290	280	278	279	284	261	268	
B. lako	177	170	211	28	274	293	310	300	
	(B. textilis and B. lako had unreplicated plots)								
Maunawili									
	27	**60**	**89**	**131**	**153**	**180**	**211**	**251**	
T. siamensis	34	34	33	40	46	56	48	72	b
B. oliveriana	85	92	90	79	81	110	119	157	a
B. heterostachya	96	102	108	106	111	121	195	191	a
B. pervariabilis	104	115	105	105	107	95	118	95	b
B. ventricosa	182	188	190	187	180	174	186	168	a
Waialua									
	0	**32**	**61**	**89**	**120**	**151**	**180**	**208**	
T. siamensis	35	35	33	42	50	65	65	63	c
B. oliveriana	79	83	68	75	98	117	125	136	ab
B. heterostachya	100	97	98	98	154	174	152	150	a
B. pervariabilis	112	105	104	110	109	98	102	98	bc
B. ventricosa	172	162	162	166	163	165	167	153	a

Table 4. Increase in plant height (cm) from the first to last measurements at the three sites.

Species	Waipahu	Waialua	Maunawili
Thyrsotachys siamensis	95.2	28.0	38.6
Bambusa oliveriana	93.8	57.0	71.8
Bambusa heterostachya	158.8	50.6	95.4
Bambusa pervariabilis	4.8	0.0	0.0
Bambusa ventricosa	37.6	0.0	0.0
Bambusa tuldoides	30.0	-	-
Bambusa oldhamii	28.7	-	-
Bambusa teftilis	0.0	-	-
Bambusa lako	123.0	-	-

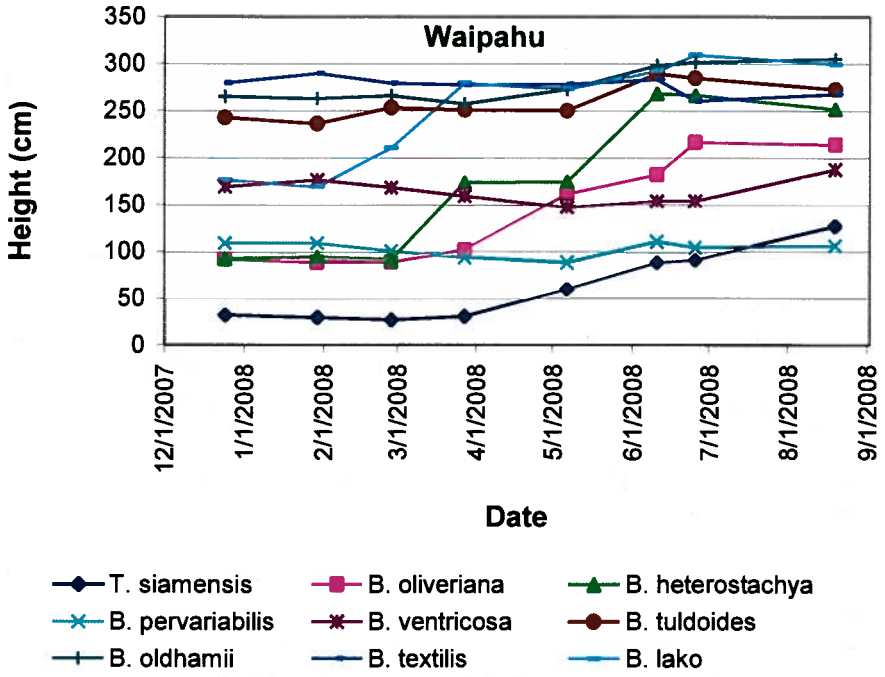


Figure 1. Relationship of plant height to date where the growth rate is the slope.

Of the species only planted at Waipahu, *Bambusa lako* was one of the tallest with a height of 3 m and with the second best growth rate of 0.51 cm/day, which is the same as *Bambusa oliveriana*. *Bambusa heterostachya* still had the best growth rate at 0.66 cm/day at Waipahu.

All of the species had little or no growth from December through April. The growth rate increased rapidly from May to August once the degree-days per month exceeded 300. This trend was similar for all sites. This rapid growth is expected to continue until November when the day length and sunlight may be limiting. A growth rate of more than 3 cm/day was measured in June at Waipahu. If this rapid growth occurs for 4 months, the canes will elongate by 3.6 m. This suggests that the best time to plant bamboo for rapid windbreak establishment is from April to June on Oahu and probably for most of Hawaii.

The combined results for the three locations in Table 5 mirrored the results at each site where *Bambusa heterostachya* had the best growth rate, tallest plants, largest volume and best windbreak rating. The location effects show that bamboo grew significantly faster at Waipahu than either at Waialua or Maunawili due to less cloud cover, adequate irrigation and higher degree-days. A significant difference was expected between Waialua and Maunawili due to weather and soil differences. Waialua had the most fertile soil, while the soil at Maunawili was leached of most nutrients. The expected difference was probably nullified by irrigation problems resulting in water stress at Waialua.

Table 5. Three sites combined data for the measurements in August 2008 for height (cm), growth rate (cm/day), volume (m^3) and visual ratings.

Species	Height (cm) Total	cm/day*	Volume (m^3)	Rating
T. siamensis	88b	0.218b	0.604c	3.9c
B. oliveriana	169a	0.348a	1.902ab	6.4ab
B. heterostachya	198a	0.408a	2.239a	7.2a
B. pervariabilis	100b	0.011c	1.641b	5.3b
B. ventricosa	170a	0.053c	1.692ab	6.8a
Location				
Waipahu	178a	0.317a	2.732a	6.3a
Maunawili	137b	0.171b	1.266b	5.8a
Waialua	120b	0.134b	0.849b	5.8a

Means with the same letter are not significantly different at the 0.05 level using the least square difference method.

New propagation methods are needed to reduce the cost per plant. Local nurseries currently sell these species at $25 to $40 per plant, which will cost $1.50 to$4.00 per linear foot of windbreak. The current propagation method is by dividing and removing the side shoots where only a few new plants can be obtain. Meristem/tissue culture techniques could be developed to produce many plantlets from a single plant. At $10 per plant and 10 ft plant spacing, the cost will be $1 per linear foot of windbreak.

Summary

The relative differences between the bamboo species at the different sites followed similar trends after eight months. The same species were the best performers at each site. The importance of water and climate was demonstrated. Almost no growth occurred in the cooler winter and spring months then very rapid growth up to 3 cm per day in summer with adequate irrigation/water. Projections suggest that the best bamboo species could grow 3 to 5 m per year, which is desirable in rapidly establishing a windbreak. More data is still needed to evaluate the performance of each species over several years.

Conclusions

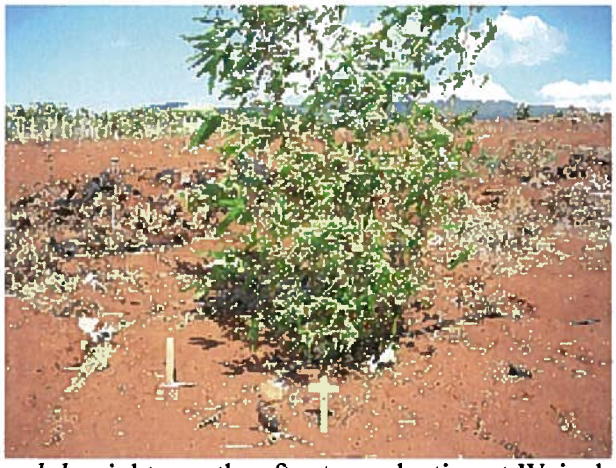
To date, the best species are *Bambusa heterostachya*, *Bambusa oliveriana*, and *Bambusa lako* (photos below). Bamboo compares favorably with other plants such as eucalyptus while being attractive, wind resistant and having valuable by-products.

References

Heu, R. A., D. M. Tsuda, W. T. Nagamine and T. H. Suh. 2005. Erythrina Gall Wasp. State of Hawaii Dept. of Ag. New Pest Advisory, No. 05-03 (updated August 3, 2005).

Bambusa heterostachya eight months after transplanting at Waipahu.

Bambusa oliveriana eight months after transplanting at Waipahu.



Bambusa lako eight months after transplanting at Waipahu.

Quindembo Bamboo. 2008. Catalog on internet at www.bamboonursery.com/catalog.asp.