DESIGNING A WINDBREAK TO IMPROVE SOIL HEALTH ON YOUR FARM

Oahu Farmer Soil Health Cohort- Session 4

April 26th (Tuesday) 4-6pm

Hua Orchards, Waialua, HI

Soil Health Benefits:

- Soil moisture
- Soil temp.
- Keeps a 'living root' in the ground to feed soil microbes
- Establishes microclimate and reduces irrigation costs associated with installing cover crop

Wind Directions Considerations in Design:

- Using wind data to select an orientation for your windbreak design
- Wind speed and direction
- Resources:
    - Generating a Wind Rose (Remote Automated Weather Station (RAWS) Data) map, https://raws.dri.edu/
    - Example: Wind Rose Map generated from Schofield Barrack's Wind Gauge Station
    - Example: Wind Rose Map generated from Dillingham's Wind Gauge Station

Spacing and species selection:

- Spacing/Density
    - Design considerations to eliminate gaps that could accelerate wind into the crop area (Refer to Design Reference 1)
- Height/Distance
    - (Refer to Design Reference 2)
- Length
- Considerations in Species Selection
- Installation Design/Number of Rows
- Design Resources:
    - https://www.agroforestryx.com/

Bamboo Windbreak For Agriculture in Hawaii:

- Bunching bamboo species review on 5 farms on Oahu
    - Projections suggest that the best bamboo species could grow 3 to 5 m per year, which is desirable in rapidly establishing a windbreak.
    -
- Hua Orchard Design
    - Cost-savings to establish cover crop with vs. without a windbreak

- Cost to establish cover crop with irrigation needed
- Cost to establish cover crop without irrigation needed

Design Reference 1: Windbreak Design Considerations for Eliminating Wind Gaps.

Excerpts below are sourced from the *Agroforestry Guides for Pacific Islands, Multiply Purpose Windbreaks: Design and Species for Pacific Islands*. (2000) Wilkinson and Elevitch. WSARE. http://www.agroforestry.net/afg/

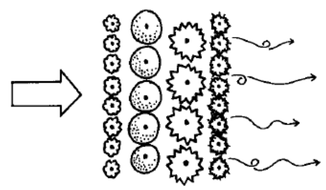


Figure 4a. Varied spacing filters and slows wind.

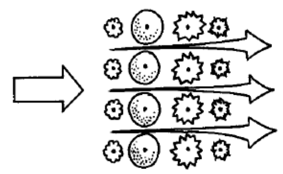


Figure 4b. Even spacing can create gaps that accelerate wind into crop area.

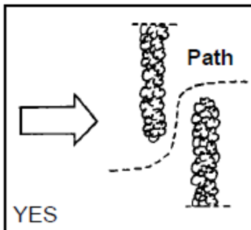


Figure 18. Windbreak overlaps the gap and management.

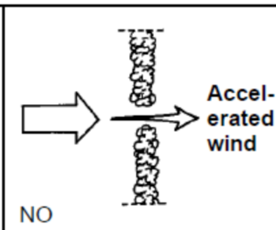


Figure 19. Gaps create a wind tunnel, accelerate the wind into crop area.

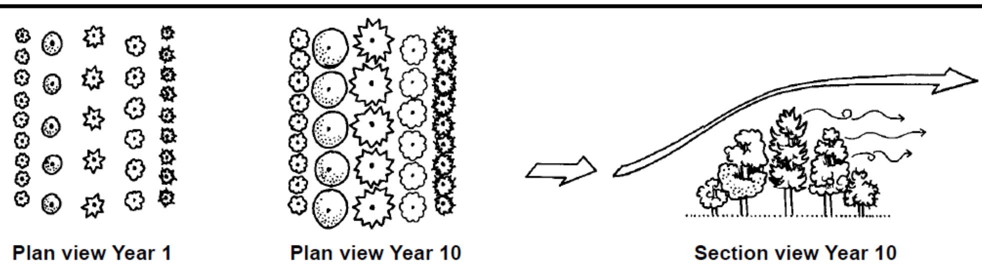


Figure 5a. Proper spacing creates a semi-permeable barrier that filters and slows wind.

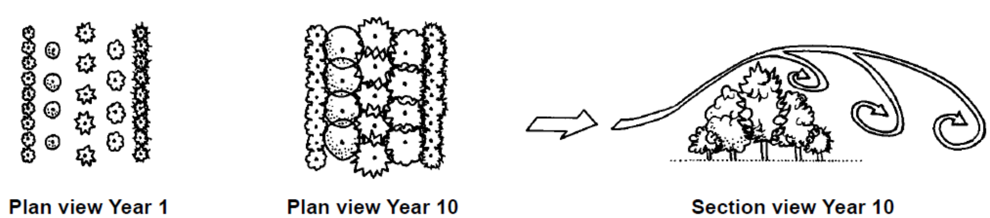


Figure 5b. An overly dense windbreak blocks wind and creates turbulence in the crop area.

Design Reference 2: Windbreak Design & Species Selection Considerations for Height

Excerpts below are sourced from the *Agroforestry Guides for Pacific Islands, Multiply Purpose Windbreaks: Design and Species for Pacific Islands*. (2000) Wilkinson and Elevitch. WSARE. http://www.agroforestry.net/afg/

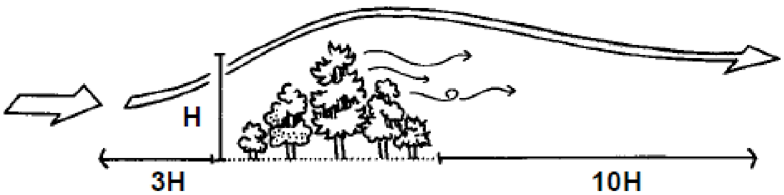


Figure 6a. Windbreak protects crop area to about 10 times the height of the tallest tree in the windbreak.

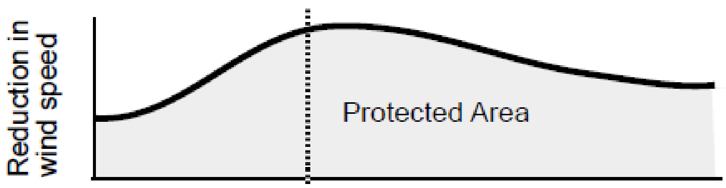


Figure 6b. The reduction in wind speed tapers off as distance from the windbreak increases.

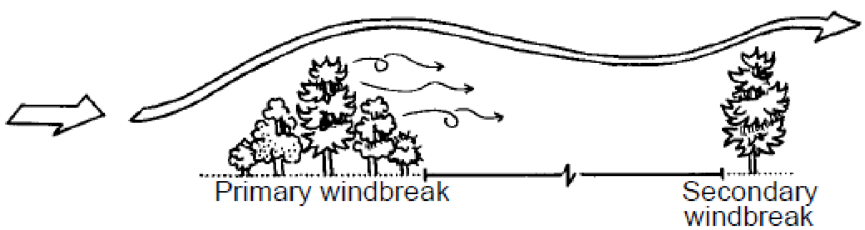


Figure 7. If crop area longer than 10X windbreak height, add secondary wind strips to continue protection.

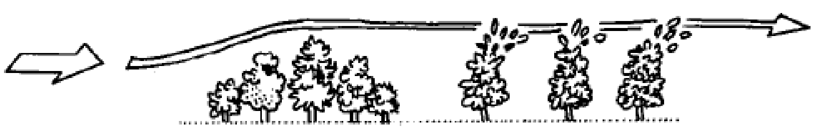


Figure 8. The tallest row of the windbreak must be taller than the crops—ideally 2X taller.

Design Reference 3: Windbreak Design Considerations for Length

Excerpts below are sourced from the *Agroforestry Guides for Pacific Islands, Multiply Purpose Windbreaks: Design and Species for Pacific Islands*. (2000) Wilkinson and Elevitch. WSARE. http://www.agroforestry.net/afg/

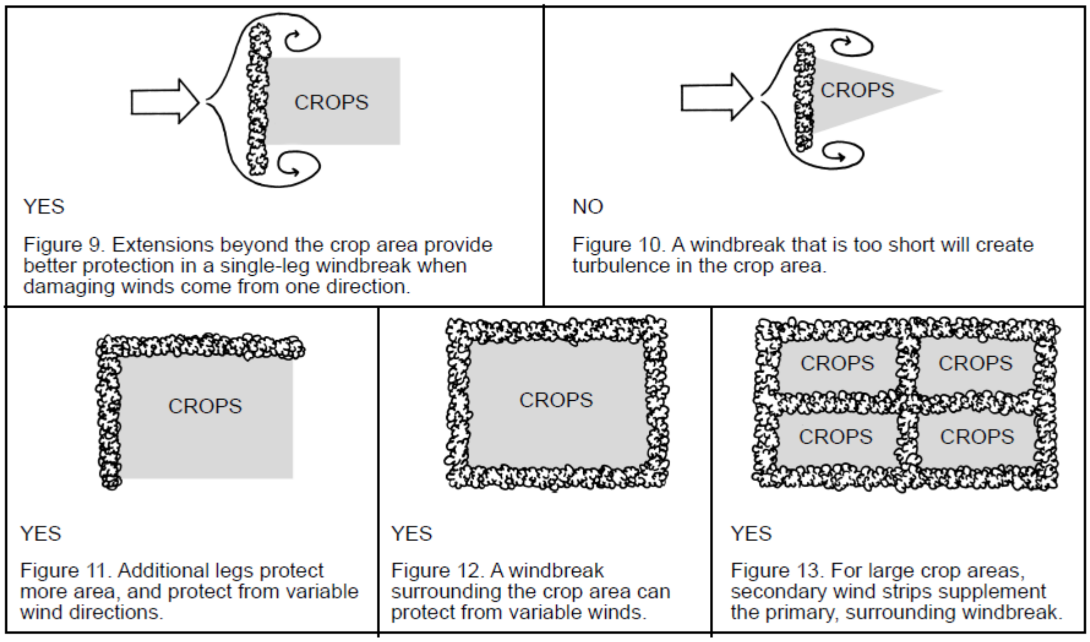


Figure 9. Extensions beyond the crop area provide better protection in a single-leg windbreak when damaging winds come from one direction.

Figure 10. A windbreak that is too short will create turbulence in the crop area.

Figure 11. Additional legs protect more area, and protect from variable wind directions.

Figure 12. A windbreak surrounding the crop area can protect from variable winds.

Figure 13. For large crop areas, secondary wind strips supplement the primary, surrounding windbreak.

Profile and number of rows

NO

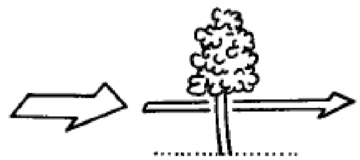


Figure 14. A single row of a tall species may have understory gaps.

GOOD

Figure 15. Single species can be effective if they have uniform, semi-permeable, wind-strong branches to the ground.

GOOD

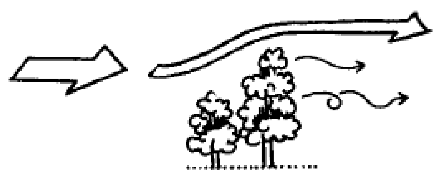
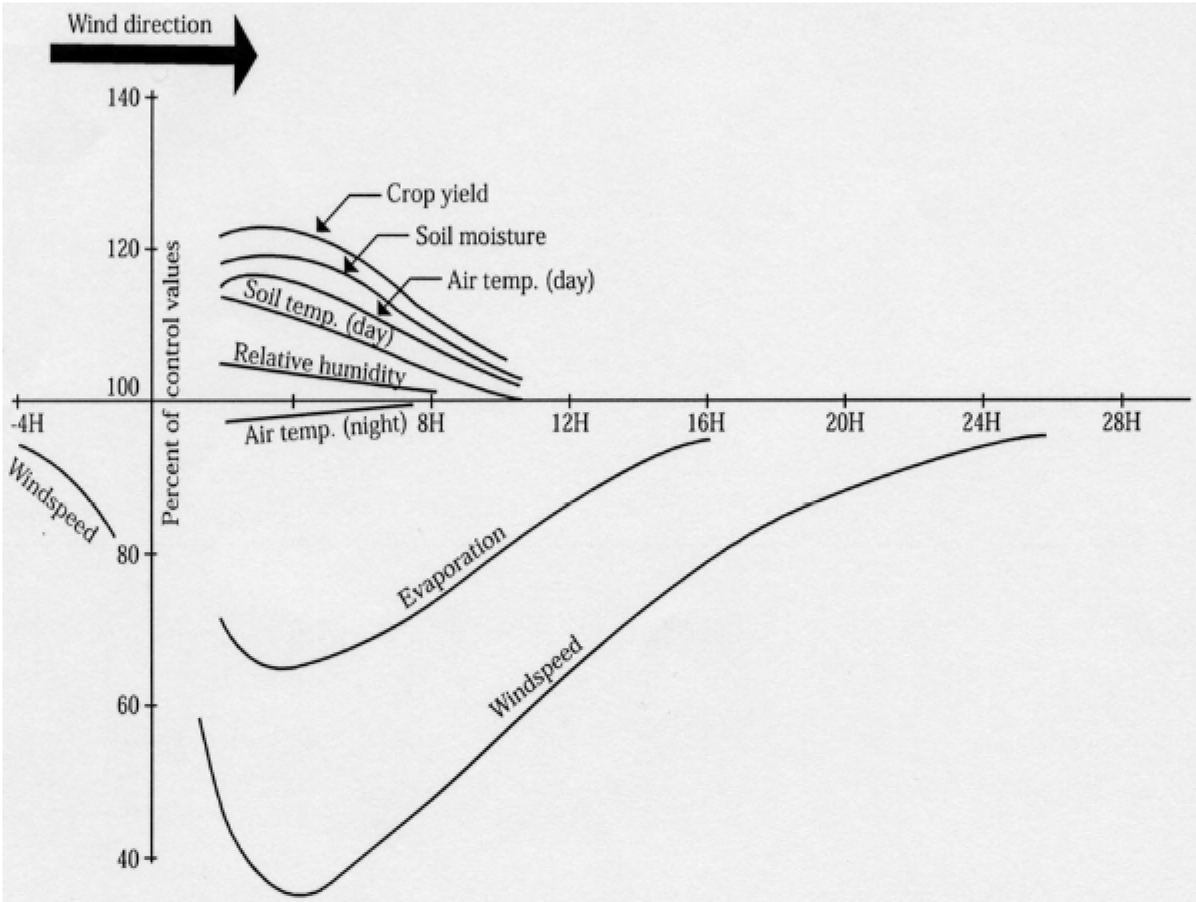
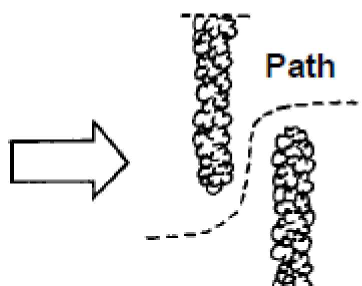


Figure 16. A short and tall row can prevent understory gaps.

GOOD

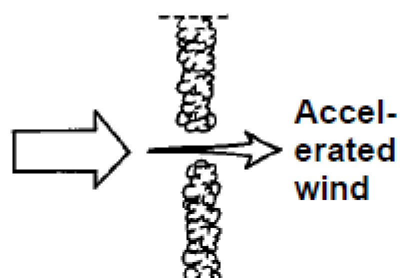
Figure 17. A multiple-row windbreak (3-5 rows) allows for more flexibility in species and management.





YES

Figure 18. Windbreak overlaps the gap and management.



NO

Figure 19. Gaps create a wind tunnel, accelerate the wind into crop area.

continuity of the windbreak and prevent the opening from becoming a wind tunnel (Figure 18).

Summary: Checklist for an Effective Windbreak

Orientation:

- Oriented perpendicular to prevailing damaging winds?
- One leg sufficient?
- Additional legs or surrounding planting necessary to protect from shifting winds?

Spacing/density:

- Number of rows sufficient for proper density (50-80% dense)?
- Spaced adequately for healthy growth?
- Crown closure in about 10 years?
- Trees on variable/staggered spacing?

Height/distance protected:

- Crops area to be protected located within 10 H zone?
- Secondary wind strips planted if crop area exceeds ten times the height of the tallest windbreak trees?
- Tallest trees in windbreak at least twice as tall as the crops?

Length:

- If single-leg windbreak, does the length extend 5 H beyond crop area on either side?
- Additional legs necessary to protect from variable winds?

Profile/number of rows:

- Understory gaps eliminated by short rows?
- Shrubs and short trees in outer rows?
- If single-species, has uniform branches to the ground?

Continuity:

- Wind funnel effects minimized (no gaps)?

Working Trees Info

Can windbreaks benefit your soil health management system?

Photo courtesy of NRCS

Soil health management systems can include single or multiple conservation practices that contribute to the four basic soil health principles:

- Use plant diversity to increase diversity in the soil
- Keep plants growing throughout the year to feed the soil
- Manage soils more by disturbing them less
- Keep the soil covered as much as possible

The most common practices include conservation crop rotation, cover crop, no-till, mulch tillage, nutrient management, and pest management. Implementation of other conservation practices, such as field windbreaks, can also improve soil health and provide long-term environmental and economic benefits.

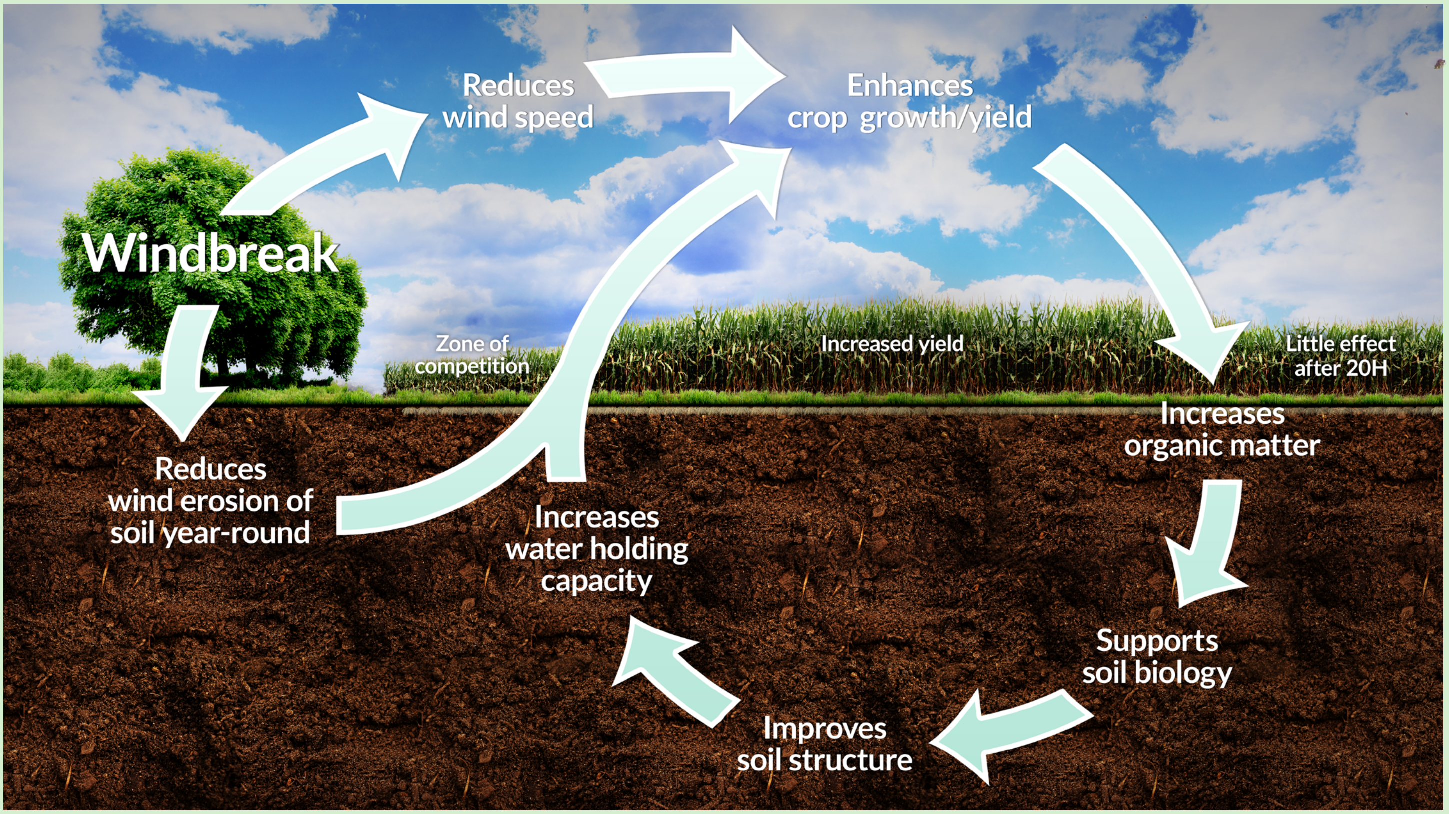
Windbreaks are strips of trees and/or shrubs planted and maintained to alter wind flow and microclimate, thereby protecting a specific area. Field windbreaks can protect a variety of wind-sensitive crops, control wind erosion, and increase bee pollination and pesticide effectiveness. It has long been known that while establishment of windbreaks requires taking some land out of crop production, the result is typically a net increase in crop production. It is important to note that windbreaks also have the potential to positively influence soil health on the protected cropland acres.

Field windbreaks reduce wind erosion by providing a zone of wind reduction on the leeward side of the trees and shrubs. The size of the area protected is determined by windbreak height and density. Windblown topsoil can contain high levels of organic matter which plays a key role in providing nutrients to plants, improving soil structure, increasing available water capacity, and feeding soil microorganisms. Windbreaks with properly-spaced tree and shrub rows reduce erosion across the field and keep organic matter on field where it benefits both the crops and soil biology.

Windbreaks also improve water-use efficiency by lowering soil evaporation rates across protected areas.

Windbreaks and the Soil Health Cycle

Windbreaks positively influence microclimate on an area much greater than the space they occupy. These influences extend into fields about twenty times the height of the windbreak (20H) and affect crops and soil environment.



Adequate soil moisture contributes to the formation of organic matter through the breakdown and consumption of plant residue by micro- and macro-organisms. This creates a beneficial "circle" of soil health improvement: as soil structure develops it results in improved bulk density and increased available water holding capacity. These improvements lead to increased crop growth and productivity and reduced water erosion.

Biological organisms in a healthy soil require the same resources as terrestrial creatures: food, water, cover, and air. Food for these organism is generally provided by two sources: root exudates from living roots and decaying crop roots and residues left in and on the soil. Soil health management systems that include windbreaks provide a more diverse, year-round living root food source for soil organisms. Leaf-drop from these woody plants also provides increased cover for the soil, resulting in winter cover that complements the crop residue. Tree roots also contribute to soil organic matter development and diversification.

With the increased frequency of extreme weather events, windbreaks used in combination with other conservation practices in a soil health management system can create a microenvironment that increases soil biology; reduces evapotranspiration, wind erosion, and water erosion; protects our natural resources; and provides economic security to America's farmers through increased crop resiliency.

Thank you to Nate Goodrich (NRCS) for providing the valuable content in this information sheet.

Contact: USDA National Agroforestry Center, 402.437.5178 ext. 4011, 1945 N. 38th St., Lincoln, Nebraska 68583-0822. https://www.fs.usda.gov/nac/

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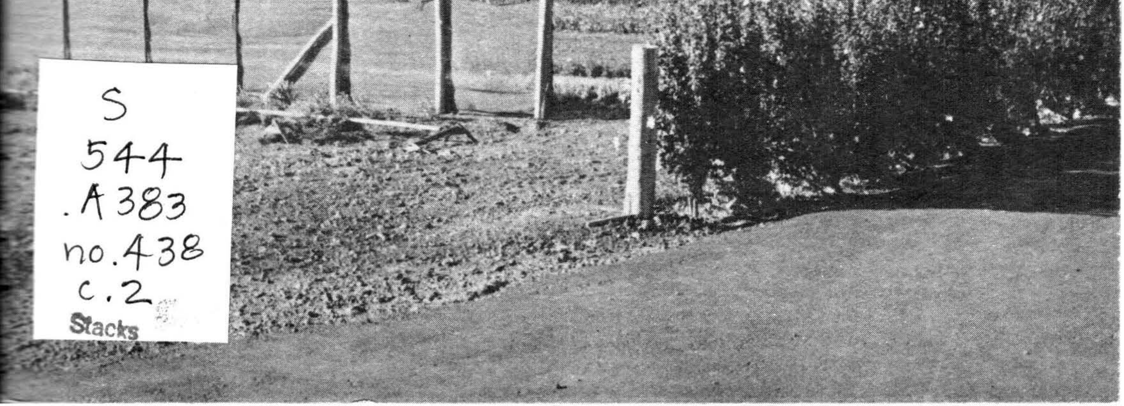
WINDBREAKS FOR HAWAII

Wade W. McCall, Gordon T. Shigeura,
and Yusuf N. Tamimi



FOREWORD

Wind is an important factor in agriculture in Hawaii. Much of the knowledge regarding windbreaks is scattered in many different publications. The purpose of this circular is to present the basic theoretical aspects of windbreak use. This is the first of a series of publications on windbreak use in Hawaii. Future publications will present information on planting materials suitable for windbreaks, constructed windbreaks, wind erosion and its control, windbreaks for urban use and other special purposes, and the results of a windbreak survey on present practices in windbreak use in Hawaii.

WINDBREAKS FOR HAWAII

Wade W. McCall, Gordon T. Shigeura, and Yusuf N. Tamimi

Hawaii is in the northern limits of the tropics. Prevailing winds are the northeasterly trades. These winds are due to the presence of a permanent high-pressure belt and are generally 8 to 20 miles per hour; gusts up to 40 miles per hour may also occur. Tradewinds blow for 250 days or more each year. During the absence of the permanent high-pressure belt, it is possible to have winds from an opposite or variable direction at any season but most often in the winter. These winds, often referred to as "Kona" winds, are usually associated with stormy weather and are of higher velocity than the "normal" tradewinds. Gusts up to 80 miles per hour or more may occur, causing considerable damage to agricultural crops. Fortunately, these winds are of short duration and are generally restricted to local areas.

Winds of different velocities have different effects upon soil, crops, animals, and people. Table 1 shows the effect of wind velocity upon soil and plant environment. The actual effect of the wind depends upon the nature of the wind, the crop, climatic factors, and the protection provided. The best protection is one that reduces wind velocities to safe levels. Reduction of wind velocity is provided by barriers that allow more favorable conditions for soil, plant, animal, and human protection and development. Any barrier used to reduce wind velocity and provide more favorable environmental conditions is known as a windbreak.

Table 1. Effect of wind velocity upon soil and plant environment

Wind effect	Wind velocity[1] Miles per hour
Soil movement[2]	10 - 15
Reduced pollination[3]	10 - 15
Reduced activity of insects	10 - 15
Mechanical damage to plants[4]	15 - 20
Increase in transpiration and evaporation[5]	
1	Calm
2.2	5
3.8	10
4.9	15
5.7	20
6.3	30

[1]Wind velocity at level of the growing plant.
[2]Depends upon soil texture and structure. Sandy soils and soils with little or no structure erode at lower velocities.
[3]Blowing of flowers and pollen. Reduced activity of insects also reduces pollination.
[4]Mechanical damage to plants due to direct effect of wind, i.e., bending over, breaking branches, etc. Soil blowing will also damage plants due to abrasion by soil particles.
[5]Relative values based upon calm conditions.

Purpose of Windbreaks

The primary purpose of a windbreak is to reduce wind velocities to a degree that will provide the necessary protection. Some secondary effects of reducing wind velocity are (1) increased temperature in the protected area, (2) increased humidity and reduced evapo-transpiration in the protected area, (3) reduced dust problems, (4) shelter and food for wildlife, and (5) improved asthetic value of the area.

Factors to Consider

When establishing windbreaks consider the following factors:

(1) Nature of crop or area to be protected. How resistant is the crop or area to wind damage? How will the crop be affected by possible shading effects of or competition from planted windbreaks.

(2) Local soil and climatic conditions of the site. These are important in determining what type of windbreak to use and the care necessary to establish and maintain the windbreak.

(3) Choice of planted (natural) windbreaks or constructed windbreaks. The type chosen should provide the necessary protection when it is needed. This often involves the use of both types. The constructed windbreak provides "instant" protection and the natural windbreak provides protection as the planted materials attain the proper amount of growth.

(4) Selection of species adapted to local conditions. Planting material adapted to the soil and climatic conditions of each site must be used. In addition, the species should provide the growth characteristics which provide the necessary protection.

(5) Location, number of rows, and spacing. In planting windbreaks, the spacing of plants in the row and spacing between rows are important. In constructing windbreaks, the spacing or density is important. Either type should be located and spaced to provide maximum protection to the area under consideration.

(6) Proper orientation. Windbreaks should be placed crosswise or perpendicular to the direction of prevailing and storm winds. This is the most effective way of reducing wind velocities to safe levels.

(7) Proper preparation of the site. For planted material, soil preparation, fertilization, and adequate moisture are necessary. For constructed windbreaks, sufficient anchorage is required.

(8) Proper care and maintenance—replanting, fertilization, protection from livestock, fire and trespassing for planted materials, and protection from livestock and fire for constructed materials. Necessary repairs to constructed materials should be made as the need arises.

(9) Side benefits or plus factors. The secondary purposes mentioned above should be considered as plus factors of using windbreaks.

When establishing the windbreak, prepare plans far enough in advance so that planting materials, supplies and equipment are available to facilitate establishment at the time desired.

Classification of Windbreaks

Windbreaks may be classified in different ways: permanent (Plate 1) or temporary (Plate 2), planted or constructed, and dense or permeable.

Permanent windbreaks or those used to provide long-term protection generally consist of trees and shrubs that grow to relatively great heights and remain in place for many years. Temporary windbreaks may be fast-growing plants or constructed materials that provide protection over a relatively short period of time. Most plans for windbreaks include a combination of both types to provide maximum protection of the crops grown. Permanent windbreaks may remain more than 100 years, and temporary ones for 10 years or less.

Planted or natural windbreaks are those consisting of living plants and may be used as permanent or temporary windbreaks. Some are tall-growing species and some low-growing; some are relatively slow growing and some fast growing. Many times tall-growing, permanent windbreaks are established between fields, and the fast-growing, shorter species are used as infield windbreaks (Plate 3).

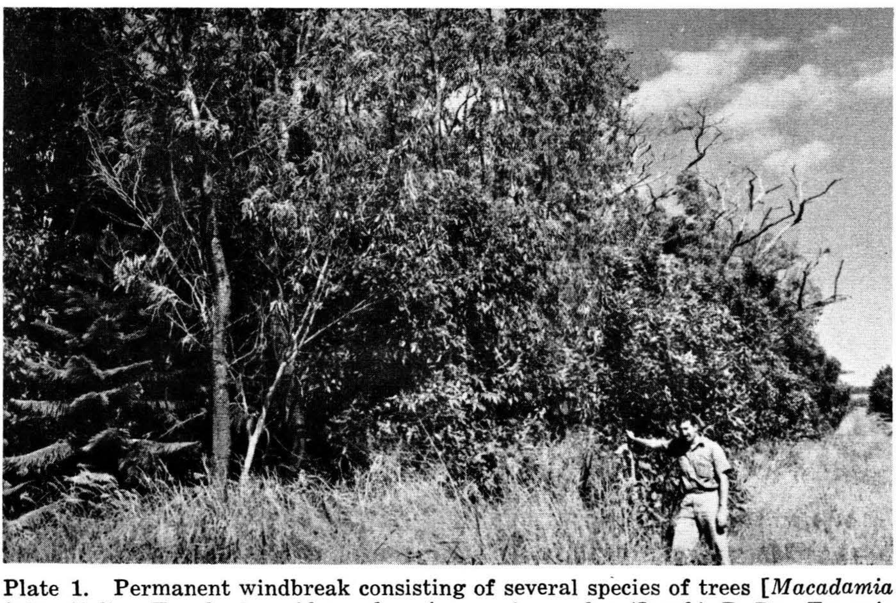


Plate 1. Permanent windbreak consisting of several species of trees [*Macadamia integrifolia, Eucalyptus sideroxylon, Araucaria excelsa* (Lamb) R. Br., *Eugenia cuminii* (L.) Druce, *Melaleuca leucadendron*(L.)] to insure wind protection even though some species may be adversely affected by disease, insects, or weather.

Plate 2. Temporary windbreak *(Saccharum spontaneum moentai* or wild cane) planted to provide protection over relatively short period of time. Note spacing to keep wind velocity at safe level for plant and soil protection.

Plate 3. Combination of permanent windbreak [*Melaleuca leucadendron* (L.) or paperbark trees] at margin of field and temporary windbreak *(Saccharum spontaneum moentai* or wild cane) in field to provide maximum protection from wind velocities.

Plate 4. Temporary constructed windbreak to provide wind protection for vegetables. This is constructed of saran cloth which has proven to be an excellent material for this purpose. Constructed windbreaks may be of a wide variety of materials other than saran cloth.

Windbreaks may be constructed from a great variety of materials such as plastic (Plate 4), wood, etc. These constructed windbreaks are usually temporary until planted materials grow sufficiently to provide the desired protection.

Dense or solid windbreaks are those that allow little or no wind through them. Permeable windbreaks allow wind through them. Figure 1 shows the effect of a solid windbreak upon wind velocity and pattern. Figure 2 shows the effect of a permeable windbreak.

Windbreak Effects

Windbreaks produce the following effects:

(1) Reduce wind velocities to the leeward or downwind side of the windbreak 70 to 75 percent up to three times the height of the windbreak, 40 to 50 percent up to ten times the height, and 20 to 30 percent up to twenty times the height (Figure 3). The windbreaks should be spaced so that a minimum of 50 percent reduction of the wind velocity is obtained.

(2) Reduce evaporation in protected area up to 40 percent of the unprotected area. This conserves soil moisture and reduces the transpiration stress on the plants.

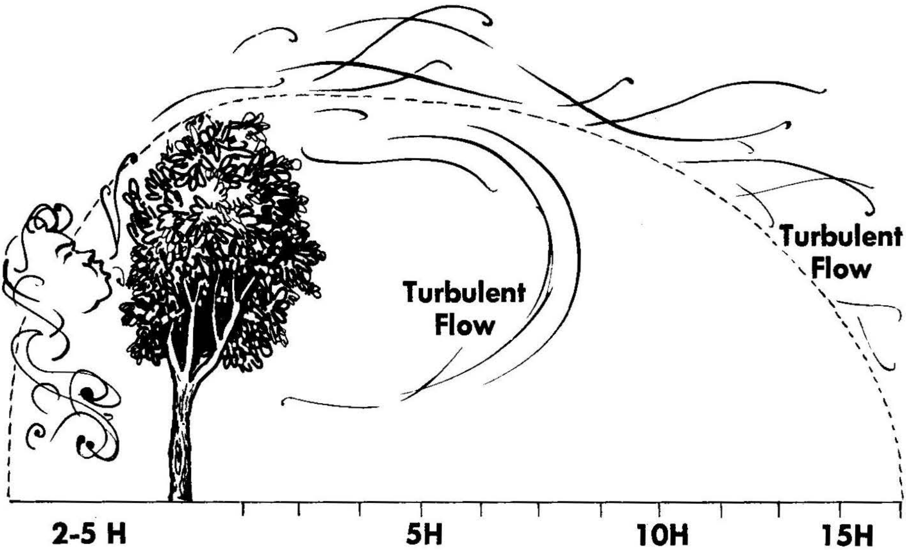


Figure 1. Effect of dense or solid windbreak on wind flow pattern. Note turbulent flow leeward of the windbreak; this may cause plant damage. NOTE: (Vertical effects have been exaggerated to illustrate effect of wind.)

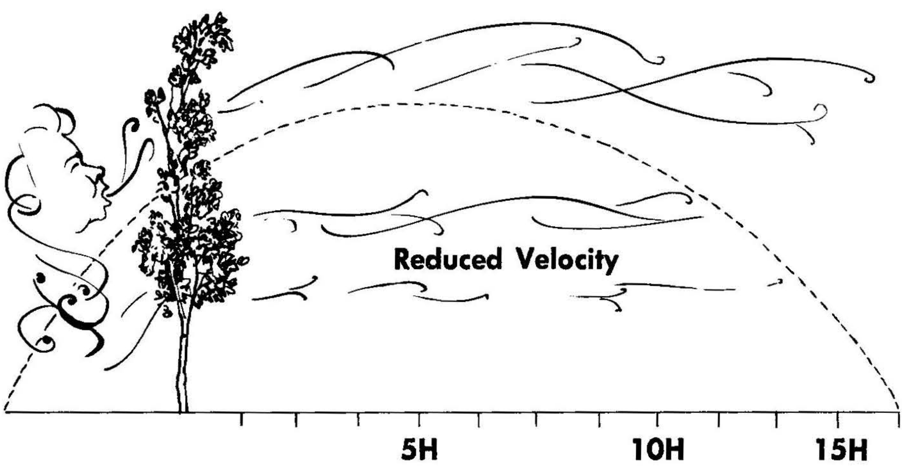


Figure 2. Effect of permeable (65 to 75 percent) windbreak on wind flow pattern. Wind velocities may be 25 to 30 percent higher at the same distance from the windbreak as compared with the dense or solid windbreak. (NOTE: Vertical effects have been exaggerated to illustrate effect of wind.)

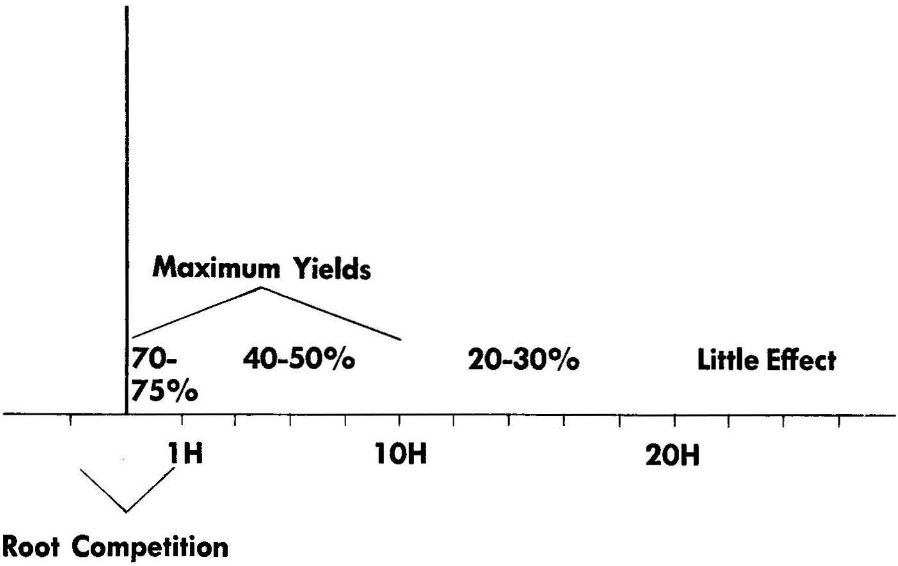


Figure 3. Effect of windbreaks upon wind velocity and crop yields based upon density of 75 to 100 percent. Reduction of 25 percent in density reduces effect from 40 to 50 percent at 10H to 33 to 45 percent at 7H.

(3) Increase temperatures in the protected areas up to 9° to 10° F.

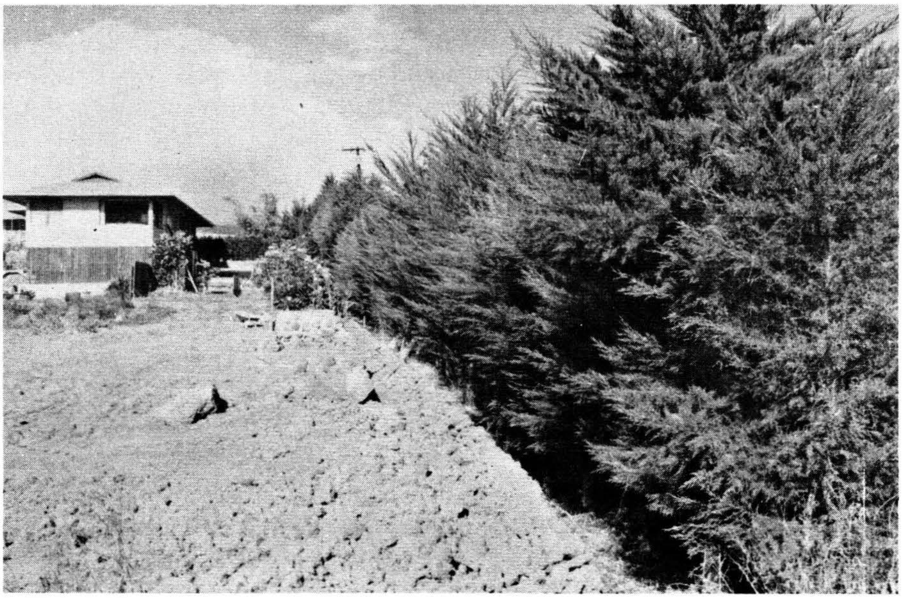
(4) Reduce soil erosion. Care should be taken that wind is not channeled through the windbreak so that erosion occurs in the area adjoining the windbreak.

(5) Reduce mechanical damage to plants. Windbreaks reduce the loss of flowers or fruits due to mechanical effects, reduce abrasion to stems and leaves due to blowing of soil particles against them, and reduce breaking of stems, branches, or other parts of the plant.

(6) Increase activity of bees and other insects and increase pollination in the protected area. Yields may be increased by 100 percent where wind is a serious problem.

(7) Compete with crop plants for distance up to 1½ height of the windbreak. This reduces yield in the area. Shading may cause the reduction in yield rather than plant competition for moisture and nutrients.

(8) Increase certain types of disease due to higher moisture and temperature in the protected area.



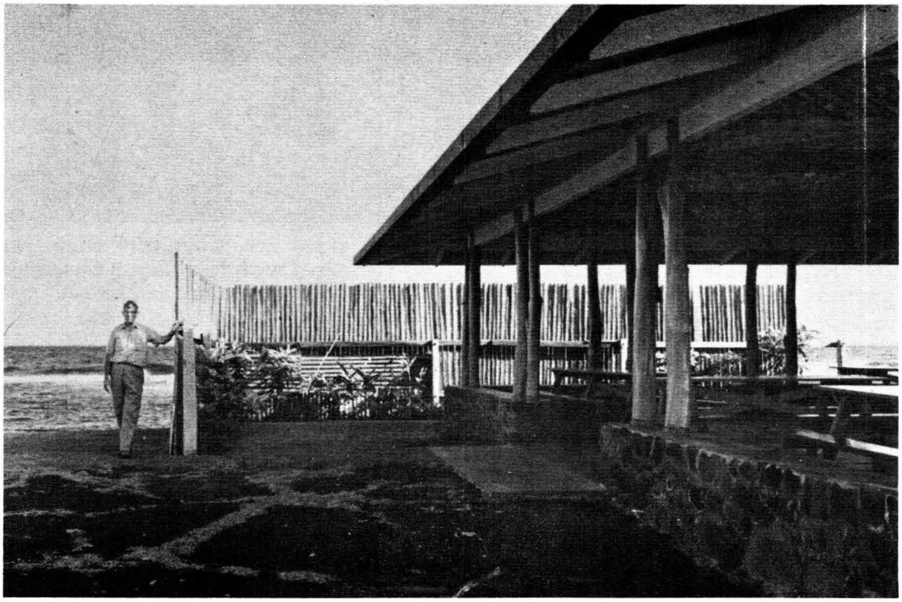


Plate 5. Windbreaks provided to increase comfort to people rather than to protect plants. A. To reduce dust and increase comfort of home with permanent planted windbreak *(Cupressus macrocarpa* Hartweg ex Gordon or Monterey Cypress). B. To provide comfort for those using the pavillion with temporary constructed windbreak.

Plate 6. Windbreaks must be maintained and cared for. This wild cane was uncared for; it is 37 feet from side to side as compared with less than 3 feet. This represents a serious loss of ground space as compared with that in Plate 3.

Where to Get Help

Trees and planting materials may be obtained from the State Tree Nursery, State Division of Forestry, P. O. Box 457, Kamuela, Hawaii 96743, and from most commercial nurseries on all islands.

The Cooperative Extension Service of the University of Hawaii has an office in each county. There are County Extension Agents in each office who can assist you with further information on windbreaks. Please feel free to call upon the agents to help you.

Cooperative Extension Work in Agriculture and Home Economics
College of Tropical Agriculture, University of Hawaii, Honolulu, Hawaii 96822
United States Department of Agriculture Cooperating
C. Peairs Wilson, Director, Hawaii Cooperative Extension Service
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Bamboo Windbreak for Agriculture in Hawaii

L. Santo, A. Yeh, M. Fitch, N. Dudley and R. McCormack

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

<u>Bamboo Species</u>

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 oldhami*i 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. (^oF)		**Degree**	**Total**
Month	**Max**	**Min**	**Days 65^oF**	**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	-	-

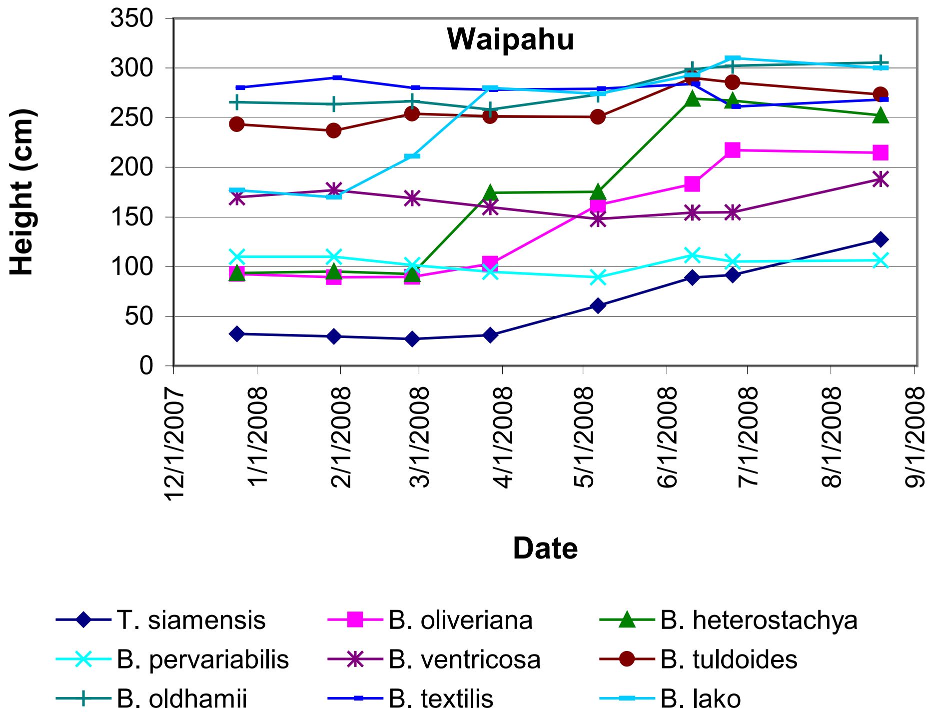

Figure 1. Relationship of plant height to date where the growth rate is the slope.

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).

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

Bambusa heterostachya eight months after transplanting at Waipahu.

Bambusa oliveriana eight months after transplanting at Waipahu.

Bambusa lako eight months after transplanting at Waipahu.