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FREEZE PROTECTION POTENTIAL OF WINDBREAKS

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Abstract. **Recent advective freezes in Florida have raised questions within the horticultural industry regarding windbreaks for cold protection. Windbreaks obviously retard the wind and are expected to render cold protection methods more effective within their wake. However, frost hazard during radiative frosts may increase but this disadvantage may be tolerable or minimized. A review of windbreak literature regarding the effects of windbreaks on turbulent transport downstream of the windbreak leads to the special consideration of orchard covers. Interrogation of models for predictions of the amount of energy that is necessary to provide protection provides estimates of the potential effect of windbreaks at low windspeeds. The heating models break down as windspeeds approach 15 mph (25 Km/hr), but the sprinkling model provides reasonable estimates. A team approach to the evaluation of the windbreaks is reported, and may provide an answer to the advective freeze protection question.**

This paper describes, in part, a response to a question asked by growers concerning protection from advective freeze damage, such as the 1983 Christmas Freeze or the January 1985 Freeze, which were characterized by windspeeds as high as 30 mph (50 Km/hr). It is generally accepted that methods exist that protect young trees from such freezes (12, 17, 18, 19, 20, 26, 27, 28, 33, 34, 35). What can be done to protect larger trees?

It has been known, and appreciated, that wind disrupts conventional cold protection methods (e.g. 7, 16). Hume (16) advocates the use of artificial or natural windbreaks in his summary of frost considerations. But he mentions problems with "covered sheds," and may have been aware of experiences that the ancestors of the senior author of this paper had with a canvas grove cover that blew all through the little town of Candler in Marion County during one of the advective freezes at the turn of the century.

Growers have known for some time (7, 16) of instances in which the proximity of hammocks to groves has reduced the amount of damage from advective freezes, and especially when heaters were fired (10). It is well known that as a grove reaches full canopy, the effectiveness of heating systems is greatly increased (22)

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The last two major freezes have been advective, i.e. accompanied by high wind speeds. It is painfully obvious that such freezes are possible in Florida. Recent studies suggest that similar freezes can not be ruled out of our winter climate until we are well out of this particular episode (9, 15, 40). There is little, if any, assurance that the current freeze prone episode is completed.

The mechanism that may be expected to provide protection during an advective freeze is straightforward: reduce the wind speed to the extent that some conventional methods of frost protection become effective. In other words, freeze protection may be accomplished by a combination of windbreaks and frost protection methods such as heating and/or irrigation (24, 27, 38, 39). The term windbreak is broadened in this case to include horizontal as well as vertical structures, i.e. orchard covers (8).

Windbreak effectiveness has been reviewed extensively in the literature (e.g. 32, 39, 6, 2, 21, 25, 1). Representatives of Allied Tube and Conduit, Chicago, contacted the Fruit Crops Department to ask if their firm could help in these investigations. Their provision of materials and the cooperative effort with Mr. Chris Blanton, Tavares, is gratefully acknowledged. Later, Mr. Reed Olszak of J. R. Brooks and Son, in conjunction with Mr. Don E. Graffram of Signode, Glenview, Ohio, discussed windbreaks for tropical fruits with our team and these have influenced this work (36, 37).

Materials and Methods

Fern growers developed column and cable shade house structures as an alternative to oak hammock canopies. The evolved structure has proved adequate under wind and rain events typical of Central Florida's climate, this column and cable design became the starting point for the development of a cover for adult trees.

Column-Cable-Cloth Structures. Shade structures consist of shade cloth stretched over a network of cables supported by poles or columns (Figure 1). Poles are typically spaced up to 20 to 30 feet (6 to 9 m) apart, but with careful design can be spaced up to 50 feet (15 m) apart. The poles may be either wooden or steel, and in some cases may be up to 20 ft (6 m) in height. Heights of 11 to 12 ft (3.5m) are expected to be sufficient for citrus. The structures used in the fern industry are frequently less than 8 ft (2.5m) in height, saving on the amount of material used in a structure and reducing the volume of air modified by cold protection methods. Structures to cover large citrus trees have to be higher than 8 ft (2.5m), but for cold protection the height should be kept to a minimum to reduce the volume of air that must be maintained in a heated and humid condition.

Several types of shade cloth can be used for the canopy of shade structures. The most widely used type of shade cloth is woven polypropylene cloth which will last up to 20 years if properly maintained. It is more expensive than other types and the cloth edges must be seamed and grommetted. Knitted polyethylene fabrics have been developed recently. These fabrics are lower in cost than woven fabrics and do not require seamed and grommetted edges. Their expected lifetime is up to 20 years; however, none is known to have been in the field that long.

Another fabric being considered for use in shade structures is nonwoven bonded nylon. This material must be seamed and grommetted but is relatively low in cost. Preliminary field tests indicate this material fails to last one season. But this type of material has shown good results when used to fabricate individual wraps for small trees for cold protection.

The shade cloth is attached on its edges to steel cable. The most commonly used size is 1/4 inch (0.635 cm) in diameter with a working tensile strength of 7000 pounds

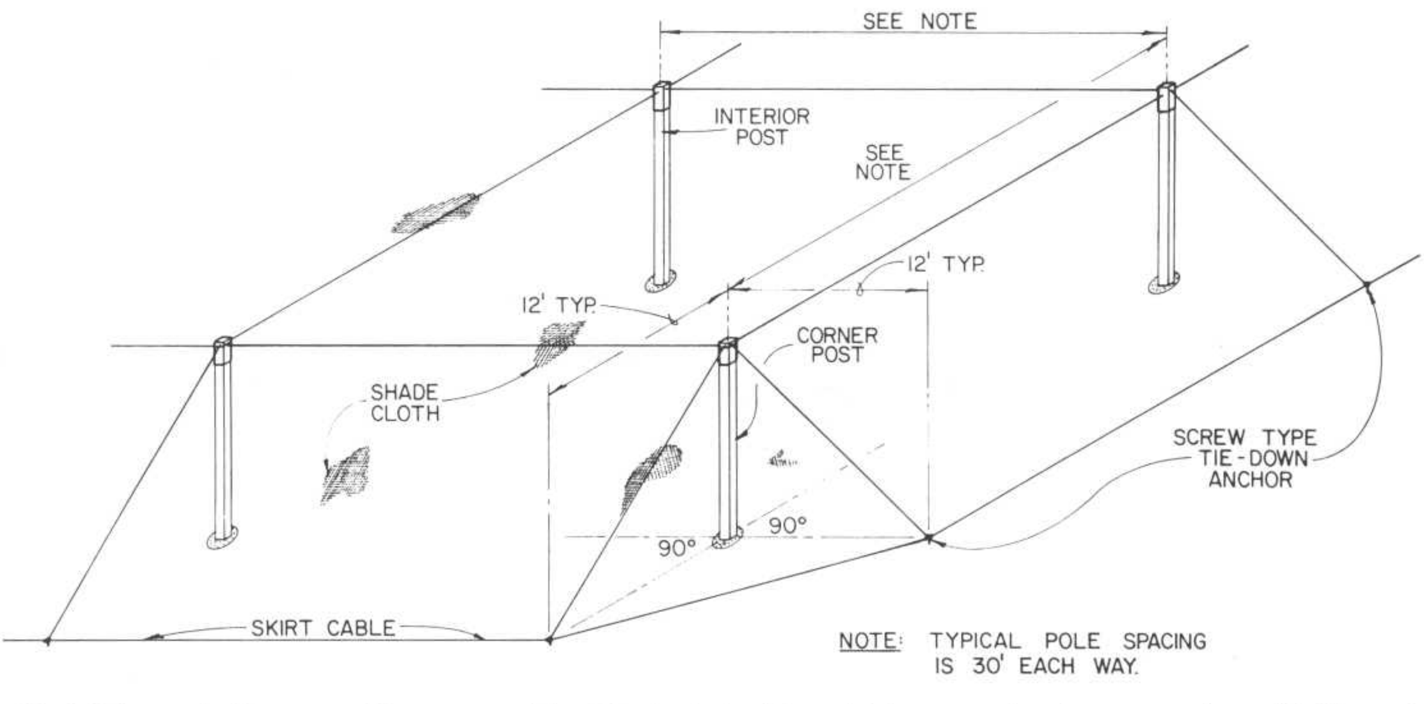

Fig. 1. Column and cable structure. The cover material used for the sloping side panels is less porous than that on top, perhaps solid. Side panels that slope about 45 degrees with respect to the ground level are desirable to minimize the drag that the structure presents to the wind, i.e. an "indian mound" appearance.

(31.15 KN). The cable runs through holes in the tops of the poles and is attached to screw anchors embedded in the ground (Figure 2). Screw anchors perform better in sandy soils than concrete deadmen.

Models. Several models are available to predict the amount of energy that must be added to provide sufficient microclimate modification to escape damage from cold temperatures. Two heating models were reviewed by Martsolf (23) and one of these had been reviewed extensively previously by Turrell (38). These heating models are known as the Crawford Model (11) and the Gerber Model (14). A series of sprinkling models stem from Businger (5). An exception (3) serves as an independent check. Perry, et al. (30, 31) have studied these models and developed one that incorporates the more desirable features of the previous models (29). Although none of these models was developed to evaluate windbreaks, the models are expected to provide indications of how energy requirement increases as a function of wind speed.

Results and Discussion

Construction of covers.

The construction of two orchard cover structures at Blanton Nursery near Tavares, FL, and of three small research structures, one on the main campus of the University of Florida in Gainesville, and the other two at the Horticultural Unit just northwest of Gainesville, have provided some experiences which are summarized as a set of instructions that follow.

The first step in the construction of a cover is to embed the poles. Metal poles will need to be embedded in concrete. Pole placement must be exact and must conform to the size of the cloth panels. Knitted fabrics can be stretched a few inches with difficulty, woven and non-woven fabrics will stretch little, if any.

Once poles are set, the network of cables is formed by stretching cables along the pole tops. Cable pullers are used to pull the cable tight. Guy lines from the outside poles to the anchors in the ground can be adjusted to provide proper tension and alignment.

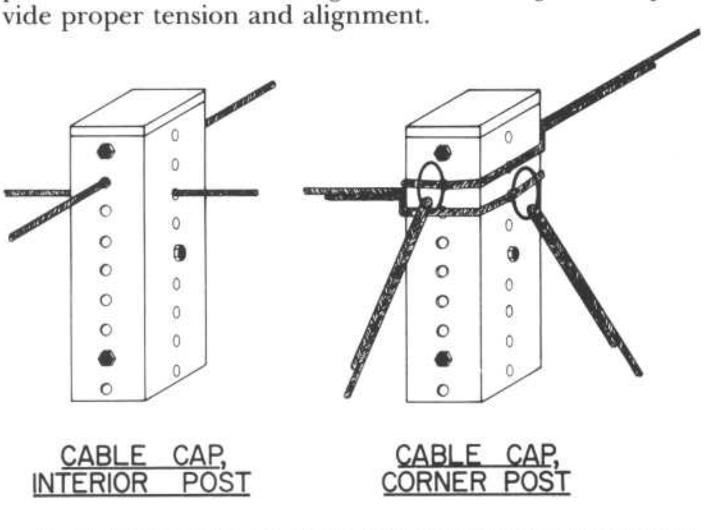

Fig. 2. Details of the top of the columns indicating the manner in which the cables are supported. Cable life is increased by the use of metal sleeves surrounding the cable where it passes through the indicated holes in the column top. The cap on top of each post is beveled and smoothed to cause less stress and wear to the cover material that passes over the top of the column.

The shade cloth is stretched between the cables. Large panels of shade cloth are very difficult to handle even in light breezes, so the cloth should be installed on as still a day as possible. Care should also be taken to avoid letting dew settle on the cloth. The weight of the moisture makes the cloth heavy and difficult to handle. The cloth should be stretched as tightly as possible and should not be left attached to the structure in a loose state. Loose cloth will billow in the wind, exerting sudden large forces on the structure which can tear down the poles, break cables, and rip cloth.

Covers must be maintained in order to achieve their maximum life. The most important maintenance procedure is to periodically tighten the shade cloth. Frayed cables and loose cable clamps should be replaced. Deteriorating poles and loose screw anchors should be replaced.

If heaters are to be used beneath the cover, shields (plume diffusers) must be attached to the top of the heater stacks to avoid a flaring heater burning a hole in the shade cloth. If sprinklers are to be used to coat the shade cloth with ice (8), the structure must be designed to accomodate the additional weight of the ice and the operator must take care that the ice load does not exceed that for which the structure was designed.

Model Predictions.

While preparing the two heating models (11, 14) it was noted that the particular inputs that are needed to verify that the model will produce the same results as the original (11) were missing from publication of the FORTRAN version (23). Table 1 is included to correct this deficiency and to aid future users of Crawford's Model. English units are used in the tables of results because these particular models were programmed to output in English units, those used to make cold protection decisions in the field.

The results of incrementally increasing wind speed in Crawford's Model while holding most of the remaining model inputs constant are shown in Table 1. The inversion strength was permitted to decrease gradually with increasing windspeed as it would be expected to do in nature. The total heat needed to provide the protection specified by Case 1 in Table 1 increased rapidly until approximately 10mph in wind speed was achieved and then began to de-

Table 1. Expected outputs from Crawford's Heating Model (11, 38) when the indicated inputs are used in the published FORTRAN program (23).

	Case 1	Case 2	Case 3
Inputs:			
Inversion strength (deg F)	11.0	6.2	14.5
Convective fraction of the fire size in (BTU)	81,800.	81,800.	74,000.
Tree height ft)	15	15	12
Temperature difference (F)	9	7	4.5
Upwind foliage height (ft)	15	15	12
Orchard area (acres)	15	15	1
Computed by model:			
Temperature, unheated (F)	23	25	27.5
Depth of heated layer (ft)	51	62	43
Outputs (million BTU/acre/hr):			
Advective loss	2.15	2.30	4.40
Induced flow loss	1.25	1.10	1.40
Net radiant loss	1.35	1.30	1.23
Total predicted loss	4.75	4.70	7.03

crease. The depth of the heated layer predicitions are included in Table 2 to demonstrate that the model began to fail above 10mph. Notice that a negative heated layer is shown for 30mph which is clearly a poor prediction of total heat required, less than for a 1mph wind speed.

A table for the Gerber Model (14, 23) is not included because it shows similar results, i.e. relatively realistic estimates below 6 mph and then a leveling off of the heat requirement as 10 mph is approached. At 15 mph Gerber's Model exhibits a discontinuity in the heat requirement. But at the lower wind speeds for which the models were designed, both show very significant reductions in heat requirement for reduced wind speeds.

The results of runs with FROSTPRO (29) for a similar range of wind speeds are shown in Table 3. The humidity was permitted to decrease with increasing wind speed as would be expected in advective freeze situations. Notice that FROSTPRO delivers convincing results up to and including 30 mph winds. However, caution is advised at the higher wind speeds. Although the model provides realistic outputs at high winds, there have been few if any verifications under high wind conditions. The point is that the amount of water that is necessary for protection increases rapidly with increasing wind speed and decreasing humidity.

A box model has been described (24) that would seem to provide a ready tool for computing the flow of energy across the facets of an orchard cover. But predictions from this model are shown to result from the measurement of reduction in wind speed and accompaning changes in temperature and moisture (13) at the facet of the box (orchard cover). Both turbulent and mean flow through the sides and top (4, 25) of the orchard cover are called for by the box model in order to predict the effect that such a cover can be expected to have on the enclosed orchard's temperature and humidity.

Practical considerations

Windbreaks can be expected to decrease the amount of energy that would otherwise have to be expended to provide protection by heating and/or irrigating during windy freezes. Some concern that the frost hazard may be increased by the reduction in cold air drainage during calm, cold conditions (frost) is justified in the case of vertical windbreaks and may be a problem in the case of the overhead cover under some conditions. Windbreaks and covers are not expected to provide sufficient protection to consider their use without supplemental frost protection.

The cost of putting up an artificial wind break increases with its height primarily because the design becomes more complex to avoid collapse in high winds. Wind speed increases logarithmically with height. Higher column strength and heavier guying is required for higher barriers. The tendency to have property lines running north-south and east-west and the advective freeze wind direction to favor the northwest quadrant results in windbreak patterns being squares having horizontal dimensions of about 15 to 20 times the height of the windbreak. Increasing the height of the windbreak to decrease the length of the windbreaks required to protect a given area increases the shade problems on the side of the windbreak opposite the sun. There are some compensating factors in the case of the north-south oriented windbreaks because trees on the north side of an east-west oriented windbreak will have a shade problem. To date, an economical transparent windbreak material is unavailable.

Windbreaks should be porous. Porosities on the order of 50% have been found to be a good compromise of design factors to extend the effect downwind as far as possible. Some questions remain to be answered regarding how the porosity should be varied in the vertical. There is a likelihood that windbreak design will benefit from research of these relationships in the future. Certainly, the most important region of the windbreak to keep porous is the region near the ground. This keeps the area of effect at its maximum during windy periods and avoids some of the tendency for the area to trap cold air during calm periods.

Concerns about 100% porosity of the orchard top in the case of vertical windbreaks have led to research of grove covers. Sloping sides seem appropriate to reduce drag and stress at the leading and following edges of the cover. These sides may need to be solid rather than porous and some questions remain as to how close to the ground they should be if not in contact with the surface. Column and cable construction seems to be the most economical. Cables or straps have been incorporated into the cover material in at least one design.

Whether covers should remain in place continuously or be periodically installed and removed seems to depend on innovative methods of inexpensively manipulating the covers. Currently the expense of taking the cover off and

Table 2. Selected runs of Crawford's Model (11, 38, 23) when the inputs are as those in Case 1 in Table 1 except for those listed. The temperature of the unheated air is 19F and the orchard area is 10 acres.

Inputs:								
Wind speed (mph)	1	2	4	6	10	13	15	30
Inversion (deg F)	8	8	6	4	2.5	1.5	1	0
Outputs: (million BTU/acre/hr):								
Total heat needed	5.5	7.4	11.6	16	17.7	13.8	7.2	1.3
Depth of heated layer	58.2	55.2	54.4	54.5	43.6	32	20.4	–633

Table 3. Selected runs of FROSTPRO (29) inputing critical leaf temperature as 28F, characteristic dimension as 1 inch, and upwind air temperature as 22F.

Inputs:								
Wind speed (mph)	1	2	4	6	10	13	15	30
R. H. (%)	100	95	90	75	60	55	50	50
Output (inch/hr)	0.11	0.17	0.29	0.42	0.57	0.69	0.77	1.11

putting it back presses toward consideration of advantages and disadvantages of a permanently covered orchard. A whole new production scheme may evolve to capitalize on water conservation during droughts, increased pest control by confining spray patterns, decreased wind scar, etc. Given the broad range of cover possibilities, a rather sophisticated model of the covered orchard seems desirable. Observations made within the several covered orchards now or soon to be in existence are expected to be useful as verification material for such a model, and as convincing evidence regarding the value of covering an orchard.

Summary

This is a progress report to growers in response to their question about the potential freeze protection value of windbreaks (including grove covers). Windbreaks and covers can be expected to reduce wind speed during advective freezes and some convincing estimates can be made in the case of vertical windbreaks, both living and artificial. A review of the vertical windbreak situation leaves some doubt in the minds of the reviewers regarding assurance that the combination of a windbreak and conventional frost protection methodology (heating and/or irrigation) will provide a method that can be expected to bring a grove through a freeze such as the recent freeze of January, 1985. Certainly a vertical windbreak can be expected to help, but considerations of how often such windbreaks must be repeated downwind, and of what happens if the wind direction fails to line up perpendicular to the windbreak, has diverted attention to flow through the top of the orchard. This leads to questions about covers, such as those used effectively in the foliage industry.

There can be little doubt that a complete grove cover, even with a porous material on top (to withstand rain and perhaps wind damage), will greatly decrease the amount of energy that must be expended in combination with the cover to provide protection even during freeze events with windspeeds as high as 30 mph. Precisely how much reduction, and whether it is economically feasible, are only two of the questions that remain incompletely answered.

Several covers are in place or in the process of construction. Communication of observations from these field experiments to modeling efforts and results from models back to the field to refine the design, will hopefully continue through the cooperative team effort supported by industry and university resources.

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