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COLD PROTECTION STRATEGIES

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Abstract. **Diversity provides growers with a spectrum of cold protection methodology with which to reduce freeze risk. Protection can be provided at several levels of intensity during radiant frosts and by combinations of two or more methods. During advective freezes, choices seem limited to methods that involve oil burning and windbreaks. Observations were made during the advective freeze night of 22-23 December 1989 in a 5 acre grove on the main campus of the University of Florida using a combination of heat and irrigation. The under-tree irrigation system was started at 4:45 PM using well water of 71°F. Winds averaged in excess of 10 mph at tree level and skies were overcast with temperature falling from near 35°F at 6 PM to 23°F just after dawn. The irrigation heater was operated during 2 periods of approximately 1 hour each with an hour between the two. Temperatures 1 foot to the SE of 90° nozzles averaged 0.86°F and 0.92°F above the temperatures averaged for both the previous hour and the subsequent hour collectively. Water temperature was increased by the heater to 110°F. This doubled the sensible heat delivered to nozzles, an additional 1.8 million BTU/hr, which increased the vapor pressure almost 4 fold.**

Freezes are a characteristic of Florida's climate due to its location on the SE corner of a relatively flat continent, frequently snow covered in winter (1, 24, 33). Invasion of cold and dry air, unimpeded and unmodified, down the axis of the state resulted in advective freezes in 3 out of 5 major cold periods in the recent decade. There is no comfort in potential global warming (e.g. 22). Freezes are credited with the movement of the citrus industry southward on the peninsula. Their effect on production is visible in the graph shown as Fig. 1a. The mean period between 22 major Florida freezes has been 10.6 years but the variation in the period lengths is quite large (as indicated by the 10.4 years S. D. from the mean in Fig. 1b). The period length seems to have decreased in the recent century but that may be due to increased documentation. The period between major freezes is quite variable and this is a key point in the development of strategies based on diversity (9, 30).

The purpose of this paper is to suggest that there are numerous methods of providing at least partial protection from cold damage. The proposed strategy is to consider as many of these methods as is practical. Evidence of renewed interest in such a diversity of methodology took the form of a workshop in Gainesville in the Spring of 1990 and a special section during the Citrus Institute during the Fall of 1990 (21, 30, 31, 13, 34). The strategies recommended at those meetings involved the implementation of more than one of these methods or combinations of methods (28). Thus the reason for the use of the plural, i.e. strategies, as the subject of this paper.

Strategies may be envisioned with the diagram in Fig. 2 in mind. The total area is simplified to a square. Portions of that square represent areas in which several levels of protection from freezes are to be developed (8, 7, 30). Since there is great uncertainty about when the next major freeze will occur, one of the areas, rather arbitrarily set at 50%, is to receive either no or only minimal resources for cold protection. This is the high risk portion. During a period in which there is no serious freeze this portion should be as competitive in production cost as any neighboring unit. This is the low cost portion.

On the lower right-hand corner in Fig. 2, occupying only 10% of the total area for example, is the block in

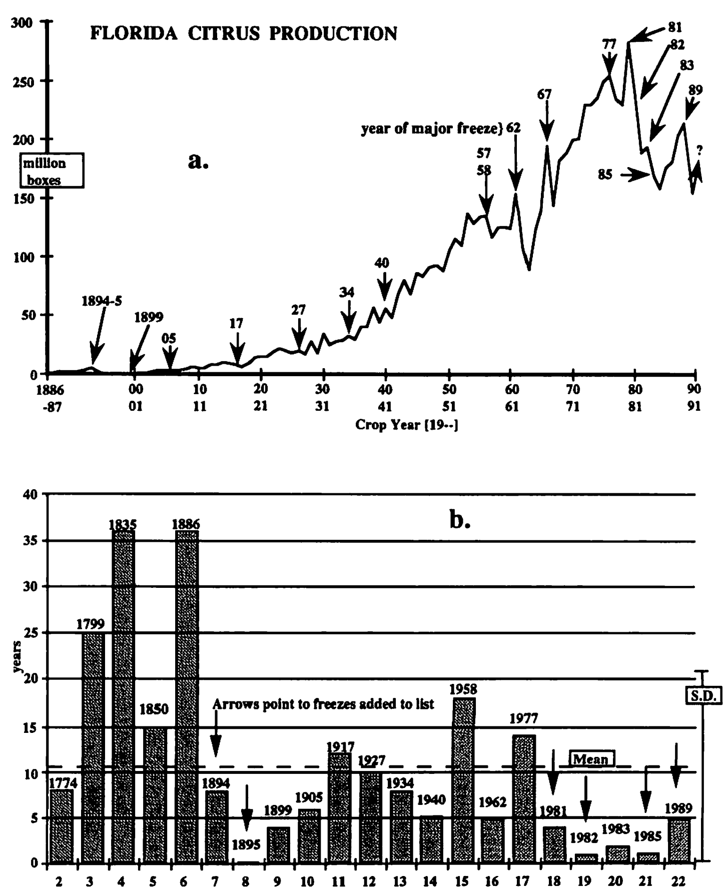

Fig. 1 (a) The plot of production records (6) provides a convincing description of the effect of the major freezes on production. (b) Time periods between major freezes (four freezes added before '84 and two after '84 to those listed in (23); indicated by arrows in section). The dashed line shows the mean of 10.6 years and the vertical bar shows a S.D. of 10.4 years.

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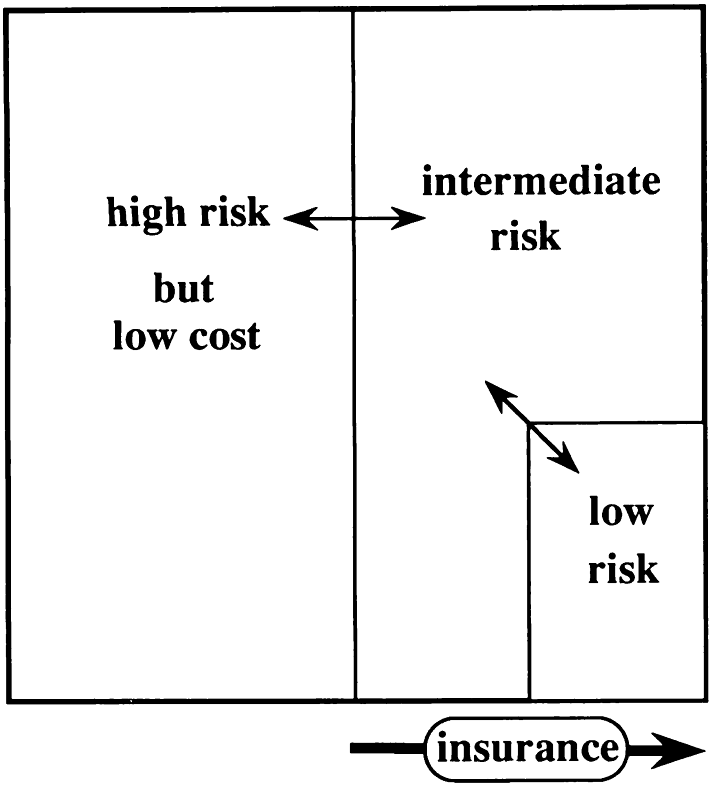

Fig. 2. Graphical representation of the partitioning of risk of cold damage between that portion of the production unit that is operated at high freeze risk but at low cost versus other portions that are operated at some intermediate level and that high insurance block that is intended to provide a base from which the production unit can again grow if there is a major devastating freeze. The double arrows indicate that the judgment involved in the partitioning of this risk is not only a critical requirement of the selection of protection methodology for the intermediate and low risk holdings but also in the portion of the holdings to handle under each of the levels of protection. The insurance analog of cold protection methodology is shown to increase from left to right in the diagram.

which the manager implements every method he finds likely to bring that block through the worst freeze in Florida history. This will cost money and it will require expert judgment, and likely some research. In between these two extremes there is at least one area in which some intermediate protective steps are taken. As the sophistication of these strategies develop it is likely that this intermediate area will subdivide into additional areas and expand into the high risk area and perhaps even into the low risk so that the various levels of intermediate risk occupy much more than 40% of the total area. Ford, et al. (8) document the cost of taking the risk when a freeze occurs.

Two examples are provided to demonstrate that the detail level is important if not crucial to successful implementation of the strategies. One example involves the use of the helicopter and the other compares a heated irrigation system with a pipeline heating system. The main body of the paper documents experiences with a heated irrigation system in Gainesville during the Christmas '89 freeze.

Helicopter feedback system. The availability of helicopters during frosts is increasing. There is little competition for other tasks at that time. Fig. 3 describes a method in which the effect of the helicopter's downwash on temperature is fed back to the pilot. A fan increases the sensitivity of the thermostat to changes in air temperature when the

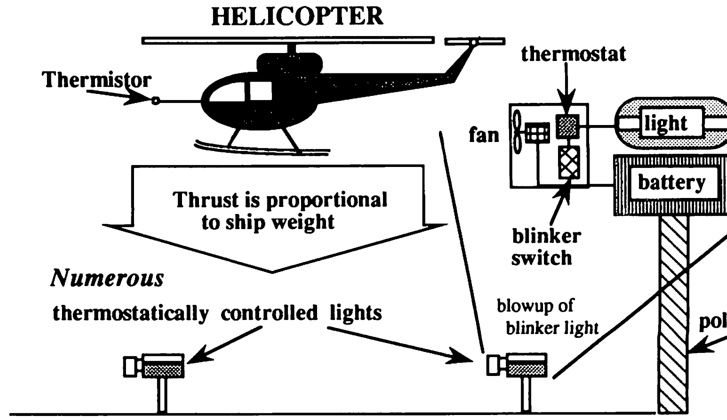

Fig. 3. An intermediate level frost protection program seems to be highly dependent on small details such as those illustrated in the case of the effect of a helicopter on the temperatures near the ground. A blow-up of the modified caution light system shows how a temperature sensor can modify the blinking rate of the light as a function of its temperature so that the pilot can see the effect that his machine is having on the temperatures at crop level. If the light system can be made to be both extensive and sensitive it is likely that the patterns that the pilot flies will be modified by trial to the point that the effectiveness of the method is maximized.

helicopter's jet is not present. The effectiveness of the method depends on a large number of temperature sensitive lights. The pilot is likely to learn to fly patterns that keep the number of blinking lights to a minimum if he has confidence in the temperature sensing system. If identification of the extent of the acreage to be protected is to be accomplished by the lights as well, the frequency of the

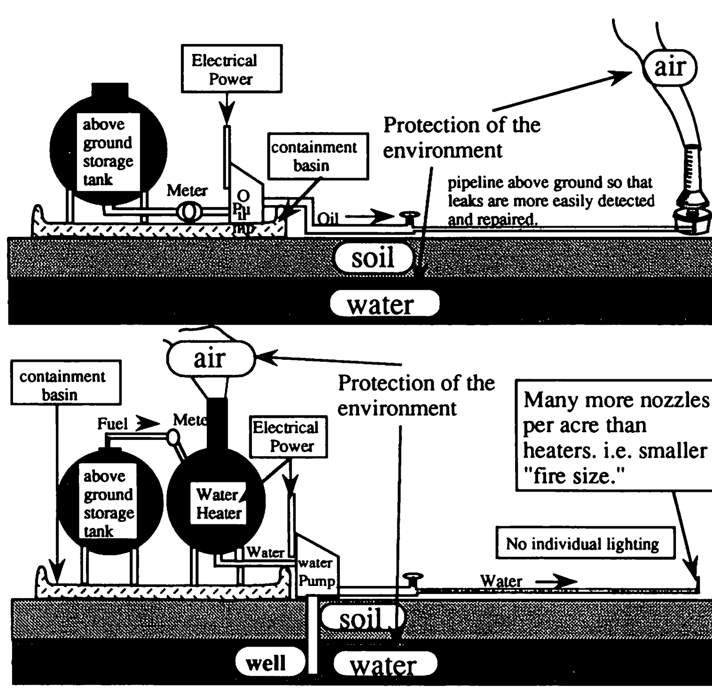

Fig. 4. Characteristics of heated irrigation (bottom) can be viewed as a series of improvements over the pipeline heating system (top) which in turn evolved from the free-standing orchard heating systems as a partial cure for the refueling labor problem of that system. Electrical power requirement of both systems is indicated in context with the experience by many during the recent freezes that electrical service cannot be relied upon during major freezes. It seems advisable to consider diesel pumps or generators to reduce this risk.

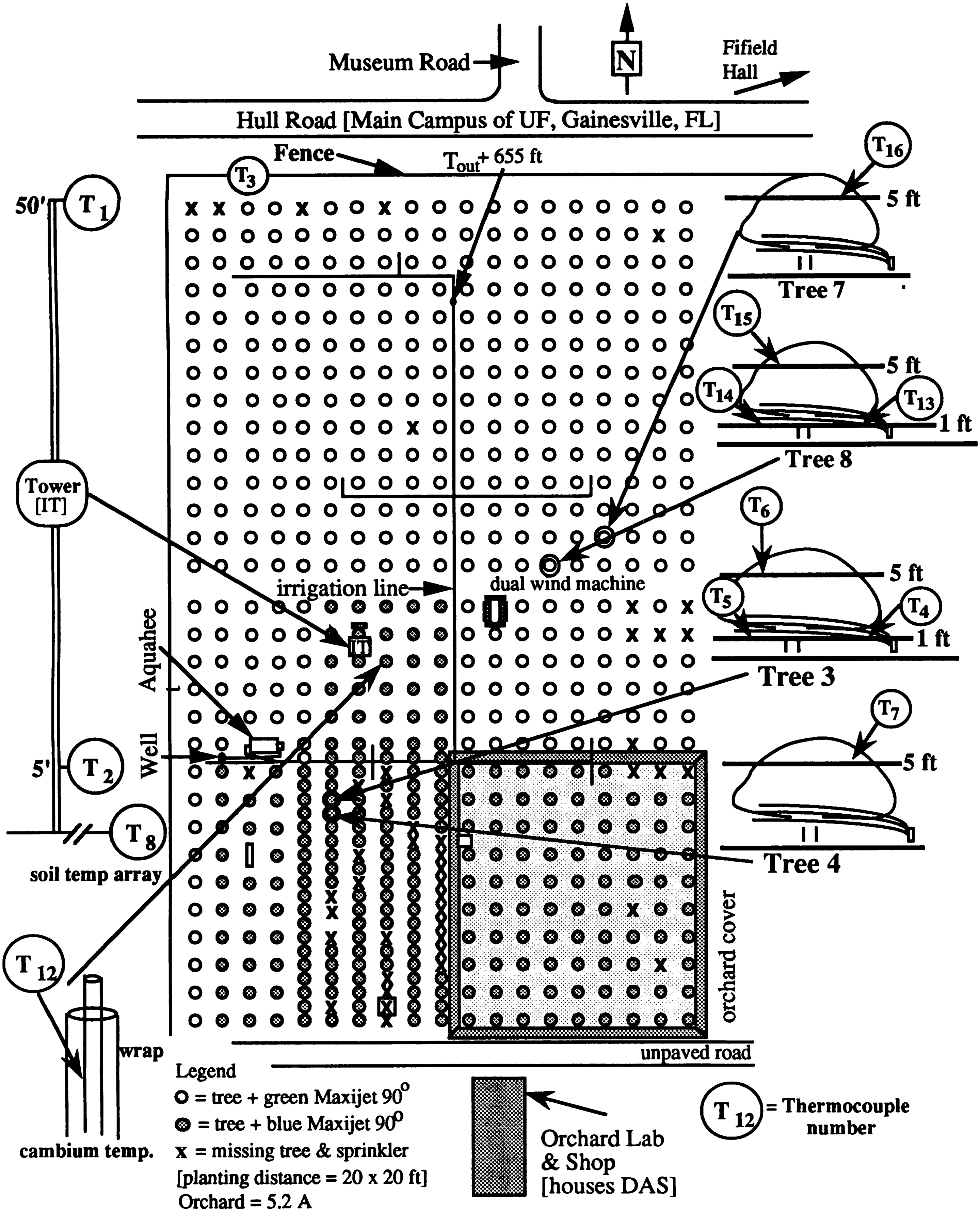

Fig. 5. Map of the orchard served by the irrigation heater showing the relative location of the well, the irrigation main line, thermocouples by number at the inversion tower [IT] and within trees, as well as the orchard lab which housed the data acquisition system.

blinking can be made to indicate the temperature so that the pilot's object becomes one of keeping the blinking frequency as high as possible. The lights are placed at the level of the largest concentration of fruit and so that their signal is not blocked by the canopies when viewed from a distance.

Heated Irrigation System Analog. The preponderance of recent advective freezes, 1983, 1985, 1989, has rekindled interest in heating for protection as one of the few methods that has proved to be at least somewhat effective in such conditions (31, 34). However, all the well known problems that accompany heating (21) seem to make the combination of heating and irrigation a more viable solution to some of these problems (Fig. 4; 19,20). The oil storage and pipelines can be limited to a containment basin. The number of outlets for the heat, i.e. the number of small fires, if you will, can be increased without adding to the lighting problem. Ignition is now a central problem but if the singular nozzle fails, the entire heating portion of the system fails. The environmental concerns can be diminished because it is more likely that a centralized, singular, burner can be designed and operated in such a way that air pollution can be minimized, and certainly the soil and water can be protected from oil spills by a required containment basin. The centralized control and refueling that made the pipeline system desirable is also a characteristic of the irrigation heater method but there are problems that attend any such systems that depend on electricity as an input. Until there is more assurance that power suppliers can be reliable on freeze nights, irrigation pumps and the associated water heater should have diesel pumps and/or generators for reliability.

Materials and Methods

Irrigation system. A well with a 5 hp electric submersible pump served a 5.2 acre grove with trees ranging in age from 1 to 11 years at the University of Florida in Gainesville (Fig. 5). There was one sprinkler per tree. Flow rate calculation is summarized in Table 1. During the night of 22-23 Dec. 1989, 213 blue and 302 green nozzles were operating at approximately 20 psi. The sprinklers were Maxijets with 90° caps, positioned NWN of the tree trunks about 3 ft and angled upward so that the fan shaped sprinkling pattern struck the tree in the scaffold branches just above the trunk wrap. All but the very largest trees were wrapped with a R-11 fiberglass tree wrap.

Irrigation water heater. The components of the irrigation heater have been diagrammed in a previous report (Fig. 2 in 18). Only two of the indicated 3 safety interlocks were functional on 23 Dec. 1990. The high stack temperature interlock had been circumvented because of previous malfunction leaving the low water pressure and the high water temperature interlocks in operation. Both of these may have failed under the ice cover from the freezing rain that coated the heater prior to its use during the afternoon and evening of 23 Dec. Although the heater was burning at idle from 4:30 PM until 7:24 PM that evening those switches may not have thawed.

Temperature measurement. The same 24 AWG, copper-constantan thermocouple loop technique described previously (18) was used and their relative locations in the grove are indicated in Fig. 5, and their relative location within the irrigation lines are indicated at the top of Fig. 8. The method of taping the thermocouple loops to leaves has been previously diagrammed and described (18).

Wind speed sensing. Thornthwaite cup anemometers and the manner in which they are utilized were described previously (16).

Data acquisition and reduction system (DAS). The DAS was the same as that described previously (19, 18, 16) except for two changes. One is that the data acquisition system was housed in a newly completed orchard lab (location shown in Fig. 5). The second is that the data were moved from the Hewlett-Packard minicomputer hard disk to disks on an adjacent Macintosh Plus and from there by floppy to a Macintosh IIx in which the analyses were developed and through which the figures and charts were printed.

Results and Discussion

The Christmas 1989 Freeze. A minimum temperature of 14°F near dawn on 24 Dec. was the same minimum reported at the Agronomy Farm northwest of Gainesville because the wind was still high enough to mix the air sufficiently that most minimums reported were the same for that morning (Fig. 6). The same explanation seems to fit the following morning, i.e. 25 Dec., when the minimum recorded by a thermocouple at location T_3 agreed exactly again (16°F) with that reported at the UF Agronomy Farm, the official climate station.

Nozzle clogging can be a problem. From 3% to 19% of the nozzles became clogged sometime during the night of 22-23 Dec. 1989, as found by mapping the grove the following

Table 1. Flow rate as computed from observed clogged nozzles on the morning of 23 Dec. 1989. Irrigation system pressure was 15 psi.

Block Name	Total Nozzles	Color Code	Number Clogged	% Clogged	Operating Nozzles	Rate (gph) per nozzle	Rate (gph) Total
SW	115	blue	3.0	3	112	9.3	1042
SE	85	blue	16.5	19	67	9.3	623
CE	75	green	4.0	5	71	13.7	973
CW	35	blue	1.0	3	34	9.3	316
CW	41	green	1.0	2	40	13.7	548
NW	63	green	2.5	4	60	13.7	822
NE	48	green	3.0	6	45	13.7	617
NB	52	green	7.0	13	45	13.7	617
WB	44	green	3.0	7	41	13.7	562
Totals:	558		41.0	7	515		6118

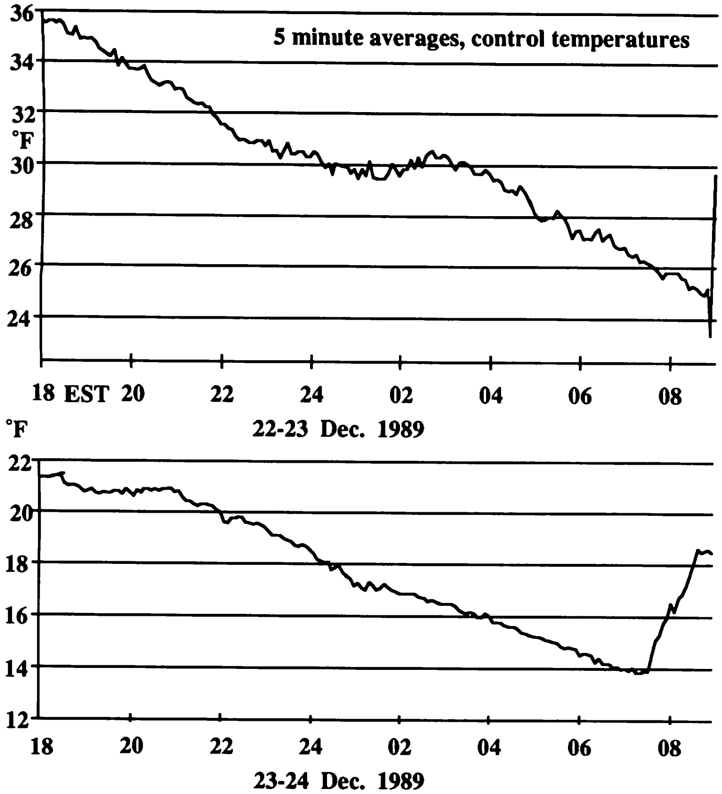

Fig. 6. A plot of 5-minute averages of the temperatures sensed by a thermocouple located at T_3 (Fig. 5) for the first two of the three nights of the advective freeze. Time averaging permits computer plotting of the night as a single figure but smooths out some of the detail of the temperature trace. n = 5.

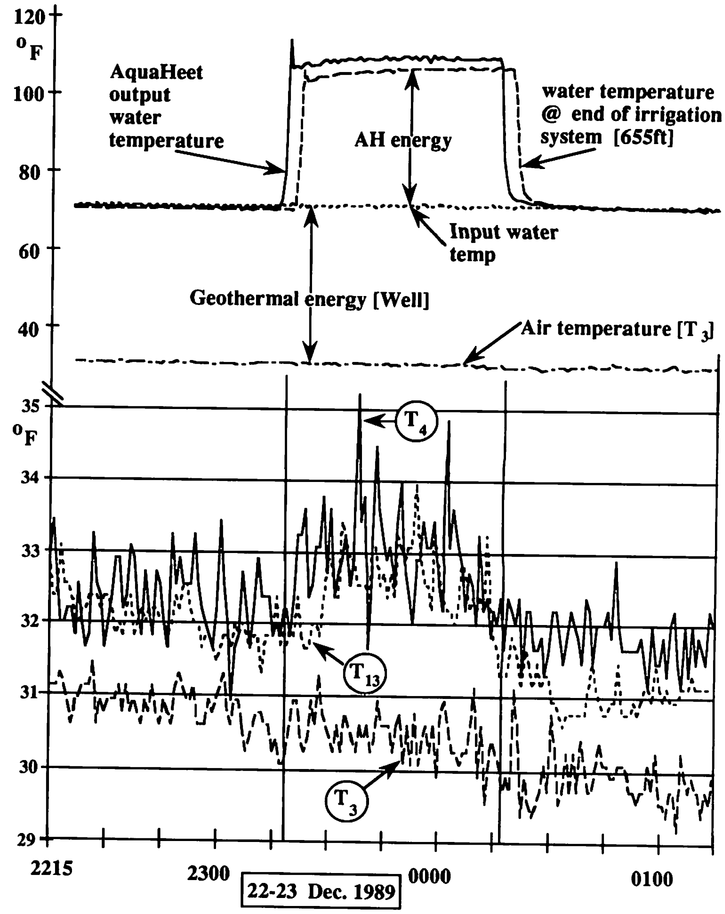

Fig. 7. A 3-hour period in which the irrigation heater during the middle hour added about 36°F to the water temperature to that of the water coming from the well (which was 71°F and about 41°F above the ambient air temperature). This almost doubled the sensible heat that the water carried to the sprinkler nozzles (upper portion of the graph). The temperature scale is expanded in the lower portion to show the detail of the temperature effect on thermocouples 1 foot from the nozzle (see Fig. 5 for sensor location and Table 2 for an analysis of the differences, barely discernible in this view).

morning (Table 1). The only filter in the system was one adjacent to the well head which placed it in front of the water heater (between Well and T_{in} in Fig. 8a). A second filter has since been installed at the output of the water heater which has been found to be a source of rust flakes which appeared to have been the main identifiable clogging agent. Since the heater manufacturer recommends that irrigation water flow through the heater coils anytime that the irrigation system is used to reduce oxidation in the heater, the additional rust filter at the heater output would seem to be advisable in every case.

Heated irrigation effect. The irrigation heater was fired during the middle hour of a three hour period beginning at 10:15 PM, 22 Dec. 1989, when the temperatures in the orchard were very near freezing but ice had not begun to accumulate in the fringe of the sprinkler patterns. No effect from the heating was noted in the thermocouple sensings except for the two closest to the sprinklers, T_4 and T_{13} (Fig. 7). Their traces are plotted on the same line as the water temperature traces showing the extent to which the irrigation heater increased the water temperature (Fig. 7). The one-minute temperature data tended to fluctuate rather wildly even before the water heater was fired. Some increase in temperature is apparent and some increase in the fluctuation may also be apparent in Fig. 7 but it takes *an analysis* of those data shown in Table 2 to realize that there was an average rise in temperature of about 0.9°F. But temperature fluctuations were much larger as indicated by standard deviations which were 1.7 and 2 times larger than those when the heater was not fired. This would seem to suggest that most of the additional heat in the smaller water droplets was lost through evaporation. It is concluded that most of the effect of the increased water temperature has been dissipated by increased evaporation (10).

Enhanced evaporation produces additional water vapor. Water vapor is buoyant in air. Only the larger droplets would seem to be arriving at the thermocouple. Their elevated temperature would increase the temperature fluctuations. The relatively small temperature increase may not mean that the irrigation heater is having but a very small effect on the orchard environment. The increased evaporation may be enhancing the latent heat transfer mechanism described previously (15, 19) in which condensation above the level of the sprinkler's droplet pattern is providing the protection that has been observed (4, 25, 3, 5, 26, 29, 32, 12, 27, 2).

Increasing the water temperature to 110°F doubled the sensible heat delivered to nozzles by adding 1.8 million BTU/hr (using the 6,118 gph rate computed in Table 1, multiply by 1 BTU/lb/°F, by 8.33 lbgal, and by 35.7°F) to the irrigation stream. This additional heat increased the vapor pressure almost 4 fold (11).

Table 2. Average temperatures, differences in temperatures, and the standard deviations (SD) for T_4 and T_{13} (see Fig. 7) for the indicated time periods on 22-23 Dec. 1989.

T_4 [°F]		T_{13} [°F]		Time [EST]		
Average	SD	Average	SD	Start	End	Comment
32.3	0.52	32.1	0.33	10:15P	11:15P	Before heated period
32.9	0.73	32.5	0.58	11:22P	12:16A	Irrigation heater on
31.8	0.36	31.0	0.25	12:20A	1:15A	Following heated period
0.86	0.29	0.92	0.29			Averaged differences

Irrigation heater blows out. Changes in temperature which occurred just before, during and shortly after the irrigation heater overheated are shown in Fig. 8. Apparently steam was produced and sufficient pressure increase to blow out the PVC irrigation line. One point is that irrigation systems lose their protection value within minutes of an interruption (Fig. 8c). It is suspected that the pump stopped in this case from either a clogged filter or ice formation in the exposed pressure switch that controlled the pump or a combination of the two. The second point is that proper operation of the automatic shut down devices on the water heater is crucial to the avoidance of a repeat of this experiment. It would seem that in addition to all the other interlocks one should devise a control that causes the water heater fuel pump to stop when the pump at the well stops and such an interconnection is planned for future experiments in which the water heater is used. This point is that the detail of the methodology seems crtitical to its success.

Both the helicopter temperature feedback system and the heated irrigation system discussions demonstrate the crucial roles played by rather minute details in the methodology. This brings up a serious problem in the recommendation that growers diversify their cold protection methods. Time becomes a limiting factor: i.e., there is likely to be sufficient time to carry diversification of methodology to some middle point. So the extent to which method diversification can be carried is limited by the time necessary to the planning and implementation of the various methods and combinations of methods (e.g. 17, 14).

Summary. It is unlikely that there is now, or has been, a best method of cold protection that should be recommended to the industry as a whole. It seems more likely that there are methods and combinations of methods that fit particular sites and management levels which are uniquely fitted to those sites by methodical consideration of the risk involved. So the general recommendation is to diversify. The strategy is to develop a series of strategies.

Two examples of cold protection methodology were provided as support for the multiple strategy statement. The irrigation heater was described in sufficient detail to provide evidence that it is in the attention to detail that the method becomes reliable and effective. So it also seems likely that management of a number of different cold protection schemes may consume an excessive amount of time forcing the manager to make some strategic choices between the methods available to him that seem to suit his location.

There seems to be a need for additional investigation of the mechanism through which under-tree and in-tree irrigation systems provide protection. Rieger (1989) reviewed papers describing progress in this direction. It would appear that the droplet size distribution, the sprinkler's pattern and its effect on ice accumulation, and on evaporation all play a much more complex role in the provision of protection than may have been expected. The role of water temperature in this process seems far from understood, at least from this author's vantage point.

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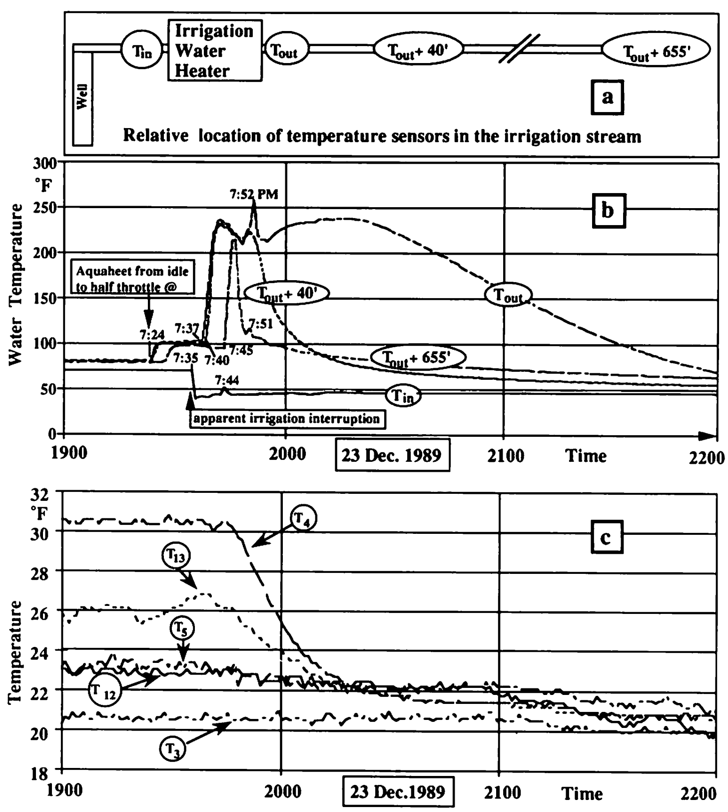

Fig. 8. Section (a) plots the relative positions of thermocouples sensing water temperature in the irrigation system. Section (b) was developed to determine the cause of a blow out of the mainline of the irrigation system shortly before 2000. The irrigation heater's fuel pump was increased from idle to half-throttle at 1924 and this shows up as rise in the output water temperatures to about 100°F. Irrigation flow appears to have ceased at 1935 (the abrupt fall in input water temperature has been observed at other times when the pump at the well has been turned off). Within 2 minutes the remaining water within the irrigation heater rises to the steam point and beyond indicating pressure rise as well and subsequent abrupt changes in temperature may indicate various stages of the blow out. Several safety switches failed. The irrigation heater was not badly damaged and the damage to plastic mainline was relatively easily repaired but not in time to save the orchard. The relatively short time, under windy conditions, in which a system must be restarted is indicated by the rapid fall in the temperature of several of the sensors (c). See Fig. 5 for sensor location.

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OBSERVATIONS ON THE SPREAD OF BLIGHT IN MATURE ORANGE GROVES ON THE RIDGE

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Abstract. **A series of aerial photographs taken by the Florida Agricultural Statistics Service graphically shows the pattern of the spread for blight in two groves over a 12-year period. The groves are located on extremely sandy ridge soil, planted to very few trees per acre, by today's standards. They received regular grove care but were essentially non-irrigated. Zinc analysis from the wood of blighted and healthy trees confirmed that blight was the problem in these groves.**

At Frostproof, blight first developed in two areas on opposite edges of the grove. In a period of 12 years, blight spread from these two areas to encompass approximately 90% of the grove. At DeSoto City, blight first developed in scattered trees along opposite sides of the grove and rapidly spread toward the center.

In Florida, citrus blight is the most serious disease that we have at this time. Blight was reported in Florida 100 years ago (11) and it was the primary reason Dr. W. T. Swingle and Dr. H. J. Webber established a U.S.D.A. laboratory in Eustis in 1892 (13). In the past decade, blight or a blight-like disease has been reported in Brazil, Argentina, Australia, Uruguay, Cuba and South Africa (18).

General Observations on Citrus Blight

It is my belief that the individual tree symptoms of blight have not changed over the years, but the pattern of spread was much easier to see in the 1960's than it is today. In the early days before diagnostic tests for blight were developed, such as water flow (4), zinc accumulation in the wood (12), water-soluble phenolics (16) and xylem amorphous plugs (2, 6, 15, 17), visual symptoms were used. This is not ideal from a scientific point of view, but few scientists who have worked with blight have trouble identifying it by visual symptoms (8, 11, 18).

During the late 1960's and 1970's the problem was referred to as sandhill decline, young tree decline or rough lemon decline, to name a few. Eventually, it was agreed that the problems had already been described and called blight in the late 1890's (11).