1935, which had a long and productive history until its end in
1996. Growers used cultural practices, site selection, wood, and later oil fueled fires, wind machines, and various irrigation practices to protect their trees from cold damage. A few experimented with grove covers, wind breaks, combinations (e.g., heated irrigation), but the tendency was to ignore the remote possibility. Networking thermometer readings, the advent of electronic communications, automated weather stations, and thermal maps from satellite images have helped growers pick sites least likely to be as cold as other sites during freezes. Even though freezes have common characteristics, they are also unique in other ways. The hope that most events would be radiative in nature (clear, calm, and dry) was dashed, but undertree sprinklers added protection even in advective freezes. There can be little hope Global Warming will decrease the number or the severity of Florida Freezes. Quite the contrary, for some predict that both the frequency and the severity will increase as Global Warming becomes more apparent. The experience of the past century suggests growers will continue to tell themselves that freezes are extremely unusual, especially in South Florida. The responsibility for turning on the irrigation system is likely to be delegated more and more often. The key seems to be in knowing when the rare event could have a distinct possibility of happening. FAWN, and perhaps DISC, show promise in this regard.

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**WHAT FREEZES OF THE PAST CENTURY TAUGHT US**


As the end of the 20th Century approaches, there is a temptation to see it as an opportunity to review what seems to have been learned by growers’ experiences with Florida freezes. The report focus is on characteristics of the freezes and what horticulturists have proposed to protect their crops. In most cases, the observation is so obvious that it is mentioned only because it may otherwise be overlooked by some of the audience. In other cases, the matter seems to have been overlooked so extensively that an argument is made with the hope that this will change. Certainly change is the key characteristic of the methodology that producers have used to protect their production, but the variability of the freezes is so great it seems folly to expect any great change in either their frequency or intensity. It rather seems sufficient to again recognize the high variability in both timing and space.

Materials and Methods

Severity and frequency. Analyses suffer from assumptions that all freezes are alike and can simply be counted. It is now realized that each freeze varied extensively from others. They vary especially in the geographically distribution of their impact over the industry or at least portions of the industry. The method leans heavily on a convincing analysis of the effect of the freezes on horticulture as shown in a recently published review (Attaway, 1997) of effect of Florida freezes on citrus production and producers.

Attaway (1997) identified five impact freezes in two centuries: 1835, 1894-95, 1962, 1983-85, and 1989. High impact freezes are indeed rare events. Notice that Attaway combines freezes when they are close together for their effect on the industry. Even if the two freezes lumped in the 19th Century and the two lumped in the 20th Century are considered separately, it increases the number of high impact freezes to only seven. What is more apparent is that the freezes are not distributed evenly in time. There is an obvious tendency to cluster, or to clump in time, for example, the recent clump of freezes in the 1980’s.

Effect on yield. Florida citrus yield is frequently plotted versus time. Freeze dates in Tables 1 and 2 stand out as dramatic drops in yield especially in the latter part of the graph where total yields grew rapidly (Fig. 1).

Protection methodology. Florida Freezes reveal the methods growers use to combat the freezes. The literature on the subject is voluminous (Rieger, 1989; Martsolf, 1992b). Attaway (1997) mentions the methodology in the context of the trauma to the growers. Perry (1998) won an ASHS award for boiling down rich diversity of frost protection to a brief summary. By far the most thorough treatment of the subject is by Turrell (1973). It is hard to ignore the rather extensive change in the methods growers have used to protect their groves. Some of this diversity is depicted in Figure 2.

Results and Discussion

Freezes as rare events. If the periods between freezes are combined to one approximating the 20th century and if one treats the combination ‘83-85 freeze as one occurring on the first date, the periods between the four major freezes ranges from 6 to 68 years with an average return period of 31.7 plus or minus 32.3 years (Table 1). Such a return period is rather useless as indicated by the large magnitude of the standard deviation. What is clear is that the freezes have tended to cluster in time. Put the ’77 Freeze in the cluster with ‘81, ‘82, ‘83, and ‘85 and it seems to rival, if not eclipse, the cluster which started in the winter of 1894-95 and continued through 1906. Table 2 was created by adding the “near im-

<table>
<thead>
<tr>
<th>Dates</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec. 29, 1894</td>
<td>68.0</td>
</tr>
<tr>
<td>Dec. 13, 1962</td>
<td>21.0</td>
</tr>
<tr>
<td>Dec. 25, 1983</td>
<td>6.0</td>
</tr>
<tr>
<td>Average</td>
<td>31.7</td>
</tr>
<tr>
<td>Standard Dev.</td>
<td>32.3</td>
</tr>
</tbody>
</table>

Table 1. List of “impact” freezes (Attaway, 1997) identified to the list in order to develop a feel for the distribution of freezes in general. The standard deviation of 7.7 years is found larger than the average period between freezes of 6.9 years.

The most obvious characteristic of Florida freezes seems to be their refusal to follow a set of generalizations. Not only do they cluster in time, defeating an otherwise useful determination of an expected return period (Tables 1 and 2), but no two of them are exactly alike. The intensity of any particular freeze varies extensively not only from one section of the industry to another, but often over much shorter distances. Satellite views of the freezes in the late 70’s and through the 80’s demonstrate the diverse nature of the freezes (Martsolf, 1994).

Freezes vary extensively in space. Horticulturists have practiced the art of good site selection for centuries, depending heavily on the water analogy of how cold air drains forming lakes behind dams and in basins (Krezdorn and Martsolf, 1984). As turbulent transfer of heat became better understood, the mixing driven by the cold air flow down slope was seen as a natural wind machine, creating a “banana belt” on the slope during calm and clear frosts. In other locations and in other freezes, hilltops suffered drying injury from the cold dry winds bringing the arctic air mass into the State. These site selection rules seem better known for a local case than for the intermediate and global scales. Satellite maps (e.g., Martsolf et al., 1984) of temperatures at the surface during freezes are useful but are still too coarse in resolution to attract grower interest. Smaller scale features are now incorporated in forecasting models (Reiter et al., Proc. Fla. State Hort. Soc. 112: 1999.
The data show (Tables 1 and 2) that only rarely does the atmosphere arrive at a particular configuration in which arctic air arrives so far south, but it can occur. There are no east/west- oriented mountain ranges between Florida and the Arctic to impede the flow of the dense cold air southward. This geographical situation can be expected to change so slowly that it can be treated as a constant. Florida will continue to be vulnerable to freezes by its location relative to the rest of the North American continent.

Economists agree rare events are frequently ignored in planning, and with reason. The likelihood of a return on an investment committed solely to protection from a rare event is low. However, if resources are at hand, such as irrigation systems for drought control, their use in cold protection will be seen as a bonus. Attaway (1997, 1999) provides colorful descriptions of the diversity of the manner in which agriculturists have dwelt with rare events.

Diversity of Methodology. A quick glance at Figure 2 should convince the reader that there has been a broad diversity of methodology employed by some growers during the century. While there are suggestions that some methods evolved from others, it seems more likely that some growers simply used resources at hand, e.g., wood available from clearing forests for grove sites. More successes than failures are reported when a method was used at the appropriate time and could be sustained throughout the cold period. Combinations of methods are especially successful. Most failures reported are due to surprise, or when a method once started could not be sustained. This is especially true in the case of the use of sprinklers.

The literature on the subject leaves one with an impression that all growers have used rather complex protection methodology. Estimates of the fraction of the total grower population practicing these various methodologies are missing through all but the last decade. Only recently have surveys revealed a surprisingly large portion (over 1) of growers responding by using their irrigation systems for cold protection (Ferguson and Israel, 1999; 1998). This now seems the exception that proves the rule. Unless there are resources available for inexpensive freeze protection, the possibility of a freeze seems ignored. Major freezes are rare events.

Most growers through the century seem to have been the silent majority. However, most utilized the recommended cultural practices (Krezdorn and Martzolf, 1984) which could be called the passive measures. Good site selection has long been a key element of horticulture. Cold air drainage was held in high regard in this process except, of course, on the East Coast where the proximity of the warm Gulf Stream was expected to compensate. In the latter part of the century, the freezes (and perhaps other pressures, but the freezes get the credit) drove more and more of the groves from the sites with good cold air drainage onto the flatwoods of southwest Florida. Attaway displays a table (page 334 in Attaway, 1999) in which the center of the industry in 1934 is approximately at Haines City, and by 1996 is ten miles south of Lake Placid.

It seems to have never been convincing to many growers that they could justify the expense or provide the skill and management that current cold protection methods demanded. Apparently, only a few at any one time became evangelists for a protection methodology. Some refined these methods to fine degrees and reported rather nostalgic experiences in the defeat of the cold. These cases now seem to have been rather isolated. The silent majority ignored both the possibilities of a freeze and the evangelists advocating control measures.

But this seemed to change during the 80’s when young trees were rather universally protected with a combination of wraps and...
90° sprinklers (Jackson and Davies, 1999). The overhead sprinkling models featured the possibility that evaporation could easily overpower the heat released as liquid water crystallized to ice. The result would be the cooling systems observed during the advective freeze of 1962 when a number of the new overhead systems were used for the first time in a freeze of this intensity. Some claim it was the largest cold protection experiment ever attempted, and the results were convincing. The sprinkling models were designed to explain why this happened. They did that well. But they failed to predict the protection that undertree sprinklers provided adult groves, especially during advective freezes. The overtree models were designed to warn the growers to refrain from running irrigation during advective freezes. During growers ran their systems anyway and proved the undertree sprinkling case doesn’t obey the overtree models (Oswalt and Parsons, 1981). Some feel the models should be refined to include the mixing that results from a portion of the evaporated water condensing within the canopy (Martsolf, 1992a). Hopefully rules acceptable to growers serving on the DISC advisory committees will be incorporated into DISC as it develops (Lin et al., 1999).

Frost/freeze prediction. Most frost and freeze protection techniques depend heavily on accurate predictions. FAWN (fawn.if-as.ufl.edu) was developed largely on the recognition of this rule (Gardner, 1999). There is little hope among the experts that global warming will decrease the frequency and/or intensity of future freezes. While some claim there is a clear and convincing relationship between the frequency of freezes and/or their severity and the El Niño oscillation, it has yet to show up in works known to this author (Hansen et al., 1998a; 1998b; 1999a; 1999b).

Summary

Freezes are likely to continue to occur in clusters, perhaps with increased intensity and frequency. The question is where! Forecasting when and where freezes will occur will improve, but with a lot more work and consequently time. Freezes will continue to be rare events, and it seems likely that producers will continue to treat them as such, even more so during this age of accountability. Methods to protect the trees (and perhaps the fruit) will continue to be developed in profusion even though it seems at any one time the ultimate method has been discovered. Good site selection will continue to be the method of choice, but with scales ranging from local to global. Frost protection methodology will continue to be ignored by all but a few producers. Significant exceptions to this rule seem to be those cases in which the cost can be be justified by protection from other more frequently occurring hazards (such as drought). The wait, perhaps longer than most would hope, will continue for plant breeding or biological engineering (biotechnology) to provide plants with built-in protection from cold damage (including materials to be sprayed on the crop just prior to the freeze).

Literature Cited