The following is a paper containing the full text of Dr. Martsolf's presentation to the chapter.

Frost Control rules

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Abstract. **Rules are simply stated recommendations. The intent of presenting these rules is to avoid cold damage or reduce the extent of potential damage. The site selection rule is and has been broadly accepted. It is intended to avoid the problem. The more effectively site selection rules are obeyed the less need remains to consider additional frost control measures. Not all freezes are alike and they are not orderly in their timing. This realization leads to incentives to utilize automated variable rate systems where economically feasible. Growers have capitalized on the rich diversity that surrounds the problem. Such systems seldom evolve without economic incentives. A combination rule evolved from a realization that the most frequent freezes are mild. The treatment should fit the problem. This implies a heavy dependence on good local forecasts. Multiple strategies seem desirable, especially in the larger plantings. Another rule capitalizes on diversity. Facilities at hand have been pressed into use, e.g., a drought control system. It became apparent that nearly all integration rules are variations of the combination rule which declares that the effect of two or more methods used in conjunction is greater than the sum of the effects of the methods used singularly. It is intended that these deliberations be considered in the development of the cold protection module of the Decision Information System for Citrus [DISC].**

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The purpose of the paper is to document results of deliberations regarding potential contents of a Cold Protection Module under development within DISC, a project funded by the Florida Citrus Production Research Advisory Council. DISC stands for Decision Information System for Citrus (DISC Team, 2001; also see Nos. 3, 7 & 8 in Table 1.).

Materials and Methods

Literature. An extensive review of the literature was made by Rieger (1989) using electronic search methodology that was relatively new at the time. That review lists 200 publications and organizes information they document into categories. It points to some previous reviews. One of these (Turrell, 1973) seems to be the most complete, comprehensive, and philosophically astute reviews of citrus frost protection methods cited by Rieger.

There were two works in progress at the time Rieger's (1989) review was published: one is a book (Kalma, et al., 1992) and the other a chapter (Martsolf, 1992). Table 1 has been developed to reduce the number of references to works published in the FSHS Proceedings. Experience in the development of a decision support program is cited (e.g., Heinemann, et al. 1994). Perry (1998), in an award winning paper provided a relatively brief but rather compete description of the numerous frost control methods available to horticulturists.

Knowledge Engineering. A knowledge engineer (KE) is one who exercises the concepts and techniques developed within the field of knowledge engineering (e.g. Barrett and Jones, 1989). The combination of a KE and an expert is a recommended technique used extensively in knowledge engineering. One rule was found to lead to or imply another. Knowledge engineering suggests any search for decision making rules by an individual is likely to be frustrating and unproductive. This is particularly true when the individual is an expert. Initially the KE served as the expert and the rule was discovered. Experts seem more likely to focus on the exceptions than the rules. The KE recognizes this rule and avoids the problem by forming a team, generally with the expert. The two authors of this paper represent such a team.

Results and Discussion

The combination rule. This rule leads the list of rules in Table 2. When two or more methods are used together, the effect is greater than the sum of the effects of the methods when used alone. The combination of wind machines and heaters (e.g. Crawford and Leonard, 1962) led most convincingly to the rule. The rule has numerous implications in making decisions. Some seem to lead to strategies. The combination rule includes a strategy.

Strategies. While the term "strategies" is listed well down in Table 2, it has application throughout the list. The associated rule, "thought is cheap" is intended to imply that economics plays a major role throughout all the considerations.

As wind machines were developed, a tendency to contrast their use with the use of heaters, describing the advantages of the wind machine over the heater developed as well. Authors responded to the question "What is the best method of frost protection?" Answers appeared to take the form of "one size fits all" even when this was not the intention. The combination of wind machines and heaters revealed the variable rate rule. But this was not the first revelation of the rule. Heating systems were variable rate from their beginning. But wind machines were fixed in both position and rate. Their combination with heaters provided a variable rate solution through the use of a strategy.

Combination of methods may imply that when the frost or freeze approaches that all will be used, but this is the worst case scenario. This is the "on or off" rule or "one size fits all" rule. These rules are questionable. The strategy that brought the combination of wind machines and heaters into existence as a popular solution recognized that in most cases only the wind machine would be used. The heaters were there to provide protection when it was too windy to use the wind machine or to add to the effect of the wind machine when additional microclimate modification was necessary.

Bigger is better. One common rule in this era of consolidation is that bigger is better. There are indications that this rule works in frost control. The combination rule, in its simplistic form, seems to suggest that bigger is better. The edge of the treated block decreases in magnitude relative to the whole as the size of the treated block increases.

The edge is treated as an enemy in most microclimate modification efforts. The mass heating effect is documented in California literature. It is likely present when a number of adjacent blocks are irrigated at the same time.

However, there is a question mark in Table 2, following the rule "bigger is better," because it was recognized in heating studies that fire size might exceed some limit at which the generated plume broke through the inversion layer. Using a greater number of smaller fires was suggested by a model that Turrell (1973) declared an important decision making tool, the Crawford Model. A lot of faith is apparent in overhead sprinkling models that declare that evaporative cooling can exceed heating supplied by ice formation. But these models fail to adequately represent the undertree sprinkling method (Oswalt and Parsons, 1981). One of the reasons may be the mixing driven by the buoyancy of the evaporated water (Cooper, et al., 1997; No. 9, Table 1).

Rare event. There are short term and longer term decisions but all are made in recognition of how rare the avoidable event is expected to be. The probability of freezes during winters in which there is a neutral phase of the El Niño / Southern Oscillation (ENSO) is much greater than during either of the extremes (No. 3, Table 1). Freezes tend to cluster and in particular those with high impacts (Attaway, 1999). When there are few if any freezes taking place, it is easy, if not advisable, to ignore the problem. Site selection, variety and rootstock considerations, irrigation system zones, row orientation, planting distances, weed control, and many other decisions are made before the event. The better some of these decisions are made, the rarer the event is likely to be. It is easy to miss an event that is both mild and rare. Forecasters agree. Computers do not need to sleep. Some advisors indicate they expect the decision making tool to be able to turn on the irrigation system should they fail to do so. Decisions in frost control must be made in view of the rare nature of the event. Costs and returns should be considered. The rule is to be frugal (Stanley and Danko, 1996)

Site selection. The literature, Janick (1963) in particular, stresses the desirability of making good site selection decisions. Reduction in frost risk is a key consideration. This rule might be simply stated as, "Avoid frost hazard." The rule includes a number of problems avoided by good site selection.

This site selection rule leads to various passive methods as Rieger (1989) and others (e.g. Bagdonas, et al., 1978) have termed them. One of the convincing ways to describe the desirability of a slope with a minimum of cold air dams, down which cold air can drain with minimum resistance, is the use of the water analogy. Another passive method is the management of the soil toward entrapment of heat and its subsequent release to retard cooling during clear, calm nights. Site selection involves considerations such as the availability of water, a market, labor sources, and so on, to the extent that seldom can a particular site provide all the desirable characteristics. Various factors must be evaluated and balanced against another in the decision making process.

Integration. Growers have wisely followed the rule to "use what is at hand." The use of irrigation systems (designed primarily for drought control) for frost control is an example of the integration rule. Most drought control systems are designed to minimize the cost of the pump and well by planning to irrigate one or a limited number of zones at one time. The use of such systems for frost control forces the manager into a triage decision. Zones that cannot be irrigated during the freeze are irrigated prior to the freeze to increase their heat holding capacity, a combination of a passive and an active method. Another implication here is the desirability to design variable rate into irrigation systems that are to be used for frost control.

Variable rate systems. Variable rate frost control systems have been around for some time and in the heating case for citrus is it the featured strategy (Turrell, 1973). The suggestion that irrigation systems will eventually have variable rate (VR) capability is not new either (Perry, et al. 1980; Davies, et al. 1987, 1988) but engineers have seemed to find less encouragement to design irrigation systems with VR capability. In some ways VR is an indication of the degree of maturation of the particular method. VR systems are needed because the freezes they face are variable in magnitude. Most frosts are relatively mild. Damage can be avoided with a fraction of the energy that more severe events require. The combination of methods is in effect a variable rate system. Examples include the use of heated irrigation as well as wind machines and heaters.

The tendency is to avoid failure by using more methodology than is necessary. This, in part, had led to the "one size fits all" rule. Advances in technology are likely to make variable rate irrigation systems more and more feasible. Computers will use models and

networks to control these systems, not simply to turn them on and off but to control their rate as well. At first only a few innovative growers will press for changes (Castle and McTeer, 2002). One of the purposes of this paper is to capture the attention of at least one innovative grower.

Suggestions

Mining. A strategy for handling the voluminous and complex details is suggested in the term "mining." Several levels of complexity are apparent in the literature. It may be well if the module permitted users to mine to the level of their interest in the details. The DISC module might be organized in such a way that users could find their way to where they wish to go on several levels of complexity, perhaps with links that would take them to experts who may volunteer to respond to questions via email. Figure 1 is included to depict the mining process.

Strategies. Incentive to do a good job of site selection lies in realization that time and money invested in good site selection will be returned later in terms of reduced cold damage. The precise return is difficult to estimate. The manager or consultant must rely on their feeling for the situation and for the future. Incentive to build frost control capability into drought control irrigations systems depends on a similar analysis regarding the future.

In large plantings the existing divisions, the blocks, offer opportunities to diversify the strategies. Even in small operations the assumption that the entire operation should be handled with the same strategy is questionable. Thought is cheap and help in the form of information and consultants is available. Mining for information is likely to be a capability built into DISC for example.

Size the treatment to fit the problem. The combination rule is not meant to imply that a combination of methods will always be necessary. The contrary is the rule. Take the combination of heaters and wind machines as examples. The strategy was to reduce the number of heaters and use them only when the wind machine effect was insufficient to handle the severity of the freeze. Most events required only the wind machine, and the heaters were not fired. The combination rule implies the use of a variable rate system.

Most events are mild events and only one element of the combination of methods available is necessary for protection.

Diversity. One suggestion that is repeated many times in the literature is that freezes in Florida divide themselves into two types, i.e., radiation frosts and advective freezes. The implication is that Mother Nature creates conditions that provide either one or the other of these two extremes when in reality most cold events are various combinations of the two. When one looks at the situation over a large area, such as the whole of the peninsula of Florida, the freezes are quite diverse in nature. No one makes this point more convincingly than Attaway (1997). The mild events are much harder to anticipate, or easier to miss. In this regard, one of the grower advisors to DISC, also a scientist associated with DISC suggested strongly that the DISC Cold Protection Module should be able to start his irrigation system on a cold night when he failed to do so.

Complexity. There are levels of complexity in the methodology that become more and more apparent as a student digs deeper and deeper into the subject. Not all users of the rules will care to become full time or even part time students of the field. Some accommodation has to be made where possible for users who approaches the subject and have decided before the fact that they wish to avoid being drawn into the depths of complexity (Fig. 1). Some users may choose to avoid the subject completely.

There are 25 papers in the FSHS Proceedings in which details are documented (Table 1). These papers contain citations to the papers known to and studied by the authors of this paper. This database is documented completely with the intent that it best describes the data base from which the rules declared in this paper were drawn and it suggests at a time when the FSHS is reviewing its value to a declining membership that the proceedings have great value in the review of a topic such as that addressed by this paper. Module developers are encouraged to permit the user of the module to follow leads to more detailed discussions of the methodology. These leads could include links to the authors of these sections through email. Most authors welcome contact with users of information they have had a part in developing, and especially with the innovative growers (e.g., Castle and McTeer, 2001).

Summary

Of the rules identified the combination rule points to the broadest concepts. At first the combination rule seems to suggest that "bigger is better," but "mining for detail" reveals a strategy linked with the combination rule. It suggests that only one method may be necessary for a mild event. This rule introduces the "variable rate rule," which is to "match the size of treatment to the problem." The "one size fits all" rule becomes questionable, as does the tendency to build systems limited to constant flow rates. The desirability of a variable rate system stems from a realization that not all freezes are alike. They come in a spectrum of sizes from mild to severe with the latter being the rarest of the lot. A legitimate strategy in dealing with rare events could be to ignore them or to decide that one cannot afford to do much about them.

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Table 1. Listing of papers published in FSHS Proceedings written by or co-authored by Martsolf during the period indicated, 1989 through the current volume. Number 1 points to this paper and Number 2 to another paper in this volume. All articles address frost control methodology in one way or another.

No	Year	Vol	Pages
1	2002	115	in press
2	2002	115	in press
3	2001	114	19-21
4	2000	113	133-137
5	1999	112	40-43
6	1999	112	95-98
7	1998	111	144-147
8	1997	110	92-96
9	1996	109	105-109
10	1995	108	118-121
11	1994	107	51-54
12	1993	106	65-70
13	1992	105	91-97
14	1991	104	139-142
15	1990	103	72-78
16	1989	102	64-69
17	1988	101	44-48
18	1987	100	67-71
19	1986	99	13-18
20	1985	98	48-52
21	1984	97	17-21
22	1984	97	21-24
23	1981	94	39-43
24	1980	93	41-44
25	1979	92	22-25

Table 2. A listing of the names of the rules with an indication of the rules with which they are associated or to which they are related. The question mark is meant to suggest the rule is questionable.

Combination

Variable rate

Bigger is better?

One size fits all?

Integration

Diversity

Using what is at hand

Site selection

Strategies

Thought is cheap

Complexity

Mining

When to start

When to stop

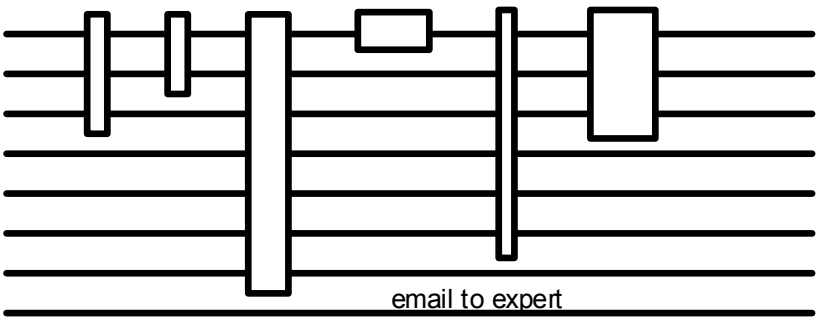

Figure 1. A diagram of how various probes into levels of complexity of the information in DISC may take place. The width of the downward probe is intended to indicate the amount of information that is extracted from the levels through which it passes.