

Citrus Cold Weather Protection and Irrigation Scheduling Tools Using Florida Automated Weather Network (FAWN) Data¹

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Introduction

With a crop value of \$597 million in 2006/2007, citrus is the most important horticultural crop grown in Florida. The 2.4 million tons of annual citrus production in Florida accounts for approximately 75% and 20% of United States and world citrus production, respectively. Agricultural water use has become a greater concern for citrus production in Florida due to increasing competition between agricultural, commercial, and residential use of limited water supplies. Tools have been developed for the FAWN that will assist citrus growers in improving frost protection and irrigation scheduling while saving water. These tools are the Cold Protection Toolkit and the Citrus Microsprinkler Irrigation Scheduler. Use of these tools, potential benefits to citrus growers, and water savings are described below.

History of the Cold Protection and Irrigation Tools

Winters in Florida are generally very pleasant with afternoon temperatures near 70°F and minimum temperatures ranging from 40°F to 60°F. These temperatures allow winter production of vegetables, citrus, strawberries, ornamental plants, ferns, and many other crops that cannot be grown in other states during this time of the year. However, Florida

is not free from frosts and freezes, and many growers must have a cold protection plan in place to deal with the sporadic arrival of cold air. Generally speaking central and south Florida growers are more concerned with freeze/frost events than those in the northern or western parts of the state.

Several methods of cold protection are used in Florida. In a few isolated situations, heaters are used to protect high-cash crops. A few citrus growers still use wind machines during calm nights to mix warm air aloft with cold air that has settled near the ground. However, these two methods of frost protection require high volumes of fuel and are becoming less used in Florida. More and more growers are using “heat blankets” to capture heat stored in the ground during the day and radiated back to the sky at night. This method of cold protection works well with low growing crops, but must be removed in a relatively short period of time to avoid damaging the plants.

By far the most widely used method of cold protection in Florida is the application of water. Some crops such as ferns and strawberries require relatively large amounts of water per acre to protect the entire crop, while citrus trees require much smaller amounts to protect primarily the tree trunk and scaffold limbs.

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When using water for cold protection, growers must determine the critical minimum temperatures for their crop(s). Then they must operate their irrigation systems to keep their crops from being damaged, while at the same time minimizing water use. Growers have followed a fairly general procedure when dealing with cold events in Florida. FAWN examined the various steps in the process and then developed methods to collect and display information useful to growers, utilizing current data from its sites and forecast products from the National Weather Service (NWS), such as its 7-day Point Forecast.

Management tools evolve over time as refinements are made and additional data are collected. The FAWN cold protection tools are a classic example of this process. The first tools provided guidance for operation of irrigation systems used for cold protection—simply turning them on and off. The Brunt Equation has provided guidance over the past 10–20 years related to estimating the minimum overnight temperature and was a minor aid used only to add a little confidence to the forecasted minimum temperature. More recently, however, the Wet-Bulb Based Irrigation Shutoff Temperature tool was developed to tell users when it is safe to turn off irrigation systems based on their critical temperature to avoid tree damage due to evaporative cooling. This tool is now considered critical for anyone using water for cold protection.

Irrigation scheduling is simply applying water to crops at the “right” time and in the “right” amount. Soils hold different amounts of water depending on their pore size distribution and their structure. The greatest amount of water available is often called “field capacity” (FC), while the lowest is called the “permanent wilting point” (PWP). The total amount of water available for plant uptake is the “available water” (AW), which is the difference between FC and PWP and is often expressed a percent by volume (volume of water/volume of sample). The “plant available water” (PAW) is determined by the root zone depth where water extraction occurs. Depletion of the water content below a “maximum allowable depletion” (MAD) is essentially the operating range of soil water content for irrigation management. For citrus, MAD is generally 25% to 33% of PAW in the spring and 50% to 66% of PAW the rest of the year. Theoretically, irrigation scheduling consists of irrigating at MAD until the depleted water has been replaced to, but not more than, the FC level, otherwise drainage and/or deep percolation will occur.

Scheduling methods often consist of grower judgment or a calendar-based schedule of irrigation events based on previous seasons. The simplest form of scheduling is the

“feel” method. Other methods are use of published tables by month or use of soil moisture sensors. Soil moisture sensors have improved greatly over the past several years but are still expensive and require maintenance and site-specific calibration to be effective. Evapotranspiration (ET) is the amount of water transpired by a crop or evaporated from the soil on a daily basis. Crop ET can be determined using weather data and is accurate for a relatively large area. The amount of ET for citrus has been determined and can be used to schedule irrigation using weather information from FAWN.

FAWN Cold Protection Tool Kit

These are several examples that demonstrate how cold protection tools have evolved over the years. Additional cold protection tools have been developed and added to FAWN, for a total of six currently available. These are described in greater detail below. All FAWN management tools contain “background” information that describes the tool and provides the names and contact information for the developers/authors of those tools.

Determining Critical Temperature

The first step in the cold protection process is to determine the critical temperature for a given crop. Many growers already know this value and can simply enter it into the tool. However, the online guide, *Determining Critical Freezing Temperatures for Plants in Florida*, provides assistance with determining the critical temperature for various crops and can be found at http://fawn.ifas.ufl.edu/tools/coldp/crit_temp_select_guide.php. Once entered, the critical temperature is saved for use with other steps in the toolkit.

Citrus is somewhat unique with regard to critical temperature as the plant acquires hardiness from exposure to cool temperature and loses hardiness if exposed to warm temperatures. Leaf freezing temperatures for several varieties of citrus have been documented over the years by several scientists. Currently, citrus leaf freezing temperatures are being studied by scientists at several locations in Florida with funding from the Southwest Florida Water Management District, and can be found at http://fawn.ifas.ufl.edu/tools/coldp/crit_temp_select_guide_citrus.php.

Fruit Frost Station Forecast

Once a critical temperature is determined, users generally wish to know when this critical temperature may occur. Forecasts are not part of the Cold Protection Tool Kit. However, FAWN provides quarterly agricultural climate outlooks from the *Southeast Climate Consortium* (<http://www.agclimate.org>), and short-range forecasts from the

National Weather Service (NWS) 7-day Point Forecasts so that growers can plan for future events.

For more than 60 years the NWS collected data during the winter from as many as 350 locations in peninsular Florida and used these data to issue a 24-hour *Fruit Frost Forecast*. Each location contained a minimum recording thermometer and a thermograph housed in a standard “government” weather shelter. During the early years of this program thermograph charts were collected weekly and were processed to provide a summary of each winter’s temperatures. Many of these shelters became notorious for low temperatures due to their cold locations. Some of the original sites are now housing developments, shopping complexes, and industrial warehouses. However, FAWN obtained the locations of 178 of these shelters and used the section, range, and township to determine the latitude and longitude coordinates for the stations’ locations. The *FAWN Fruit Frost Station Forecast* tool uses these coordinates to retrieve a NWS 7-day Point Forecast for the three (3) mile square area centered on the latitude/longitude coordinates. Locations of interest are selected from a table of approximately 180 of the prior “government shelter” locations. Upon selecting a station, a NWS 7-day Point Forecast for that location is shown, providing an overview of whether cold protection may be needed during the following week. This tool can be found at http://fawn.ifas.ufl.edu/tools/coldp/ffs_forecast_links.php. Future implementations of this tool will display the locations on a map and, upon selecting a site, a 7-day graph so users can determine the NWS forecast for known cold areas.

Forecast Tracker

Once a forecast for the week ahead has been obtained, the *FAWN Forecast Tracker* offers a unique “look” at individual cold events. Users can select a FAWN site and view a 48-hour graph (Figure 1) that displays the NWS forecasted temperature (24 hours prior to and ahead of the current time) and the FAWN observed temperature (24 hours prior to the current time). This tool, called the Forecast Tracker, allows users to examine how well the forecast has performed over the past 24 hours. A critical temperature can also be displayed on the graph to assist the user in determining the likelihood of the forecasted temperature for the FAWN site reaching its critical temperature and the length of time the temperature is expected to remain at (or below) that level.

NWS forecast has a granularity of three hours. FAWN data is hourly.

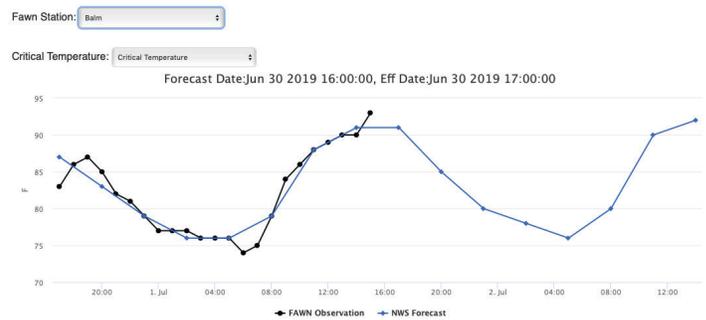


Figure 1. Forecast Tracker

A Visual display of the Forecast Tracker is available on the FAWN website. This tool provides a forecast from the National Weather Service for a selected area of Florida with past 24 hour data from the nearest Florida Automated Weather Network station.

This tool is extremely useful for short term forecast evaluations but is not intended to discount a forecast. Local conditions such as land surface, terrain, and landscape may cause the forecasted temperature to vary from the actual temperature and these variations, though usually small, can be significant when considering crop livelihood. The Forecast Tracker can be found at http://fawn.ifas.ufl.edu/tools/coldp/forecast_tracker.php.

Minimum Overnight Temperature

The Minimum Overnight Temperature tool can be used to further evaluate the likelihood of the forecasted temperature occurring. This tool utilizes the Brunt equation, which requires an air temperature and dew point temperature at sunset. The sunset air and dew point temperature can be either manually submitted (ideally for the user’s location) or obtained from the nearest FAWN site. Air temperature can vary considerably over a short distance, while the moisture content of the air generally does not. Therefore, a local air temperature and FAWN dew point temperature are generally suitable for use in this tool. This tool can be found at http://fawn.ifas.ufl.edu/tools/minimum_temperature/

Evaporative Cooling Potential

There is always a risk when using irrigation systems (e.g., micro-sprinkler or conventional sprinkler) for cold and/or frost protection. Dry and windy conditions can result in a wet bulb temperature 5°F to 6°F degrees lower than the air temperature. When air blows over a wetted plant surface in dry conditions, evaporation occurs, and this can cool the plant surface to temperatures lower than the air temperature. This *evaporative cooling* may result in plant damage when the wet bulb temperature is below the critical

temperature for that plant. Therefore, on nights when the air temperature is close to the critical temperature, introduction of water could produce more damage than if no action was taken at all.

The risk of damage due to evaporative cooling can be determined by considering two factors: 1) the difference between the air and wet bulb temperatures and 2) the wind speed. FAWN utilizes the Jackson/Cross/Fayrna Evaporative Cooling Table, which shows four categories of risk and criteria for each category. In its current format, user-supplied forecasted values of air temperature, wet bulb temperature, and wind speed are used in conjunction with the table to make a determination of whether evaporative cooling is possible. Future implementations of this tool will automatically obtain these values and provide a level of risk for each FAWN site.

This tool in conjunction with leaf freezing temperature data mentioned previously can have a significant impact on the use of water for cold protection of citrus. There are many nights that are unsuitable for the use of water for cold protection. Using this tool can aid growers in saving both dollars and water and at the same time eliminate evaporative cooling damage to the plant. The Evaporative Cooling tool can be found at http://fawn.ifas.ufl.edu/tools/coldp/evaporative_cooling.php.

Wet-Bulb Based Irrigation Cutoff Temperature

The last tool in the Cold Protection Tool Kit is Wet-Bulb Based Irrigation Cutoff Temperature tool. This tool simplifies the basic cold protection recommendation to *discontinue irrigation when the wet bulb temperature reaches the critical temperature of the crop being protected* (Harrison, et al., 1974). However, it is difficult to know when the wet bulb temperature is going to equal the critical temperature. As mentioned previously, the moisture content of an air mass does not vary much over a short distance. Therefore, the wet bulb temperature at the closest FAWN site is a good indicator of moisture content for nearby locations. This tool retrieves a current air and wet bulb temperature (both calculated every 15 minutes) from each FAWN site, calculates the difference between these, and then calculates a “new” wet bulb temperature at the user-supplied critical temperature. This “new” wet bulb temperature is the temperature at which the system can be safely shutdown. Water and dollar savings from this simple tool can be tremendous.

FAWN Citrus Microsprinkler Irrigation Scheduler

Citrus is typically produced on sandy soils with poor water holding capacity of 0.04 to 0.09 cm³ cm⁻³ in Florida. Adequate supply of both irrigation water and fertilizer on an annual basis are therefore required for optimal citrus production. The key to plant water status is soil water availability, thus soil water content must be maintained within a relatively narrow range such that water availability to the crop does not limit growth or adversely impact yield or quality. The Citrus Microsprinkler Irrigation Scheduler estimates the soil water balance in multiple soil areas and layers under a mature citrus tree using tree spacing and irrigation system information provided by the user (Figure 2). A 2-week irrigation schedule is provided for the user based on evapotranspiration (ET) rates obtained from FAWN sites (Figure 3).

Citrus MicroSprinkler Irrigation Scheduler

Please enter the specifications of your irrigation system and click [Create Schedule] to create a 2-week irrigation schedule.

Tree Row Distances	Between-Row: <input type="text"/> ft (10 - 40) In-Row: <input type="text"/> ft (4 - 30)
Emitter	Diameter: <input type="text"/> ft (1 - 25) Rate: <input type="text"/> gals/hr (1 - 30) Pattern: <input type="text"/> 360 deg (0 - 360) System Efficiency: <input type="text"/> 85 % (50 - 100)
Other Variables	Soil Type (Field Capacity): <input type="text"/> Apopka (.09) <input type="button" value="v"/> Irrigation Depth: <input type="text"/> 36 <input type="button" value="v"/> in. Irrigation Trigger Depth: <input type="text"/> 6 <input type="button" value="v"/> in. FAWN Station: <input type="text"/> --choose-- <input type="button" value="v"/>

Figure 2. Input data required to determine irrigations schedule for citrus using the FAWN Citrus Microsprinkler Scheduler.

In a three-year field evaluation of weather and soil moisture data, it was concluded that this Web-based tool provides the accuracy needed for grower irrigation decisions. Furthermore it was concluded that FAWN stations and not grove-sited weather stations can provide reliable data for these grower irrigation schedules and not require growers to maintaining their own weather station. Irrigation scheduling tools for other crops are being evaluated.

Citrus MicroSprinkler Irrigation Scheduler

Please enter the specifications of your irrigation system and click [Create Schedule] to create a 2-week irrigation schedule.

Tree Row Distances	Between-Row: 22 ft (10 - 40) In-Row: 15 ft (4 - 30)
Emitter	Diameter: 15 ft (1 - 25) Rate: 16 gals/hr (1 - 30) Pattern: 360 deg (0 - 360) System Efficiency: 85 % (50 - 100)
Other Variables	Soil Type (Field Capacity): Candler (.08) Irrigation Depth: 36 in. Irrigation Trigger Depth: 12 in. FAWN Station: Lake Alfred ET: 0.1883"

Create Schedule

Irrigation Schedule for 7/1/2019 to 7/15/2019

Irrigate every 4 days for 7 hours and 34 minutes. During this period...

Figure 3. Display of irrigation schedule provided by FAWN Citrus Microsprinkler Irrigation Scheduler using grower provided information.

Value of the Cold Protection Tool Kit and Citrus Microsprinkler Irrigation Scheduler

Accountability is extremely important to FAWN. Financial support for the program comes from a number of public agencies and private sources, and each need to know their support is making a positive impact through FAWN.

According to the members of the Agricultural Weather Task Force, FAWN has had a multi-million dollar impact on agriculture through more informed production, harvesting, and marketing decisions. While there has been no major attempt to document the overall impact, feedback from non-agricultural users indicates substantial use and value. For example, The NWS uses FAWN data when evaluating fire risks and developing high-resolution surface maps; the Florida Division of Emergency Management uses the data when tracking the southward progression of cold air, to monitor wind speeds during hurricanes, and in making decisions regarding potential risks from weather events; the Florida Division of Forestry relies on the information in issuing burning permits and in monitoring smoke plumes; the University of Florida DISC (Decision Information System for Citrus) project uses FAWN data for model input; and various media outlets have incorporated the data into numerous articles and presentations (WESH in Orlando, FL uses FAWN data for early morning reports, for example).

It has been shown that users of FAWN data and tools for cold protection can potentially save substantial amounts of water and numerous dollars. Using information from the Florida Agricultural Statistics Service, Florida Citrus Mutual, the Florida Strawberry Association, the Florida Fern Growers Association, the Florida Nurserymen, Growers and Landscape Association, and the Florida Fruit and Vegetable Association, estimates of potential savings have been calculated and are presented below.

The table below shows the average amount of water applied per acre per hour, the number of acres protected, and the total number of gallons of water used per hour for several Florida industries. It costs \$14.17 to apply 1 acre with 1 inch of water. Using this information and the hourly water usage from above, the cost per hour and total cost per industry can be estimated, and are presented below. Therefore, 1,803,840,000 gallons of water are required for one hour of irrigation for cold protection at a cost of \$945,042.

FAWN Cold Protection tools provide growers with a guide for when to start and stop irrigation used for cold protection. Use of FAWN Cold Protection tools can save an estimated 2 hours of irrigation per cold event, which can bring about substantial savings over a winter season. For example, during a relatively warm winter, 1 to 3 nights may require cold protection for a total savings of 2 to 6 “irrigation-hours.” A cold winter, however, may produce 4 to 10 nights requiring cold protection for a savings of 8 to 20 hours. Therefore, the average number of gallons of water and dollars saved during relatively warm and cold winters can be estimated, and are shown below. Therefore, depending on the number of nights that need protection, 7–25 billion gallons of water and \$3–13 million can potentially be saved by using FAWN Cold Protection tools.

From data provided by participants testing the Citrus Microsprinkler Irrigation Scheduler, growers saved approximately 20% of the water used prior to initiation of the project. Using an estimated cost of \$166 per acre per year for irrigation, a 20% savings would be approximately \$33 per acre per year. This savings would be low for the small 100 to 500 acre grower (\$3,300 to \$16,500); however, the annual savings would be large for the 1000 to 5000 grower organizations (\$33,000 to \$165,000). Large corporate citrus operations of several tens of thousands of acres are becoming commonplace. Irrigation savings for these large growers would be greater than \$330,000 per year assuming 20% savings.

Conclusion

For ten (10) years FAWN has been meeting its mission of “providing a wide variety of users with timely and accurate weather information.” FAWN has taken its weather information and developed cold protection and citrus irrigation scheduling tools that have saved billions of gallons of water and reduced cold protection costs by millions of dollars. FAWN has demonstrated that an Internet-delivered weather network in Florida provides essential information in a timely and efficient manner. FAWN has been a major asset to the citizens of Florida.

Table 1.

Industry	Average Water Applied per acre (gallons)	Area Protected (acres)	Total Water Use (gallons)
Citrus	2,100	500,000	1,050,000,000
Strawberry	16,200	6,200	100,440,000
Fern	13,500	7,400	99,900,000
Vegetables	10,800	40,000	432,000,000
Ornamentals	8,100	15,000	121,500,000
Total			1,803,840,000

Table 2.

Industry	Cost per hour per acre (USD)	Total Cost per hour (USD)
Citrus	1.10	550,000
Strawberry	8.48	52,576
Fern	7.09	52,466
Vegetables	5.66	226,400
Ornamentals	4.24	63,600
Total		945,042

Table 3.

Hours Saved	Winter Type	Average # of Nights Protected	Total Volume Saved (gallons)	Total Cost Saved (USD)
2	Warm	2	7,215,216,000	3,780,168
2	Cold	7	25,242,600,000	13,230,588