Optimization of copper application timing

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The renewed copper model, the Citrus Copper Application Scheduler, was introduced in 2010 (http://www.agroclimate.org/tools/cudecay/). The goal of the scheduler is to assist growers with the timing of the next copper application.

The efficacy of copper applications is often unsatisfactory, but this is usually because the timing of applications is not well placed to avoid gaps in coverage. These gaps can lead to unacceptable levels of disease, such as citrus canker, melanose, alternaria brown spot or greasy spot on fruit. Use of the copper model can minimize the gaps, but it is not always feasible to follow the model; so a calendar-based schedule will also be presented in this article. The calendar-based schedule minimizes the risk of inadequate copper coverage for disease control in the spring.

The copper model is intended for groves where melanose and other foliar fungal diseases have been problematic. Concerns about inadequate disease control with copper, fruit phytotoxicity or stippling, and toxic buildup of copper residues in the soil continue, especially with the need for applications throughout the summer for citrus canker and black spot. The tool helps growers to determine the residue remaining on fruit surfaces after an application and the timing of additional applications. It is thus possible to avoid unnecessary copper sprays and to reduce production costs where feasible but, conversely, to warn when residue levels are lower than necessary so that a subsequent application can be made before the next rain event.

Copper residues are affected by two main factors: fruit growth and rain. When fruit are growing, the fruit surface area expands, but the copper deposit does not, leaving the areas in between copper deposits exposed to infection. Rainfall is also important because it reduces copper residues below effective levels, leaving fruit vulnerable to disease. The current model used in the Citrus Copper Application Scheduler is based on growth and residue data that ended in late June. Although this may not be accurate for the later season applications, the model provides reasonable estimates of residue levels throughout the summer. To improve the summer season accuracy, we are collecting residue and fruit growth data to modify the model for the July-to-October period.

An example of how the copper model can improve application efficacy for fruit protection without increasing the number of applications is shown in Fig. 1. For this example, a simulation was run for grapefruit in Lake Alfred in 2012. The average peak bloom occurred on March 21. In the top panel, applications of 0.75 lb./acre metallic copper in 125 gal./acre were made with a 21-day interval, the default option in the copper model. With the relatively dry weather of spring 2012, the 21-day interval is effective for the first three applications, never dipping below the warning levels of copper residue on the fruit (0.5-0.26 $\mu g/cm^2$ fruit surface area; $\mu g/cm^2$ stands for micrograms per centimeter squared).

However, with the high rainfall in June, the coverage falls into the danger levels (less than 0.25 $\mu g/cm^2$ fruit surface area), where average residue levels are approaching the level of copper that is no longer effective for disease control (0.1 $\mu g/cm^2$ fruit surface area). This means that on some fruit, residues were likely below the effective residue level and vulnerable to infection. Later in the season, copper is likely applied too frequently; thus

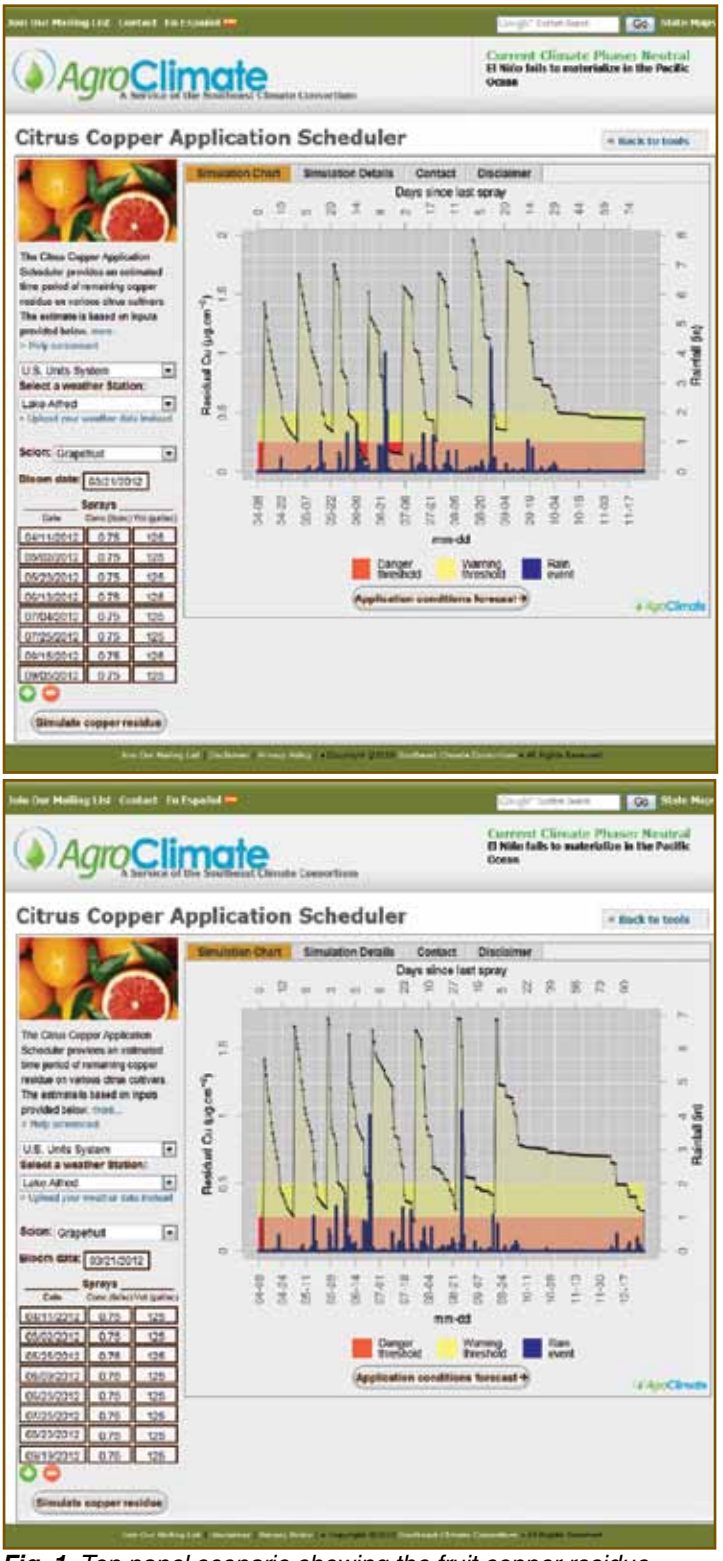

Fig. 1. *Top panel scenario showing the fruit copper residue reduction over time using the citrus copper application scheduler with continuous 21-day applications on grapefruit in Lake Alfred of 0.75 lb./acre of metallic copper in 125 gal./acre of water. Lower panel: A scenario of the fruit copper residue reduction over time using the Citrus Copper Application Scheduler to ensure the copper residue did not go below 0.25 µg/cm² fruit surface area on grapefruit with the same spray parameters as above. The black line is the copper residue, the blue bars are rainfall, the yellow band is the warning threshold between 0.5-0.26 µg/cm² and the red band is the danger threshold below 0.25 µg/cm².*

applications can be delayed.

In the lower panel, applications (same concentration and volume as above) were timed so that ideally the residue levels never fell below the warning levels of copper residue on fruit. The same number of applications were made, but without the increased risk of disease. In the case of the lower panel, it may be possible to skip the last application, depending on the year and destination of fruit. The scenario in the lower panel, of course, assumes that movement of equipment can be easily done and that applications occur when the model suggests. We are aware that this is not always possible and have developed an optimized copper application schedule that is described below.

MODIFICATIONS TO ORIGINAL SCHEDULER

Some modifications have been made to the Citrus Copper Application Scheduler since the release in 2010. The layout has been modified slightly. The bloom date needs to be entered before the application data can be entered. Rainfall data can still be uploaded from a file or a Florida Automated Weather Network (FAWN) station. There is now a choice between U.S. or metric units, with U.S. units being the default. The largest change is that the data from the four previous seasons can be uploaded individually. This allows growers to review seasons where there has been good or poor disease control so that improvements can be made in following years. A mobile version that should work on all smart phone platforms has also been introduced (http://www.agroclimate.org/mobile/citrus/). It has all of the functions of the web-based version, but relies on FAWN data rather than uploaded rainfall data, and is restricted to the current year. A log-in system is in development so that data does not need to be entered every time.

A calendar application schedule has several advantages, especially for operations with limited equipment or a large area to cover. The greatest advantage is that equipment and personnel can be planned for well in advance of an application. However, the traditional 21-day application schedule often leaves copper coverage gaps early in the season and can have an excess of residue later in the season.

We used 55 years of rainfall data from Highlands, Hendry, Indian River, Polk and Lake counties to optimize a copper application schedule for early- (March 10), average- (March 20) and late- (March

Table 1. Schedules (days since last application) resulting from optimized copper residue simulations. These results are for 55 years of weather data from Highlands, Hendry, Indian River, Polk and Lake counties with 0.75 lb./acre metallic copper and volume of 125 gal./acre.

Application	Days since last application		
	Early bloom	Average bloom	Late bloom
Peak bloom	March 10	March 20	March 30
1st	21	21	21
2nd	20	19	22
3rd	24	24	22
4th	20	16	19
5th	20	17	17
6th	18	17	--
Sum of unprotected days (<0.1 µg/cm²copper) over 55 years*	547	420	922
% reduction of unprotected days compared to 21-day schedule	19	51	13

*(µg/cm² stands for micrograms per centimeter squared)

Table 2. Comparison of the number of unprotected days over 55 years from the 21-day schedule and the optimized schedules over all citrus production regions

County	Unprotected days over 55 years (<0.1 µg/cm² copper)*		
	21-day schedule	Optimized schedule	Reduction %
Early peak bloom			
Highlands	162	112	31
Hendry	196	160	18
Lake	112	97	13
Indian River	103	83	19
Polk	99	85	14
Average peak bloom			
Highlands	178	76	57
Hendry	282	141	50
Lake	123	55	55
Indian River	115	59	49
Polk	159	89	44
Late peak bloom			
Highlands	260	203	22
Hendry	292	247	15
Lake	181	158	13
Indian River	158	146	8
Polk	165	168	-2

*(µg/cm² stands for micrograms per centimeter squared)

30) peak bloom. To do this, we based our calculations on the worst-case scenario of cultivars, which is the mandarin. All other cultivars should be better protected than the mandarin so the cultivar in itself should not be a concern for the use of this schedule. The copper residue levels over the 55 years were estimated by the copper model in the Citrus Copper Application Scheduler until mid-July, when the data for the original model ends (Table 1). We considered any day where the fruit copper residue levels were below 0.1 $\mu g/cm^2$ of fruit surface area to be unprotected. Below this residue level, there is not enough copper residue to prevent infection.

We then evaluated how well the optimized schedules performed in the various citrus production areas of Florida (Table 2). The optimized application schedule worked best for the average peak bloom with reductions of unprotected days over 55 years of between 44 and 57 percent. It made modest improvements of 13 to 31 percent fewer unprotected days for the early peak bloom. However, for late peak bloom, the effect was minor in some regions and an improvement in Polk County was not observed. Since the optimized application schedule is an average over 55 years, it may not improve coverage in some years over the 21-day schedule, but in most years, it should. We plan to extend the optimized schedule over the summer when the new model is completed.

Copper application timing is still a problem for many growers. When fruit copper residues dip below 0.1 $\mu g/cm^2$ fruit surface area, diseases are no longer controlled. Fruit residues are reduced by fruit growth and rainfall. Growth is responsible for a slow-but-steady decline in residue levels, but rainfall can suddenly and dramatically reduce fruit residue below effective levels if insufficient copper is present before the rain event. It is not always easy to determine how much residue levels have decreased since the last application, but there are two new tools available to make copper applications more efficacious; the Citrus Copper Application Scheduler and the Optimized Copper Application Schedule.

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