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A Fungicide Application Decision (FAD) Support System for Postbloom Fruit Drop of Citrus (PFD)

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Abstract

Postbloom fruit drop (PFD) caused by *Colletotrichum acutatum*, affects citrus flowers and produces abscission of young fruitlets. PFD is a serious problem in most humid citrus production areas of the Americas. Because a predictive model previously developed in Florida to time fungicide applications was inadequate for use in many other regions, an expert system (PFD-FAD) with broader applicability was developed and implemented in Java Servlet. The PFD-FAD system considers previous history of PFD in the grove, susceptibility of the citrus species, the stage of the bloom as well as rainfall, duration of leaf wetness following the rain, and the current inoculum levels in the grove. It predicts the need for a fungicide application based on these factors and the time since the last application. The PFD-FAD system is easy to use and minimizes the need for scouting of groves and acquisition of exact weather information, and is more widely applicable to other regions. The PFD-FAD system was compared to the PFD model, the grower's program, and to a nonsprayed control in Brazil in 2001. The PFD model indicated 2 sprays were needed, PFD-FAD indicated one spray, and the grower made 3 applications. All programs reduced counts of persistent calyces by about 50% and increased fruit counts by about 20%. Cost savings with the use of PFD-FAD was about $47/ha.

Introduction

Postbloom fruit drop (PFD) of citrus is caused by the fungus, *Colletotrichum acutatum* J. H. Simmonds (8). This fungus infects citrus flowers producing orange-brown necrotic spots or affecting the entire petal (Fig. 1). Fruitlets on affected inflorescenses do not develop or abscise, but the calyx and floral discs remain attached to the peduncle (Fig. 2). These persistent calyces, commonly called buttons, are diagnostic for the disease and may persist for many months after flowering.

Fig. 1. Necrotic spots on petals of sweet orange caused by *Colletotrichum acutatum*.

Fig. 2. Persistent calyces produced following flower infection and abscission of fruitlets.

PFD can be severe when the flowering period is extended and rains occur during the bloom. Losses may approach 100% in some locations in certain years. Yield loss to PFD in Florida is sporadic with serious epidemics in some years and virtually no losses in others (5). In São Paulo State, Brazil, epidemics are more frequent and some losses may occur annually. In humid, tropical areas such as Belize, southern Mexico, and Costa Rica, PFD is a limiting factor in citrus production (3,4,10).

Properly timed applications of fungicides, such as benomyl, have been effective in reducing losses to PFD. A model was developed in Florida to predict epidemics and to schedule fungicide applications (11,13). The model was based originally on the number of infected flowers observed on 20 trees and the amount of rainfall during the last 5 days. It was subsequently modified to include the leaf wetness duration following rainfall events (8,9). Fungicide applications timed according to the model increased fruit counts 30 to 600% and use of the model prevented unnecessary fungicide applications (13).

However, even in Florida, the model has some shortcomings. In cases where some infected flowers are present and high rainfall (> 25 mm) associated with cold fronts occurs, an application of fungicide is usually indicated by the model. However, in such events, moisture dries quickly, the rain is followed by cool temperatures, and PFD epidemics rarely develop. Inclusion of leaf wetness duration in the model helped minimize that problem, but the model is additive and even if the leaf wetness factor is zero, sprays are often indicated. Thus, the model is conservative and occasionally indicates sprays that are not necessary.

The model as developed in Florida cannot be used effectively in other locations. The fungus survives periods without flowers as appressoria on leaf surfaces (1,2,14). The model assumes that inoculum must be dispersed by rains from localized sources. However, in tropical areas, citrus trees often flower 2 to 3 times per year and PFD occurs every year. Thus, inoculum is present in large amounts in virtually every tree. Multiple rains are not needed to promote inoculum build up and 1 to 2 rain events or even heavy dews or fogs can result in considerable infection (L. W. Timmer and N.A.R. Peres, personal observations).

The PFD model continues to be very useful in Florida and is often effective in subtropical areas such as southern São Paulo State in Brazil, but a more widely applicable system would be desirable. The decision support system described herein includes many of the principles developed in the PFD models (10,11,13), but also incorporates the experience of the authors in working with PFD and its control in Brazil, southern Mexico, Central America, and the Caribbean.

Development of the PFD-FAD System

Many factors are considered in the assessment of the risk of PFD and the need for fungicide applications. First, we must consider risk factors that affect PFD incidence inherent in any planting. Climatological factors can affect PFD directly, but can also have indirect impacts. Locations or species of citrus with multiple blooms are more prone to disease because inoculum may be maintained at high levels all year. Some species or cultivars of citrus are more susceptible than others. The presence of declining trees which flower out of season may increase PFD incidence especially in areas with a single annual bloom. In addition, we must consider factors which could affect inoculum build-up such as the frequency of occurrence of PFD in previous years, the number of buttons remaining from the previous year, and occurrence of PFD on scattered flowers appearing prior to the main bloom. The number of rainfall events that occurred during the main bloom period but prior to the period under consideration are also taken into account.

The primary factors determining the potential for an epidemic in the immediate future are inoculum availability, rainfall, and leaf wetness duration, and these are basically the factors considered in the PFD model. However, the PFD-FAD system provides more flexibility in dealing with these factors than the PFD model did. Lastly, the stage and amount of bloom present is critical in decisions as to whether or not to make fungicide applications.

Stage of Bloom. This factor is considered first because if the situation at flowering time is not appropriate, no sprays are indicated regardless of the history, inoculum presence, or weather factors. The underlying principles are discussed below.

Sufficient flowers. In order to justify an application, there must be sufficient flowers in the planting to pay for the application if fruit set is increased. Research in Florida indicates that for each 100 buttons formed, 6 fruit are lost (12). However, the percentage of flowers which set fruit varies tremendously in different growing areas. Also, the value of fruit varies greatly with the species or cultivar involved, the time of year that the fruit will be harvested, and the economic conditions and costs of applications.

In many areas, losses to PFD can be substantial and orchard care costs must be paid regardless of the yield or losses to PFD. Thus, fungicide applications may be economically justified even when fruit prices are low. Fungicide sprays may be needed in order to have some yield to offset care costs even if net return is negative. Fungicide applications are not justified only if the crop will have little value and it is likely that the fruit will not be harvested.

In the more temperate citrus-growing areas with one bloom per year, flowering is abundant and occurs once per year. In these situations, decisions are less complicated. However, in tropical areas flowering often occurs 2 to 3 times per year and may vary greatly in intensity within and between groves. Poorly-managed plantings often have weak, sporadic blooms and there are insufficient flowers to justify an application. Thus, it is often more important to improve fertilization, weed control, water management, and control of greasy spot than to invest in fungicides for PFD control. Uniform blocks of well-foliated vigorous trees are much more likely to produce the abundant and uniform blooms needed to justify fungicide applications for PFD. Ultimately, the grower must make the economic decision as to whether it is worthwhile to even consider applications for control of PFD.

Inoculum availability. The other major consideration in assessing the need for fungicide applications is the effect of bloom stage on inoculum availability. Applications made early in the bloom, prior to the presence of open flowers on the main bloom are largely ineffective. Benomyl applied to diseased flowers does not kill spores nor reduce the potential for future disease development (6). If no rain occurs or few open flowers are available, these affected petals simply fall to the ground where they do not represent a potential for spread. While flower buds and unopened flowers can be infected, these flowers are not very susceptible and do not serve as a major source of inoculum. Thus, the only conditions under which we recommend that applications even be considered is during a major bloom which will yield sufficient fruit to justify the cost of application. Fungicide applications can protect flowers from infection and benomyl can prevent symptom development if applied up to 48 h after infection begins (6). At the end of the bloom where there are no longer any unopened flowers present, sprays are likewise not justified. Regardless of what has occurred during the main bloom, applications at this time will no longer control the disease or increase yield.

Prebloom Risk. The most important factors in determining whether an epidemic of PFD occurs or not are the weather during the bloom period and the amount of inoculum available at that time. Nevertheless, the geographic location of a planting and the previous history of the disease in a grove play a role in decisions. The other important factors are the inherent susceptibility of the cultivar planted and the relative frequency of flowering periods during the year. Thus, the highest risk values are assigned to the most susceptible varieties grown in tropical areas where trees tend to have two or more bloom periods per year, with lower values given to the same varieties grown in areas with single blooms. In areas with a single bloom, declining trees which flower off-season can serve to maintain inoculum levels and thus increase risk. Declining trees in areas with multiple blooms do not greatly increase disease risk. Risk values are assigned accordingly.

Disease history. With regard to the past occurrence of the disease in the plantings, points are assigned according to the history over the past 5 years to take into account the overall situation and to consider inoculum carried over from the previous year. Points are assigned according to the number of economically significant outbreaks over the last 5 years (Table 1). Disease severity from the previous year is assessed by estimating the number of persistent calyces on the trees from the last season. The number of persistent calyces are assessed by observing 20 trees in each planting and the values assigned as shown in Table 1. If scattered flowers that may occur prior to the main bloom become infected, inoculum can build up and increase risk for the main bloom. Risk values are added to the prebloom values as shown in Table 1.

Table 1. Factors considered and points assigned to conditions occurring prior to the bloom in the development of PFD-FAD.

Factor		
	Condition	**Risk value**
Number of outbreaks in the last 5 years		
	None	1
	1-2	3
	3-4	7
	Every year	10
Number of buttons/tree		
	None	0
	1-100	5
	>100	10
PFD on early bloom		
	None	0
	Present	5
Varietal Susceptibility and number of blooms*		
Highly susceptible - lemons, limes, Navel, Natal, and Pera sweet oranges		
	Multiple	10
	Single	8
Moderately susceptible - Valencia orange, most tangelos		
	Multiple	10
	Single	5
Susceptible - early and mid-season oranges		
	Multiple	7
	Single	3
Tolerant - grapefruit		
	Multiple	3
	Single	1

* In the case of single blooms, points are added according to the number of declining trees in the grove: None, 0; few scattered, 1; more than 10%, 2.

Varietal susceptibility and number of blooms. The citrus species and cultivar and the number of flowering periods per year are considered in conjunction with one another (Table 1). In the case of a single bloom, points are added to the scores for the number of blooms and citrus variety according to the prevalence of declining trees in the planting, but no points are added for groves with multiple blooms.

The sum is taken for all of the values for: (1) PFD in the last 5 years; (2) persistent calyces from the previous season; (3) cultivar susceptibility, number of blooms per tree, and the frequency of declining trees; and (4) the presence of PFD on the early bloom are summed. Since all prebloom risk is low compared to the risk factors occurring during the bloom, this value is divided by 7 before adding to the other risk values.

Weather Risk

Rainfall. Rain is needed for epidemic development to supply moisture for infection and, as importantly, to disperse conidia by the force of droplets impacting on spore-laden petals. The amount of rain is considered in the system, but the force of the rain is as important. Fortunately, these two factors are highly related and the amount of rainfall is a good indicator of conidial dispersion.

Leaf wetness. At least 8 h of moisture are needed for infection and the amount of infection increases as the duration of wetness increases. We consider only the number of hours of wetness that occurred during and after a rain in the last 5 days. Without the force of rainfall, conidia are not dispersed. Dews and fogs are not considered since only localized infection results from even extended wetting periods. Dew can result in local infection of flowers from leaves or infected flowers, which increases available inoculum. This is considered under inoculum level. The risk values assigned are presented in Table 2.

Table 2. Weather factors considered during the bloom and points assigned in the development of PFD-FAD.

Factor				
	Condition			
		Rainfall total - last 5 days (mm)	**Wetting during and after rain (h)**	**Risk value**
Rain and leaf wetness				
		<5	<8	0
			9-16	1
			>16	2
		5-15	<8	1
			8-16	3
			>16	5
		15-25	<8	1
			8-16	4
			>16	7
		25-50	<8	1
			8-16	6
			>16	10
		>50	<8	1
			8-16	8
			>16	10
Previous rain				
	Number of rainfall events prior to last 5 days			
		0		0
		1-3		1
		>3		3

In the PFD model (9), very high rainfall occasionally can result in the prediction of the need for a fungicide application even when there is no inoculum present for dispersal. Similar problems occurred in the development of this advisory system. Thus, we introduced a condition such that "*if* disease history and the disease risk values are zero, *then* no application is recommended."

Previous rain. Rains which occur during the bloom period but prior to the last 5 days must also be considered. Such rains bring about build-up of unseen inoculum such as large numbers of conidia on dried petals or on the surface of vegetative structures. The only rains considered are those that occur after formation of white pinhead or button bloom. Risk values are assigned according to the number of events which have occurred prior to the last 5 days (Table 2).

Inoculum Level Risk. The inoculum availability is crucial to development of an epidemic. Propagule levels on leaves from the previous season are always low and are generally in the range of 1 to 100 propagules per leaf (1,12). In contrast, infected petals with abundant acervuli may bear as many as 1-10 million conidia per petal (6). Thus, if there is no PFD on the current bloom, the risk of an epidemic is small even with heavy rains and extended wetting periods. However, in order to achieve good disease control, fungicides must be applied when the number of diseased flowers (i.e., the inoculum levels) are low, generally 1 to 10 infected flowers per tree. Once infection levels exceed 10 diseased flowers per tree, PFD becomes extremely difficult to control. The risk values assigned are presented in Table 3.

Table 3. Points assigned according to the disease situation in the grove in the development of PFD-FAD.

Condition	Risk value
No PFD evident on the current bloom	0
No PFD evident on the current bloom	0
Few, scattered foci in grove	5
Low levels (1 to 10 affected flowers per tree)	7
Many infected flowers (> 10 per tree)	10

Total risk. The total risk value for a given situation is obtained by the following formula:

Total risk score = (Prebloom risk/7) + weather risk + inoculum level risk.

Trigger values. The total risk score needed to trigger a fungicide application varies according to the time of the most recent application (Table 4). If fungicide has been applied recently, higher trigger values are needed.

Table 4. Values required to trigger a spray according to the time of the last fungicide application.

Condition	Trigger value
No fungicide last 14 days	> 11
Fungicide application 10-13 days ago	> 13
Fungicide application 7-9 days ago	> 15
Fungicide application in the last 6 days	No spray

Implementation and Output

The PFD-FAD system was implemented as a Java servlet (Sun Microsystems, Inc., Santa Clara, CA) that interacts with an HTML form (7) (Fig. 3). Users can specify factors and answer questions by using pull-down lists on the form. On the right side of each list, there is a button that can be used to access additional information and further explanation of each item. Once users have answered questions and specified all conditions, they submit the form. Answers are sent to the Java servlet which resides on a remote server. The servlet analyzes the user's answers and returns a recommendation in the form of an HTML page that appears on the user's Web browser (Fig. 4). A summary of the factors submitted and a recommendation are presented.

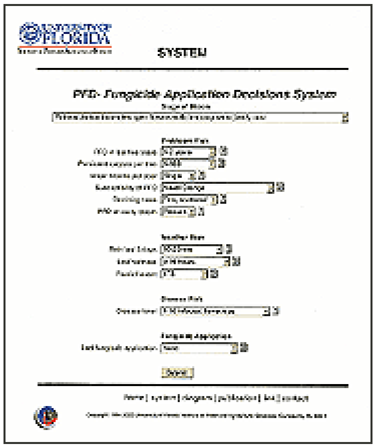

Fig. 3. The PFD-FAD input screen. Users make selections from pull-down lists and then submit to obtain a recommendation.

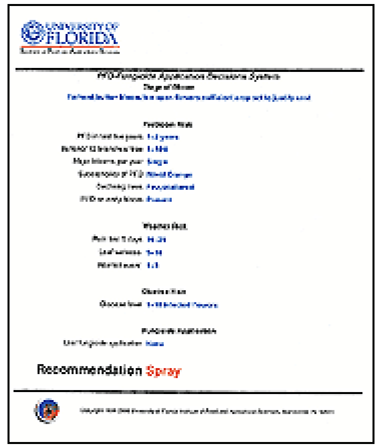

Fig. 4. The PFD-FAD recommendation. The Java servlet generates an HTML file containing a summary of the factors entered by the user along with a recommendation.

In addition, a flow diagram of how the decisions are made and further information can be accessed. A citation for the complete publication can be obtained and links are provided to other related and useful sites. The authors can be contacted to discuss the development of the system (N. A. R. Peres and L. W. Timmer) or its implementation (S. Kim and H. W. Beck).

The PFD-FAD system can be accessed directly at: http://it.ifas.ufl.edu/disc/pfd (7).

Assessment of PFD-FAD

Field tests were conducted in 2001 at a large farm near Itapetininga, São Paulo, Brazil, to compare spray timing using PFD-FAD, the PFD model, the grower's program and an unsprayed control. Fungicides were applied to one row of trees with a guard row between treatments. Each treatment was replicated twice in each of seven blocks of trees, five of Pera sweet orange and two of Natal. The fungicides were applied with a Jacto Arbus 2000 sprayer using a spray volume of 780 liters/ha on the dates indicated in Table 5.

Table 5. Effect and value of different systems for timing of fungicide applications for control of postbloom fruit drop.

Treatment	**Spray dates**[a]	**Buttons/12 branches /tree**	**Fruit/12 branches /tree**	**Appli-cation cost/ha**	**Fung-icide cost/ha**	**Total**
Control	-	91	23.9	0	0	0
PFD-FAD[b]	8/24	54	29.2	$8.70 (x1)	$32.50	$41.20
PFD Model[b]	7/27-30, 8/23-24	45	32.9	$8.70 (x2)	$65.00	$82.40
Grower program[c]	7/26-27, 8/22-24, 8/28-29	46	31.3	$8.70 (x3)	$97.50	$123.60
Least significant difference (*P* > 0.05)		28	5.0			

a Ranges of spray dates indicate the timing of the sprays in the 7 different locations.

b Fungicide used for the PFD model and PFD-FAD was Derosal (carbendazin) at 0.78 liters/ha in all cases.

c Grower usually applied Derosal at 0.39 liters/ha + Folpan (folpet) at 0.74 kg/ha; but sometimes used Derosol at 0.59 liters/ha + Dithane PM (mancozeb) at 6.94 liter/ha, Score (difenoconazole) at 0.02 liters/ha, or Score at 0.02 liters/ha + Dithane PM at 0.78 liters/ha.

Counts of persistent calyces and fruit were made in December 2001. Ten trees were selected arbitrarily in the treated row for evaluations. Three branches about 0.7 m long were selected in each quadrant of the tree and the number of persistent calyces and fruit counted. Data were expressed as the number per 12 branches per tree. Approximate fungicide and application costs and fruit prices were obtained from local growers, distributors, and other citrus industry sources.

All spray programs significantly reduced the number of persistent calyces per tree and increased the fruit production compared to the unsprayed control. There were no significant differences among the different systems used to time applications. The PFD model reduced spray cost by more than 50% and PFD-FAD reduced costs to about one-third of that in the grower program.

Discussion

The PFD-FAD system is designed to be slightly conservative. That is, occasionally an application will be recommended that would not be required. Growers may wish to introduce some additional judgment into the system based on economics and other factors. For example, if the risk value is marginal, growers may want to make an application for high value crops and accept more risk for low value crops. It is probably better to accept less risk in the earlier stages of the bloom and take more chances late, especially if a large crop has already been set.

The PFD model (9) required exact figures for the number of diseased flowers per tree as well as for rainfall and leaf wetness. The PFD-FAD system requires only a general assessment of the disease incidence, essentially the inoculum availability. Thus, scouting of plantings for PFD is simplified. Likewise, ranges on the rainfall and leaf wetness are used in the PFD-FAD system. Therefore, if this information is not available for the specific block, estimates can be made from nearby locations. Use of the PFD-FAD system for forecasting disease and predicting the need for fungicide applications should be simplified. Growers can gain a better understanding of the disease by entering theoretical conditions and observing the response of the system.

The PFD-FAD system should eliminate unnecessary applications which are now made as a precaution without assuming great risk. We feel that indications would be at least as accurate as the PFD model for use in Florida. This decision support system would eliminate sprays indicated by the PFD model following intense rains of short duration. The PFD-FAD system should be useful in most areas where PFD is a problem.

Applications of fungicide to control PFD are essential for good yields. In the field experiment in São Paulo State in Brazil, the yield increase was greater than 20%. Assuming a price of $3.30 US per 40-kg box and a yield of 1000 boxes per hectare, the return was more than $660 US per hectare above that in the control. The savings by using PFD-FAD was about $82.40 per hectare.

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Literature Cited

1. Agostini, J. P., and Timmer, L. W. 1994. Population dynamics and survival of strains of *Colletotrichum gloeosporioides* in citrus in Florida. Phytopathology 84:420-425.
2. Agostini, J. P., Timmer, L. W., and Mitchell, D. J. 1992. Morphological and pathological characteristics of strains of *Colletotrichum gloeosporioides* from citrus. Phytopathology 82:1377-1382.
3. Fagan, H. J. 1979. Postbloom fruit drop, a new disease of citrus associated with a form of *Colletotrichum gloeosporioides*. Ann. Appl. Biol. 91:13-20.

4. Orozco Santos, M., and Gonzalez Garza, R. 1986. Caída de fruto pequeño y su control en naranja 'Valencia' en Veracruz. Agric. Tec. Mex. 12(2):259-269.
5. Peres, N. A. R., Souza, N. L., and Timmer, L. W. 2002. Postbloom fruit drop in Brazil and Florida: occurrence and control by fungicides. Proc. Int. Soc. Citriculture (in press).
6. Peres, N. A. R., Souza, N. L., Zitko, S. E., and Timmer, L. W. 2002. Activity of benomyl for control of postbloom fruit drop of citrus caused by *Colletotrichum acutatum*. Plant Dis. 86:620-624.
7. Peres, N. A. R., Timmer, L. W., Beck, H. W., Kim, S. 2001. PFD-FAD system. Online. University of Florida Institute of Food and Agricultural Sciences.
8. Timmer, L. W., and Brown, G. E. 2000. Biology and control of anthracnose diseases of citrus. Pages 300-316 in: Host Specificity, Pathology, and Host-Pathogen Interactions of *Colletotrichum*. Prusky, D., Freeman, S., and Dickman, M. B., eds. American Phytopathological Society, St. Paul, MN.
9. Timmer, L. W., Roberts, P. D., and Chung, K. R. 2002. Postbloom fruit drop. Pages 85-88 in: 2002 Florida Citrus Pest Management Guide. L. W. Timmer. University of Florida Cooperative Extension Service, IFAS, Gainesville, FL.
10. Timmer, L. W., Agostini, J. P., Zitko, S. E., and Zulfiqar, M. 1994. Postbloom fruit drop of citrus, an increasingly prevalent disease of citrus in the Americas. Plant Dis. 78:329-334.
11. Timmer, L. W., and Zitko, S. E. 1993. Relationship of environmental factors and inoculum levels to the incidence of postbloom fruit drop of citrus. Plant Dis. 77:501-504.
12. Timmer, L. W., and Zitko, S. E. 1995. Early season indicators of postbloom fruit drop of citrus and the relationship of disease incidence and fruit production. Plant Dis. 79:1017-1020.
13. Timmer, L. W. and Zitko, S. E. 1996. Evaluation of a model for prediction of postbloom fruit drop of citrus. Plant Dis. 80:38-383.
14. Zulfiqar, M., Brlansky, R. H., and Timmer, L. W. 1996. Infection of flower and vegetative tissues of citrus by *Colletotrichum acutatum* and *C. gloeosporioides*. Mycologia 88:121-128.