A Forecasting Model for Fire Blight of Pear

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ABSTRACT

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Bactericide applications for control of fire blight, caused by *Erwinia amylovora,* were forecast by using daily mean orchard temperatures. Bacteria were detected in pear flowers in 11 of 12 orchards in 1977 within 2 wk after the mean temperature in the orchards exceeded a prediction line drawn from 16.7 C on 1 March to 14.4 C on 1 May. During 1974, 1975, and 1976, bacteria were detected in 93% of the orchards 22 days or more after the crossing of the prediction line. These epiphytic bacteria were isolated from healthy pear flowers before any fire blight appeared in the orchard in 100% of the orchards monitored during 1974–1977. Treatments initiated soon after the mean temperature exceeded the prediction line gave control equal to a spray program initiated at 10% bloom, which entailed more applications. Reduction in the number of applications depends on spring temperatures. In 1974 and 1975, the number of applications in test orchards was reduced by more than 60% (from 16 to 6, 14 to 6, and 7 to 3); in 1977, however, the reduction averaged only one application. In 1978, estimates in California indicate a savings of three spray applications per grower on about 16,200 ha of pears for a total savings of $1.2 million. Modifications of this technique may be applicable to other geographic areas where pears are grown.

Until the early 1970s, the common practice in California to control fire blight of pear, caused by *Erwinia amylovora*, was to spray or dust trees with copper or antibiotic materials at 5-day intervals throughout the flowering period (8). Because of the mild winters in the pear-growing districts, where Bartlett is the predominant cultivar, the flowering period may last 3 mo, resulting occasionally in as many as 20 applications of bactericide. In spite of these efforts, many growers observed that fire blight frequently occurred late in spring after spraying was discontinued. They also noted that in some years thousands of dollars were spent on blight control in their orchards while little was done to control blight in neighboring orchards where the level of disease was almost identical. These and other reports suggested that timing of bactericide applications is critical in fire blight control.

In the late 1970s, a technique for monitoring flower populations of *E. amylovora* was used to determine when to apply bactericides (12), but the technique was expensive, time-consuming, and not available to all growers. Furthermore, the long-range objective of the monitoring program was to develop a predictive system relating the occurrence of *E. amylovora* in flowers to specific weather conditions. Although many attempts have been made to relate disease incidence to such factors as winter and spring temperatures, moisture and humidity, prevalence of insects, incidence and activity of holdover cankers, and fertility regimes (1,2,4–7,9), the complexity of interrelationships has prevented clear definition of a set of factors that predict when disease will occur. It seemed more reasonable in California, therefore, to develop a predictive system based on the conditions leading to population buildup because *E. amylovora* colonizes flowers epiphytically before disease develops (12). Optimally the predictive approach should signal when to apply protective bactericides to flowers, thus preventing population buildup that ultimately may lead to disease when environmental conditions are favorable. A preliminary report has been published (13).

MATERIALS AND METHODS

Orchards were selected in all major pear-growing counties in California, including Lake, Mendocino, Solano, Santa Clara, Contra Costa, El Dorado, Glenn, Napa, Sacramento, Yolo, and Yuba. Flowers were sampled for the presence of *E. amylovora* as previously outlined (12). Weather and bacterial population monitoring data from 1974, 1975, and 1976 were compared to determine which environmental conditions correlated most closely and consistently with the onset of bacterial populations in the flowers. Temperatures and relative humidity in each orchard were determined with a 7-day recording hygrothermograph (Weather Measure Corp., Sacramento, CA) or in a few cases with a maximum-minimum thermometer (Taylor Instrument, Arden, NC). Leaf wetness was determined with the deWitt 7-day recorder (Agrotec, Beirut, Lebanon).

Mean temperatures for each day were calculated by determining the average of the maximum and minimum temperatures from midnight to midnight. The number of days from when the actual mean temperature exceeded a baseline mean temperature to when bacteria were detected in the flowers was determined for each orchard. Data are presented as the percentage of orchards where bacteria were detected in flowers within a specified number of days after the mean temperature crossed the prediction line. The baseline mean temperatures were changed and the percent of orchards fitting the conditions was determined for each line. The monitoring data collected in 1977 were compared with our prediction model, derived from 1974, 1975, and 1976 data, to determine if the model was valid for data not used in structuring the model.

Methods for determining when to initiate bactericide applications were compared in pear orchards in different counties during 1976 and 1977. Each orchard was divided into three sections, and applications were initiated using one of three methods. In the first method, applications were begun at 10% bloom and continued every 5 days until flowering was complete. With the second approach, treatment was initiated when the mean temperature exceeded a baseline mean temperature prediction line drawn from 16.7 C on 1 March to 14.4 C on 1 May. In the third approach, treatment was initiated when fire blight bacteria were first detected in the flowers. In this case, treatments were applied as soon after bacteria were detected as possible, usually within 48 hr. Chemicals were applied in replicated plots with a concentrate sprayer at the rate of 935 L/ha. Streptomycin sulfate (17%) was used in some orchards at 700 g/ha and cupric hydroxide (Kocide 101) in others at 0.86 kg a.i./ha. Subsequent sprays were applied at 5-day intervals with all three methods. Control plots received no bactericides, and applications were discontinued on the same day in each orchard. The number of fire blight

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infections was counted several times during the season and totaled at the end of the study.

RESULTS

The evaluation of 4 yr of monitoring data from 132 orchards indicated a definite relationship between spring temperatures and the first occurrence of *E. amylovora* in flowers. A comparison of 1977 data with the model derived from data of 1974, 1975, and 1976 showed excellent agreement. Bacteria were most likely detected in flowers after the daily mean temperature exceeded temperatures demarcated by a sloping line drawn from 16.7 C on 1 March to 14.4 C on 1 May (Fig. 1). This line provided the best fit to the data for predicting when *E. amylovora* would most likely be present in pear flowers. For example, Table 1 shows that when the mean temperature crossed the line, bacteria were detected in flowers of 30 and 43% of the 120 orchards in the following 7 and 14 days, respectively. However, bacteria were detected in 93% of the 120 orchards 22 days or more after the crossing of the mean temperature.

The error column in Table 1 represents orchards where bacteria were detected in flowers before the mean temperature crossed the selected threshold line. The 7% in the error column represents eight orchards; of these eight orchards, bacteria were detected only 1 day before crossing the line in four orchards, 2 days before in two orchards, and 3 days before in two orchards. By the time flowering was complete in 1974–1977, bacteria were present as epiphytes in 100% of the healthy blossoms in the orchards monitored.

Table 1 also shows that other mean temperature thresholds were less effective in predicting the occurrence of *E. amylovora* in flowers in the 120 orchards because the crossing of the lines resulted either in a very low detection percentage (eg, 14.4–13.3 C) or in a slightly higher detection percentage but with more orchards where bacteria were detected before the mean temperature crossed the selected threshold (eg, line 17.8–14.4 C).

Monitoring and weather data for 12 orchards in 1977 were then compared with the data of 1974–1976 to verify the model. Excerpts of the data for the 12 orchards (Table 1) showed that the 16.7–14.4 C line again provided a good prediction of when bacteria would colonize flowers. Bacteria occurred in flowers in 7 (58%) and 11 (92%) of the orchards within 7 and 14 days, respectively. No fire blight bacteria were detected in flowers before the period predicted by the temperature method. Although the 16.7–16.7 C line was better for predicting more closely when bacteria would appear in flowers, it allowed a 38% error in the 1974–1976 studies.

No other environmental conditions were found that were more useful than the mean temperature in predicting the occurrence of fire blight bacteria. This entailed a comparison of degree days (baseline temperatures: 14.4, 15.6, 16.7, and 17.8 C) and accumulated hours over the same baseline temperatures. As indicated by the deWitt wetness recorder, free moisture was present every night, and we concluded that free moisture was not a limiting factor for bacterial multiplication in California.

Data from a few representative orchards indicates that fire blight control by the temperature prediction method was as good as the normal calendar program (sprays every 5 days from beginning of flowering) in orchards where the first application of bactericide was delayed until the mean temperature in the orchard exceeded the 16.7–14.4 C prediction line (Table 2). In 1976 and 1977 the number of bactericide applications was reduced by more than 60% (14 vs 6, 16 vs 6, and 7 vs 3) because mean temperatures were late in crossing the specified threshold (Table 2). However, spring temperatures in 1977 were warm and consequently the mean temperature threshold was crossed early in the spring,

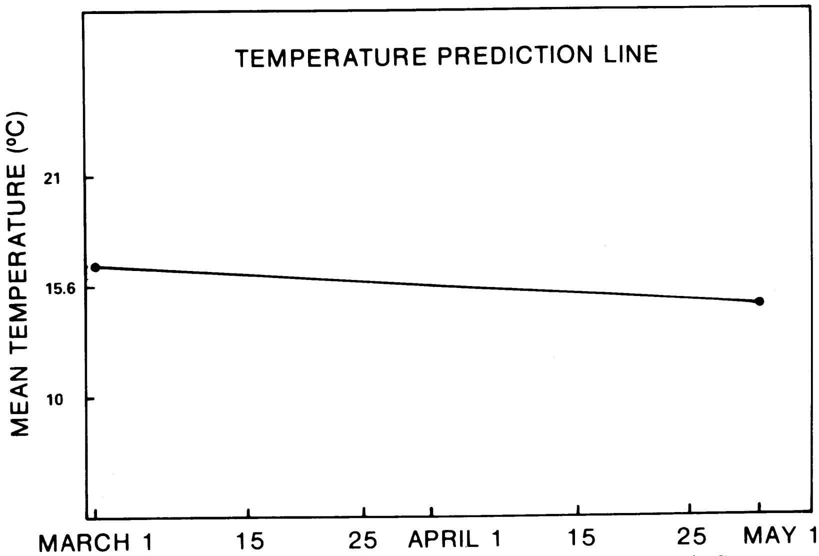


Fig. 1. Populations of *Erwinia amylovora* during bloom are usually detected in flower samples taken shortly after the mean temperature exceeds the prediction line.

Table 1. Percent of orchards where *Erwinia amylovora* was detected in flowers within a specified number of days after the mean day temperature exceeded a mean temperature threshold

Mean temperature threshold[a]		Orchards (%) with *E. amylovora*[b]				
		Days after threshold				
March 1	May 1	7	14	21	>22	Error[c]
120 orchards, 1974, 1975, and 1976						
14.4	13.3	7	15	23	100	0
15.6	13.3	10	25	35	100	0
16.7	13.3	10	32	42	97	3
17.8	13.3	28	43	52	92	8
14.4	14.4	13	22	27	100	0
15.6	14.4	22	33	38	98	2
16.7	14.4[d]	30	43	50	93	7
17.8	14.4	35	42	50	82	18
15.6	15.6	22	30	36	90	10
16.7	14.5	23	32	42	68	32
16.7	16.7	25	35	45	62	38
17.8	16.7	30	43	47	67	33
12 orchards, 1977						
15.6	14.4	15	75	92	100	0
16.7	14.4[d]	58	92	92	100	0
15.6	15.6	25	75	92	100	0
16.7	15.6	50	92	92	100	0
16.7	16.7	67	92	100	100	0

[a] The mean temperature threshold was determined by drawing a line between selected mean temperatures on 1 March and 1 May.
[b] Percent of orchards in which *E. amylovora* was detected in flowers within a certain number of days after mean temperature exceeded the mean temperature threshold. Daily mean temperatures represent the maximum of the day and the minimum of the night from midnight to midnight.
[c] Percent of orchards where *E. amylovora* was detected before the mean temperature exceeded the mean temperature threshold.

resulting in a savings of only one or two applications. Delaying applications until detection of *E. amylovora* in flowers usually resulted in fewer applications but occasionally at the expense of slightly higher levels of infection (Table 2).

A comparison of use of the three techniques—monitoring for the first occurrence of blight bacteria in flowers, the mean temperature predictive system, or the calendar spray approach based on flower development—for determining when to apply bactericides is shown in representative orchards in Glenn and Yolo counties (Fig. 2A,B). In the Glenn County orchard, bacteria were detected in the blossom wash on 21 April, 9 days after the mean temperature had exceeded the prediction line on 12 April (Fig. 2A). *E. amylovora* was detected in flowers 24 days after bactericide applications would normally have begun (10% bloom) by using the calendar program. Applications of cupric hydroxide were started on 23 April based on blossom populations and continued every 5 days for a total of seven applications. Infections were first observed on 4 May and averaged only 0.1 per tree (Fig. 2A). If control had been based on flower stage, spray applications would have started on 29 March, whereas applications based on mean temperatures would have begun on 13 April.

When the mean temperature exceeds the prediction line during a period of heavy bloom, the orchard probably will be severely infected, especially if rain occurs during a warm period. The Yolo County orchard in 1976 demonstrates this potential (Fig. 2B). The mean temperature in the orchard exceeded the prediction line on 16 March during 1% bloom, and rain occurred on 18 and 19 March. *E. amylovora* was detected in the flower sample on 25 March, and the population remained high during the full bloom period. Infections were first noted on 27 April with total infections averaging 11.5 per tree (Fig. 2B). Bactericide applications were initiated late on 6 April.

DISCUSSION

The 16.7–14.4 mean temperature line is a good predictor of when to initiate bactericide applications in pear orchards. Bacteria were detected before the mean temperature exceeded the prediction line only in an occasional orchard. In most of these cases, the mean temperature in the orchard was only 0.5–1 C below the prediction line before detection of bacteria. The accuracy of the thermograph and its placement in the orchard could be major problems when using this technique and may have decreased our accuracy. If the temperatures in an orchard vary considerably because of terrain, additional thermographs should be used. Thermographs also should be placed in the warmest part of the orchard to provide the earliest prediction.

Use of the daily mean temperature to predict the need for bactericide applications will usually result in more bactericide applications than the monitoring technique will. However, the temperature technique is simple and inexpensive and can be accomplished by the grower with a recording thermograph or even with a maximum-minimum thermometer.

Applicability of this technique in other geographic areas is uncertain. A mean temperature technique is used in Washington and gives equally satisfactory results (3). However, the monitoring technique has not revealed a similar relationship in Michigan (11) or New York (1). Billing (4) developed a technique of fire blight prediction for southeast England based on temperatures and rainfall, which appears to accurately predict when fire blight symptoms will be most likely. The main objective of Billing's predictive system is to indicate periods of high disease risk and to insure early detection and removal of infected trees or parts of them. This technique has not been used in California because delaying the bactericide applications until disease is predicted could result in a serious outbreak of disease. In the future, this technique may be justified if bactericides with eradicative properties become available.

With respect to fire blight, some geographic differences are observed in California. The mean temperature technique provides excellent correlation with the presence of *E. amylovora* in flowers in orchards in the Sacramento Valley, such as Butte, Sacramento, Yolo, and Yuba counties. However, the prediction line is less accurate in North Coast Range areas such as Lake and Mendocino counties because the mean temperature line is frequently exceeded excessively long before bacterial detection. These differences are probably due to the amount of fluctuation in day and night temperatures. Lake and Mendocino counties generally have lower temperatures at night than the Sacramento area. These conditions suggest that other environmental conditions may be important. Degree days, hours exceeding baseline temperature, relative humidity, and free moisture were compared, but we were not able to determine a relationship as accurate as the mean temperature technique. The interaction of these environmental conditions is complex, and we believe that further examinations will reveal techniques that more accurately predict the occurrence of *E. amylovora*. Each geographic area may need to develop a unique temperature line or similar approach.

In orchards where *E. amylovora* was not detected for 2–3 wk after the mean temperatures exceeded the prediction line, several factors were observed that might account for this delay. These orchards had few overwintering cankers, and thus bacterial populations probably took longer to multiply to detectable levels. In many cases, the mean

Table 2. Comparison of fire blight control of Bartlett pear by using the monitoring program, temperature prediction system, or stage of flowering (calendar system) as the indicator for initiating applications of bactericides

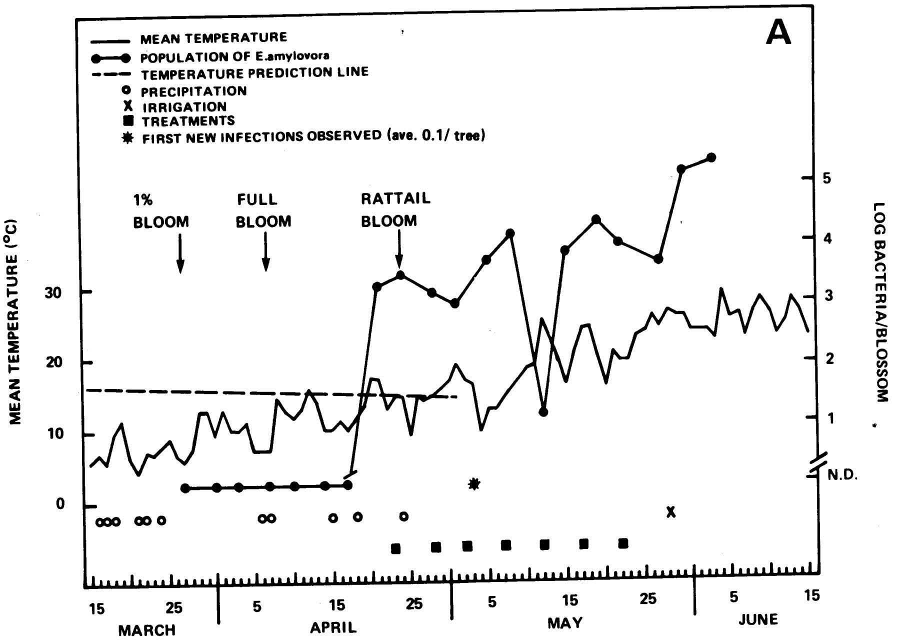
First application based on[a]	No. of applications	No. of infections/tree[b]
Yolo County, 1976		
Flower stage	14[c]	2 x
Mean temperature	6	4 x
Check	0	29 y
Santa Clara County, 1976		
Flower stage	16[c]	1 x
Mean temperature	6	12 x
Detection	5	8 x
Check	0	50 y
Solano County, 1976		
Flower stage	7[c]	1.6 x
Mean temperature	3	2.0 x
Detection	2	2.4 x
Check	0	7.6 x
Sacramento County, 1977		
Flower stage	9[d]	0.9 x
Mean temperature	8	1.2 x
Detection	6	2.8 y
Check	0	6.8 z
Yuba County, 1977		
Flower stage	13[d]	0.9 x
Mean temperature	11	1.2 x
Detection	10	3.2 y

[a] Initial applications of bactericides were based on 10% bloom, mean orchard temperature exceeding a line demarcated by 16.7 C on 1 March to 14.4 C on 1 May, or detection of *Erwinia amylovora* in a sample of 200 pear flowers.

[b] Means followed by different letters are significantly different at $P = 0.05$ according to Duncan's multiple range test. Each orchard was analyzed separately.

[c] Streptomycin sulfate (17%), 700 g in 935 L/ha.

[d] Cupric hydroxide, 1.1 kg in 935 L/ha.



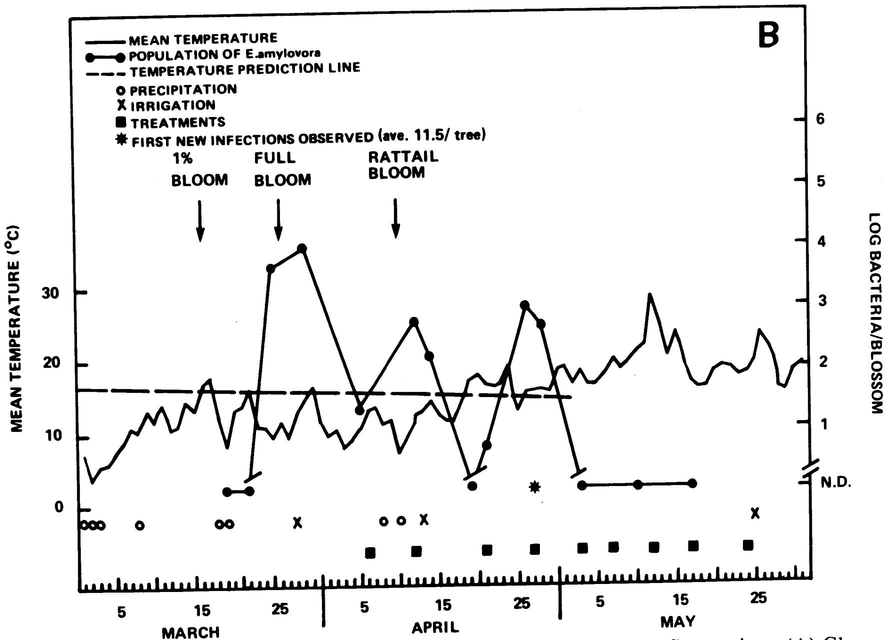


Fig. 2. Monitoring record for populations of *Erwinia amylovora* in pear flowers in a: **(A)** Glenn County orchard, 1975. **(B)** Yolo County orchard, 1976.

temperature was exceeded only on a single day with cool temperatures immediately before and after the crossing of the temperature threshold. A sustained warm period of 2–3 days apparently is more conducive to an increase in population of bacteria.

In the 1978 season it was estimated that growers saved an average of three applications. Each application cost an average of \$24.70/ha (\$10/acre). Therefore, with 16,200 ha of pears in California, this reflects a savings of \$1,200,000 per year (1978 dollars). In some years, growers may omit more, less, or no sprays compared with the 5-day calendar program, but control of fire blight will still be assured. In some years, the mean temperature may cross the prediction line early in the season during the full bloom period. This situation requires careful control procedures since this is when fire blight epiphytotics have been most severe. This temperature relationship appears to be the reason that pears cannot be successfully grown in the southern San Joaquin Valley (10).

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