Evaluation of FAST as a Forecasting System for Scheduling Fungicide Sprays for Control of *Stemphylium vesicarium* on Pear

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ABSTRACT

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The influences of temperature on mycelial growth and of temperature and relative humidity on germination of conidiospores were studied in six strains of *Stemphylium vesicarium* isolated from lesions on pear fruit (*Pyrus communis*) grown in areas of Catalunya, Spain. Optimal temperatures were 15–25 C for mycelial growth and 20–30 C for germination of conidia. Conidia germinated only when relative humidity ranged from 98 to 100% and free moisture encompassed the conidia. Comparison of these data with weather parameters during epidemics indicated that under climatic conditions in Spain, the principal limiting factor for epidemic development is duration of wetness. The FAST model developed for forecasting of early blight on tomato was evaluated in relation to its accuracy for predicting infection periods of pear fruit spotting and its usefulness in scheduling fungicide sprays for control of this disease. Trees were monitored from May to October in 1989, 1990, and 1991. Final disease incidence at harvest, after 4-wk exposure periods to natural inoculum when trees were not sprayed, revealed periods of infection that coincided with those predicted by the FAST model to favor disease development. Fungicide applications scheduled by FAST limited the development of pear fruit spotting to the same level achieved with the commonly followed 7-day commercial schedule but with 28% fewer fungicide applications in moderately diseased orchards.

Necrotic spotting of pear (*Pyrus communis* L.), caused by *Stemphylium vesicarium* (Wallr.) E. Simmons (teleomorph *Pleospora allii* (Rabenh.) Ces. & De Not.), is a disease of economic importance in Mediterranean pear production areas. The disease is currently one of the most common fungal diseases of pear and is comparable in economic importance to scab in certain regions. The affected areas include the fruit-growing regions of Emilia-Romagna and Veneto in Italy (2,18), Provence in southeastern France (3,5), and Catalunya in northeastern Spain (25).

Infections and necrosis occur on leaves, fruit, and to a lesser extent on twigs as a result of fungal penetration of stomata and lenticels and the production of a host-specific necrotoxin (18). Maximum levels of disease incidence are generally attained just before fruit cropping, and the infected fruit are non-marketable. Epidemics may be severe. Low levels of disease (5–10%) one year may be followed by up to 90% infected fruit the next year (25). Host susceptibility differs among cultivars; Abate Fetel, Passe Crassane, Alexandrine, Conference, and Doyenne du Comice, which are very abundant in Europe (17), are the most susceptible.

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Studies on inhibition of mycelial growth and conidial germination and of protective and after-infection activity of several fungicides in the laboratory as well as in experimental field trials have shown that procymidone, thiram, ziram, captan, mancozeb, and iprodione are effective for the control of *S. vesicarium* (4,5,19,25). On the basis of fungicide cost and efficacy, our Crop Protection Services recommends protectant sprays of thiram or ziram at nearly 7-day intervals from May to September (20 to 25 applications), regardless of the timing of infection periods.

The objectives of this investigation were 1) to determine the influence of temperature on mycelial growth and of temperature and relative humidity on conidial germination of strains of *S. vesicarium,* 2) to identify specific periods of infection in orchards, and 3) to evaluate the applicability of the FAST forecasting model for predicting infection periods and timing fungicide applications for disease control. (The acronym FAST was originally described for a forecaster of *Alternaria solani* on tomato [16]).

MATERIALS AND METHODS

Isolation, culture conditions, and preservation of strains. The fungus was isolated from necrotic lesions on surface-sterilized fruit of cultivar Passe Crassane collected from commercial orchards in the regions of Lerida and Girona in Catalunya, Spain. Cultures were grown on potato-dextrose agar (PDA) at 25 C. Strains were preserved up to about 3 mo on PDA slant tubes at 5 C. For long-term storage, conidia and fragments of mycelium were suspended in 15% glycerol and maintained at −25 C.

Production of conidia and virulence tests. Conidia were produced by placing disks of mycelium or spore suspensions in the center of PDA in petri dishes and incubating them for 10 days at 25 C under a 12-hr photoperiod. Conidial suspensions were obtained by washing the surface of colonies with sterile distilled water with one drop of Tween 20 per liter, filtering the suspension through cheesecloth, centrifuging the effluent, resuspending the pellet, and adjusting the concentration to about 10^5 conidia per milliliter. Strains were tested for virulence by inoculating detached pear leaves. Leaves were washed with a 1% sodium hypochlorite solution for 1 min, rinsed in sterile distilled water, dried with airflow in a sterile cabinet, and inoculated by placing five 10-μl drops of a suspension of 10^5 conidia per milliliter on the abaxial face. The leaves were then placed in petri dishes containing moistened filter paper disks and incubated at 25 C under a 12-hr photoperiod.

Effect of temperature on mycelial growth and conidial germination in vitro. Mycelial disks, 5 mm in diameter, were cut from the margins of actively growing cultures of *S. vesicarium* with a sterilized cork borer. The disks were placed in the center of PDA dishes and incubated in darkness in controlled temperature chambers at 5, 10, 15, 20, 25, 30, and 35 C. The temperature within each incubation chamber was maintained within ±0.2 C. Colony diameters were measured at approximately 12-hr intervals for 5 days. The effect of temperature on conidial germination was studied at the same temperatures by placing suspensions of 10^5 conidia per milliliter in a solution of agar in distilled water (6 g/L) in wells of microtitration plates. Germination was stopped at various time intervals by adding 1% formaldehyde. The plates were then inverted, and the conidia were observed through a microscope to determine the percentage of germination. Spores with at least one germ tube were considered germinated. Mycelial growth and germination of conidia were studied in six strains; experiments were repeated three times at each temperature.

Effect of relative humidity on conidial germination. The effect of relative

humidity (RH) on the germination of conidia was evaluated on glass slide coverslips placed in the dark in controlled temperature chambers at 20 ± 0.2 C. Four coverslips were attached to the internal surface of a 9.0-cm diameter plastic petri dish lid. Conidial suspensions were deposited in 10-μl drops on the surface of each coverslip and dried down in a laminar flow sterile cabinet. Atmospheres of 33, 55, 81, 92, 98, 99, or 100% RH were obtained by placing 15 ml of different salt solutions in individual petri dishes; these were allowed to equilibrate for 12 hr at 20 C (6). The covers were then replaced by the covers containing the coverslips with conidia, and the dishes were sealed with Parafilm. The slides were examined under microscope at 3 and 12 hr from the start of the experiment. Different plates were used for each time period. The experiment was performed for six strains and with four replications for each relative humidity.

Determination of infection periods by sequential omission of fungicide sprays. Thiram (Thylate 65WP) was applied with a handgun sprayer at a rate of 3 g a.i./L of active ingredient in a pear orchard (orchard B) in 1989 and 1990. A total of 264 11-yr-old Passe Crassane trees grown in three rows was used. The trees were sprayed to the point of runoff. Sprays were applied weekly from May to October except during 4-wk exposure periods that were imposed throughout the season to give a total of 20 exposure periods. Accordingly, trees in period 1 were not treated during weeks 1–4 but were sprayed thereafter until harvest; those in period 2 were not treated during weeks 2–5 but were sprayed during week 1 and after week 5, etc.; and those in period 20 were sprayed during weeks 1–19 but not during weeks 20–23. The experimental design was a randomized complete block with 22 treatments (20 exposure periods, nontreated, and sprayed weekly). Each treatment was replicated three times on four-tree plots. Disease incidence was evaluated at harvest on 100 leaves and on all fruit per tree and expressed as a percentage.

Evaluation of FAST for determining infection periods. The FAST model was used to identify likely infection periods of *S. vesicarium* on pear as described for *Alternaria solani* on tomato (16). Hours of leaf wetness and mean air temperature during wetness periods were combined to derive daily severity values (S). Mean air temperature, hours of relative humidity greater than 90%, and total rainfall were used to calculate a daily severity rating value (R). Temperature, relative humidity, duration of wetness, and rainfall amounts were measured in the test orchard from May to November each year. Temperature and relative humidity were measured with a 7-day recording hygrothermograph and duration of wetness with a 7-day recording leaf wetness meter (Jules Richard Instruments, Belgium). Rainfall was measured with a 12-cm diameter rain gauge. At the end of the 1989 and 1990 seasons, 7-day cumulative severity (CS) values and 5-day cumulative rating (CR) values generated by the FAST model were compared with final disease ratings for each of the 20 exposure periods.

In a second experiment, the sprays were actually timed using the FAST model. Treatments consisted of nontreated controls, weekly fungicide applications, and two or three spray schedules based on FAST models. Each treatment was replicated five times on five-tree plots. A total of 100 trees in orchard B and 125 in orchard A, planted in two rows, was used. Thiram applications were initiated when cumulative S values after full bloom equaled 35. Subsequent sprays were made according to CS values and within 24 hr of attaining the CS threshold. In 1990 in orchard A, CS thresholds corresponded to 11, 14, or 16. In 1991 in orchard B, thiram was applied when CS values were 14 or 16. Thiram was assumed to provide 7 days of protection even when the observed CS value surpassed the preselected CS except when rainfall exceeded 20 mm. When more than 20 mm of rain fell after spraying, trees were sprayed again. Standard insecticides and miticides were applied to all treatments. Disease progress was assessed weekly in each treatment by evaluating the incidence of infection on 50 leaves and 25 fruit per tree. Disease incidence at harvest was assessed by evaluating the incidence of infection on all fruit in each plot.

Data analysis. Statistical analyses were made with the Statistical Analysis System (21). Kinetics of conidial germination were analyzed by probit analysis with a normal probability model (12) and regressing the probits of the percentage of germinated spores on time. Effective exposure time for germination of 50% conidia was calculated from the regression equations. Data on disease incidence were transformed and tested for monocyclic and polycyclic disease progress models (26). The apparent infection rates, *r*, were calculated from the slopes of the regression lines. Disease incidence at harvest and infection rates were compared among treatments by analysis of variance with the ANOVA procedure and with the Ryan-Einot-Gabriel-Welsh multiple range test.

RESULTS

Effect of temperature on mycelial growth and conidial germination. The maximum rates of radial growth of mycelium on PDA (about 0.25 mm/hr) occurred between 15 and 25 C and were maximal at 21 C (Fig. 1). There were no significant differences among growth rates within this temperature range for the six strains studied. Little mycelial growth was observed at 5 or 35 C. Germination of conidia on water agar was extremely rapid for spores of all the strains at temperatures between 20 and 30 C. At these temperatures, about 50% of the conidia initiated germ tube formation within 1 hr (Fig. 2). At 10 or 35 C, most conidia germinated within 3 hr.

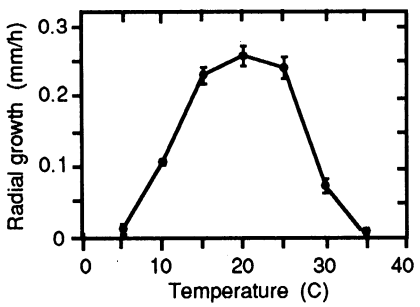

Fig. 1. Radial growth of mycelium of *Stemphylium vesicarium* on potato-dextrose agar at various temperatures. Results are the mean of six strains isolated from pear orchards in the region of Catalunya, Spain. Bars represent confidence intervals for the means. The regression equation is $y = 0.002x^2 - 0.0000637x^3 - 0.022373$ ($R^2 = 0.780$), where y is the radial growth, x is the temperature, and R is the regression coefficient.

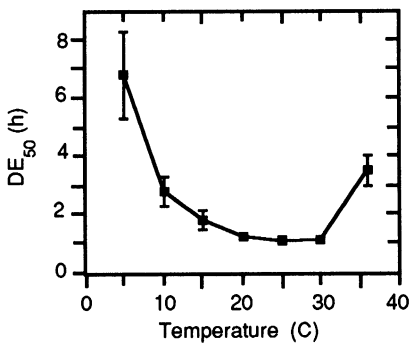

Fig. 2. Germination of conidia of *Stemphylium vesicarium* on water agar at various temperatures. The DE_{50} is the effective dose of time needed for germination of 50% of the conidia. Each data point is the mean of six strains. Bars represent confidence intervals for the means. The regression equation is $y = 9.857 - 0.788x + 0.017x^2$ ($R^2 = 0.948$), where y is DE_{50}, x is the temperature, and R the regression coefficient.

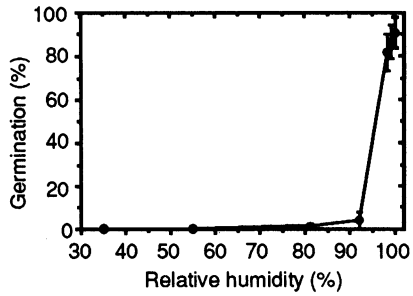

Fig. 3. Germination of conidia of *Stemphylium vesicarium* after 12 hr of incubation at 20 C on the surface of glass slide coverslips at various relative humidities. Each data point is the mean of six strains. Bars represent confidence intervals for the means.

Effect of air relative humidity on conidial germination. No germination occurred below 92% RH. Significant germination was observed only at 98, 99, and 100% RH (Fig. 3). At these humidities, a continuous minute layer of condensation was observed on the conidia-laden coverslips during incubation. Condensation was not observed at relative humidities of less than 92%.

Relation of observed infection periods and risk predictions by the FAST forecaster. The infection periods observed in commercial orchard B (4-wk exposures) were predicted by FAST during 1989 and 1990. However, the levels of disease predicted by FAST were not correlated with disease levels assessed after controlled 4-wk exposures.

During 1989, the mean air temperature during periods of surface wetness was commonly between 12 and 25 C, and the daily duration of wetness ranged from 4 to 24 hr (Fig. 4). Disease incidences at harvest in nonsprayed checks were 20% for fruit and 35% for leaves, whereas in the trees sprayed weekly they were 2% for both fruit and leaves. Four peaks of infection on leaves and fruit were observed above the background level of 2% disease incidence. These peaks could be grouped into four main periods of infection corresponding to exposure periods 4, 9–10, 13–15, and 19–20. The first infection period occurred during June after spring mean temperatures of 15 C, rainfall of 60 mm, and several days with 10–22 hr of surface wetness. The second infection period occurred in late July under less favorable conditions of surface wetness and rainfall. The third infection period was detected in August after temperatures of 22–25 C, 20 mm rainfall, and several days with 10–20 hr of surface wetness. The fourth infection period appeared in September-October before harvest and was observed after temperatures of 15–20 C, rainfall of 20 mm, and several days of continuous surface wetness. FAST predicted four main CS peaks above a background level of 14. CR values indicated three main risk periods corresponding to the first, third, and fourth infection periods.

During the 1990 season, the range of mean air temperatures during periods of surface wetness and the duration of wetness periods were similar to those in 1989; however, accumulated rainfall was higher (Fig. 5). Final disease levels in

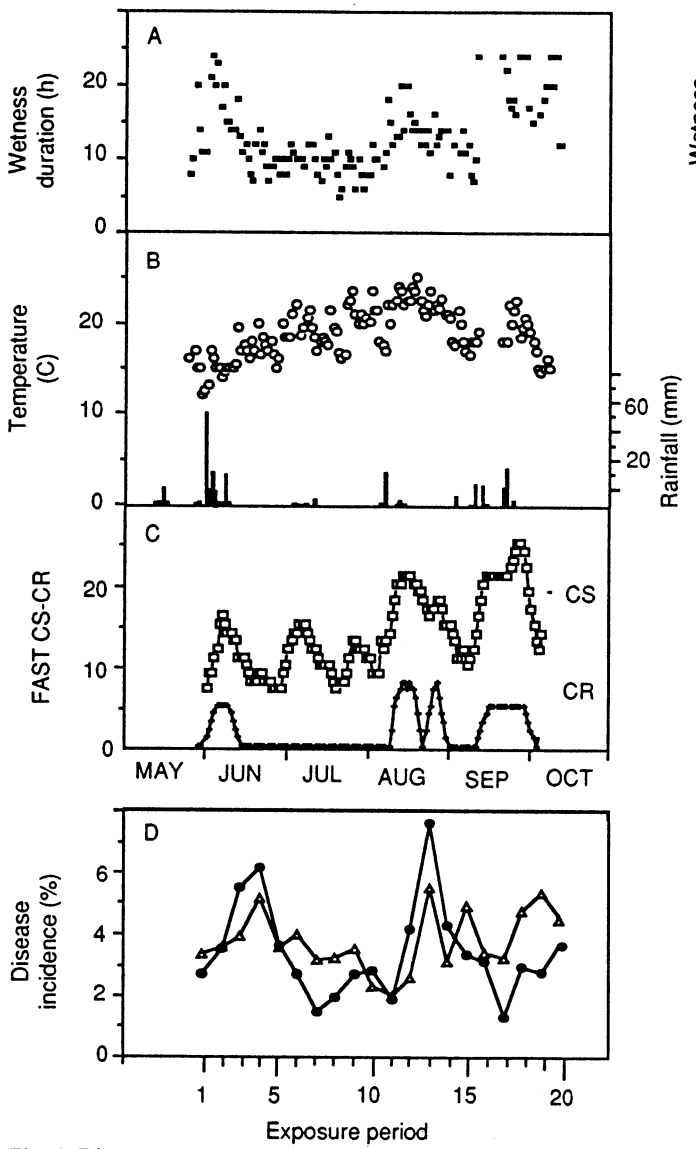

Fig. 4. Disease incidence on fruit (△) and leaves (●) for each of the 20, 4-wk exposure periods to natural inoculum in relation to daily duration of surface wetness **(A)**, mean temperature of hours of surface wetness and daily rainfall **(B)**, 7-day cumulated severity values for each day (CS), and 5-day cumulated severity ratings for each day (CR) according to the FAST forecaster **(C)** in the cultivar Passe Crassane in orchard B during the 1989 growing season. The values in **(D)** correspond to the last day of the fourth week of each 4-wk exposure period.

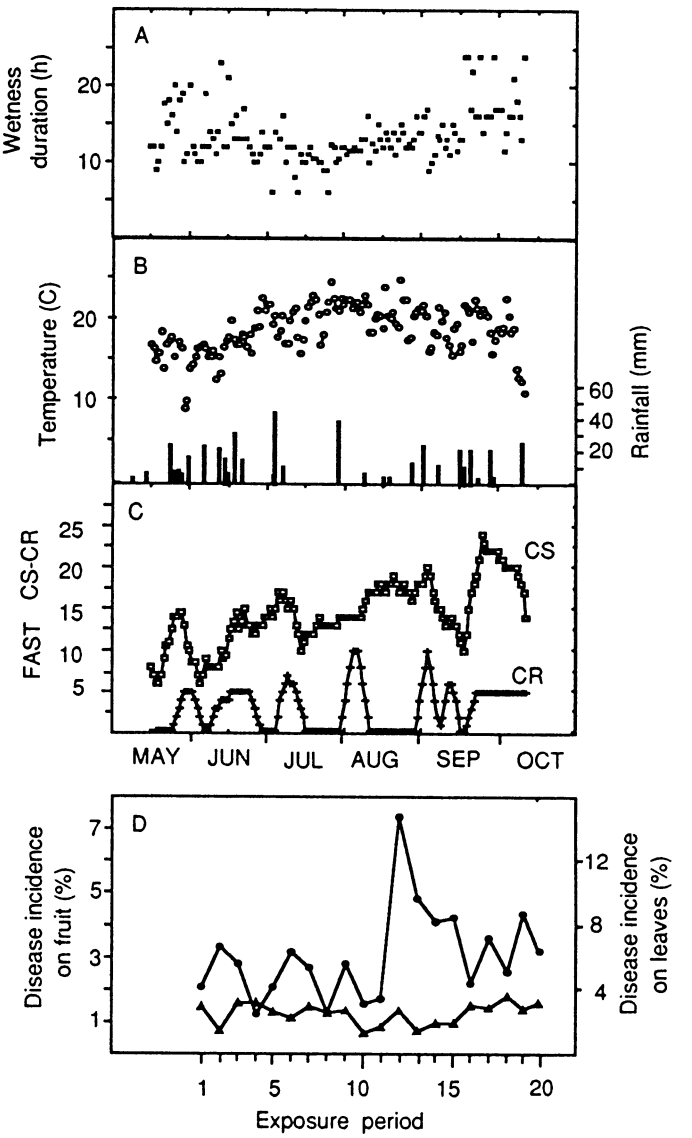

Fig. 5. Disease incidence on fruit (▲) and leaves (●) for each of the 20, 4-wk exposure periods to natural inoculum in relation to daily duration of surface wetness **(A)**, mean temperature of hours of surface wetness and daily rainfall **(B)**, 7-day cumulated severity values for each day (CS), and 5-day cumulated severity ratings for each day (CR) according to the FAST forecaster **(C)** in the cultivar Passe Crassane in orchard B during the 1990 growing season. The values in **(D)** correspond to the last day of the fourth week of each 4-wk exposure period.

nonsprayed checks were 52% in leaves and 8.3% in fruit, whereas in trees sprayed weekly, 15% of the leaves and 1% of fruit were infected. Seven periods of leaf infection (six peaks and one shoulder) were observed above a background level of 2% at exposure periods 2, 6, 9, 12, 15, 17, and 19. Disease incidence on fruit at harvest after 4-wk exposures was below background level. FAST predicted six risk periods above a CS threshold of 14 and seven periods based on CR warnings. The peaks of infection from June, July, and early August (exposure periods 2, 6, and 9) were accurately predicted from increases in CS and CR values in late May, middle June, and early July. The major infection peak in late August (exposure period 12) was predicted from CR values for early August and less definitely from CS ratings for middle August. The shoulder in middle September (exposure period 15) was predicted by CS and CR peaks in early September. The last two infection peaks in September-October (exposure periods 17 and 19) were more accurately predicted by CR than by CS.

Table 1. Timing of a thiram spray schedule for the control of *Stemphylium vesicarium* on pear[y]

Weeks after start	Orchard A, 1990				Orchard B, 1991		
	CS 16	CS 14	CS 11	Weekly	CS 16	CS 14	Weekly
1	+[z]	+	+	+	+	+	+
2	...	...	...	+	...	...	+
3	...	+	++	++	...	...	+
4	...	...	+	+	...	...	+
5	...	...	...	+	...	...	+
6	...	...	+	++	...	...	+
7	...	+	+	+	...	...	+
8	...	+	+	+	...	...	+
9	+	+	+	+	...	+	+
10	...	...	+	+	...	...	+
11	...	+	+	+	...	...	+
12	...	+	+	+	...	+	+
13	+	+	+	+	++	++	++
14	+	+	+	+	+	+	+
15	+	+	+	+	...	+	+
16	+	+	+	+	+	+	+
17	+	+	+	+	+	+	+
18	+	+	+	+	+	+	+
19	+	+	+	+	+	+	+
20	+	++	++	++	+	+	+
21	+	+	+	+	++	++	++
22	+	+	+	+	+	+	+
Sprays (total)	12	18	22	25	12	15	24

[y]Three experimental schedules were timed with the FAST model based on 7-day cumulative severity (CS) values of 11, 14, and 16 in orchard A in 1990 and of 14 and 16 in orchard B in 1991. Weekly = conventional 7-day schedule.
[z]One application (+), or treatment repeated (++) after more than 20 mm of rainfall following the initial fungicide application.

Table 2. Disease at harvest and apparent infection rates (k) of pear in a 1990 field trial to evaluate different cumulative severity (CS) threshold values for timing of fungicide sprays to control *Stemphylium vesicarium*[x]

Treatment	No. of sprays	Leaves		Fruit	
		Disease incidence[y] (%)	k[z] (day^{-1})	Disease incidence (%)	k (day^{-1})
Unsprayed	0	74.1 a	0.0134 a	22.2 a	0.0018 a
CS 16	12	62.8 b	0.0082 b	11.8 b	0.0013 b
CS 14	18	39.2 c	0.0040 c	3.6 c	0.0003 c
CS 11	22	25.4 c	0.0028 d	2.7 c	0.0003 c
Sprayed weekly	25	23.4 c	0.0025 d	2.3 c	0.0002 c

[x]Pear cv. Passe Crassane in orchard A monitored from June to October 1990.
[y]Means are the average of five plots of five trees. Values in the same column followed by the same letter are not significantly different ($P = 0.05$) according to the Ryan-Einot-Gabriel-Welsh multiple range test.
[z]The apparent infection rate was calculated by linear regression of the $\ln(1/1 - y)$ transformed disease incidence values on time, according to a monocyclic model. The monocyclic model, $y = 1 - \exp(-kt)$, was fitted to the data by transforming disease incidence into $\ln(1/1 - y)$ and regressing on time. The rate value, k, was calculated from the slope of the regression line. For the polycyclic model of the logistic form $y = 1/[1 + \exp(-kt]$, data were transformed to logits, $\ln(y/1 - y)$ and regressed on time. The apparent infection rate, k, was calculated from the slope of the regression line. All apparent infection rates were significant at $P < 0.01$.

Validation of FAST under standard production conditions. On the basis of the previous results, values of CS 11, 14, and 16 were chosen for triggering spray applications in orchard A during 1990 and of CS 14 and 16 in orchard B during 1991 (Table 1). Disease progress curves for fruit and leaves for the five treatments applied in orchard A during 1990 increased linearly with time, and a monocyclic model of disease progress adequately described the data (Fig. 6). Disease levels were significantly higher on leaves than on fruit for the duration of the epidemics. The effectiveness of the different spray schedules in controlling disease in orchard A was evaluated by comparing final disease incidence and apparent infection rates for the five treatments (Table 2). There were no significant differences, either for disease incidence on fruit and leaves at the time of harvest on 7 October, or for apparent infection rates among trees sprayed according to the commercial schedule (weekly) or those sprayed using the FAST threshold CS values of 11 and 14. However, the values of disease incidence at harvest were significantly higher for trees sprayed according to a threshold CS value of 16 and were higher yet for the nonsprayed check. Scheduling sprays according to a CS threshold value of 14 permitted a decrease of seven fungicide applications compared with a normal commercial spray schedule (28% reduction) while still maintaining comparable disease control.

In orchard B during 1991, the levels of disease incidence were lower than in orchard A (Table 3). During this trial, only final disease incidences for leaves and fruit at harvest were evaluated. There were no significant differences between disease incidence in fruit for treatments at CS 16, CS 14, and the conventional schedule, all of which were significantly lower than for the nonsprayed check treatment. The results for leaves indicated that treatments at CS 16 and CS 14 did not differ significantly from either the nonsprayed treatment or from the commercial schedule. A CS value of 16 permitted a decrease of 12 applications (50%), and a CS value of 14 permitted a decrease of nine applications (38%) relative to the standard commercial schedule while still maintaining comparable levels of disease control. However, the low disease incidence on fruit of the nontreated control limits the value of the results of this test from a commmercial standpoint.

DISCUSSION

The rates of germination of conidia and mycelial growth of strains of *S. vesicarium* isolated from lesions on pear fruit and leaves were very high in comparison with many other fungi (1,7, 8,23). The conidia are polyspermic and produce from one to six germ tubes, thus

increasing the probability of infection thorough lenticels in fruit and stomata in leaves. Conidia responded quickly to wetness; 50% began germination in less than 1 hr at the optimal temperatures. Mycelial growth was also rapid; growth rates of about 0.25 mm/hr were observed at the optimum conditions. These findings agree with results obtained with strains isolated from Provence in France (5). However, our data should not be regarded as definitive for extrapolation to the field, since age and conditions of production may affect germination rates of conidia (22,24). Also, our data agree with a report by Cugier and Humbert (5) in which 4–5 hr of wetness followed by 48–96 hr of incubation in dry climatic chambers was sufficient for symptom expression in the pear cultivar Alexandrine inoculated with strains of *S. vesicarium* isolated from France. All these findings suggest that incubation periods for *S. vesicarium* under orchard conditions should be very short.

Disease progress curves were fitted by a monocyclic model, and apparent infection rates of 0.0134/day for leaves and 0.0018/day for fruit were commonly observed. Disease progress curves are described by monocyclic models when most inoculum is present throughout the duration of the epidemic or comes from a reservoir, such as the soil (26). Leaves and fruit severely infected with *S. vesicarium* that accumulate on the soil surface during the season may constitute the reservoir for the next year. There is evidence that the pathogen overwinters on this debris and produces a species of *Pleospora*, the sexual form of *S. vesicarium* (9,18). Further studies on the overwintering of the pathogen are of interest, since complementary measures for elimination of the primary inoculum should be taken into account in disease management programs.

In the Mediterranean area where our orchards are located, mean temperatures during periods of surface wetness (10–25 C) generally do not constitute a significant limiting factor for conidial germination or for fungal growth. However, moisture availability, expressed as hours of surface wetness, is variable (0–24 hr per day) as are periods of relative humidity higher than 90%. When our laboratory results were compared with climatic data of other Mediterranean areas during periods of disease development, it appeared that duration of wetness periods and relative humidities higher than 90% might be the limiting factors that trigger the infection process in orchards.

We selected FAST for use as a forecasting system for pear fruit spotting because the method for calculation is relatively simple, easy to program in data loggers, and based on parameters governing spore germination on the plant surface (e.g., temperature and duration of wetness). Since the results we obtained for effects of temperature and moisture on germination of *S. vesicarium* were not significantly different from those on *A. solani* (24), and because both fungi are taxonomically related (on the basis of spore morphology and ontogeny), the original model was not modified.

The dynamics of final disease incidence in 4-wk cumulated exposures to *S. vesicarium* natural inoculum revealed periods of infection that were previously predicted by the FAST forecaster with minor exceptions. However, the quantitative degree of disease measured by FAST as relative peak heights of CS and CR values did not agree with the relative peak intensity obtained for disease incidence after 4-wk cumulated exposures. Variations in inoculum availability during the season could explain the differences. Another explanation could be that, despite many biological similarities, there still exist important differences between the infection biology of *A. solani* on tomato and *S. vesicarium* on pear.

Timing of fungicide sprays for control of *S. vesicarium* during 1990 and 1991 in two commercial orchards that were scheduled with the aid of the FAST model at CS 14 threshold warnings maintained disease levels comparably to the 7-day commercial schedule, with 28–38% fewer fungicide applications.

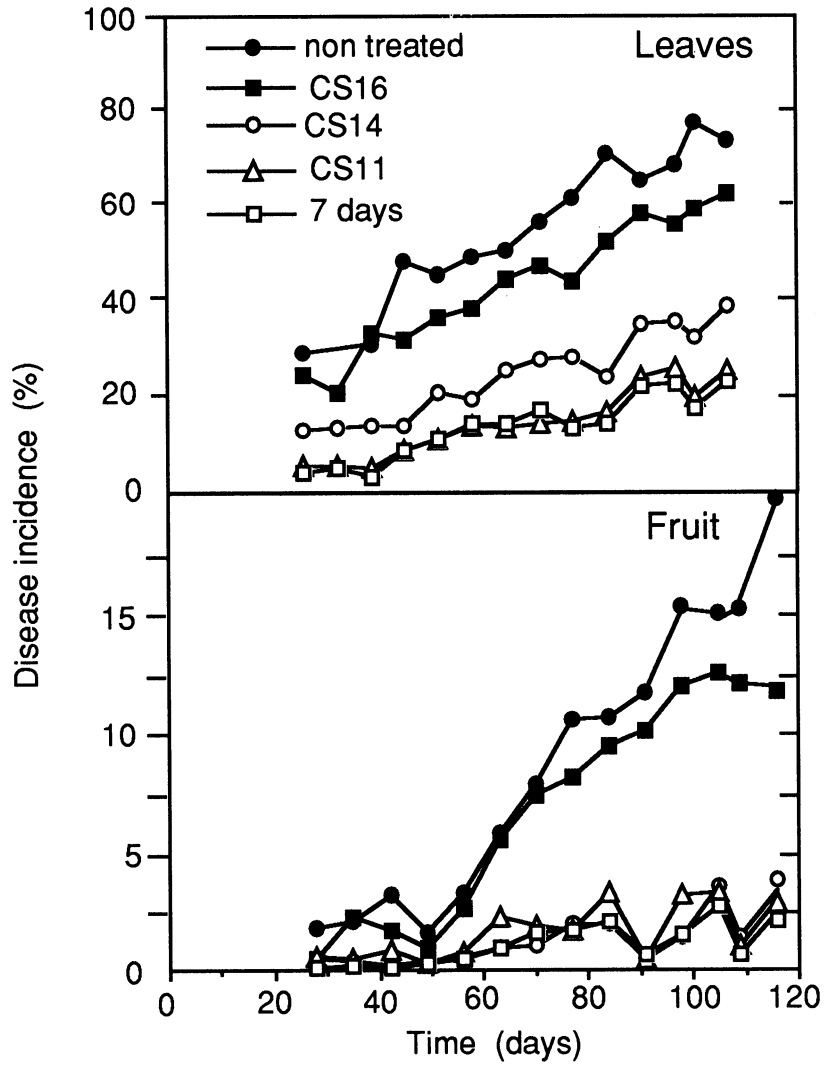

Fig. 6. Disease progress curves for leaves and fruit for the five treatments tested for validation of the FAST forecaster in commercial orchard A during 1990. Time indicates days from 1 June 1990.

Table 3. Disease of pear at harvest in a 1991 field trial to evaluate different cumulative severity (CS) threshold values for timing of fungicide sprays to control *Stemphylium vesicarium*[x]

Treatment	No. of sprays	Disease incidence[y] (%)	
		Leaves	Fruit
Unsprayed	0	20.1 a[z]	2.2 a
CS 16	12	15.2 ab	1.0 b
CS 14	15	14.5 ab	0.9 b
Sprayed weekly	24	12.0 b	0.6 b

[x] Pear cv. Passe Crassane in orchard B monitored from June to October 1991.
[y] Values correspond to the average of five plots of five trees.
[z] Values in the same column followed by the same letter are not significantly different ($P = 0.05$) according to the Ryan-Einot-Gabriel-Welsh multiple range test.

The savings obtained is in the range of the 25–35% reported in similar studies using forecasting models to schedule fungicide applications to control early blight of tomatoes (16), early blight of potatoes (20), apple scab (10), and grape black rot (11,13).

Data from commercial orchards in our study area indicated that the incidence of disease was lower in plots of untreated trees in orchards that had been previously treated for several years than in orchards not previously treated (*data not reported*). This is probably a result of a decrease in inoculum density. These results suggest that threshold values triggering fungicide applications should be adjusted for each orchard depending on history (inoculum). Therefore, an effective strategy could be to use an intensive spray schedule, such as fungicide applications at 7-day intervals after a severe epidemic, and then use CS threshold values to progressively decrease the number of sprays in subsequent years for maintenance. Measures for decreasing inoculum on the soil surface, avoidance of sprinkler irrigation systems, and other complementary actions may also be recommended. Also, during drier years or under less humid climatic conditions, reductions may be more important than in wet years or humid areas.

The advantages of decreasing the number of spray applications are not only reduced fungicide costs but also decreased labor and equipment costs (13). The economic savings may be increased by taking advantage of electronic equipment used for other forecasting programs (e.g., apple and pear scab) (14,15), by implementing warning stations, or by combining fungicide applications for scab and necrotic spotting of pear.

For greater forecast accuracies and potentially greater reductions in spray applications, the model should be modified and adapted specifically to the biology of *S. vesicarium*. Reliable data on germination, lesion development, and conidiospore and spore formation under several environmental conditions are needed for different pear cultivars and strains of *S. vesicarium* isolated from different epidemic areas. Also, we tested only CS warnings for reasons of simplicity of experimental design; however, combinations of CS and CR warnings may increase the accuracy of the system and have the potential to further reduce the number of fungicide applications.

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