FAST, a Forecast System for Alternaria solani on Tomato

L. Madden, S. P. Pennypacker, and A. A. MacNab

Graduate Assistant, Assistant Professor, and Associate Professor, respectively, Department of Plant Pathology, The Pennsylvania State University, University Park, PA 16802.

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ABSTRACT

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A computerized forecasting system for *Alternaria solani* on tomato (FAST) has been developed to identify periods when environmental conditions are favorable for tomato early blight development and to provide a schedule for efficient fungicide applications. The forecasting system incorporates two empirical models based on the following daily environmental parameters: maximum and minimum ambient air temperature, hours of leaf-wetness, maximum and minimum temperature during the wetness period, hours of relative humidity greater than 90%, and rainfall. Disease severity data from epidemics subjected to FAST-generated spray schedules were compared with a nonsprayed check and with weekly spray schedules that were started 2 and 4 wk after transplanting. There were no significant differences among the FAST schedules and the weekly schedules with regard to final disease severity and apparent infection rates. The disease levels corresponding to these spray schedules were significantly less than the nonsprayed check. The FAST-generated schedules required fewer fungicide applications to achieve the same level of control as the weekly schedules.

Additional key words: epidemiology, pest management, *Lycopersicon esculentum*.

The principal foliar disease of tomatoes in the northeastern USA is early blight which is caused by *Alternaria solani* (Ell. and G. Martin) Sor. The disease is characterized by dark lesions with concentric rings, first evident on the lower leaves. Eventually, defoliation becomes pronounced as the disease progresses.

The procedures for controlling early blight include crop rotation on a 3- to 5-yr schedule, use of disease-free transplants, and the application of fungicides (1, 2, 3). The first two methods reduce the initial inoculum, and the third method reduces the apparent infection rate (16). Fungicides are the most effective disease control measure when environmental conditions favor the occurrence and development of disease and a source of inoculum is present. Current recommendations are to initiate sprays when first fruit are set and thereafter to spray at 7- to 10-day intervals regardless of environmental conditions (2, 3, 10).

Timing the initial spray application for early blight control has been of concern for at least 30 yr (10). It would be desirable to delay spraying as long as possible and still obtain effective disease control. For example, Harrison et al. (8) detected the start of secondary spread of potato early blight with spore traps. When the number of spores increased markedly, spraying was initiated which resulted in control equal to that obtained from a standard timed spray program initiated at the beginning of the season.

A forecaster of *Alternaria solani* on tomato (FAST) was developed to: (i) identify periods when environmental conditions are favorable for early blight development and (ii) provide an efficient fungicide application schedule.

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MATERIALS AND METHODS

Forecasting system.—The FAST forecaster uses two empirical models to determine periods when environmental conditions are favorable for early blight disease development. The models were derived from the synthesis of previous works (6, 7, 8, 10, 11, 13, 17) and they utilize selected environmental parameter combinations arbitrarily chosen to depict the observed relationships between *A. solani* and its microenvironment.

The hours of leaf wetness and mean air temperature during the wetness period are combined to derive daily severity (S) values (Table 1). As illustrated by this matrix, early blight is favored by warm, wet weather. The value of S increases as duration of leaf wetness increases. To obtain a given S value, fewer hours of wetness are

TABLE 1. Early blight of tomato. Disease severity values (S) as a function of leaf wetness period and average ambient air temperature during the wetness period

Mean temp (C)	Leaf-wetting time (hr) required to produce daily disease severity values (S)[z] of: 0	1	2	3	4
13-17	0-6	7-15	16-20	21+	
18-20	0-3	4-8	9-15	16-22	23+
21-25	0-2	3-5	6-12	13-20	21+
26-29	0-3	4-8	9-15	16-22	23+

[z]The scale of S-values range from 0 (environmental conditions unfavorable for *Alternaria solani* spore formation) to 4 (highly favorable conditions).

required as temperatures increase. The temperature intervals correspond to those reported by Waggoner and Horsfall (17) for *A. solani* conidiophore and spore formation.

The second model derives daily severity-rating (R) values from measurements of three environmental parameters (Table 2). These R values are based on the mean air temperature for the past 5 days, hours of relative humidity (RH) greater than 90% for the past 5 days, and total rainfall for the past 7 days. This approach quantitatively synthesized observations which indicated early blight disease severity increases with increases in temperature, RH, and rainfall (6, 7, 11, 13).

The forecasting program analyzes daily environmental data and maintains a record of the (i) total of all S values (TS) since the beginning of the growing season, (ii) 7-day cumulative severity value (CS) calculated by totaling S values for the past 7 days, and (iii) 5-day cumulative rating value (CR) calculated by totaling R values for the past 5 days. The first early blight spray application is recommended when TS reaches a 'critical level' of 35 and the plants are in the field for at least 5 wk (10). Subsequent fungicide applications are scheduled when CS or CR equal or exceed prespecified critical limits. Several limits for CS and CR were tested during the 1976 growing season.

The forecasting system was computerized for rapid and accurate data analyses. The program was written in FORTRAN IV for the IBM 370/168 computer. The daily environmental data input to the program consisted of: maximum and minimum air temperatures, hours of leaf wetness, maximum and minimum temperature during the leaf-wetness period, hours of RH greater than 90%, and rainfall.

Environmental monitoring.—Temperature and RH were recorded with a standard 7-day recording hygrothermograph in a white wood instrument shelter (15), the base of which was approximately 35 to 40 cm above ground. The shelter was located beside a tomato row. Hours of leaf wetness were estimated with a Taylor Dew Meter (14), modified to record for a maximum of 5 days. Rainfall was measured with a 12-cm plastic rain guage. Environmental monitoring began 1 June 1976.

Verification of the FAST forecaster.—Field verification of the forecasting system consisted of comparing early blight epidemics in six different treatments during the 1976 growing season. The spraying criteria for each treatment is listed in Table 3. We considered the range encompassed by the critical limits for CS and CR in treatments 5 and 6 to contain the best estimates to determine spray recommendations. These selections were determined by comparison of CS and CR values calculated from previous years' environmental data and the corresponding disease ratings. In treatment 4, high levels of CS and CR were used for comparative purposes only.

Cultural conditions.—Each treatment plot consisted of five 20-m rows of tomatoes (*Lycopersicon esculentum* Mill. 'Merit'). Rows were spaced 1.8 m apart and plants were at 23-cm spacings within the rows. An entire plot, including extra space to facilitate spraying, measured 25

TABLE 2. Early blight of tomato. Disease severity rating values (R) as a function of average ambient air temperature, hours of relative humidity greater than 90%, and total rainfall

Temperature average[w] (C)	Hours RH>90[x]	Total rain[y]	R[z]
<22	<60	<2.5	0
>22	<60	<2.5	0
<22	>60	<2.5	1
<22	<60	>2.5	1
<22	>60	>2.5	1
>22	>60	<2.5	2
>22	<60	>2.5	2
>22	>60	>2.5	3

[w]Average temperature for past 5 days (C).
[x]Hours of RH>90% during past 5 days.
[y]Total rainfall for past 7 days (cm).
[z]Disease severity rating scale: 0 indicates environmental conditions unfavorable for *Alternaria solani* spore formation and infection of tomato; 3 indicates that conditions are highly favorable.

TABLE 3. Spray schedules evaluated for the control of tomato early blight during the 1976 growing season

Treat-ment	Spraying criteria	Sprays	Spray schedule[w] June 14	June 21	June 28	July 5	July 12	July 19	July 26	August 2	August 9	August 16	August 23	August 30
1	None	0	−	−	−	−	−	−	−	−	−	−	−	−
2	7 days; starting with first fruit set	10	−	−	+	+	+	+	+	+	+	+	+	+
3	5-7 days; starting two wk after transplanting	13	+	+	+	+	+[z]	+	+	+	+	+	+	+
4	CS⩾16[x]: 7-day schedule CS⩾16 and CR⩾12[y]: 5-day	1	−	−	−	−	−	−	−	−	−	+	−	−
5	CS⩾14: 7-day schedule CS⩾14 and CR⩾09: 5-day	3	−	−	−	−	+	−	+	−	−	+	−	−
6	CS⩾11: 7-day schedule CS⩾11 and CR⩾08: 5-day	7	−	−	−	−	+	+	+	+	+	+	−	+

[w]Listed date is the Monday of each week when the plot was either sprayed (+) or not sprayed (−).
[x]Abbreviation CS indicates the 7-day total of severity (S) values (cumulative severity).
[y]Abbreviation CR indicates the 5-day total of severity-rating (R) values (cumulative rating).
[z]Plot was sprayed twice during this week.

by 11 m. All six treatments were located within a 0.4-ha block at The Pennsylvania State University Plant Pathology Research Farm, Rock Springs, PA 16868. Plots were separated by 14 m of field corn to reduce interplot interference (16). These plots were surrounded by corn on three sides, except on one end of the 0.4-ha block where there were no adjacent tomatoes; here only two sides were adjacent to corn rows. Treatments were replicated three times in a randomized complete block design.

Tomatoes were seeded 26 April 1976 in peat pots. Transplanting to the field was performed 28 May. All plots received equal fertilization, cultivation, and weed and insect control. Fields were fertilized with 0-336-336 kg/ha of nitrogen-phosphate-potash. Weeds were controlled with Diphenamid (Enide) applied before and after transplanting, at a rate of 9.0 kg and 4.5 kg per ha, respectively. Row cultivation was carried out twice after transplanting.

Fungicide application.—Chlorothalonil, a flowable protectant fungicide (BRAVO 6F, Diamond Shamrock Corp., Painesville, OH 44077), was sprayed on the tomato plants at a rate of 3.5 liters/ha. The fungicide was applied with a one-row, tractor-mounted boom sprayer. Tee-Jet hollow cone nozzles (Spraying Systems Co., Wheaton, IL 60187) fitted with D3-23 orifice disk and core components, delivered the fungicide to each row at a pressure of 17.6 kg/cm^2. Tractor speed was held at 3.2 km/hr. Total sprayer output was 400 liters/ha.

Disease assessment.—The three center rows in each treatment plot were utilized in disease assessment. In these rows, single plants were marked with wood stakes at approximately 1.5-m intervals, 2 wk before assessments began. A total of 21 plants per treatment plot were marked. Disease severity of each marked plant was estimated as the sum of the proportion of defoliation (X) and the proportion of leaf area covered by lesions multiplied by (1.0 − X). As the season progressed and individual plants were no longer distinguishable, 40-cm-long row sections of plant growth were used in disease estimation. The Horsfall-Barratt (9) rating scale was employed to estimate disease severity and a computer program was written to convert the ratings into disease proportions per row, per plot, and per treatment. Disease severity readings were taken at weekly intervals from 6 July to 30 August. During any given week, all plots were evaluated within one 24-hr period.

Spore sampling.—Spores were trapped in a nonsprayed plot with a battery operated Rotorod Spore Sampler (Metronics Assoc., Palo Alto, CA 94302), using I-shaped rods coated with silicone gel. Trap efficiency was estimated at greater than 95% (5). The spore sampler was operated for 2 to 3 days per wk starting 30 June, and rods were changed every 24 hr. Trapped particles were transferred to a microscope slide using adhesive tape and spores were counted in two 3-cm-long sections under ×100 microscope power.

Data analyses.—The logit transformation (16) was

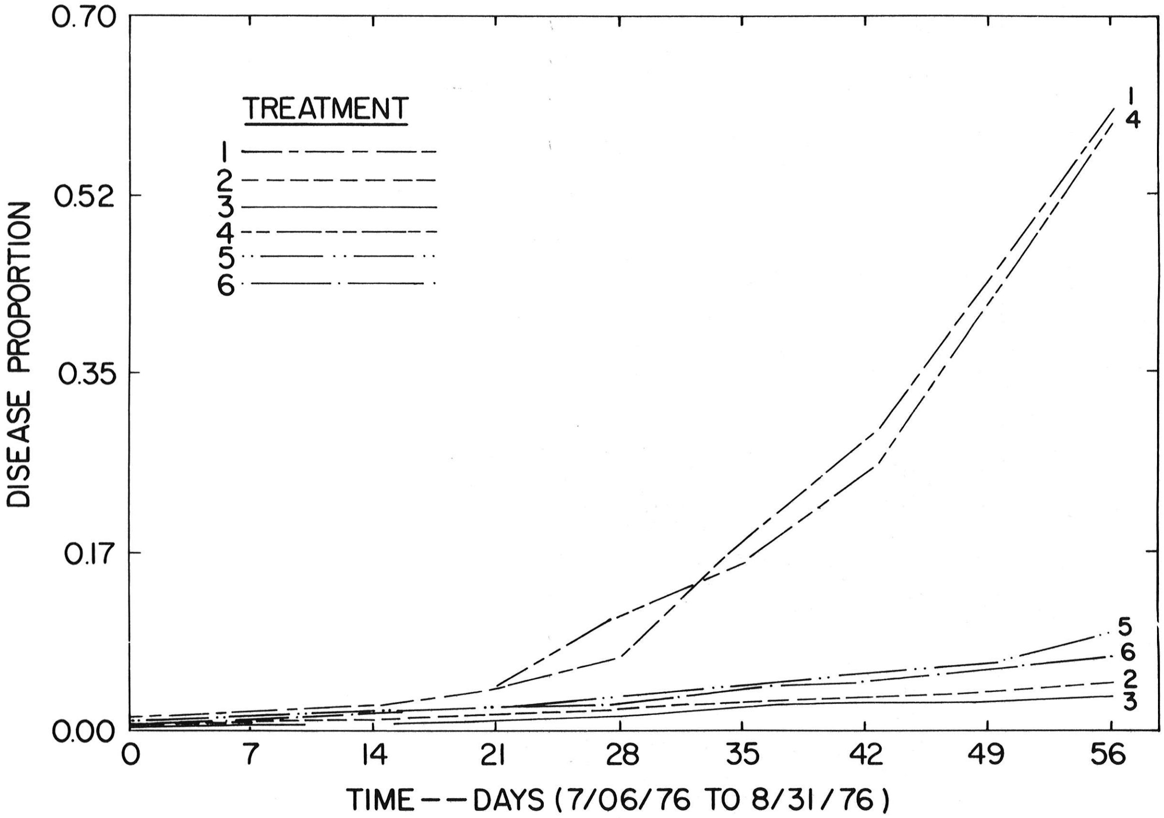

Fig. 1. Disease progress curves for six tomato early blight treatment plots. Treatments: 1 = no spray, 2 = 10 sprays, 3 = 13 sprays, 4 = one spray, 5 = three sprays, and 6 = seven sprays.

made on the disease severity estimates. Apparent infection rates were calculated by regressing logits on time and were compared by t-tests in which the Bonferroni simultaneous confidence technique (12) was utilized. Final disease ratings were analyzed by analysis of variance and means were compared by Duncan's modified least significant difference test (4).

RESULTS

Spray applications.—The criteria presented in Table 3 were used to establish the spray schedules for the six treatments. The three recommended schedules generated by the forecasting system ranged from one to seven spray applications. High critical limits of CS and CR used to establish treatment 4 resulted in scheduling only one spray very late in the season. Spray schedules in treatments 5 and 6 were initiated the week of 12 July; i.e., 2 wk after the commercial schedule and 4 wk after the more frequent schedule. The three forecast-based treatments received fewer sprays than the commercial schedule (treatment 2) and the more frequent schedule (treatment 3).

Final disease severity.—The effectiveness of the different spray schedules in controlling early blight was evaluated by comparing disease ratings and apparent infection rates for the six treatments. The disease severity estimates of 30 August, 95 days after transplanting (Table 4), indicated there were no significant differences ($P = 0.05$) among the commercial schedule (treatment 2), a more frequent schedule (treatment 3), and the two forecast-based schedules associated with treatment plots 5 and 6. Likewise, there was no difference between the nonsprayed check (treatment 1) and the forecast-based schedule applied to treatment plot 4. The final proportions of disease in treatment plots 1 and 4 differed significantly from those of the other four treatments. The disease proportion estimates on 30 August in treatment plots 1 and 4 were at least six times greater than the assessed values for the other four treatments.

Apparent infection rates.—Disease progress curves for the six treatments are presented in Fig. 1. The curves that characterize treatments 1 and 4 are grouped together as are the representative curves for treatments 2, 3, 5, and 6. As with disease ratings, infection rates among treatment plots 2, 3, 5, and 6 were not significantly different, nor were rates between plots 1 and 4 different. Infection rates associated with treatments 1 and 4 were significantly greater than the calculated rates for the other four treatments.

Spore sampling.—Spores were trapped for 2 to 3 days per week (Fig. 2). The relative trend revealed that very few spores were present in the nonsprayed control plot during the first half of July. The sharp increase in the number of spores on 16 July (day 15 of Fig. 2) occurred during the week when the initial spray forecasts were issued for treatments 5 and 6. Trapping results after this date were erratic but the numbers remained substantially higher than before 16 July. The other marked increase in spore numbers on 30 July (day 29) corresponded to the week when the second spray forecast was issued for treatment number 5. After this date no pattern was evident in the spore-collection data.

DISCUSSION

Timing of the initial spray application for tomato early blight control is of major importance to minimize the total number of applications required to manage the disease. The FAST system provided a means of dealing with spray schedule initiation. During the 1976 growing season, the conditions necessary for the onset of disease as determined by FAST (plants in the field for at least 5 wk and TS = 35) were not met until 12 July. This was 2 wk after the first-fruit-set date when the commercial spray schedule would have been initiated. The low number of trapped spores prior to 16 July also indicated that that week may have been the proper time to initiate spray applications to control early blight for the 1976 season.

The disease severity and infection rate results indicate that spray recommendations based on environmental data and scheduled by the forecasting program may control early blight as effectively and with fewer spray applications than the commercial or more frequent schedules. Spraying only when environmental conditions are favorable for disease increase in the field is the key to effective and efficient control. The limits of CS and CR used in treatment 4 were too high for effective control as

TABLE 4. Final tomato early blight disease severity estimates and apparent infection rates (r) for the period 6 July to 30 August 1976

Treatment	Disease proportion[y]	r (unit/day)[z]
1	0.61 a	0.102 a
2	0.05 b	0.036 b
3	0.03 b	0.044 b
4	0.59 a	0.092 a
5	0.10 b	0.044 b
6	0.07 b	0.047 b

[y]Values (average of 63 assessments) in the same column followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's modified significant difference test.

[z]Values in the same column followed by the same letter are not significantly different ($P = 0.05$) according to Bonferroni's simultaneous confidence technique.

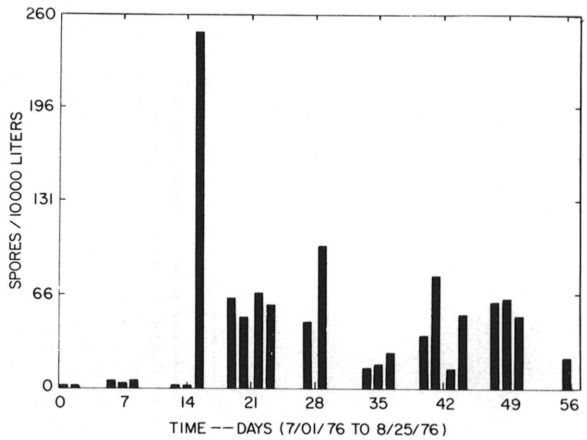

Fig. 2. Number of *Alternaria solani* spores trapped per day during the 1976 growing season in a nonsprayed control plot.

can be seen by the high disease level and infection rate. The critical limits of CS and CR used in treatments 5 and 6 resulted in optimal timing of fungicide applications. Although these treatment plots were sprayed less than the commercial schedule, the apparent infection rates and final disease severities were similar.

The forecasting system is relatively simple and easier to understand than other computer simulators and many statistical models. It requires monitoring of only a few selected environmental parameters, but it was very effective for determining spray schedules for effective control of tomato early blight in field tests during the 1976 growing season. We believe similar models and forecasting systems can be developed for other crops and other pathogens. Although forecasting systems as simple and effective as FAST will not eliminate the need for more complex models and simulators of plant disease, they should be studied and used where applicable.

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