A Microcomputer-Based Instrument to Predict Primary Apple Scab Infection Periods

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ABSTRACT

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An electronic instrument was constructed to monitor temperature, leaf wetness, and relative humidity in apple orchards and was programmed to predict apple scab infection periods. It accurately predicted the minimum conditions for primary infection, as determined by disease development on small apple trees exposed to high densities of ascospore inoculum during eight wetting periods. The effects of relative humidities of ⩾90% after wetting periods, the effects of sequential wetting periods, and Mills' table were used to make the predictions. The disease control obtained by eradicant schedules timed with the instrument and by protectant schedules applied at a standard time interval commonly used by apple growers did not differ significantly.

Additional key words: epidemiology, *Venturia inaequalis*

Most apple scab spray advisory programs (16,18) are based on Mills' (8,9) system for predicting apple scab infection caused by *Venturia inaequalis*. This system gained prominence when Hamilton (2) and Hamilton et al (3) established that certain fungicides, if applied a few hours after infection was predicted, would effectively control disease. Although a computer program was developed to provide Mills' predictions from weather monitoring data entered by Teletype from remote locations (4,5), infection periods were often identified too late to assist growers in making disease control decisions. Moreover, operating and maintenance costs for the system were high.

To overcome these problems, we developed an instrument combining environmental sensors with a microcomputer designed to provide on-site identification of apple scab infection periods and to predict disease severity. This research was undertaken to check the accuracy of the predictions. The instrument has been described (1,7), and the preliminary validation published (6).

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MATERIALS AND METHODS

Operation of the microcomputer. The instrument was placed in a 3-yr-old apple orchard (cv. McIntosh on M26 rootstock) in East Lansing, MI. A wetness sensor placed in an apple tree about 1 m above ground and two temperature sensors (linear thermistors) enclosed in a standard weather shelter 2 m above ground in the orchard were connected to the instrument. One thermistor measured dry-bulb or ambient temperature; the other, inserted in a wet wick, measured wet-bulb temperature. Temperature, relative humidity (RH), and leaf wetness also were measured with a standard 7-day recording hygrothermograph in the same shelter and with a deWit 7-day recording leaf wetness meter (M. deWit, Hengelo, The Netherlands) at 1.5 m above ground level. The calibration of the sensors and the hygrothermograph was checked weekly.

The microcomputer was visited daily (more frequently during critical periods), and the values for the environmental sensors, clock, and predictive routine and the temperature and RH values of the hygrothermograph were recorded. The criteria used to predict each infection period were retrieved periodically from memory using keyboard and liquid-crystal display (LCD). By transferring this information via an auxiliary memory into a second computer, permanent copies of the stored data were obtained. Infection predictions made by the instrument were compared with predictions derived from Mills' table (9) and with disease development on small apple trees exposed during each wetting period.

Forecast model. The program in the instrument initiated, at the correct time and in the proper order, subprograms for: 1) monitoring leaf wetness and dry-bulb and wet-bulb air temperatures, 2) organizing and storing selected weather and infection data in memory for later retrieval through a keyboard and LCD, 3) determining and displaying the hours remaining for effective use of eradicant fungicides, and 4) identifying the apple scab infection periods and predicting disease severity. A priority interrupt scheduling system coordinated the execution of the subprograms (1).

The model for identifying the infection periods and predicting disease severity was based on previous studies (8,10,16) and contained the following rules: 1) leaf wetness duration was measured from the time the leaf wetness sensor became wet to the time the RH dropped below 90%, and 2) wet periods were added together if the wetness sensor again became wet within 8 hr from the time the RH fell below 90%. Predictions were based on Mills' table and were displayed as "none," "low," "moderate," or "high" on the LCD. The program was written in assembler language.

Monitoring ascosopre discharge and infection periods. A high level of inoculum was provided by spreading overwintered apple leaves containing apple scab perithecia on the ground in two areas about 8 × 8 m located roughly 50 m from the instrument but outside the orchard. Discharge of ascospores of *V. inaequalis* from the leaves was monitored with 10 Rotorod samplers (17), one in the center and one in each of the four quadrants of each area. The rods, coated with silicone gel, were removed after rain and examined microscopically for ascospores.

Putative infection periods were verified by placing 10 unsprayed potted McIntosh apple trees in the areas with overwintered leaves before, and removing them after, each leaf wetness period. One tree was placed between each of the four samplers in each area, and a fifth tree was placed near the center of each area. After exposure, the trees were held in an isolated cold frame for about 3 wk before the number of apple scab lesions was counted. Trees kept in the cold frame throughout the season served as controls.

Fungicide application. Captan (Captan 50% a.i. WP, Stauffer Chemical Company, Westport, CT 06880) was sprayed on a protectant schedule at the rate of 454 g and 908 g of formulation per 378.5 L of water and on an eradicant schedule at 908 g per 378.5 L. Dodine (Cyprex 65% a.i. WP, American Cyanamid Company, Princeton, NJ 08540) was sprayed on an eradicant schedule at 227 g per 378.5 L of water. In the protectant schedule, which was typical of a type used by many Michigan growers, sprays were applied at about 7-day intervals until 5 June, then at 14-day intervals. Fungicide treatments were applied with a handgun at 2,418 kPa (350 psi) to three replications of three trees each. The protectant treatments were made on 5, 10, 16, 24, and 31 May; 7, 14, and 22 June; 5 and 19 July; and 2 August. The eradicant treatments were on 9, 13, 16, 24, and 31 May; 8 and 22 June; and 20 July. Eradicant fungicides were applied when advised by the instrument.

RESULTS

Analysis of infection periods. The times of rain onset and moisture retention measured by the deWit recorder and the microcomputer were in close agreement. Therefore, only one set of leaf wetness data is reported (Table 1). Mills' system predictions were based on the hours of leaf wetness. Predictions by the microcomputer were based on hours of leaf wetness combined with the hours of RH ≥90% after leaf wetness and the hours of RH <90% between wetness periods. Predictions by the Mills system and by the microcomputer used the same mean temperature values.

Eight wetting periods were recorded during the period of primary apple scab from 4 May to 8 June 1978 (Table 1). The microcomputer but not the Mills system predicted that apple scab infection would occur from wetting periods 1, 2, and 7. Ascospores of *V. inaequalis* were detected and scab lesions developed on apple trees exposed during these periods. The microcomputer and the Mills system both predicted that apple scab infection would occur from wetting periods 3, 4, and 8, and trees exposed during these periods were infected. Period 4 resulted in the most infection. The leaves were wet for about 2 days and ascospore discharge was at its maximum for the year. Trees exposed to ascospore inoculum during the first 15 2/3 hr of this period developed 50.8 lesions per tree, and those exposed during the remaining 30 1/3 hr (actual 24½ hr because the trees were changed during the period of low RH) developed 34.9 lesions per tree.

No infection was expected from wetting periods 5 and 6, but infection developed on apple trees exposed during period 5. This wetting period followed a heavy rain (15.5 mm) on the afternoon of 20 May and the leaves remained wet for 3–3½ hr (Fig. 1). The RH was <90% for 4 hr after the rain, then increased in the evening to give 13½ hr of ≥90% RH at an average temperature of 7.78 C. The duration of high RH at night would be insufficient to permit infection according to Mills' table. However, the period from the beginning of the rain on May 20 to when the RH dropped below 90% on May 21 was of sufficient duration (21 hr at 11.46 C) for moderate infection according to Mills' table. Although the microcomputer did not function through period 5 due to damage from lightning, it would not have predicted infection because the second increase in RH was not initiated by rain.

Apple scab lesions on trees exposed through 20 May probably were initiated only by ascospores because primary lesions were not observed until 23 May on the potted or orchard trees, and conidia of the scab fungus were not observed on spore traps until 4 June. On 9 June examination of apple trees kept in the cold frame from early April indicated two lesions on 30 trees or 0.06 lesions per tree.

Disease control. The proportions of disease in the control treatment (no fungicide) on 6 June, 7 July, and 5 September were significantly greater than the values for the spray treatments (Table 2). There was no difference between the protectant and eradicant schedules based on infection predictions. On 6 June, the eradicant schedule with captan had less disease than the dodine treatment, but this difference was not significant in later assessments.

Table 1. Apple scab infections predicted by a microcomputer and by the Mills system for eight leaf wetness periods in spring 1978 at East Lansing, MI

Wetting period		Duration and makeup of wetting periods (hr)				Mean temperature	Apple scab predictions		Lesions	Ascospores trapped[b]
		Leaf wetness	Relative humidity		Total length					
No.	Date		≥90%	<90%		(°C)	Mills	Microcomputer	per plant[a]	(no.)
1	May 4	23 1/6	13 2/3	0	36 5/6	4.44	None	Moderate	1.0	23.5
2	May 7	6 1/6	35 5/6	0	42	12.20	None	Heavy	3.6	192.7
3	May 11	10 5/6	4 5/6	7 1/3	23	15.00	Light	Heavy	29.6	25.7
4	May 12[c]	8 1/3	7 1/3	0	15 2/3	13.88	...	...	50.8	1,037.7
	May 12	29 1/6	11	5 5/6	46	11.66	Heavy	Heavy	34.9	494.3
5	May 20	3	1/2	0	3 1/2	18.33	None	...[d]	3.1	561.3
6	May 31	3	6 1/2	0	9 1/2	14.44	None	None	0	8.0
7	June 4	7 1/2	7 1/3	0	14 5/6	10.55	None	Low	9.5	31.4
8	June 8	10	11	0	21	13.88	Light	Moderate	1.6	1.3

[a] Mean of 10 McIntosh apple trees with one shoot exposed per wetting period.
[b] Mean number of ascospores per plastic "I" rod (64 mm length). Twenty rods from 10 Rotorod samplers were examined microscopically by counting all ascospores observed in one longitudinal pass. The rod surface examined was 23.6 mm^2 or 24.8% of the forward impaction face of each rod.
[c] Plants were changed between a split wetting period and before the prediction was complete.
[d] Equipment malfunctioned but would have predicted none.

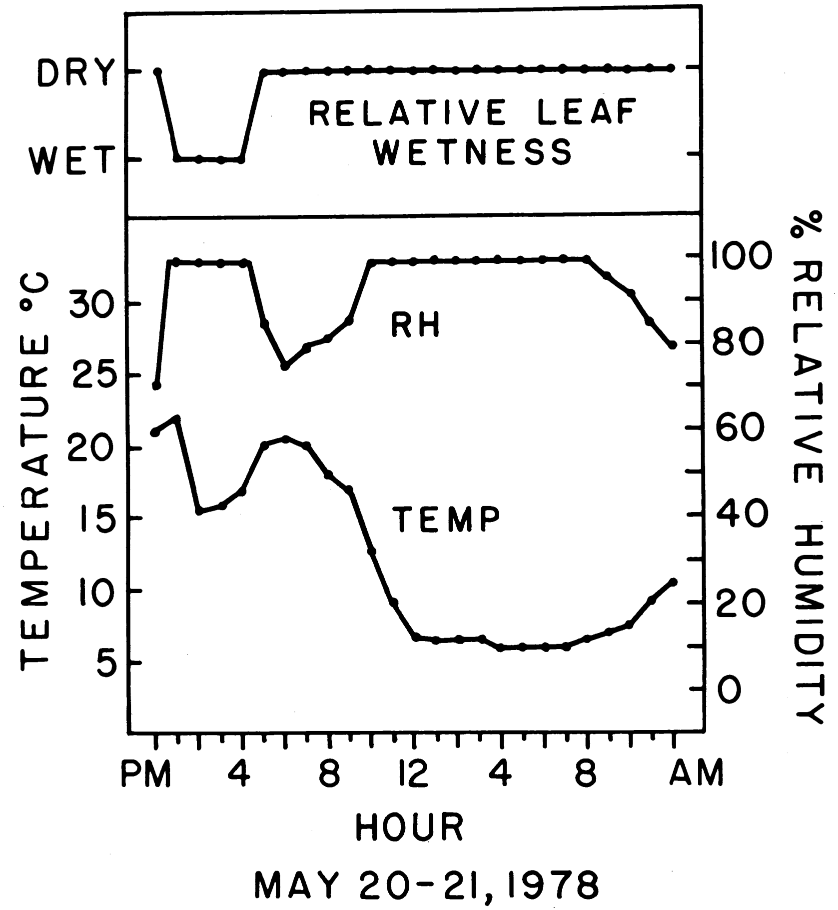

Fig. 1. Hourly air temperatures, relative humidity, and leaf wetness for wetting period 5 (Table 1). This period consisted of a short leaf wetness period, 4 hr of dryness, and then an extended period of high humidity at night without leaf wetness; it resulted in infection from ascospores of the apple scab fungus to McIntosh trees in pots exposed during this period.

Table 2. Fungicidal control of scab on leaves of terminal shoots on actively growing 3-yr-old McIntosh apple trees with fungicides

Fungicide, per 378.5 L (100 U.S. gal) of water	**Proportion of leaves with apple scab**[z]		
	6 June	**7 July**	**5 Sept.**
Protectant schedule			
Captan 50% a.i. WP 908 g	0.035 ab	0.016 a	0.020 a
Captan 50% a.i. WP 454 g	0.072 ab	0.027 a	0.043 a
Eradicant schedule			
Captan 50% a.i. WP 908 g	0.018 a	0.028 a	0.047 a
Dodine 65% a.i. WP 227 g	0.094 b	0.085 a	0.085 a
Control (no fungicide)	0.314 c	0.560 b	0.864 b

[z]Means in the same column followed by the same letter are not significantly different ($P = 0.05$) based on Duncan's modified least significant difference test.

DISCUSSION

Our results suggest that the curve indicating light infection in Mills' graph (8) does not describe the minimum conditions for infection. A similar conclusion can be made from data in Fig. 2 of Preece's article (11), since appreciable infection occurred on six occasions when the hours of leaf wetness and temperature conditions fell below the curve for light infection. Mills recognized this, because the published curve for predicting light infection was much thicker and thus harder to interpret than the curves for moderate and heavy infections.

No provisions were made in the model to predict infection from conidia after fewer hours of wetting than are required for infection by ascospores (9). Studies by Roosje (15,16) and by Moore (10) indicate the duration of wetting required for infection by conidia is as long as or longer than the duration required for infection by ascospores.

The severity of apple scab infection predicted by the microcomputer often exceeded that by the Mills system. This happened because the microcomputer interpreted the duration of leaf wetness as the duration of wetness measured by a leaf wetness sensor plus the duration of RH ≥90% after the leaf wetness sensor became dry. In the Mills system, only wetness measured by the wetness sensor is considered. Modifying the model to predict moderate and heavy infections only according to the hours of wetness measured by the leaf wetness sensor would correct for this objection. Previously, Preece and Smith (12) observed that "Smith periods," or the hours of 90% or more RH after rain, could be substituted for hours of leaf wetness in Mills' table. Our results agree with this conclusion, but the severity of scab infection predicted is often too great.

Advantages of the microcomputer-based instrument, compared with the electronic scab warning equipment of Richter and Haussermann (13,14), are that: 1) a record of the predictions and the data are retained for later reference and 2) changes in the predictive model are made by reprogramming rather than by modifying the construction of the instrument. Moreover, our instrument will handle intermittent and otherwise complicated weather patterns.

Although the microcomputer was designed and constructed to predict apple scab, it can be programmed for other applications (7). Using the knowledge gained with this instrument, we are currently testing a second prototype with expanded memory for operating more complex models.

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