Evaluation of an Electronic Apple Scab Predictor for Scheduling Fungicides with Curative Activity

M. A. ELLIS, Associate Professor, L. V. MADDEN, Assistant Professor, and L. L. WILSON, Agricultural Technician I, Department of Plant Pathology, Ohio Agricultural Research and Development Center, Ohio State University, Wooster 44691

ABSTRACT

Ellis, M. A., Madden, L. V., and Wilson, L. L. 1984. Evaluation of an electronic apple scab predictor for scheduling fungicides with curative activity. Plant Disease 68: 1055-1057.

A microcomputer for use in predicting primary apple scab infection periods was evaluated in Ohio during two growing seasons. The unit predicted 10 and 14 primary infection periods in 1982 and 1983, respectively. Bitertanol, fenarimol, etaconazole, and triforine applied at 72 hr and all fungicides except triforine applied at 96 hr after initiation of predicted infection periods provided excellent control. Captan provided excellent scab control when applied in a standard protectant spray program but was not effective when applied 72 hr after predicted infection periods. The apple scab predictor was as effective as the Mills system in predicting primary scab infection periods under Ohio conditions. Well-timed curative spray programs of bitertanol, fenarimol, etaconazole, and triforine were as effective as protective spray programs of captan and Dikar in controlling apple scab but were more efficient because three or four fewer sprays were used to achieve control.

Additional key words: disease forecasting, ergosterol-inhibiting fungicides, *Venturia inaequalis*

In Ohio, control of apple scab, caused by *Venturia inaequalis* (Cke.) Wint., is achieved primarily through a protectant fungicide spray program. In a protectant program for primary scab control, fungicides are generally applied after every 7–10 days of new growth or 1 in. (2.54 cm) of rain. Applications are made regardless of whether infection periods have occurred. In wet growing seasons, Ohio growers make up to 15 fungicide applications for scab control.

An alternative to a protectant program is the after-infection or curative spray program. In a curative program, the fungicide is applied after the initiation of an infection period but before symptom development. Since Mills and his co-workers published their findings on the environmental parameters necessary for scab infection (7,8), we have had the ability to monitor infection periods. Although apple scab spray advisory programs (9,12) have been developed on the basis of Mills' system, they have not been widely accepted and are currently not used by growers in Ohio. One factor contributing to the lack of grower acceptance of scab prediction systems has been the lack of fungicides with dependable curative activity up to 3 or 4 days after the initiation of an infection period. The introduction of the ergosterol-biosynthesis-inhibiting (EBI) fungicides, which have excellent curative activity (5,10,11), could make scab prediction systems more attractive to growers because they would have the ability to control scab after infection periods were identified.

A computer program was developed to provide Mills' prediction from weather monitoring data entered by teletype from remote locations (2,3); however, infection periods were often identified too late and the operating and maintenance costs for the system were high. Lillevik et al (6) developed an instrument that combined electronic environmental monitoring sensors with a microcomputer designed to provide simple and rapid on-site identification of apple scab infection periods. The instrument has been described (1,6) and validation experiments published (4). This unit has evolved into the apple scab predictor (ASP) presently being manufactured and marketed by Reuter-Stokes, Inc., Cleveland, OH. Our objective was to establish the effectiveness of the ASP for scheduling several EBI fungicides that have postinfection control activity against apple scab.

Salaries and research support provided by state and federal funds appropriated to the Ohio Agricultural Research and Development Center, Ohio State University. Journal Article 9-84.

Accepted for publication 8 May 1984.

The publication costs of this article were defrayed in part by page charge payment. This article must therefore be hereby marked "*advertisement*" in accordance with 18 U.S.C. § 1734 solely to indicate this fact.

MATERIALS AND METHODS

Field trial (1982). All fungicide treatments were applied to four single-tree replicates of the cultivars McIntosh, Delicious, and Golden Delicious on MM106 rootstock arranged in a randomized complete-block design. The 13-yr-old trees were planted 4.6 m apart with 8.8 m between rows on Wooster silt loam. Trees were sprayed to runoff with fungicide in 1,515 L of water per acre with a handgun at 3,102 kPa. Apple scab infection periods were determined by the ASP. Infection periods were verified with a deWit leaf wetness meter and a hygrothermograph in conjunction with the Mills table (8). The following EBI fungicides and rates (a.i./ha) were applied 72 and 96 hr after initiation of predicted infection periods: bitertanol (Baycor 50WP, 561 g), fenarimol (Rubigan 1EC, 106 g), and etaconazole (Vangard 10WP, 69 g). When primary scab infection periods ended (20 June), protectant cover sprays of benomyl (Benlate 50WP, 207 g) plus captan (captan 50WP, 2.24 kg) were applied to all curative treatments. Bitertanol at 560 g and captan at 3.36 kg were applied in full-season protectant programs for comparison. The treatments 72 and 96 hr after infection were applied on 10 and 11 May, 22 and 23 May, 4 and 5 June, and 18 and 19 June, respectively. Curative treatments were not repeated for 7 days even if additional infection periods were predicted. Protectant cover sprays were applied to treatments in the curative program on 30 June, 9 and 21 July, and 9 and 12 August. Application dates and growth stages of treatments applied in the standard protectant program of Dikar were 20 April (half-inch green); 28 April (tight cluster); 4 May (pink); 11 May (full bloom); 18 May (petal fall); 25 May (first cover); 2, 15, 22, and 30 June; 9 and 21 July; and 9 and 26 August.

The percentage of leaves with primary scab lesions was determined from five cluster leaves per cluster for each 10 clusters per tree on 10 June. The percentage of leaves with secondary scab lesions was determined from all terminal leaves for each of 10 shoots per tree on 7–9 September. The percentage of fruit infected was determined for 100 fruits per tree on 21–23 September.

Field trial (1983). The trial was conducted as described for 1982, with the following exceptions. The cultivar Delicious was not used. Triforine (Funginex 1.6EC, 630 g) was included in the curative program at 72 hr after initiation of an infection period and in a standard protectant program. When the curative program ended on 2 June, protectant cover sprays of benomyl (207 g) plus mancozeb (Manzate 200 80WP, 13.54 kg) were made to all treatments in the curative program. Treatments 72 and 96 hr after infection initiation were applied on 9 and 10 April, 1 and 2 May, 14 and 15 May, 22 and 23 May, and 1 and 2 June, respectively. Protectant cover sprays were applied to treatments in the curative program on 13 and 28 June; 5, 18, and 28 July; 18 August; and 6 September. Application dates and growth stages of treatments applied in the standard protectant program were: 8 April (half-inch green); 15 April (tight cluster); and 25 April (open cluster); 5 May (pink); 11 May (full bloom), 18 May (petal fall) and 26 May (first cover); 2, 13, and 28 June; 5, 18, and 28 July; 18 August; and 6 September.

Primary leaf scab counts were made on 15 June. Secondary leaf scab counts were made on 6–8 September and the percentage of fruit infected was determined on 19–21 September. For both years, analysis of variance was used to evaluate the effect of fungicide treatment on scab. Each cultivar was analyzed separately. Differences of means were tested with Duncan's new multiple range test ($P = 0.05$).

RESULTS AND DISCUSSION

In 1982 and 1983, 10 and 14 primary scab infection periods were recorded by the ASP, respectively. All infection periods were verified according to the Mills table (8). In both years, disease incidence was high. Primary scab lesions first developed on foliage about 10 and 14 days after the first infection period in 1982 and 1983, respectively. Mean temperatures and wetness durations recorded by the ASP were very similar to those recorded by the deWit meter and hygrothermograph.

In both years, EBI fungicides provided excellent scab control when applied 72 hr after the initiation of predicted infection periods (Tables 1 and 2). However, captan applied at 72 hr in 1983 did not provide satisfactory control. The failure of captan applied at 72 hr indicates the greater postinfection activity of the EBI fungicides. We suspect the limited control obtained with captan in the curative program was due to protectant activity against subsequent infection periods during the 7-day period after application.

When applications were made 96 hr after initiation of infection periods, control was still excellent with bitertanol, etaconazole, and fenarimol. Triforine did not provide satisfactory control at 96 hr. Chlorotic flecks were common on leaves of trees treated at 96 hr. Sporulation was not observed in these chlorotic flecks, whereas typical sporulation was observed in the captan treatment applied at 72 hr, triforine at 96 hr, and in the control. These chlorotic flecks were believed to be scab lesions that were inactivated before they could develop fully.

Excellent control was achieved with all treatments applied in the protectant program. In most cases, only slight differences in control were observed between the curative and protectant programs; however, four and three fewer sprays were made in the curative program

Table 1. Effectiveness of ergosterol-biosynthesis-inhibiting fungicides in spray programs for control of apple scab in 1982

Fungicide and rate (a.i./ha)	Primary scab leaves (%)			Secondary scab leaves (%)			Fruit scab (%)		
	McIntosh	Delicious	Golden Delicious	McIntosh	Delicious	Golden Delicious	McIntosh	Delicious	Golden Delicious
Curative program for five sprays, then five protectant sprays									
Bitertanol 50WP, 561 g (72 hr)[y]	1.8 c[z]	1.5 c	1.3 c	1.5 b	0.8 b	0.5 b	1.0 b	0.5 b	0.3 b
Bitertanol 50WP, 561 g (96 hr)	4.0 b	3.8 b	2.8 b	2.0 b	1.5 b	1.3 b	2.5 b	1.0 b	1.3 b
Fenarimol 1EC, 106 g (72 hr)	0.8 c	0.3 d	0.5 d	0.5 b	0.3 c	0.5 b	0.3 c	0.3 b	0.0 c
Fenarimol 1EC, 106 g (96 hr)	4.5 b	3.2 b	3.0 b	2.0 b	1.8 b	1.3 b	3.3 b	1.5 b	1.8 b
Etaconazole 10WP, 69 g (72 hr)	0.5 c	0.8 d	1.0 c	0.3 b	0.0 c	0.5 b	0.3 c	0.0 b	0.3 b
Etaconazole 10WP, 69 g (96 hr)	4.0 b	4.3 b	3.8 b	3.0 b	2.5 b	1.5 b	2.8 b	1.8 b	1.0 b
Protectant program (14 sprays)									
Bitertanol 50WP, 561 g	0.8 c	0.5 d	0.3 d	1.0 b	0.3 c	0.0 c	0.8 b	0.3 b	0.5 b
Dikar 80WP, 5.38 kg	1.3 c	0.8 d	1.0 c	2.3 b	1.5 b	1.0 b	1.3 b	0.5 b	0.8 b
Control (no fungicide)	100.0 a	97.5 a	96.0 a	100.0 a	98.5 a	99.5 a	100.0 a	99.5 a	98.5 a

[y]Treatments applied 72 and 96 hr after the initiation of predicted infection periods. Infection periods that occurred within 7 days of application were disregarded. Curative programs ended on 20 June, and protectant applications of benomyl 50WP (207 g) plus captan 50WP (2.24 kg) were applied on a 14-day schedule. A total of 10 sprays were made.

[z]Numbers followed by the same letters within columns do not differ significantly ($P = 0.05$) according to Duncan's new multiple range test.

Table 2. Effectiveness of ergosterol biosynthesis inhibiting fungicides in spray programs for control of apple scab in 1983

Fungicide and rate (a.i./ha)	Primary scab leaves (%)		Secondary scab leaves (%)		Fruit scab (%)	
	Golden Delicious	McIntosh	Golden Delicious	McIntosh	Golden Delicious	McIntosh
Curative program for five sprays, then seven protectant sprays						
Bitertanol 50WP, 561 g (72 hr)[y]	0.5 d[z]	0.0 e	0.0 e	0.3 e	0.5 e	0.5 e
Bitertanol 50WP, 561 g (96 hr)	0.0 e	0.0 e	0.5 e	0.3 e	0.5 e	0.3 e
Fenarimol 1EC, 106 g (72 hr)	0.0 e	0.0 e	0.5 e	0.0 e	0.0 e	1.0 e
Fenarimol 1EC, 106 g (96 hr)	1.5 d	0.0 e	0.5 e	0.3 e	0.1 e	1.5 e
Etaconazole 10WP, 47 g (72 hr)	0.0 e	0.0 e	0.3 e	0.3 e	0.3 e	0.5 e
Etaconazole 10WP, 47 g (96 hr)	0.5 d	0.5 e	1.0 e	1.3 d	1.0 e	1.0 e
Triforine 1.6EC, 630 g (72 hr)	1.0 d	0.0 e	0.3 e	0.5 e	0.3 e	1.8 e
Triforine 1.6EC, 630 g (96 hr)	15.8 c	19.4 c	15.5 c	18.6 c	23.3 c	27.3 c
Captan 50WP, 3.36 kg (72 hr)	41.0 b	47.3 b	41.8 b	48.0 b	63.4 b	67.8 b
Protectant program (15 sprays)						
Captan 50WP, 3.36 kg	2.0 d	3.0 d	2.3 d	1.8 d	1.8 d	3.2 d
Control (no fungicide)	51.5 a	59.7 a	99.0 a	100.0 a	99.5 a	100.0 a

[y]Treatments applied 72 and 96 hr after the initiation of predicted infection periods. Infection periods that occurred within 7 days of application were disregarded. Curative programs ended on 13 June, and protectant applications of benomyl (207 g) plus mancozeb (3.54 kg) were applied on a 14-day schedule. A total of 12 sprays were made.

[z]Numbers followed by the same letters within columns do not differ significantly ($P = 0.05$) according to Duncan's new multiple range test.

Table 3. Data on infection periods collected from the apple scab predictor and fungicide application dates for the curative and protectant program in 1982

Wetness or infection period	Severity[x]	Avg. temp. (C)	Wetness duration	Date	Fungicide application[y]
Wetness	None	7.2	15 hr, 0 min	20 April	Half-inch green (protectant)
Wetness	None	13.3	8 hr, 30 min	26 April	
Wetness	None	4.4	25 hr, 30 min	27 April	
				28 April	Tight cluster (protectant)
				4 May	Open cluster (protectant)
Infection	Moderate	11.7	17 hr, 0 min	7 May	
				10 May	Curative application[z]
				11 May	Full bloom (protectant)
				18 May	Petal fall (protectant)
Infection	Moderate	16.1	19 hr, 30 min	19 May	
Infection	High	16.1	44 hr, 0 min	20 May	
				22 May	Curative application
Infection	High	18.3	33 hr, 0 min	23 May	
				25 May	First cover (protectant)
Infection	Low	17.2	10 hr, 0 min	28 May	
Infection	Moderate	18.3	21 hr, 30 min	29 May	
Infection	Moderate	16.7	16 hr, 0 min	1 June	
				2 June	Second cover (protectant)
				4 June	Curative application
Infection	High	13.3	31 hr, 30 min	5 June	
Infection	Moderate	18.9	15 hr, 0 min	9 June	
Infection	High	17.8	36 hr, 50 min	15 June	Third cover (protectant)
				18 June	Curative application

[x] The instrument recorded the severity of each infection period as low, moderate, or high.
[y] The curative program ended on 20 June, and all treatments received five additional protectant applications of fungicide.
[z] Dates listed with curative application are for 72 hr after the initiation of an infection period. Applications were also made at 96 hr but are not listed in the table.

in 1982 and 1983, respectively.

Table 3 contains data on infection periods recorded by the ASP and fungicide application dates for the protectant and curative programs in 1982. An examination of this table reveals how four fungicide applications were saved. Three protectant applications (half-inch green, tight cluster, and open cluster) were made before the first infection period. Although three wetness periods occurred during this period, none were infection periods and fungicide application was not required. Through disregarding infection periods that occurred within 7 days of curative applications, additional sprays were saved. The same general results were obtained in 1983.

Economic advantages of reducing the number of spray applications through the use of EBI fungicides need to be studied. The reduction of any pesticide application may be beneficial to the environment. Disease prediction or "forecasting" systems such as the one studied here offer an alternative to prophylactic applications of fungicide in standard protectant programs.

It is also important to note that in growing seasons with excessive rainfall in Ohio, many conscientious growers with extensive protectant programs still endure significant losses to scab. Improper timing of fungicide applications is at least partially responsible. A monitoring program such as used in this study could greatly improve the timing of fungicide application by warning growers on a protectant program when scab pressure is high. If they are concerned that their protection is not adequate, they can still apply a curative compound.

In dry growing seasons especially, a curative spray program for scab could reduce the number of fungicide applications. In wet seasons, a curative program may not reduce the number of applications but may be beneficial in improving the timing of fungicide applications.

In summary, the data from this study indicate that 1) the ASP was as effective as the Mills table in predicting scab infection periods under Ohio conditions and 2) the EBI fungicides at the rates we tested will control apple scab when applied within 72 hr of the initiation of an infection period, and all except triforine will provide good control when applied up to 96 hr after infection.

LITERATURE CITED

1. Fisher, P. D., and Lillevik, S. L. 1977. Monitoring system optimizes apple tree spray cycle. Pages 125-127 in: Electronics 50. Part IV.
2. Jones, A. L. 1976. Systems for predicting development of plant pathogens in the apple orchard ecosystem. Pages 120-122 in: Modeling for Pest Management Concepts, Techniques and Application. R. L. Tummala, D. L. Haynes, and B. A. Croft, eds. Michigan State University Press, East Lansing. 247 pp.
3. Jones, A. L. 1976. Apple scab predictive and monitoring systems. Pages 78-82 in: Proceedings of US-USSR Symposium: The integrated control of the arthropod, disease and weed pests of cotton, grain sorghum and deciduous fruit. Texas Agric. Exp. Stn. Publ. MP-1276. 216 pp.
4. Jones, A. L., Lillevik, S. L., Fisher, P. D., and Stebbins, T. C. 1980. A microcomputer-based instrument to predict primary apple scab infection periods. Plant Dis. 64:69-72.
5. Kelly, R. D., and Jones, A. L. 1981. Evaluation of two triazole fungicides for postinfection control of apple scab. Phytopathology 71:737-742.
6. Lillevik, S. L., Fisher, P. D., and Jones, A. L. 1977. A predictive CMOS-based instrument for agriculture. Pages 275-286 in: Microcomputer Design and Applications. S. C. Lee, ed. Academic Press, New York. 368 pp.
7. Mills, W. D. 1944. Efficient use of sulphur dusts and sprays during rain to control apple scab. N.Y. Agric. Exp. Stn. (Ithaca) Ext. Bull. 630. 4 pp.
8. Mills, W. D., and Laplante, A. A. 1951. Diseases and insects in the orchard. N.Y. Agric. Exp. Stn. (Ithaca) Ext. Bull. 711:21-27.
9. Roosje, G. S. 1963. Research on apple and pear scab in the Netherlands from 1938 until 1961. Neth. J. Plant Pathol. 69:132-137.
10. Schwabe, W. F. S. 1980. Curative activity of fungicides against apple leaf infection by *Venturia inaequalis*. Phytophylactica 12:199-207.
11. Szkolnik, M. 1981. Physical modes of action of sterol-inhibiting fungicides against apple diseases. Plant Dis. 65:981-985.
12. Wicks. T. J. 1970. Our apple blackspot warning service. Ext. Bull. Dept. Agric. S. Aust. 7 pp.