Economic Analysis of Protectant and Disease-Forecast-Based Fungicide Spray Programs for Control of Apple Scab and Grape Black Rot in Ohio

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ABSTRACT

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Fungicide trials were conducted from 1982 through 1988 at the Ohio Agricultural Research and Development Center, Wooster, to compare after-infection spray programs with protectant spray programs for control of apple scab and grape black rot. The timing of curative (after-infection) sprays was based on predicted infection periods determined by a commercially available microprocessor that monitors weather conditions and predicts infection. Except during 1984 on grapes, there were no significant differences between the after-infection and the protectant programs in disease control during all 7 yr of testing on both grape and apple. However, the after-infection program resulted in 26 and 34 fewer applications over 7 yr on apple and grape, respectively. An economic comparison of the two programs, based on the cost of fungicides, labor, and equipment, indicated a reduction in cost per unit of area with the after-infection program. The total cost reduction due to the after-infection program for grape during the 7-yr period in hypothetical 8.1-, 16.2-, and 32.4-ha (20-, 40-, and 80-acre) vineyards was estimated to be $16,234, $25,232, and $35,365, respectively, or $286, $222, and $156/ha ($116, $90, and $63/acre) annually. The total cost reduction over the same period for 8.1-, 16.2-, and 32.4-ha apple orchards was $4,385, $9,566, and $13,994, respectively, or $77, $84, and $62/ha ($31, $34, and $25/acre) annually. The curative fungicide program resulted in lower fungicide costs than the protectant program, but the savings were primarily due to reductions in labor and equipment costs.

The cost of establishing an apple orchard or grape vineyard can be U.S. $7,000–$12,000/ha ($3,000–$5,000/acre), excluding land costs (18). The initial investment may not be recovered for several years. In addition, high real interest rates, declining land values, and imports of fruit products are resulting in narrow profit margins. The cost of disease control chemicals (primarily fungicides) and their application adds greatly to production costs. However, without the use of these chemicals in a humid climate, fruit production would not be profitable.

In Ohio, control of apple scab, caused by *Venturia inaequalis* (Cke.) Wint., and grape black rot, caused by *Guignardia bidwellii* (Ellis) Viala & Ravaz, is achieved primarily through protectant fungicide spray programs. For primary apple scab control, fungicides are generally applied after every 7–10 days of new growth or 2.54 cm of rain. In wet growing seasons, Ohio growers apply up to 15 fungicide treatments. Grape growers use a similar protectant fungicide program for black rot control, which often results in 10–14 applications. In both cases, fungicide is applied regardless of whether infection periods have occurred.

An alternative to a protectant program is an after-infection or curative spray program. In an after-infection program, the fungicide is applied after the initiation of an infection period but several days before symptom development. Since Mills and co-workers published their findings on the environmental conditions necessary for scab infection (25,26) and Spotts (28) published the temperature-wetness relations necessary for leaf infection by conidia of *G. bidwellii*, reliable guidelines have been available for determining infection periods for scab and black rot.

The use of this information for predicting apple scab and grape black rot infection periods has not been widely accepted. One factor contributing to the lack of grower acceptance of 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 (21,22,27,29,30), could make scab and black rot prediction systems more attractive to growers, because they would have the ability to control these diseases after infection periods were identified.

Instrumentation has been developed that combines electronic environmental monitoring sensors with a microcomputer to provide simple and rapid on-site determination of apple scab and grape black rot infection periods (2,4,6,16,21,23,24). The apple scab predictor (ASP) and black rot predictor (BRP) have been validated in the field and are marketed commercially by Reuter-Stokes, Inc. (Edison Park, Twinsburg, OH) (4,6,20). This type of instrumentation combined with EBI fungicides makes disease-forecasting systems more practicable.

Although the use of new technology such as disease predictors and EBI fungicides may have potential in reducing the number of fungicide applications in dry growing seasons, the actual cost benefit to the grower has not been evaluated. With the introduction of this new technology, there is a corresponding introduction of new costs (i.e., the cost of predictive units and EBI fungicides). When new technology is introduced, a cost analysis should be conducted to aid growers in making financial decisions (19). The purpose of this study was to conduct an economic analysis comparing the costs of after-infection and protectant spray programs for the control of apple scab and grape black rot. Portions of the field results (1982–1988) were previously reported without an economic analysis (4–15).

MATERIALS AND METHODS

Apple fungicide trials (1982–1988). All treatments in the apple fungicide trials were applied to four single-tree replicates of the cultivar McIntosh on MM.106 rootstock arranged in a randomized complete block design at the Ohio Agricultural Research and Development Center, Wooster (4). In 1982, the trees were 13 yr old. They were planted 4.6 m apart, with 8.8 m between rows. The trees were sprayed to runoff with fungicide in 3,636 L of water per hectare from a handgun at 3,102 kPa. Fungicides were applied in a full-season protectant program and in an after-infection program based on predicted infection periods for comparison. In 1982 and 1983, after-infection sprays were applied for primary scab control 72 hr after the initiation of an infection period, as determined by the ASP. From 1984

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through 1988, they were applied as soon as possible after the initiation of an infection period, but within 72 hr. After-infection treatments were not repeated for 7 days if additional infection periods were predicted. Upon the termination of primary scab control, trees with the after-infection treatments received protectant cover sprays of fungicide. Application dates for each year and spray program, fungicide treatments and application rates, and data on the percentage of primary and secondary leaf scab and the percentage of fruit scab were previously published (4,5,7,9,11,12).

Grape fungicide trials (1982–1988). All treatments in the grape fungicide trials were applied to two vines in each of four replications of the cultivar Aurore, spaced 2.1 m apart, with 3 m between rows (6). The vineyard was located at the Ohio Agricultural Research and Development Center. In 1982, the vines were 8 yr old. They were trained in an Umbrella Kniffen system. Fungicides were applied in 1,870 L of water per hectare with an 11.3-L CO_2-pressurized hand sprayer at 274 kPa. Triadimefon (Bayleton 50WP) at 140 g a.i./ha (2 oz a.i./acre) was applied in an after-infection program based on predicted infection periods. Ferbam 76WP at 2.5 kg a.i./ha (2.2 lb a.i./acre) was applied in a full-season protectant program for comparison. During 1982 only, black rot infection periods were determined by means of a deWit 7-day recording leaf wetness meter (Valley Stream Farms, Orano, Ontario, Canada) for leaf wetness and a 7-day recording hygrothermograph (Belfort Instrument Co., Baltimore, MD) for temperature. Spotts's temperature-wetness relations (28) were used to calculate infection periods. During 1983–1988, the BRP was used to determine infection periods. The timing of after-infection applications was as stated previously for apple scab. Application dates for each year and spray program, data on the percentage of berry infection and the percentage of leaf infection, 10-cluster weights, and total berry weight per vine were previously published (6,8,10,13–15).

Economic analysis. The difference in costs between the after-infection and protective programs were calculated from 1988 prices for fungicides, labor, and equipment (Table 1). Labor rates were based on the average income for a farm family of four plus amounts for the Federal Insurance Contributions Act (FICA) and workmen's compensation, for a total labor cost of $8.00/hr. The cost of a tractor with cab having a rating of 46 kW (62 hp) and a 1,514-L (400-gal) power take-off sprayer was calculated according to standard equations in the Agricultural Engineers Handbook (1). The costs for farms with 8.1, 16.2, and 32.4 ha (20, 40, or 80 acres) of fruit were based on records published by Funt (17). The costs of fungicides were obtained from local dealers in 1988. Because growers in the United States measure land in acres and not hectares, certain costs and savings are presented in terms of acres as well as hectares.

Where after-infection programs were used, the ASP or BRP costs were calcu-

Table 1. Cost per unit of materials for protectant and after-infection fungicide spray programs for apple and grape in Ohio, 1988

Item	Cost per unit[a]
Apple	
Protectant fungicides	
Dikar	$ 4.47/kg ($2.03/lb)
Mancozeb	$ 3.43/kg ($1.56/lb)
Benlate	$27.96/kg ($12.71/lb)
After-infection fungicides[b]	
Funginex	$16.57/L ($62.73/gal)
Polyram	$ 4.05/kg ($1.84/lb)
Rubigan	$69.51/L ($65.76/qt)
Captan	$ 2.88/kg ($1.31/lb)
Machinery[c]	
Tractor with cab	
150 hr/yr	$31.22/hr
300 hr/yr	$21.57/hr
600 hr/yr	$16.05/hr
Sprayer, 1,514-L (400-gal)	
75 hr/yr	$21.59/hr
150 hr/yr	$10.79/hr
300 hr/yr	$ 5.40/hr
Microprocessor—RSS-412 (disease predictor)[d]	
8.1 ha (20 acres)	$73.41/ha ($29.72/acre)
16.2 ha (40 acres)	$36.70/ha ($14.86/acre)
32.4 ha (80 acres)	$36.70/ha ($14.86/acre)
Grape	
Protectant fungicide	
Ferbam	$ 5.60/kg ($2.27/lb)
After-infection fungicide	
Bayleton	$103.65/kg ($41.96/lb)
Machinery	Same as for apple

[a] Includes depreciation, repair, insurance, taxes, and fuel, depending on the type of equipment. All costs are quotes from local dealers.
[b] Polyram and captan are protectant fungicides that were used in combination with Funginex and Rubigan, which have after-infection activity.
[c] The times required for each application were 29.6 min/ha for apple and 74.1 min/ha for grape. All calculations are based on applying fungicides in 748 L of water per hectare (80 gal/acre).
[d] A maximum of 16.2 ha per predictive unit was used in this study.

Table 2. Costs of curative and protectant fungicides for apple and grape in Ohio, 1982–1988

Year	Number of sprays		Fungicide cost per hectare[a]		Difference between protectant and curative fungicide costs per hectare
	Curative	Protectant	Curative	Protectant	
			Apple		
1982	9	14	$ 340.71	$ 481.35	$ 140.64
1983	12	15	440.45	521.46	81.02
1984	12	14	462.38	481.35	18.97
1985	8	13	355.01	441.24	86.23
1986	10	13	504.18	339.08	−165.09
1987	11	13	469.57	431.21	−38.36
1988	7	13	400.78	606.63	205.85
Total	69	95	$2,973.08	$3,302.34	$ 329.26
			Grape		
1982	7	10	$ 181.37	$ 168.20	$ −13.17
1983	6	10	155.46	168.20	12.75
1984	7	11	181.37	185.02	3.66
1985	6	9	155.46	151.39	−4.08
1986	6	10	155.46	115.60	−39.87
1987	5	13	129.55	218.67	89.12
1988	2	10	51.82	115.60	63.78
Total	39	73	$1,010.50	$1,122.69	$ 112.19

[a] Costs are based on 1988 prices.

lated over a 10-yr life with estimated repairs, maintenance, and interest charges at 10%. It was assumed that the cost of learning to use the predictor was zero. This seemed reasonable from our experience (24). It was also assumed that the 8.1- and 16.2-ha farms had one disease predictor and the 32.4-ha farm had two predictors.

RESULTS AND DISCUSSION

Except for disease control on grapes in 1984, there were no significant differences in disease control between the after-infection and protectant programs during all 7 yr of testing on both apple and grape (4–15). Disease incidence on grapes was significantly higher under the after-infection program in 1984, but there were no significant differences in yield between the two programs. The after-infection program resulted in 26 and 34 fewer applications over the 7 yr on apple and grape, respectively (Table 2). In the economic analysis that follows, we assumed equal disease control and crop yield for the protectant and after-infection programs and also that disease control would be as effective on a commercial farm as in the experimental plots.

On apple, the total cost of fungicide in the after-infection program was $329/ha ($133/acre) less than that in the protectant program for the 7-yr period (Table 2). The annual cost of labor and equipment to apply protectant fungicides was $421, $279, and $204/ha ($170, $113, and $82/acre) for the 8.1-, 16.2-, and 32.4-ha (20-, 40-, and 80-acre) orchards, respectively (Table 3). Primarily as a result of the reduced number of applications, the after-infection program reduced annual application costs by approximately $41, $40, and $19/ha ($16, $16, and $8/acre), respectively, in these orchards (Table 4). The total reductions in annual application costs over the 7-yr period were $330, $632, and $602/ha, respectively (Table 4). Over 7 yr, the after-infection program resulted in total savings of $4,385, $9,566, and $13,994, respectively, or annual savings of $77, $84, and $62/ha ($31, $34, and $25/acre) (Table 5).

On grapes the cost of fungicide in the after-infection program was only $112/ha ($45/acre) lower than in the protectant program over the 7-yr period studied (Table 2), compared to a difference of $329/ha for apples. The annual cost of labor and equipment to apply protectant fungicides was $761, $508, and $374/ha ($308, $206, and $151/acre) for the 8.1-, 16.2-, and 32.4-ha (20-, 40-, and 80-acre) vineyards, respectively (Table 3). Because of the reduced number of applications, the after-infection program resulted in annual savings in labor and equipment of $287, $203, and $138/ha, respectively (Table 4). The total annual savings in labor and equipment costs were $2,325, $3,281, and $4,467, respectively (Table 4). The total cost reductions due to the after-infection program over the 7-yr period were $16,234, $25,232, and $35,365, respectively, or annual savings of $286, $222, and $156/ha ($116, $90, and $63/acre) (Table 5).

Our results indicate that after-infection spray programs may be beneficial in reducing the number of fungicide applications, especially during dry growing seasons, while achieving disease control equal that of a conventional protectant program. In wet growing seasons, after-infection programs may not substantially reduce the number of applications but may be beneficial in improving the timing of the applications. The reduction of any pesticide application should be beneficial to the environment, and our results show that reductions in applications have definite economic benefits. Over the 7 yr of this study, environmental conditions during the growing season ranged from very wet (in 1986) to extremely dry (in 1988), and yet we still observed an average reduction of 3.7 and 4.8 sprays per year on apples and grapes, respectively. We believe that the years encompassed in this study are representative of weather conditions in Ohio. Historical weather records could not be used in this study to determine the potential savings over long periods (e.g., 30 yr), because leaf wetness records have not been kept.

Most of the savings from the after-infection program, especially for grapes, resulted from the reduction of application costs on small farms with relatively high equipment costs per hectare. When considering the economic benefits of reducing the number of fungicide applications, most growers consider only the cost of fungicide. Many growers also feel that the cost of the disease predictor can be excessive (2,24). Our results suggest that with the additional cost of a disease predictor and with relatively little difference in fungicide costs between the after-infection and protectant programs (Table 2), there can be a major reduction

Table 3. Average annual labor and equipment costs of applying protectant fungicides to apple and grape

Farm size (ha)	Annual cost per hectare[a]			
	Labor[b]	Tractor[c]	Sprayer	Total
		Apple		
8.1	$ 55.33	$215.93	$149.30	$420.56
16.2	55.33	149.19	74.62	279.13
32.4	55.33	111.00	37.34	203.67
		Grape		
8.1	$108.68	$385.57	$266.64	$760.88
16.2	108.68	266.39	133.26	508.33
32.4	108.68	198.22	66.69	373.59

[a] Assumes an average of 10 sprays per year on grape and an average of 14 sprays per year on apple.
[b] Assumes a family of four earning $18,000/yr ($7.00/hr) plus FICA and workmen's compensation to equal $8.00/hr.
[c] Assumes a tractor with cab, straight-line depreciation, 10% interest, diesel fuel at $0.26/L ($1.00/gal), insurance, and shelter; includes no tax.

Table 4. Average annual labor and equipment costs of protectant and curative fungicide programs for apple and grape in Ohio, 1988

Farm size (ha)	Annual labor and equipment costs per hectare		Difference between protectant and curative costs		Reduction (%)
	Protectant	Curative[a]	Per hectare	Per farm[b]	
			Apple		
8.1	$420.56	$379.84	$ 40.72	$ 329.91	9.7
16.2	279.13	240.10	39.05	632.61	14.0
32.4	203.67	185.10	18.57	601.67	9.1
			Grape		
8.1	$760.88	$473.82	$287.06	$2,324.94	37.7
16.2	508.33	305.79	202.54	3,281.15	39.8
32.4	373.59	235.71	137.87	4,467.31	36.9

[a] Cost for apple includes annual operating cost of predictor minus 3.71 sprays (1.84 hr/ha) that are not applied; cost for grape includes annual operating cost of predictor minus 4.8 sprays (5.93 hr/ha) that are not applied.
[b] As equipment costs increase and hours saved increase, savings increase; the opposite is also true.

in costs over time. Savings, however, depend on the year. The difference in annual costs for a 16.2-ha apple orchard with an after-infection program would have ranged from a savings of $4,676 (in 1988) to a loss of $2,299 (in 1986) over the 7 yr of this study (Table 5). A grape vineyard of the same size would also have had considerable variation in annual savings but, because of higher labor and equipment costs, would never have had a loss in any of these years. Over a relatively short period of time (7 yr or less), the savings due to the predictors became quite large.

There was a greater reduction in costs per hectare for small farms than for large farms. This indicates the more efficient use of equipment and the effect of farm size on costs. Farm size is an important factor that growers need to consider when making large investments in equipment. For this study, our calculations are based on the use of two predictive units for the 32.4-ha farm. We feel that this is very conservative. It is possible that one unit would be sufficient for a 32.4-ha farm, thus substantially increasing the benefits of the predictor. The cost reductions observed in this study would be different if growers hired custom applicators to apply fungicides, but custom application of fungicides is rare in Ohio orchards and vineyards and was not considered in this study.

Although small farms following an after-infection disease control program have a greater economic gain per unit of area than larger farms, the larger farms save more per farm over the long term (Table 5). Cooley (3) compared the cost of a fungicide with curative activity (Rubigan) and conventional protectant fungicides for primary apple scab control. He estimated application costs in Massachusetts and New York to be $13.60 and $39.51/ha for each application, respectively, which generally agrees with our values. Depending upon farm size, our estimated application costs ranged from $14.80 to $32.10/ha. Cooley indicated that if application costs exceed $32.10/ha, it would be less expensive to apply the after-infection than the standard protectant treatment. However, he found that applying a curative fungicide plus a protectant fungicide without following a curative schedule was more expensive than the standard protectant program. In a standard protectant program, six applications of Rubigan at 438 ml/ha (6 oz/acre) plus mancozeb 80W at 2.5–5 kg/ha (2.25–4.5 lb/acre) were used, whereas in an after-infection program using a predictor, three to five applications per year of Rubigan alone at 876 ml/ha (12 oz/acre) were used, with cover sprays of captan for the rest of the season. Cooley estimated that the after-infection program saved two or three sprays out of nine per season (a 33% reduction); in our study over a 7-yr period, 3.7 sprays per season were saved (a 27% reduction). In similar studies over a 5-yr period in Michigan and a 3-yr period in New York, an average of 3.3 sprays were saved per season (20).

The reduction in labor and equipment hours per unit of area is significant; with farms ranging in size from 8.1 to 32.4 ha, each farm could save 14–194 hr/yr or use that time more effectively on other management duties elsewhere during a busy growing season. The time saved could also allow flexibility in growing or in marketing new crops that would not have been available to a grower. Reducing equipment hours may also mean a reduction in soil compaction during extremely wet springs and greater productivity.

In today's apple and grape production systems, fungicide sprays may be combined with insecticides, miticides, antibiotics, growth regulators, and foliar nutrients. Most spray schedules are much more complicated than those studied here, and they may become even more complicated in the future. The number of additional applications of pesticide, growth regulator, or foliar nutrient that may be required during a specific growing season varies greatly from region to region and between orchards and vine-

Table 5. Cost reduction (increase) due to after-infection apple and grape fungicide programs compared to protectant programs for hypothetical orchards and vineyards in Ohio

	Fungicide cost reduction (increase) per hectare	Labor saved[a] (hr/ha)	Equipment cost reduction (increase) per hectare[b]			Total cost reduction (increase) per farm[c]		
			8.1-ha farm	16.2-ha farm	32.4-ha farm	8.1-ha farm	16.2-ha farm	32.4-ha farm
				Apple				
1982	$140.64	2.5	$ 57.03	$ 43.23	$ 16.28	$ 1,760.60	$ 3,297.60	$ 5,722.40
1983	81.02	1.5	4.84	11.26	(4.92)	791.20	1,686.24	2,848.80
1984	18.97	1.0	(21.20)	(4.74)	(15.51)	45.60	358.40	368.00
1985	86.23	2.5	57.03	43.23	16.28	1,320.00	2,416.40	3,960.00
1986	(165.09)	1.5	4.84	11.26	(4.92)	(1,201.60)	(2,299.36)	(5,722.40)
1987	(38.36)	1.0	(21.24)	(4.74)	(15.51)	(418.60)	(570.00)	(1,488.80)
1988	205.85	3.0	23.71	59.20	26.87	2,088.02	4,676.40	8,305.60
Total	$329.26	13.0	$ 105.01	$ 158.70	$ 18.57	$ 4,385.20	$ 9,565.70	$13,994.00
Percentage reduction	10	27	10	14	9	16	27	29
				Grape				
1982	$(13.17)	3.7	$ 122.27	$ 83.19	$ 42.78	$ 1,123.40	$ 1,614.00	$ 1,919.20
1983	12.75	4.9	187.47	123.15	69.26	1,941.20	2,840.80	3,936.00
1984	3.66	4.9	187.47	123.15	69.26	1,867.60	2,693.60	3,641.60
1985	(4.08)	3.7	122.27	83.19	42.78	1,197.00	1,893.20	2,213.60
1986	(39.87)	4.9	187.47	123.15	69.26	1,515.20	1,988.80	2,232.00
1987	89.12	9.9	374.95	283.01	175.22	4,397.60	7,306.40	11,121.60
1988	63.78	9.9	374.95	283.01	175.22	$ 4,192.40	6,896.00	10,300.80
Total	$112.19	41.9	$1,556.84	$1,101.87	$643.78	$16,234.40	$25,232.40	$35,364.80
Percentage reduction	10	46	38	40	37	37	43	41

[a] Assumes 29.6 min/ha (12 min/acre) for each spray on apple and 74.1 min/ha (30 min/acre) for each spray on grape.
[b] Includes predictor cost per hectare, from Table 1.
[c] Area (8.1, 16.2, or 32.4 ha) times the sum of the following: the difference in fungicide cost per hectare plus the difference in labor cost per hectare (hours of labor saved per hectare times $8/hr) plus the difference in equipment costs per hectare.

yards within a region. Most applications in the northeastern United States involve fungicide, but it is impossible to directly extrapolate these data to existing farms without further studies to determine the economics of chemical application within a total integrated production system. Our data suggest that curative or after-infection disease control programs do offer an alternative to applying fungicides in a prophylactic protection program and result in reduced fungicide applications in most seasons. Any reduction in fungicide application has obvious benefits in reducing environmental contamination and may result in substantial economic benefits as well.

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