Effects of an Apple Scab-Resistant Cultivar on Use Patterns of Inorganic and Organic Fungicides and Economics of Disease Control

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ABSTRACT

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An inorganic (sulfur) and a conventional organic fungicide spray program were evaluated on an apple scab-resistant (Liberty) and a scab-susceptible (McIntosh) cultivar for control of scab and for cost effectiveness. Trees of both cultivars were either nontreated, treated with inorganic fungicides only, or treated with a conventional fungicide program. McIntosh trees received full-season fungicide applications and Liberty trees received only the summer cover sprays (after petal fall) for control of summer diseases. In 1991, the number of fungicide applications ranged from 0 for nontreated Liberty to 12 for the full-schedule inorganic program on McIntosh, with both treatments providing excellent scab control. All nontreated McIntosh fruit were unmarketable due to scab infection. Due to a dry growing season and lack of summer disease development, nontreated Liberty fruit was of high quality. In 1992, the number of fungicide applications ranged from 0 for nontreated Liberty to 14 for the full-schedule inorganic treatment on McIntosh, with both treatments providing good to excellent disease control. Results were very similar in 1993. Scab incidence was low for all treatments except the nonsprayed McIntosh over all years. Over 3 years of testing, the conventional fungicide program resulted in an average of 9 and 5 applications per year for McIntosh and Liberty, respectively, compared to 12.6 and 7 applications, respectively, for the inorganic fungicide program. The large reduction in the number of sprays for both programs was due to the elimination of all pre-petal-fall applications on Liberty; post-petal-fall applications are needed to control summer diseases such as flyspeck and sooty blotch. An economic analysis for total cost of fungicide applications for each spray program and cultivar was conducted for hypothetical 4.0-, 8.1- and 16.2-ha farms. Regardless of farm size, the cost of fungicides per ha varied among treatments and cultivars. The inorganic and conventional spray program for McIntosh had similar total costs. On Liberty, the inorganic and conventional programs had 73 and 57% less total cost, respectively, than on McIntosh. Fungicides for the conventional program on Liberty were 1.45 times more costly per ha than fungicides in the inorganic program, but the inorganic program required more applications, resulting in a small difference in total treatment cost per ha.

Apple scab, caused by *Venturia inaequalis* (Cooke.) G. Wint., is the most destructive and economically important apple (*Malus × domestica* Borkh.) disease in Ohio. Control of scab is achieved primarily through a protectant fungicide spray program. In a protectant program, fungicides are generally applied when new growth first appears in spring, and then at regular intervals after 7 to 10 days of new growth or 2.54 cm of rain (18). In wet growing

seasons, when poor control of primary scab was achieved, growers in Ohio have made up to 15 fungicide applications per season for scab control. Although other diseases, such as powdery mildew, caused by *Podosphaera leucotricha* (Ellis & Everh.) E. S. Salmon, and cedar-apple rust, caused by *Gymnosporangium juniperi-virginianae* Schwein., can be important, apple scab drives the early season fungicide program (from the green tip stage through second or third cover).

Public concerns over pesticide residues in food have generated a great deal of interest in reducing fungicide use on all food crops. Several strategies aimed at reducing fungicide use on apples have been employed with varying degrees of success (26). Disease predictors or forecasters have been developed that combine electronic environmental monitoring sensors with a microcomputer to provide simple and rapid on-site determination of apple scab infection periods (6,14,20). This type of instrument combined with the ergosterol

biosynthesis-inhibiting fungicides make after-infection or curative programs more practicable. Funt et al. (17) reported that an after-infection program resulted in a significant reduction in the number of fungicide applications and lower total treatment cost as compared to a conventional protectant program. This approach can significantly reduce fungicide applications for scab control. However, growers have not widely adopted this new technology.

The introduction of apple cultivars with resistance to apple scab would be the only way to eliminate the use of fungicides for scab control in Ohio. At present, nurseries offer several high quality scab-resistant apple cultivars (SRCs) with resistance to scab, as well as resistance to powdery mildew and cedar-apple rust (1,22). Although several of these cultivars have resistance to the most important early season diseases (apple scab, powdery mildew, and cedar apple rust), they are not resistant to the summer disease complex composed of bitter rot (*Colletotrichum* spp.), bot rot (*Botryosphaeria dothidea*), black rot (*B. obtusa*), sooty blotch (a disease complex caused by *Peltaster fructicola*, *Leptodontidium elatius*, and *Geastrum polystigmatis*), and flyspeck (*Zygophiala jamai-censis*). Thus, even if resistant cultivars eliminate the need for early season fungicide applications, fungicides still probably will be required for control of summer diseases (25). The extent to which SRCs can reduce current fungicide use needs to be evaluated.

Concerns about pesticide residues in fruit also have generated a great deal of interest in organic apple production. In Ohio, organic production generally implies the use of inorganic fungicides such as copper or sulfur for disease control. Due to the lack of interest in the inorganic fungicides by most commercial growers over the past 25 to 30 years, we have not extensively evaluated the efficacy of these fungicides in season-long disease management programs in modern production systems. Several growers in Ohio have expressed interest in developing organic apple orchards based primarily on the use of SRCs and inorganic fungicides.

The cost of disease control chemicals and their application adds greatly to production costs. However, under Ohio's environmental conditions, apple production would not be profitable without effective

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fungicides. The relative high cost of most conventional organic fungicides compared to the low cost of inorganic fungicides leads many growers to believe that organic production systems are less expensive to maintain.

The objectives of this study were (i) to evaluate the impact of a SRC on fungicide use; (ii) to evaluate and compare the efficacy of inorganic (sulfur) fungicides and conventional organic fungicides for season-long disease control; and (iii) to conduct an economic analysis on the impact of SRCs and inorganic fungicides on the current apple disease management program in Ohio. For the economic analysis, hypothetical situations for three orchard sizes were considered.

MATERIALS AND METHODS

The experimental orchard was established in May 1989 at Snyder Farm on the Wooster Campus of the Ohio Agricultural Research and Development Center. Apple trees of the SRC Liberty and the scab-susceptible cultivar McIntosh on M.9 rootstock were planted as a high-density system trained to a 3-wire trellis. Trees were spaced with 2.1 m between trees and 3.7 m between rows. Treatment replicates within plots consisted of 6 trees per cultivar, and there were four blocks of each treatment in a completely randomized block design. The following treatments were initiated in the orchard at the beginning of its third growing season (spring 1991): Liberty, nontreated; Liberty with inorganic fungicide (flowable sulfur [Liquid sulfur Six 720 g/liter, Helena Chemical Co., Memphis, TN]) in post-petal-fall cover sprays

only, applied on a 14-day schedule; Liberty with conventional organic fungicides (benomyl [Benlate 50W, E.I. DuPont de Nemours Co., Wilmington, DE] alternated with captan [Captan 50W, Micro Flo Co., Lakeland, FL]) in post-petal-fall cover sprays only, applied on a 21-day schedule; McIntosh, nontreated; McIntosh with inorganic fungicides (Lime Sulfur Solution 29%, Miller Chem. Co., Hanover, PA) applied on a 7-day protectant schedule from 1.3-cm green leaf tissue through first cover, then flowable sulfur 720 g/liter on a 14-day schedule in remaining post-petal-fall covers; McIntosh with conventional organic fungicides (myclobutanil [Nova 40W, Rohm and Haas Co., Philadelphia] plus captan) applied on a 10- to 14-day extended protectant program from 1.3-cm green leaf tissue through second cover, then benomyl alternated with captan on a 21-day schedule in remaining covers. The trees were sprayed to runoff with fungicide in 3,636 liters water per hectare from a handgun at 3,102 kPa.

Timing and dates of fungicide application for various treatments in 1991 were as follows: Liberty inorganic cover sprays only, first cover (21 May), remaining covers (4 and 20 June; 5 and 19 July; 2, 16, and 30 August); Liberty conventional cover spray only, first cover (21 May), remaining covers (6 June; 3 and 24 July; 14 and 28 August); McIntosh inorganic full schedule, 1.3-cm new growth (16 April), tight cluster (23 April), bloom (30 April), petal fall (8 May), first cover (16 May), remaining covers (30 May, 13 and 27 June; 11 and 25 July; 8 and 22 August); McIntosh conventional full schedule, 1.3-cm

new growth (16 April), bloom (30 April), petal fall (10 May), first cover (21 May), remaining covers (12 June; 3 and 24 July; 14 and 28 August). Timing and dates of fungicide application in 1992 were as follows: Liberty inorganic cover spray only, first cover (29 May), remaining covers (12 and 25 June; 9 and 23 July; 11 and 26 August); Liberty conventional cover sprays only, first cover (29 May), remaining covers (19 June; 10 and 30 July; 20 August); McIntosh inorganic full schedule, 1.3-cm new growth (19 April), tight cluster (25 April), open cluster (2 May), bloom (9 May), late bloom (16 May), petal fall (22 May), first cover (29 May), remaining covers (5, 19, and 30 June; 14 and 28 July; 11 and 26 August); McIntosh conventional full schedule, 1.3-cm new growth (19 April), tight cluster (25 April), bloom (7 May), petal fall (19 May), first cover (29 May), remaining covers (8 and 29 June; 20 July; 10 August). Timing and dates of fungicide applications in 1993 were as follows: Liberty inorganic cover sprays only, first cover (10 June), remaining covers (24 June; 8 and 22 July; 5 and 19 August); Liberty conventional cover sprays only, first cover (10 June), remaining covers (1 and 22 July; 12 August); McIntosh inorganic full schedule, 1.3-cm new growth (23 April), tight cluster (29 April), pink (6 May), petal fall (14 May), first cover (21 May), remaining covers (28 May; 11 and 24 June; 8 and 22 July; 5 and 19 August); McIntosh conventional full schedule, 1.3-cm new growth (23 April), open cluster (4 May), bloom (16 May), first cover (27 May), remaining covers (6 and 27 June; 18 July; 8 and 29 August).

Table 1. Efficacy of scab resistance and conventional versus inorganic fungicides on control of foliar and fruit infections by apple scab in 1991

Treatment	Fungicide and rate a.i./ha (timing and spray interval) ^v	Infected leaves (%)		Infected fruit scab ^y (%)	No. of fungicide applications
		Primary scab ^w	Secondary scab ^x		
Liberty	No spray	0.0 b ^z	0.0 c	0.0	0
McIntosh	No spray	68.9 a	97.2 a	100.0	0
Liberty Inorganic fungicide, cover sprays only	Sulfur 16.9 kg (14-day)	0.0 b	0.0 c	0.0	8
McIntosh Inorganic fungicide, full schedule	Lime sulfur 26.9 kg (1.3 CNG-PF) then sulfur 16.9 kg (RC-14 day)	1.9 b	7.9 b	2.0	12
Liberty Conventional fungicide, cover sprays only	Benomyl 419 g alternated with captan 3.4 kg (21-day)	0.0 b	0.0 c	0.0	6
McIntosh Conventional fungicide, extended protectant full schedule	Captan 3.4 kg (1.3 CNG) then myclobutanil 138 g plus captan 2.3 kg (TC-2C) (10-14-day), then benomyl 419 g alternated with captan 3.4 kg (21-day)	0.3 b	0.42 c	1.1	9
Least significant difference (LSD) 0.05		7.1	2.4	...	...

^v Timing: 1.3 CNG = 1.3 cm new growth, 1C = first cover, 2C = second cover, TC = tight cluster, RC = remaining covers, PF = petal fall.

^w Determined as the percentage of cluster leaves with at least 1 primary scab lesion on 10 clusters per tree.

^x Determined as the percentage of leaves with at least 1 secondary scab lesion on the 10 most terminal leaves on 10 lateral branches per tree.

^y Determined as the percentage of fruit with at least one scab lesion on 25 fruit per tree.

^z Numbers followed by the same letter within columns do not differ significantly according to Duncan's modified (Bayesian) LSD test ($P = 0.05$). Data for fruit scab was not statistically analyzed in 1991.

In 1991, the orchard was in its third growing season and trees of the cultivar McIntosh set a very light crop; therefore, sufficient fruit were not available to conduct fruit scab ratings. For the 1991 season only, the same fungicide treatments were established on McIntosh trees in another orchard located approximately 50 m from the experimental orchard. Therefore, in 1991, fruit scab data for McIntosh were obtained from 5-year-old McIntosh trees on Mark rootstocks in an adjacent orchard. Fungicide treatments and timing were identical to that in the experimental orchard. Since randomized blocks were not available for fruit scab analysis in 1991, fruit scab data for that year could not be analyzed using standard statistical tests. Data for leaf infection on McIntosh were obtained from the experimental orchard. Liberty trees had sufficient fruit for the test. All other data in all years of testing were obtained from trees in the experimental orchard.

The experiment was repeated in 1992 and 1993. Primary scab incidence was determined as the percentage of cluster leaves with at least one primary scab lesion on 10 clusters per tree during early June of each season. Secondary scab incidence was determined as the percentage of leaves with at least one secondary scab lesion on the 10 youngest leaves on 10 lateral branches per tree during mid- to late July of each season. Fruit scab incidence was

determined as the percentage of fruit with at least one scab lesion on 25 arbitrarily selected fruit per tree at harvest during each season. Incidence of sooty blotch and flyspeck was recorded at harvest in 1992 as the percentage of fruit with any visible sooty blotch or flyspeck on 25 arbitrarily selected fruit per treatment. Total yield (kg) per tree was recorded at harvest in 1992 and 1993. Insect and weed control was the same for all treatments and followed standard Ohio State University Extension recommendations (13).

Economic analysis. An economic analysis of the cost for fungicides, including application costs, was conducted for each treatment in all 3 years of testing. Labor, fungicide, and equipment costs were based on 1992 prices. Labor costs included benefits. The amount of fungicide per hectare, labor, and equipment hours were derived from the fungicide trials in 1991. These were based on a high-density orchard having 1,296 trees per hectare (518 trees per acre). All costs remained the same for the 1991 to 1993 period when the treatments were made.

The size of equipment was matched to farm size. Each hypothetical farm had 4.0, 8.1, or 16.2 ha of high-density orchard. The size of the tractor was selected to provide sufficient power for the sprayer. Larger farms had a high-capacity sprayer to be able to cover the fruit plantings rapidly at critical times throughout the year (15,16). Farms

with small plantings operate their equipment for fewer hours per year than farms with larger plantings. Therefore, small farms have greater number of years of equipment use and greater number of years for depreciation than larger farms.

Total minutes per hectare per application were calculated from previous data (16) for high-density orchards. A travel speed of 3.3 km/h and the low-volume rate of 460 liters/ha were used to calculate the time per spray.

RESULTS AND DISCUSSION

Results clearly demonstrate that it is not feasible to produce scab-susceptible apples without the use of fungicides under Ohio conditions. On untreated McIntosh trees, primary scab incidence on leaves ranged from 42 to 69%, secondary scab incidence on leaves ranged from 86 to 100%, and fruit scab incidence was 100% for all 3 years of testing (Tables 1, 2, and 3). In 1991, both the inorganic and conventional fungicide programs provided excellent scab control on McIntosh. Although the level of secondary scab in 1991 was significantly higher in the inorganic than conventional treatment, there were no significant differences between treatments in the percentage of primary scab (Table 1). Excellent control of fruit scab was obtained from all fungicide treatments. Although fruit scab data is presented (Table 1), it could not be statistically analyzed in 1991 because it was collected in an adja-

Table 2. Efficacy of scab resistance and conventional versus inorganic fungicides on control of foliar and fruit infections by apple scab and sooty blotch and fly speck in 1992

Treatment	Fungicide and rate a.i./ha (timing and spray interval) ^v	Infected leaves (%)		Infected fruit scab ^y (%)	Sooty blotch ^y (%)	Fly speck ^y (%)	No. of fungicide applications	Yield/tree (kg)
		Primary scab ^w	Secondary scab ^x					
Liberty	No spray	0.0 b ^z	0.0 c	0.0 b	77.3 a	78.3 a	0	25.3 a
McIntosh	No spray	55.7 a	86.4 a	100.0 a	81.9 a	91.7 a	0	1.5 b
Liberty								
Inorganic fungicide, cover sprays only	Sulfur 16.9 kg (14 day)	0.0 b	0.0 c	0.0 b	2.2 b	9.8 b	7	28.5 a
McIntosh								
Inorganic fungicide, full schedule	Lime sulfur 26.9 kg (1.3 CNG-PF) then sulfur 16.9 kg (RC-14 day)	0.0 b	4.0 b	0.2 b	2.1 b	6.4 b	14	20.4 a
Liberty								
Conventional fungicide, cover sprays only	Benomyl 419 g alternated with captan 3.4 kg (21 day)	0.0 b	0.0 c	0.0 b	0.0 b	0.0 a	5	24.6 a
McIntosh								
Conventional fungicide, extended protectant full schedule	Captan 3.4 kg (1.3 CNG) then myclobutanil 138 g plus captan 2.3 kg (TC-2C) (10-14 day) then benomyl 419 g alternated with captan 3.4 kg (21 day).	0.3 b	3.2 bc	1.1 b	0.0 b	0.0 a	9	17.1 a
Least significant difference (LSD)		3.9	3.4	4.1	19.2	16.5	...	11.9

^v Timing: 1.3 CNG = 1.3 cm new growth, 1C = first cover, 2C = second cover, TC = tight cluster, RC = remaining covers, PF = petal fall.

^w Determined as the percentage of cluster leaves and first 5 terminal leaves with at least 1 primary scab lesion on 10 clusters per tree.

^x Determined as the percentage of leaves with at least 1 secondary scab lesion on the 10 most terminal leaves on 10 lateral branches per tree.

^y Determined as the percentage of fruit with at least one scab or any visible sooty blotch or fly speck lesion on 25 fruit per tree.

^z Numbers followed by the same letter within columns do not differ significantly according to Duncan's modified (Bayesian) LSD test ($P = 0.05$).

cent orchard. The conventional fungicide program resulted in three fewer sprays than the inorganic program. In 1992, both programs provided excellent control with no significant differences in primary, secondary, or fruit scab incidence (Table 2). However, the conventional program resulted in five fewer sprays than the inorganic program. In 1993, secondary and fruit scab incidence in the inorganic program was significantly higher than the conventional program, with no significant differences in primary scab control (Table 3). Fruit scab incidence (9%) was commercially unacceptable and the inorganic program resulted in three more sprays than the conventional program.

No scab developed on leaves or fruit of Liberty in any treatment (Tables 1, 2, and 3). Sooty blotch and flyspeck developed only in 1992. Although disease incidence was high for sooty blotch and flyspeck in the untreated plots for this year (77 and 78%, respectively), disease severity was very low (less than 2% surface area covered [*data not shown*]). Due to this low disease severity, infected fruit were considered marketable. The inorganic program provided excellent control of sooty blotch but was not as effective on flyspeck (Table 2). The conventional program provided 100% control of both diseases. During each year of testing, the inorganic program resulted in two more sprays than the conventional program. In 1991 and 1993, when no sooty blotch or flyspeck developed, untreated Liberty fruits were blemish-free and 100% marketable while untreated McIntosh fruit were unmarketable (100% scab-infected).

The yield on unsprayed McIntosh trees was 86 and 34% less than that of trees sprayed with the conventional fungicide program in 1992 and 1993, respectively (Tables 2 and 3). In addition, fruit from unsprayed trees were unmarketable, even for cider. Yields increased for each cultivar from 1992 to 1993 since the trees were expanding in height and width. It was not

the intent of this study to compare yields per tree between cultivars and treatments. The purpose for recording yield per tree was to demonstrate the impact of apple scab on a nonsprayed susceptible and resistant cultivar. In 1992, mean yield from the inorganic and conventional McIntosh programs were 20.4 and 17.1 kg/tree, respectively, compared to 1.46 kg/tree from

Table 4. Estimated equipment size, cost, and hours of use per year per ha for applying fungicides to apples for a 4-, 8.1-, and 16.2-ha orchard in 1991

Time	Farm size (ha) ^t		
	4.0	8.1	16.2
Tractor			
Size ^u	45D/2 cab	55D/2 cab	55D/2 cab
Initial price	\$25,850	\$28,500	\$28,500
Hours/year ^v	150	300	600
Depreciation (years)	20	18	15
Total cost/h ^w	\$22.57	\$14.49	\$9.71
Sprayer (power take-off)			
Size	371 liters	1,113 liters	1,113 liters
Initial price	\$6,150	\$9,200	\$9,200
Hours/year ^v	80	160	320
Depreciation (years)	20	18	15
Total cost/h ^w	\$9.40	\$7.41	\$4.17
Ha/tank ^x	0.8	2.4	2.4
Total minutes/spray/ha ^y	86	61	61
Total cost/spray/ha ^z	\$58.23	\$31.17	\$23.01

^t Each farm has 4.0, 8.1, or 16.2 ha of high density apples at 1,296 trees per hectare.

^u The size of the tractor is based on the power take-off (PTO) and load requirement of the selected sprayers. A 4.0-ha farm has a 45 horsepower diesel tractor, with two-wheel drive and cab. Larger farms have a 55 horsepower diesel tractor with two-wheel drive and cab.

^v Hours of equipment use are estimated based on previous reports (16).

^w The total cost per hour includes straight-line depreciation, interest (10%), repair, fuel (\$1.10/gal, no tax) and lube as required, insurance, and shelter.

^x For low-volume sprays the rate is 460 liters/ha.

^y The total min per ha per application is based on speed of 3.3 km/h plus turn-around time and refill time of 15 min/tank.

^z The total cost per spray includes equipment cost as shown plus labor at \$8.75/h, which includes benefits.

Table 3. Efficacy of scab resistance and conventional versus organic fungicides on control of foliar and fruit infections by apple scab in 1993

Treatment	Fungicide and rate a.i./ha (timing and spray interval) ^v	Infected leaves (%)			No. of fungicide applications	Yield/tree (kg)
		Primary scab ^w	Secondary scab ^x	Infected fruit scab (%) ^y		
Liberty	No spray	0.0 b ^z	0.0 d	0.0 c	0	32.9 a
McIntosh	No spray	42.5 a	100.0 a	100.0 a	0	6.6 e
Liberty						
Inorganic fungicide, cover sprays only	Sulfur 16.9 kg (14 day)	0.0 b	0.0 d	0.0 c	6	30.2 a
McIntosh						
Inorganic fungicide, full schedule	Lime sulfur 26.9 kg (1.3 CNG-PF) then sulfur 16.9 kg (RC-14 day)	2.3 b	32.7 b	9.2 b	12	16.0 d
Liberty						
Conventional fungicide, cover sprays only	Benomyl 419 g alternated with captan 3.4 kg (21 day)	0.0 b	0.0 d	0.0 c	4	28.0 b
McIntosh						
Conventional fungicide, extended protectant full schedule	Captan 3.4 kg (1.3 CNG) then myclobutanil 138 g plus captan 2.3 kg (TC-2C) (10-14 day) then benomyl 419 g alternated with captan 3.4 kg (21 day)	0.1 b	16.4 c	1.0 c	9	19.5 c
Least significant difference(LSD)		8.0	6.3	2.3	...	3.4

^v Timing: 1.3 CNG = 1.3 cm new growth, 1C = first cover, 2C = second cover, TC = tight cluster, RC = remaining covers, PF = petal fall.

^w Determined as the percentage of cluster leaves and first 5 terminal leaves with at least 1 primary scab lesion on 10 clusters per tree.

^x Determined as the percentage of leaves with at least 1 secondary scab lesion on the 10 most terminal leaves on 10 lateral branches per tree.

^y Determined as the percentage of fruit with at least one scab lesion on 25 fruit per tree.

^z Numbers followed by the same letter within columns do not differ significantly according to Duncan's modified (Bayesian) LSD test ($P = 0.05$).

unprotected trees, and 16.0 and 19.5 kg/tree for these programs, respectively, compared with 6.6 kg/tree on unprotected trees in 1993. Similarly with Liberty, the yield from trees on the inorganic and conventional programs was 28.5 and 24.6 kg/tree compared to 25.3 kg/tree on unprotected trees in 1992, and 30.2 and 28.0 kg/tree for these programs, respectively, compared to 32.9 kg/tree on unprotected trees in 1993.

Over the 3 years of testing, the conventional spray program resulted in an average

of 9 and 5 applications per year for McIntosh and Liberty, respectively. This 44% reduction in the number of sprays was due to the elimination of all early-season (prior to petal fall) fungicide applications for Liberty. The inorganic program resulted in an average of 12.6 and 7 applications per year for McIntosh and Liberty, respectively. This also represents a 44% reduction in the number of applications for Liberty. The increased number of applications in the inorganic compared to the conven-

tional program was due to the reduced interval between sprays when inorganic (sulfur) fungicides were used. Due to the relatively weak protectant activity and lack of curative activity of sulfur, early-season sprays for scab control need to be applied on at least a 7-day protectant schedule, and post-petal-fall (summer cover) sprays should not exceed a 14-day interval (5,9–12,19,23). Using conventional organic fungicides with good protectant activity (captan) combined (tank-mixed) with a fungicide with good curative activity (myclobutanil), the early-season program can be extended up to 10 to 14 days (7,8,17,27). Incorporation of a benzimidazole fungicide (benomyl) into the summer cover spray program may allow an extended interval up to 21 days (24). The ability to extend spray intervals results in a substantial reduction in the number of sprays per season (7,8,17,28).

Although sulfur fungicides are generally less expensive than conventional fungicides, the shorter spray interval results in more applications, which greatly increases total cost. In addition, the relatively poor efficacy of sulfur fungicides makes them risky to use (9–12,21). In 1993, the inorganic program did not provide an acceptable level of fruit scab control (Table 3). In this study, summer disease pressure was very low; therefore, the inorganic program provided effective control. Under heavy disease pressure, sulfur will probably not provide effective summer disease control (10,11).

The use of a SRC greatly reduced the number of fungicide applications required to achieve acceptable disease control. The number of fungicide applications was reduced up to 50% where only summer cover

Table 5. Cost of fungicides per hectare^y to apple in Ohio during 1991 to 1993

Treatment ^z	Liberty	McIntosh
1991		
No spray	\$ 0.00	\$ 0.00
Inorganic fungicide, cover sprays only	113.81	...
Inorganic fungicide, full schedule	...	423.65
Conventional fungicide, cover sprays only	189.35	...
Conventional fungicide, full schedule	...	438.38
1992		
No spray	0.00	0.00
Inorganic fungicide, cover sprays only	172.90	...
Inorganic fungicide, full schedule	...	626.59
Conventional fungicide, cover sprays only	315.57	...
Conventional fungicide, full schedule	...	570.67
1993		
No spray	0.00	0.00
Inorganic fungicide, cover sprays only	147.46	...
Inorganic fungicide, full schedule	...	375.39
Conventional fungicide, cover sprays only	126.22	...
Conventional fungicide, full schedule	...	472.14
TOTAL—3 years		
No spray	0.00	0.00
Inorganic fungicide, cover sprays only	434.17	...
Inorganic fungicide, full schedule	...	1,425.63
Conventional fungicide, cover sprays only	631.13	...
Conventional fungicide, full schedule	...	1,481.18

^y Cost of fungicides only, based on 1992 prices: sulfur 6F (\$1.06/liter); benlate 50W (\$32.89/kg); captan 50W (\$5.25/kg); Nova 40W (\$129.89/kg) and lime sulfur (\$0.87/liter).

^z Treatments consisted of no treatment, inorganic cover sprays only, inorganic fungicide full schedule, conventional cover sprays only, and conventional fungicide extended protectant full schedule.

Table 6. Total cost^z per hectare to apply fungicides to a 4.0-, 8.1-, and 16.2-hectare apple orchards in Ohio during 1991 to 1993

Treatment	Liberty			McIntosh		
	4.0 ha	8.1 ha	16.2 ha	4.0 ha	8.1 ha	16.2 ha
1991						
No spray	\$ 0	\$ 0	\$ 0	\$ 0	\$ 0	\$ 0
Inorganic fungicide, cover spray only	580	368	301	...	...	...
Inorganic fungicide, full schedule	...	...	...	1,123	805	706
Conventional fungicide, cover only	538	380	330	...	...	...
Conventional fungicide, full schedule	...	...	...	963	723	649
1992						
No spray	0	0	0	0	0	0
Inorganic fungicide, cover only	580	417	301	...	...	...
Inorganic fungicide, full schedule	...	...	...	1,442	1,072	956
Conventional fungicide, cover only	607	474	432	...	...	...
Conventional fungicide, full schedule	...	...	...	998	758	684
1993						
No spray	0	0	0	0	0	0
Inorganic fungicide, cover only	496	338	288	...	...	...
Inorganic fungicide, full schedule	...	...	...	1,074	756	657
Conventional fungicide, cover only	360	254	219	...	...	...
Conventional fungicide, full schedule	...	...	...	998	758	684
TOTAL—3 years						
No spray	0	0	0	0	0	0
Inorganic fungicide, cover only	1,656	1,123	890	...	...	...
Inorganic fungicide, full schedule	...	...	...	3,639	2,633	2,319
Conventional fungicide, cover only	1,505	1,108	981	...	...	...
Conventional fungicide, full schedule	...	...	...	2,959	2,239	2,017

^z Includes equipment, labor, and fungicides. Cost per hectare for 4.0, 8.1, or 16.2 ha orchards planted at 1,296 trees/ha. Values rounded to nearest \$1.00.

sprays were applied to Liberty. Using cultivars with resistance to scab, powdery mildew, and cedar apple rust (the major early-season diseases in Ohio and surrounding states) could result in the elimination of all fungicide applications prior to petal fall. Furthermore, the use of SRC combined with various cultural practices (4) and disease forecasting models (3) for summer diseases such as sooty blotch and flyspeck could eliminate the need for fungicides during drier growing seasons. In wet growing seasons, the total elimination of fungicide use is probably not feasible. The need to control summer rots and fruit blemishes will most certainly require some use of fungicide (22,24–26). In addition, as fungicide use is reduced, new disease problems may develop. Rosenberger et al. (25) reported that Liberty apple trees sprayed with fungicides defoliated approximately 2 weeks later in October than unsprayed trees, and that early defoliation resulted in reduced yield and fruit set. In our study, we also observed a 1- to 2-week early defoliation in unsprayed Liberty trees; however, we did not observe a reduction in yield or fruit set. The cause of early defoliation is not clear, but may be due to interactions of fungicides and apple leaf microflora (2).

Economic analysis. An economic analysis was conducted based on the disease control results found here. The total cost per spray per hectare for labor and equipment only was highest with the smallest farm size (Table 4). The largest farm had a 60% lower labor and equipment cost per spray per hectare than the smallest. Regardless of farm size, the cost of fungicides per hectare varied among treatments and cultivars (Table 5). Fungicide cost for the conventional cover spray program was 1.45 times higher than the inorganic cover spray program for Liberty (Table 5). However, total cost of application per hectare for a 4-ha orchard over the 3-year period was \$1,656 and \$1,505 for the inorganic and conventional programs, respectively (Table 6), because an increased number of applications resulted in higher total cost even with lower fungicide cost. For McIntosh, fungicide costs per hectare were similar, with \$1,426 and \$1,481 for the inorganic and conventional programs, respectively, for the 3-year period (Table 5). As with Liberty, the increase in number of applications for the inorganic program resulted in 1.6 times higher cost (\$3,639/ha) than the conventional program (\$2,959/ha) over the 3-year period for a 4-ha orchard.

The elimination of pre-petal-fall fungicide sprays on the SRC greatly reduced costs. For the 3-year period, fungicide costs for the inorganic and conventional programs were 3.3 and 2.3 times higher, respectively, for McIntosh than for Liberty (Table 5). Total application costs for an inorganic program on the 4-ha orchard was

2.2 times higher for McIntosh (\$3,639/ha) than for Liberty (\$1,656/ha). For the conventional program, total cost was twice as high for McIntosh (\$2,239/ha) as for Liberty (\$1,505/ha). Similar differences were found for larger orchards.

In summary, our data suggest that SRCs could result in $\approx$ 50% reduction in fungicide use while still achieving acceptable disease control. When combined with the use of various cultural practices and disease forecasting programs for summer disease control, the reduction in fungicide use could be greater. Although SRCs have great potential for reducing our overall use of fungicides in apple production systems, further research is needed before large-scale commercial production of SRCs is recommended. SRCs may have limitations relative to fruit size, color, storage ability, and tree growth management. In addition, there are problems with introducing and promoting new cultivars for mass market retail sales. At least in the short term, the use of SRCs by home fruit producers, organic growers, and the apple processing industry may have the greatest potential. Our results showed no economic or biological advantage in using an inorganic (sulfur) fungicide program over a conventional organic fungicide program; lower product costs were offset by increased application costs. In addition, conventional organic fungicide programs appear to be more efficacious for disease control on a year-to-year basis (10–12,26; Table 4). However, lime sulfur and sulfur do appear to be viable fungicides for growers wishing to produce organically grown fruit.

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