Development and Evaluation of an Integrated, Reduced-Spray Program Using Sterol Demethylation Inhibitor Fungicides for Control of Primary Apple Scab

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ABSTRACT

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An integrated, reduced-spray program for control of primary apple scab infections was developed and evaluated for three consecutive years in nine commercial apple orchards and for 2 of the same 3 yr in five additional orchards in western New York. Growers were advised to make four applications of a sterol demethylation inhibitor fungicide (i.e., fenarimol, flusilazol, or myclobutanil), whose timings were to be independent of the occurrence of apple scab infection periods but were to coincide with applications of insecticides or acaricides at or near the following four phenological stages: 1) tight cluster; 2) pink bud; 3) petal fall; and 4) approximately 10 days after petal fall (first cover spray). This schedule contrasts with a traditional primary scab control program averaging six or seven fungicide applications commencing shortly after budbreak and timed according to anticipated or recent weather events. The mean incidence of apple scab on fruit at harvest in all orchards was 0.2, 1.0, and 1.6% in 1988, 1989, and 1990, respectively, during which an average of 5.2, 14.4, and 8.2 primary scab infection periods occurred in these locations; however, when data from one orchard were not considered, mean fruit scab incidence was only 0.4 and 0.5% in 1989 and 1990, respectively. Including early-season copper sprays applied in some orchards for control of fire blight, the mean number (and range) of fungicide sprays actually applied in the trial orchards during the period of primary scab development was 4.1 (3–5), 4.4 (4–5), and 4.5 (3–6) in 1988, 1989, and 1990, respectively; within these ranges there was no apparent relationship between the number of sprays applied and the degree of control obtained. This program has reduced fungicide use and pesticide application events simply and effectively, although its limitations are acknowledged and discussed.

Additional keywords: integrated pest management, *Venturia inaequalis*

Apple scab, caused by *Venturia inaequalis* (Cooke) Wint., is the most economically important disease of apples in a majority of the production regions of the world (2). Losses may be due to direct reductions in yield and quality of infected fruit, but in the majority of commercial orchards economic losses more commonly accrue from the costs of labor, spray equipment, and fungicides expended in programs to control the disease. For instance, in the tree fruit production districts near the southern shore of Lake Ontario in western New York, wherein approximately 15,000 ha of commercial apple orchards are cultivated, growers in the recent past have typically applied an average of six or seven protectant fungicide sprays from budbreak until 1–3 wk after petal fall. Such sprays are applied chiefly to control primary apple scab infections and secondarily to control powdery mildew, the only consistently important fungal diseases in western New York during this part of the year.

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Programs that can reliably control apple scab with a minimum number of fungicide sprays are desired by most apple growers for a variety of personal, economic, and sociopolitical reasons. However, previous integrated pest management programs designed to limit apple scab sprays have met with limited success and acceptance in western New York. For instance, scheduling sprays only within 72 hr following a predicted primary infection period (4) has often necessitated a fungicide application under windy conditions or at a time that is not well coordinated with sprays needed to control arthropod pests. Furthermore, because primary apple scab infection periods are usually numerous in this region, a strict postinfection program has seldom reduced the number of sprays below that of a standard protectant schedule enough to compensate for these factors and the increased costs of the sterol demethylation inhibitor (DMI) fungicides that must be used in such a program. Similarly, delaying sprays until weekly monitorings of ascospore development indicate the presence of functional inoculum has had little effect, since at least some mature ascospores are detectable at or shortly after budbreak most years in this region (19).

In contrast to these previous approaches, a broader program for minimizing fungicide applications and integrating them with sprays for arthropod pests has recently been proposed for apple orchards in the northeastern United States (7). The cornerstone of this program is the elimination of early-season sprays directed solely against apple scab, contingent upon the presence of low levels of primary inoculum within participating orchards. Although the program proved effective in seven commercial orchards in New Hampshire and the Hudson Valley of New York in 1986 (7), unacceptable levels of apple scab developed during the 1987 season in several Hudson Valley orchards in which it was tested or adopted independently by growers; such failures may have been due to inaccurate assessments of primary inoculum levels and a strict reliance on protectant fungicides once sprays were initiated (D. A. Rosenberger, *personal communication*). Consequently, we developed and field-tested a modification of this program that 1) accounts for typical patterns of crop development and arthropod control strategies in western New York, 2) is based upon a qualitative rather than quantitative assessment of seasonal primary inoculum potential, and 3) relies heavily upon sequential applications of DMI fungicides to maximize the post-infection, presymptom, and postsymptom activities of these materials (3,9,15,20).

MATERIALS AND METHODS

The program was evaluated in nine commercial orchards for three consecutive seasons, 1988–1990, and in five additional orchards for 2 of those 3 yr. For identification purposes, each orchard has been assigned a different alphabetical letter, which is used consistently throughout this report. All orchards were located 1–15 km south of Lake Ontario in a band extending approximately 150 km from east to west through the counties of Niagara, Orleans, and Wayne. Cooperating growers were provided commercial formulations of either fenarimol, flusilazol (1988–1989 only), or myclobutanil and asked to apply only four fungicide sprays for control of primary apple scab. The timings of fungicide applications were to be independent of the occurrence of apple scab infection periods and flexible, so as to coincide with applications of insecticides or acaricides at or near the following four phenological stages: 1) the tight cluster (TC) stage of blossom bud development; 2) the pink (P) stage of blossom development; 3) petal fall (PF); and 4) approximately 10 days after the petal fall (the first cover [1C] spray). Virtually all apple growers in western New York apply insecticides at PF and 1C, and the majority apply oil (for control of mites) at TC and an insecticide at P. Previous research suggested that such a DMI program also should provide very good control of powdery mildew (1).

The recommended rate (a.i.) of fenarimol in the first and third sprays was 82 g/ha or 2.7 mg/m^3 of canopy volume if growers preferred to determine their rates in this manner (9 fl oz per acre of Rubigan 1E or 3 fl oz/100 gal of spray solution dilute basis, assuming dilute coverage of 7.0×10^{-4} gal/ft^3 of canopy volume) and was 55 g/ha or 1.9 mg/m^3 (6 fl oz per acre or 2 fl oz/100 gal) in the second and fourth sprays. It was also recommended that fenarimol be applied in combination with 50% of the typically recommended rates of mancozeb (2,020 g/ha or 67.2 mg/m^3 [36 oz per acre or 12 oz/100 gal of an 80WP formulation]) or captan (1,680 g/ha or 56.0 mg/m^3 [48 oz per acre or 16 oz/100 gal of a 50WP formulation]) in all sprays except the first. Flusilazol was recommended for use alone in the first three sprays at a rate of 56 g/ha or 1.9 mg/m^3 (4 oz per acre or 1.33 oz/100 gal of Nustar 20DF) and in the fourth spray at 75% of that rate in combination with mancozeb or captan applied at the same rates recommended for the fenarimol combinations. Similarly, myclobutanil was recommended for use alone in the first three sprays at a rate of 140 g/ha or 4.7 mg/m^3 (5 oz per acre or 1.67 oz/100 gal of Nova 40W) and in the fourth spray at 80% of that rate in combination with the aforementioned rates of mancozeb or captan. Subsequent fungicide sprays during the summer were left to the discretion of the grower, depending upon weather, intended crop utilization, the need to control secondary apple scab, and the desire to continue controlling powdery mildew. The program was to be imposed over an entire block of trees (about 2–4 ha), using each grower's standard spray equipment and application procedures, the sole stipulation being that the grower felt he had obtained good control of apple scab (estimated incidence of fruit infection <1–2%) in the same block the year before initiating the program.

Control of primary apple scab was evaluated in the early summer by determining disease incidence on all leaves of 25 fruiting clusters and 10 terminal shoots and on 100 fruit on each of five arbitrarily selected trees per orchard. Individual clusters, shoots, and fruit were selected from locations representative of all sections of the tree within the first 2 m above ground level. If more than one variety was grown in the test block, that which was most susceptible to apple scab was chosen for evaluation. Just prior to harvest, disease incidence was reassessed on terminal leaves and fruit of five additional arbitrarily selected trees in each orchard. Fruit scab incidence was determined at this time on a sample of 100 fruit per tree (200 in 1988), obtained by picking all apples from the top to the bottom of the tree in one to three representative sectors. Because disease incidence data were so similar for cluster and terminal leaves in the early rating, only terminal leaf data are presented.

Records obtained from each grower were used to determine the dates of spray applications and the amount of fungicide and volume of water applied per hectare of orchard. Tree canopy volume (m^3/ha) was calculated for each orchard by measuring three representative trees and multiplying (mean tree height) $\times$ (mean canopy width) $\times$ (linear meters of row per hectare), and this value was used to convert application rates from an area (per hectare) to a volumetric (per m^3 of canopy) basis. In 1988 and 1989, records also were obtained from four and eight growers, respectively, showing fungicide usage in comparison blocks of the same cultivars on other parts of their farms, which were managed using each grower's standard procedures.

Primary apple scab infection periods and their severities were determined according to Mills's criteria (14), using temperature and leaf wetness duration data collected from the nearest of four (1988 and 1990) or five (1989) weather stations operated by the Cornell Integrated Pest Management Program

Table 1. Weekly assessments of the relative availability of primary inoculum of *Venturia inaequalis* in apple leaves from an unsprayed orchard in Geneva, New York, 1988–90

Year Date	Phenophase[a]	% of Asci[b] Immature	Mature	Discharged	Ascospore discharge test (ascopores/100× field)[c]
1988					
14 April	GT	95	5	<1	6
21 April	0.5 cm	88	11	1	11
28 April	1 cm	85	13	2	4
5 May	TC	83	14	3	29
20 May	BL	41	22	37	83
26 May	PF	34	18	48	118
2 June	...	11	18	71	94
9 June	...	6	10	84	154
16 June	...	2	8	90	73
1989					
21 April	GT	98	2	0	0
27 April	1 cm	97	3	<1	<1
5 May	2 cm	92	7	1	27
11 May	TC	83	13	4	20
18 May	P	45	47	8	149
26 May	BL	28	46	26	230
1 June	PF	16	39	45	96
7 June	1 cm-f	3	11	86	52
16 June	...	1	1	98	9
1990					
29 March	ST	94	6	0	<1
5 April	GT	83	16	1	13
12 April	0.5 cm	67	31	2	28
19 April	1 cm	70	25	5	35
26 April	TC	56	37	7	64
4 May	BL	...	...	7	217
10 May	BL	32	45	23	214
17 May	PF	27	31	42	24
24 May	0.5 cm-f	19	25	56	112
1 June	...	10	19	71	86
8 June	...	5	13	82	178
14 June	...	3	6	91	35

[a] Phenological stage of development of fruit buds on the cultivar McIntosh. ST = silver tip; GT = green tip; 0.5, 1, and 2 cm = lengths of exposed green tissue; TC = tight cluster; P = pink; BL = bloom; PF = petal fall; 0.5 cm-f, 1 cm-f = fruitlet diameter.

[b] Mean percentage of asci from 20 crushed pseudothecia rated according to the methods of Szkolnik (19). The number of asci per pseudothecium was determined on each sampling date, and the percentages of immature and discharged asci adjusted to reflect a total mean number of 120 asci per pseudothecium, as suggested by Gadoury and MacHardy (5).

[c] Mean number of ascospores observed in 40 microscopic fields at 100× magnification following a 1-hr discharge test, using the methods of Szkolnik (19).

throughout the Lake Ontario fruit district, one of which was located within 0.5–5 km of each test orchard except orchard H, which was 10 km distant. Each year, the development of primary inoculum was monitored on a weekly basis by examining the contents of 20 crushed pseudothecia of *V. inaequalis* (5,19) obtained from apple leaves in an unsprayed orchard at Geneva, New York, and the potential for primary infection was considered to have ended once such assessments indicated that >90% of the asci within these pseudothecia had discharged their ascospores (Table 1). After primary inoculum was depleted, secondary infection periods were determined, using a criterion of subtracting 3 hr from the number of hours of leaf wetness presumed by Mills to be required for light primary infection (13). Weather data for these periods were available from only one (1989) and two (1988 and 1990) different stations and are potentially less accurate for some individual orchards than primary infection data; however, they are presented to indicate the relative environmental potential for secondary disease development in each season.

RESULTS

1988 season. The early growing season was cool and dry, and with the exception of orchard G, the first apple scab infection period did not occur until approximately 3 wk after budbreak (i.e., 5–9 days prior to the first fungicide spray) (Table 2, Fig. 1). On average, only slightly more than four additional primary apple scab infection periods occurred throughout the remainder of the season, principally during a 5- to 6-day period near full bloom in mid-May (Fig. 1). Because this intense weather system arrived about 10 days before the anticipated date of the petal fall spray, some growers chose to apply their third DMI spray during an intervening dry period rather than wait for petal fall. Nevertheless, the 11 growers participating in the trial applied an average of only 4.1 fungicide sprays for control of primary scab. Among the four growers from whom comparison block records were available, three applied two fewer sprays in their test block than in their standard program, whereas one applied the same number in both (Table 2). With the exception of the final primary infection period in mid-June, the weather was very dry for 7–8 wk after bloom, limiting the potential for secondary disease development (Fig. 1).

Apple scab control was very good to excellent in all orchards, with a mean incidence at harvest of only 0.3 and 0.2% on terminal leaves and fruit, respectively. There was no difference in control between growers who applied their third spray during bloom, 6–10 days after the pink spray, and those who applied it at petal fall or beyond, 14–24 days after the pink spray; similarly, there was no difference in control among growers who made three, four, or five fungicide applications during the period of primary disease development (Table 2).

1989 season. In contrast to 1988, the spring of 1989 was extremely wet, with 13–16 primary apple scab infection periods occurring throughout the region of the test orchards. Eleven of the 13 participating growers delayed their first fungicide spray until 20–27 days after budbreak (i.e., 9–15 days after the first infection period) (Table 3, Fig. 2). Rain was frequent during the bloom period; in orchard G, for example, two infection periods of moderate intensity and two additional infection periods of severe intensity occurred between the sprays applied on 31 May and 14 June, at the pink and petal fall stages, respectively (Fig. 2). Despite such conditions following the pink spray, nearly all growers delayed their next spray until petal fall, with an average interval of more than 13 days between these sprays. For the season, the mean number of fungicide sprays applied to control primary apple scab was 4.5, and the eight growers from whom comparison block records were available applied an average of 2.4 fewer sprays in their test block than under their standard program (Table 4). Approximately 10 secondary infection periods occurred after primary inoculum was exhausted, although a 4-wk dry period from late June to late July may have limited the potential for secondary

Table 2. Number of fungicide applications, infection periods, and disease incidence in 11 commercial orchards using an integrated, reduced-spray program for control of apple scab in 1988

		Primary infection period				Remainder of season		Apple scab (%)			
				Spray interval (days)				Terminal leaves[e]		Fruit[f]	
Orchard	Cultivar	Infection periods[a]	Fungicide sprays	Green tip to first spray[b]	Pink to next spray[c]	Infection periods[d]	Fungicide sprays	June	Sept.	June	Sept.
A	Idared	5	4	26 (6)	14	9	2	0.0	0.0	0.0	0.1
C	McIntosh	5	4	28 (8)	15	9	1	0.0	0.1	0.0	0.9
D	Cortland	5	5 (−2)[g]	25 (5)	8	9	4	0.0	0.2	0.0	0.2
F	McIntosh	6	5[h]	17[h] (0)	6	6	1	0.3	0.0	0.0	0.0
G	Cortland	7	4 (−2)	30 (30)	7	6	1	0.0	1.3	0.0	0.0
H	20-Ounce	4	4	29 (9)	16	9	1	0.0	0.0	0.0	0.2
I	Spartan	5	4	25 (5)	10	9	2	0.0	0.0	0.0	0.0
J	Red Delicious	6	4	27 (3)	8	6	1	0.0	1.3	0.0	0.0
L	McIntosh	6	4 (0)	23 (0)	7	6	2	0.0	0.0	0.0	0.0
M	McIntosh	5	4[i]	21 (1)	10	9	0	0.3	0.4	0.0	0.5
N	McIntosh	5	3 (−2)	27 (7)	24	9	3	0.0	0.0	0.0	0.0
Mean		5.3	4.1 (−1.5)	25.3 (6.7)	11.4	...	1.6	0.05	0.3	0.0	0.2
Range		4–7	3–5 (0 to −2)	17–30 (0–30)	7–24	...	0–4	0–0.3	0–1.3	none	0–0.9

[a] Number of primary apple scab infection periods determined from weather data collected within 0.5–10 km of each orchard, using the criteria of Mills (14).
[b] Number of days elapsed from green tip until the first fungicide application. Values in parentheses denote the number of days elapsed from the start of the first infection period until the first fungicide application; a value of zero is given if the first fungicide application preceded the first infection period.
[c] Number of days elapsed between the fungicide application at pink bud and the subsequent fungicide application.
[d] Number of secondary apple scab infection periods determined from regional weather data, using the criterion that secondary infection requires three fewer hours of leaf wetness than that proposed by Mills for primary infection (13). Secondary infection periods were not determined until >90% of primary inoculum was assessed to have been discharged at Geneva, New York.
[e] Mean disease incidence determined for all leaves on 10 terminal shoots on each of five replicate trees per orchard.
[f] Mean disease incidence determined on 100 (June) and 200 (Sept.) fruit on each of five replicate trees per orchard.
[g] Number in parentheses refers to the difference in the number of sprays applied for control of primary apple scab in the test block relative to a comparison block of the same cultivar managed by the same grower on another part of the farm in the same year.
[h] Includes one application of copper hydroxide when 0.5–1.0 cm of green tissue had emerged from fruit buds.
[i] Alternate-row-middle application technique. Value given refers to the number of sprays applied directly to any given row.

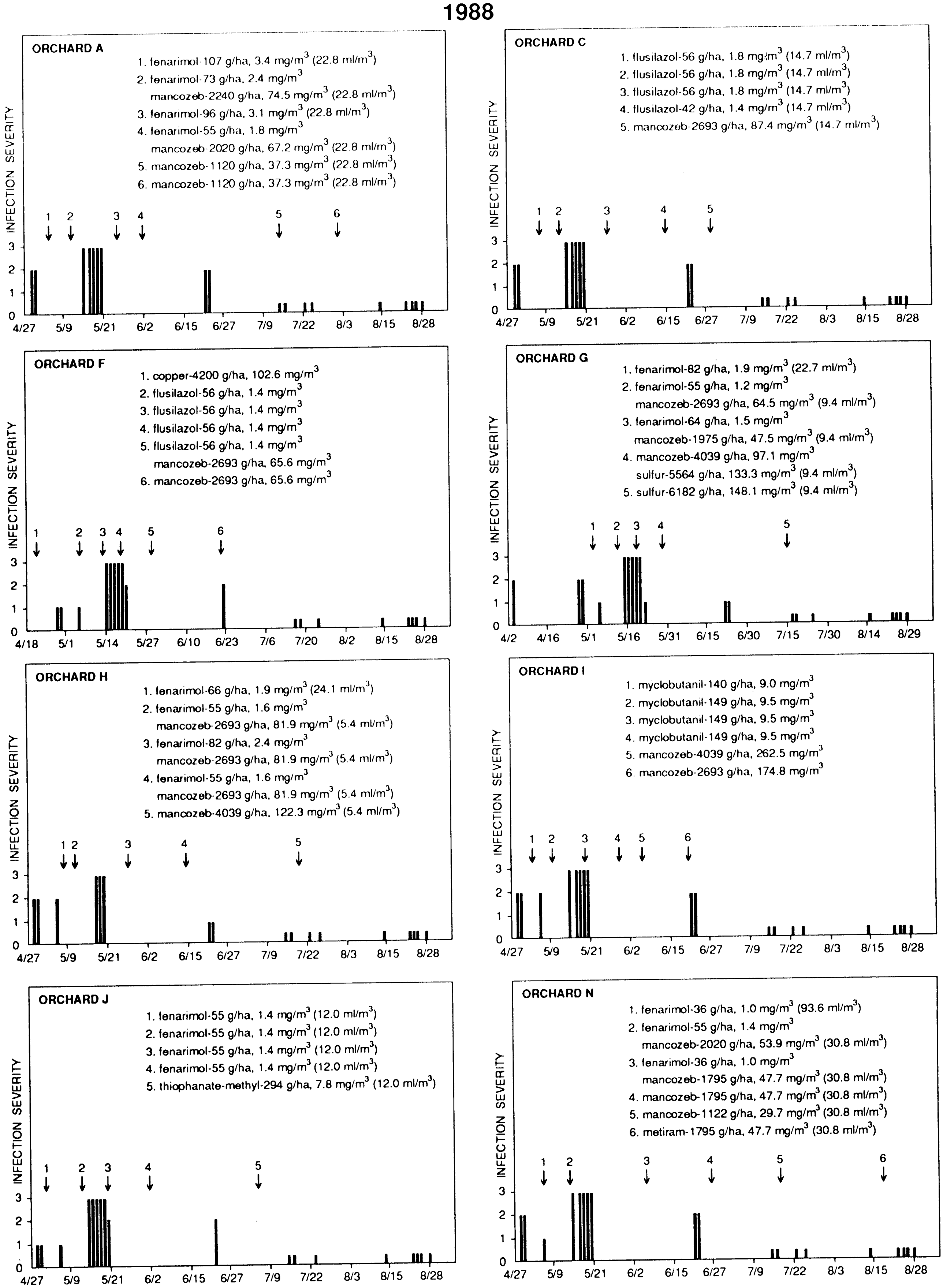

Fig. 1. Dates of fungicide applications and apple scab infection periods in eight representative trial orchards in 1988. Light, moderate, and severe primary infection periods (14) are designated by vertical bars denoting infection severities of 1, 2, and 3, respectively, on the accompanying scale; secondary infection periods that occurred after primary inoculum was depleted are designated by bars denoting an infection severity of 0.5. Arrows denote timings of fungicide applications. Corresponding numbers list each fungicide active ingredient applied at that time and its rate in g/ha and mg/m^3 of tree canopy volume; the volume of water in which fungicides were applied (ml/m^3 of tree canopy volume) is also given when known.

inoculum production.

Regardless of whether four or five fungicide sprays were applied during the period of primary disease development, control of leaf scab was excellent and control of fruit scab was good to excellent in 12 of the 13 orchards, with mean incidences of 0.03 and 0.5% at harvest, respectively. However, the incidence of fruit scab was 7.4% at harvest in orchard J (Table 3), in which the grower applied five sprays of fenarimol for control of primary scab (three with no companion fungicide, two in combination with thiophanate-methyl) and no fungicides for the remainder of the season; because of a large canopy volume (3.8×10^4 m^3/ha), the fenarimol rate in all sprays was only 1.4 mg/m^3 of canopy (Fig. 2). Comparisons of fruit scab incidence in July and September suggest that secondary infections accounted for over half of the total incidence at harvest in this orchard (Table 3). The benzimidazole sensitivity of isolates of *V. inaequalis* within this orchard was not determined.

1990 season. The first infection period of the season occurred at the green-tip stage of development in all orchards, and the second approximately 10 days later. Three growers applied fixed copper sprays (primarily for control of fire blight) between these two events, but the remaining 10 growers delayed their first fungicide spray until 14–27 days after budbreak (i.e., 14–26 and 4–16 days after the first and second infection periods, respectively) (Fig. 3). For the third consecutive year, rain was frequent during the bloom period, but growers waited an average of 11.5 days after the pink spray until their next fungicide application, and seven of the 13 growers waited ≥14 days. For instance, myclobutanil was applied at the pink stage in orchard C on 8 May, followed by an infection period of moderate intensity on 13–14 May, a severe infection period 16–17 May, and another severe infection period 19–21 May, before the next application of myclobutanil was made at petal fall on 22 May (Fig. 3). A total of eight or nine primary infection periods occurred in the test orchards, and growers applied an average of 4.5 fungicide sprays for their control (4.2 sprays, omitting early-season copper applications). Ten additional secondary infection periods occurred from late June through late August, seven during the first month of that time span (Fig. 3).

Control of leaf and fruit scab was good to excellent in 12 of the 13 orchards, with mean incidences of 0.07 and 0.4% at harvest, respectively. In contrast, the incidence of fruit scab was 16.4% at harvest in orchard H (Table 4). In this orchard, the grower applied one spray of copper shortly after budbreak and four sprays of myclobutanil (one in combination with captan) during the period of primary scab development; however, the last three of these sprays delivered only 6.7 ml of spray solution per m^3 of canopy volume, about 7% of that required for full dilute coverage. One additional spray of sulfur was applied during the early summer (Fig. 3). At harvest, it was noted that most infections were confined to leaves and fruit near the top and center of the trees, although differences among locations within a tree were not quantified. Comparisons of fruit scab ratings in July and September suggest that secondary spread accounted for the majority of fruit infections in this orchard at harvest (Table 4).

When fungicide usage rates were compared in each year of the trial, it was apparent that the rate applied per hectare varied less among growers than did the rate per m^3 of canopy volume, suggesting that growers generally chose not to adjust the per hectare rates to account for varying tree sizes. For instance, in 1989, flusilazol was applied in orchards G, M, and N at the same area-basis rate of 56 g/ha but at volumetric rates ranging from 1.4–2.1 mg/m^3 (Fig. 2). Similarly, myclobutanil was applied at the same area-basis rate of 140 g/ha in six

Table 3. Number of fungicide applications, infection periods, and disease incidence in 11 commercial orchards using an integrated, reduced-spray program for control of apple scab in 1989

		Primary infection period				Remainder of season		Apple scab (%)			
				Spray interval (days)				Terminal leaves[e]		Fruit[f]	
Orchard	Cultivar	Infection periods[a]	Fungicide sprays	Green tip to first spray[b]	Pink to next spray[c]	Infection periods[d]	Fungicide sprays	July	Sept.	July	Sept.
A	Idared	14	5[g] (−2)[h]	10[g] (0)	10	9	3	0.0	0.0	0.0	0.0
B	Monroe	14	4 (−2)	26 (14)	13	9	1	0.0	0.0	0.0	0.4
C	McIntosh	14	5 (−2)	27 (15)	13	9	1	0.0	0.1	1.0	1.6
D	Cortland	13	4 (−2)	22 (10)	13	9	4	0.0	0.0	0.0	0.2
E	Idared	15	5	20 (10)	17	9	3	0.0	0.1	0.0	1.0
F	McIntosh	15	4	20 (10)	14	9	1	0.2	0.0	0.0	1.8
G	Cortland	16	4	21 (10)	14	9	1	0.1	0.0	0.0	0.0
I	Spartan	13	4 (−4)	26 (14)	12	9	1	0.0	0.0	0.0	0.0
J	Red Delicious	15	5	21 (10)	10	9	0	0.3	0.5	3.0	7.4
K	Rome Beauty	15	4	25 (14)	23	9	1	0.0	0.0	0.0	0.2
L	McIntosh	15	5 (−1)	13 (2)	10	9	0	0.0	0.0	0.0	0.0
M	McIntosh	15	5 (−3)	26 (9)	13	9	0	0.2	0.0	0.0	0.2
N	McIntosh	13	4 (−3)	27 (15)	9	9	2	0.0	0.2	0.0	0.2
Mean (all)		14.4	4.5 (−2.4)	21.8 (10.2)	13.2	9	1.4	0.06	0.07	0.3	1.0
Mean (J omitted)		14.3	4.4 (−2.4)	21.5 (9.9)	13.4	9	1.5	0.04	0.03	0.08	0.5
Range		13–16	4–5	10–27	9–23	none	0–4	0.0–0.3	0.0–0.5	0.0–3.0	0.0–7.4

[a] Number of primary apple scab infection periods determined from weather data collected within 0.5–10 km of each orchard, using the criteria of Mills (14).

[b] Number of days elapsed from green tip until the first fungicide application. Values in parentheses denote the number of days elapsed from the start of the first infection period until the first fungicide application; a value of zero is given if the first fungicide application preceded the first infection period.

[c] Number of days elapsed between the fungicide application at pink bud and the subsequent fungicide application.

[d] Number of secondary apple scab infection periods determined from regional weather data, using the criterion that secondary infection requires three fewer hours of leaf wetness than that proposed by Mills for primary infection (13). Secondary infection periods were not determined until >90% of primary inoculum was assessed to have been discharged at Geneva, New York.

[e] Mean disease incidence determined for all leaves on 10 terminal shoots on each of five replicate trees per orchard.

[f] Mean disease incidence determined on 100 fruit on each of five replicate trees per orchard.

[g] Includes one application of copper hydroxide when 0.5–1.0 cm of green tissue had emerged from fruit buds.

[h] Number in parentheses refers to the difference in the number of sprays applied for control of primary apple scab in the test block relative to a comparison block of the same cultivar managed by the same grower on another part of the farm in the same year.

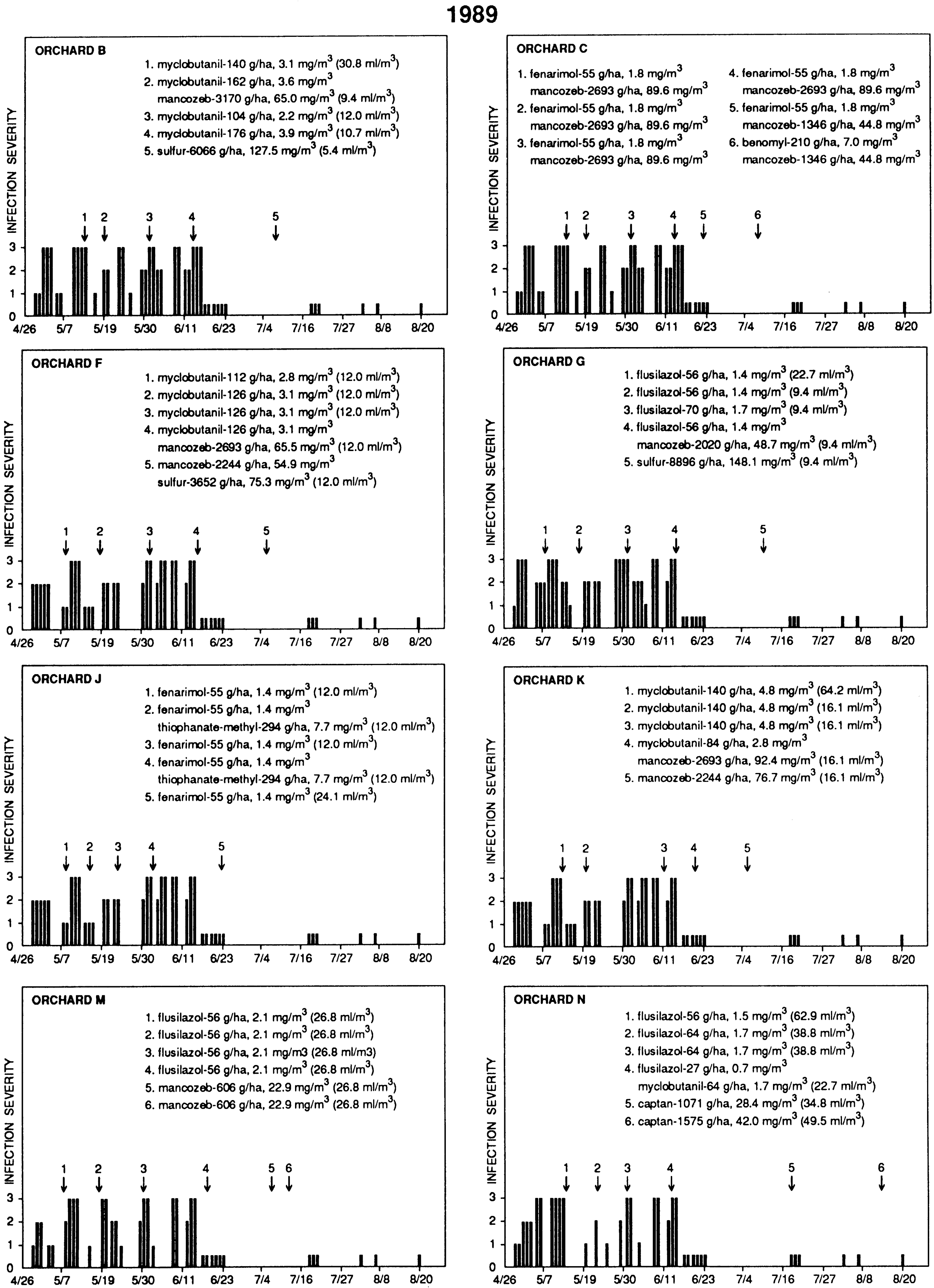

Fig. 2. Dates of fungicide applications and apple scab infection periods in eight representative trial orchards in 1989. Light, moderate, and severe primary infection periods (14) are designated by vertical bars denoting infection severities of 1, 2, and 3, respectively, on the accompanying scale; secondary infection periods that occurred after primary inoculum was depleted are designated by bars denoting an infection severity of 0.5. Arrows denote timings of fungicide applications. Corresponding numbers list each fungicide active ingredient applied at that time and its rate in g/ha and mg/m^3 of tree canopy volume; the volume of water in which fungicides were applied (ml/m^3 of tree canopy volume) is also given when known.

orchards in 1990, but because of different tree sizes, this rate converted to a range of 3.1–4.8 mg/m^3 of canopy volume in the same orchards (Fig. 3).

DISCUSSION

This report presents the evaluation of a program designed to minimize the number of fungicide sprays needed to control primary apple scab in western New York and provide suitable flexibility in their timing to allow fungicide applications only when insecticide and acaricide sprays are normally required in this region. Because it is an evaluation of an experimental program implemented by commercial apple growers, the report also illustrates the variations likely to occur when different growers adapt a suggested protocol to their own individual orchards and management styles. Nevertheless, we believe that the program has been tested successfully under a wide range of environmental and managerial conditions, and that the generally positive results obtained confirm its flexibility and robustness to protocol. However, the poor control obtained by one out of 13 growers in both 1989 and 1990 also illustrates its limitations.

Although our program is a modification of that proposed by Gadoury et al (7), the two differ in several noteworthy respects. For instance, the former program 1) strives to delay the first fungicide spray until the pink stage of blossom bud development, a practice based upon a precise formula that accounts for the incidence and severity of foliar scab the previous autumn and for the density of leaf litter in the orchard prior to budbreak (6); 2) assumes that the pink stage of blossom bud development is usually reached about 20 days after budbreak; 3) delays the second fungicide application until petal fall; and 4) suggests the use of postharvest eradicant fungicides, if necessary, to reduce primary inoculum to low levels the following spring (7). In contrast, our program incorporates a largely qualitative assessment of inoculum potential, utilizing the basic principle that fungicide applications can be delayed beyond budbreak in well-managed orchards with low seasonal levels of primary inoculum (6); however, it also relies on the recognition that only a very low frequency of the season's supply of ascospores is discharged during the first few weeks following budbreak (Table 1) (8,19). Furthermore, our program provides for three fungicide applications through petal fall, since it delays the first application only until tight cluster. This stage was not reached until more than 20 days after budbreak in 2 of the 3 yr of our trial, and most growers in western New York must anyway begin their spray programs (oil for control of mites) by TC. Finally, our program does not consider a postharvest eradicant treatment.

Central to our program is a reliance on the extended postinfection and presymptom activities (20) of the DMI fungicides and the concept that these activities are significantly enhanced when a specific fungicide application is followed about 1 wk later by a second (15). We have assumed that when thus applied, such enhancements provide control of incubating infections well beyond 96 hr following the start of an infection period, which is the maximum duration of postinfection activity suggested on United States labels for fenarimol and myclobutanil. Specifically, it was hypothesized that the extended postinfection and presymptom activities from the TC + P applications would prevent lesion development or suppress sporulation from the relatively few infections that might be initiated between budbreak and the start of the fungicide program, whereas the same activities following the PF + 1C applications would control infections that may be initiated during the long interval between the P and PF sprays. The good to excellent control obtained in almost all orchards following significant infection periods well before the first fungicide application in 1989 and 1990 and numerous extended infection periods between P and PF in all 3 yr of the trial supports this hypothesis. It

Table 4. Number of fungicide applications, infection periods, and disease incidence in 11 commercial orchards using an integrated, reduced-spray program for control of apple scab in 1990

		Primary infection period				Remainder of season		Apple scab (%)			
				Spray interval (days)				Terminal leaves[e]		Fruit[f]	
Orchard	Cultivar	Infection periods[a]	Fungicide sprays	Green tip to first spray[b]	Pink to next spray[c]	Infection periods[d]	Fungicide sprays	July	Oct.	July	Sept.
A	Idared	8	4	18 (17)	12	10	3	0.0	0.0	0.0	0.0
B	Monroe	8	3	27 (26)	15	10	0	0.0	0.0	0.0	1.4
C	McIntosh	8	4	19 (18)	14	10	1	0.0	0.0	0.0	0.0
D	Cortland	8	5[g]	13[g] (10)	9	10	3	0.2	0.0	0.0	0.4
E	Idared	8	6[g]	11[g] (11)	9	10	3	0.0	0.0	0.4	0.2
F	McIntosh	8	4	19 (19)	14	10	2	0.4	0.4	0.0	0.8
G	Cortland	9	5	21 (16)	14	10	2	0.0	0.9	0.0	0.6
H	Monroe	9	5[g]	9[g] (9)	10	10	1	0.4	2.0	1.2	16.4
I	Spartan	8	5	20 (20)	12	10	1	0.0	0.0	0.0	0.0
J	Red Delicious	8	5	14 (14)	14	10	2	0.2	0.2	0.0	0.6
K	Rome Beauty	8	4	17 (17)	15	10	2	0.0	1.7	0.0	0.6
L	McIntosh	8	4	14 (14)	17	10	4	0.0	0.1	0.0	0.0
M	McIntosh	8	4.5[h]	19 (18)	8	10	3[g]	0.0	1.5	0.4	0.4
Mean (all)		8.2	4.5	17.0 (16.2)	11.5	10.0	2.1	0.09	0.5	0.15	1.6
Mean (H omitted)		8.1	4.5	17.7 (16.8)	11.6	10.0	2.2	0.07	0.4	0.07	0.4
Range		8–9	3–6	9–27 (9–26)	8–17	none	0–4	0.0–0.4	0.0–2.0	0.0–1.2	0.0–16.4

[a] Number of primary apple scab infection periods determined from weather data collected within 0.5–10 km of each orchard, using the criteria of Mills (14).

[b] Number of days elapsed from green tip until the first fungicide application. Values in parentheses denote the number of days elapsed from the start of the first infection period until the first fungicide application.

[c] Number of days elapsed between the fungicide application at pink bud and the subsequent fungicide application.

[d] Number of secondary apple scab infection periods determined from regional weather data, using the criterion that secondary infection requires three fewer hours of leaf wetness than that proposed by Mills for primary infection (13). Secondary infection periods were not determined until >90% of primary inoculum was assessed to have been discharged at Geneva, New York.

[e] Mean disease incidence determined for all leaves on 10 terminal shoots on each of five replicate trees per orchard.

[f] Mean disease incidence determined on 100 fruit on each of five replicate trees per orchard.

[g] Included one application of copper hydroxide when 0.5–1.0 cm of green tissue had emerged from fruit buds.

[h] Alternate-row-middle application technique. Value given refers to the number of sprays applied directly to any given row. Fractional value indicates that final spray was applied to alternate rows without subsequent application to remaining rows.

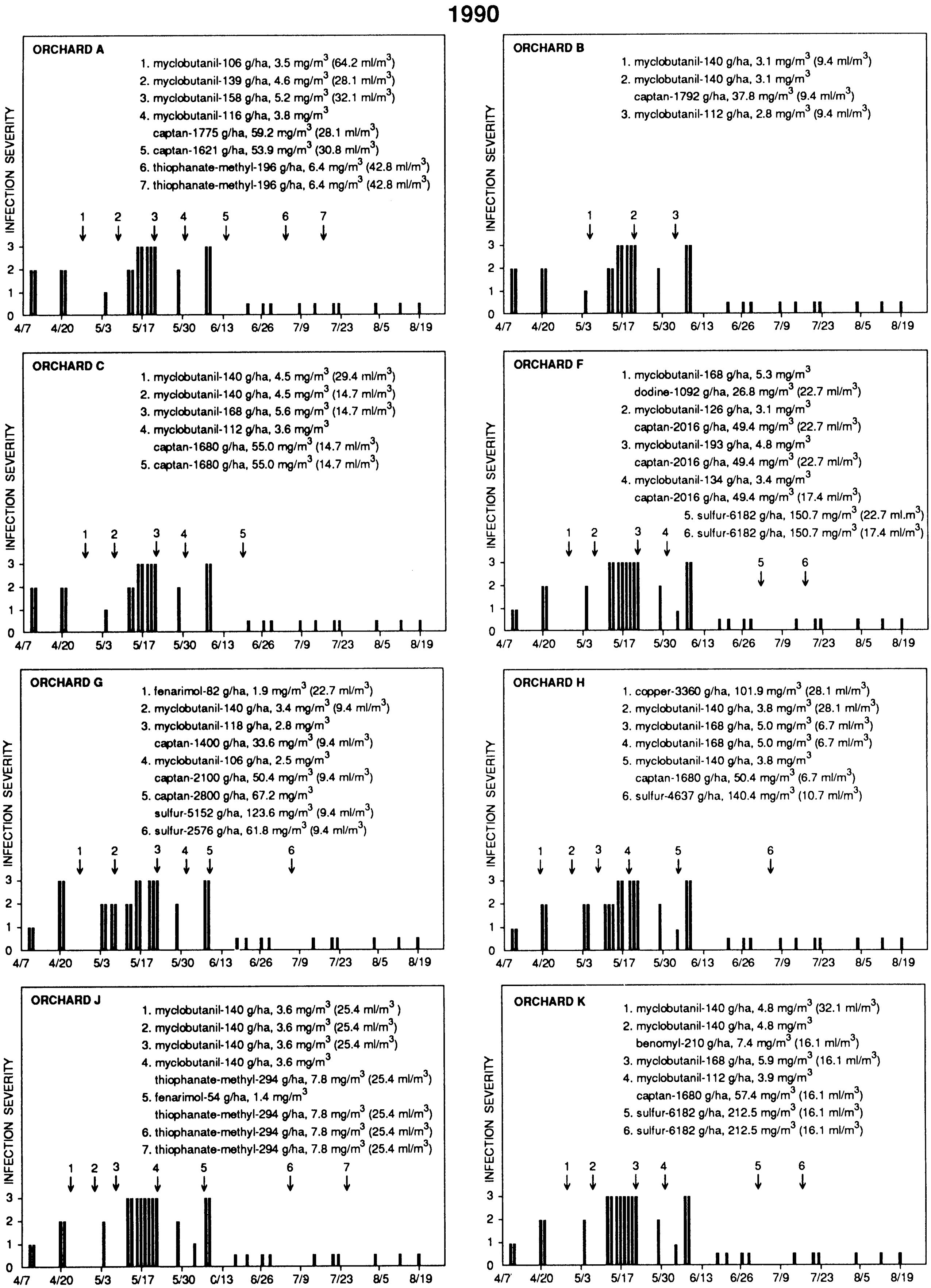

Fig. 3. Dates of fungicide applications and apple scab infection periods in eight representative trial orchards in 1990. Light, moderate, and severe primary infection periods (14) are designated by vertical bars denoting infection severities of 1, 2, and 3, respectively, on the accompanying scale; secondary infection periods that occurred after primary inoculum was determined to have been depleted are designated by bars denoting an infection severity of 0.5. Arrows denote timings of fungicide applications. Corresponding numbers list each fungicide active ingredient applied at that time and its rate in g/ha and mg/m^3 of tree canopy volume; the volume of water in which fungicides were applied (ml/m^3 of tree canopy volume) is also given when known.

is also assumed that the protectant activities of the DMIs themselves (17,21) and of the contact fungicides that were sometimes applied in concert with them contributed to the levels of control achieved (20,21), but the magnitude of these contributions cannot be determined.

Recently, the development of pathogen resistance and various legal and commercial restrictions have markedly decreased the number of fungicides previously available in the United States for control of apple scab. These developments have greatly increased the importance of the DMI fungicides for apple pest management programs in many regions and have emphasized the need to adopt fungicide-use patterns that minimize the risk of selecting pathogen populations resistant to these materials. The inherent risk of selecting subpopulations of *V. inaequalis* highly resistant to the DMI fungicides apparently is not of the same magnitude as it is for the benzimidazoles, yet the potential exists that a "directional" shift towards a reduced mean population sensitivity can occur after sufficient exposure of the pathogen to the DMIs (10,12). Although mixing a broad-spectrum contact fungicide (e.g., captan, mancozeb) with a DMI has been recommended to reduce the risk of selecting isolates of *V. inaequalis* resistant to these materials (16), economic considerations usually cause growers or advisors to rely upon relatively low rates of both fungicides in such mixtures. However, the frequency of the population of *V. inaequalis* that is sensitive to a DMI fungicide is directly proportional to the concentration of that material (11,12,18), and a low rate of a contact fungicide may not provide control of isolates insensitive to a correspondingly low rate of a DMI, particularly when extended spray intervals are employed. Therefore, we view any DMI application as a potential selection event, and our primary antiresistance strategy is to minimize pathogen exposure to these materials by limiting their use to four applications in a discrete block of time during which fungicidal activity can be maximized (i.e., TC-1C). Thus, we have based our consideration of whether or not to mix a contact fungicide with the DMI solely upon 1) the efficacy of the DMI itself (e.g., when applied without a contact fungicide, flusilazol and myclobutanil have more protective activity and generally provide better control of apple scab than does fenarimol [21], especially on fruit [23]); 2) the need to control other pathogens that may be active during the period of DMI use, but against which these fungicides have little activity; and 3) the need to extend the period of protectant activity following the last DMI application, particularly with respect to fruit infections.

Although our program has proved to be simple and effective, we recognize its current limitations. Chief among structural limitations is the reliance upon a largely subjective determination of primary inoculum potential. Whereas most commercial orchards in western New York would meet our criterion for participation in the program (estimated incidence of fruit scab $<$1-2% the previous year), this standard is arbitrary and merely suggests the relative magnitude of the potential ascospore dose (6) in the orchard for the current season. Although it also may be overly restrictive, the high incidence of scab that developed when this program was tested in two high-inoculum experiment station orchards in 1989 and 1990 (22,23) affirms that it should be avoided when primary inoculum potentials are above an as yet undetermined threshold.

Furthermore, although the combination of protectant, postinfection, and presymptom activities of the DMI fungicides apparently provides considerable flexibility in the timing of their application, disease control with these locally systemic materials appears to be much more dependent on thorough spray coverage than is control with traditional contact fungicides, whose surface residues are redistributed well to unsprayed tissues by rainfall (20). In our experience, both in orchard H during 1990 and in other area orchards not involved in these trials, suboptimal control of apple scab by the DMIs has usually been associated with poor application conditions or other factors suggesting poor spray coverage (unpruned or very tall trees, highly concentrated sprays delivering $<$15 ml of spray solution per m^3 of canopy volume). Finally, the degree to and precise manner by which use rates of individual DMIs should be adjusted to account for varying tree sizes is still unclear. It is likely that further research on the basic properties of the DMI fungicides and additional experience under commercial orchard conditions will suggest ways of refining our program or adapting it for other apple-growing regions.

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