Evaluating a Wetness-based Warning System and Reduced-risk Fungicides to Manage Sooty Blotch and Flyspeck of Apple

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Summary. **The effectiveness of a disease-warning system and efficacy of reduced-risk fungicides for management of sooty blotch (*Peltaster fructicola*, *Leptodontium elatius*, *Geastrumia polystigmatis*) and flyspeck (*Schizothyrium pomi*) (SBFS) of apple (*Malus* ×*domestica*) were evaluated in Illinois, Iowa, and Wisconsin in 2001 and 2002. Warning system-timed applications of the second-cover fungicide spray occurred when 175 h of leaf wetness had accumulated; wetness data were derived either from a sensor placed beneath the canopy of apple trees (on-site) or according to remotely sensed estimates. In replicated experiments, using sensor measurements as inputs to the warning system saved one to three (mean 1.8) and zero to four (mean 2.3) fungicide sprays per season in 2001 and 2002, respectively. Because remotely estimated wetness hours accumulated more rapidly than did on-site measurements, the warning system using remotely sensed wetness data saved**

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only zero to one (mean 0.3) and zero to two (mean 0.7) sprays per season in 2001 and 2002, respectively. SBFS incidence in the integrated pest management (IPM) plots did not differ significantly from that of conventional calendar-based fungicide sprays plots in 11 of 12 site-years. When on-site wetness measurements were used in demonstration trials at 14 cooperating commercial orchards in 2001 and 2002, the SBFS warning system saved one to six (mean 2.6) and two to seven (mean 3.1) sprays per season, respectively. Incidence of SBFS in IPM plots did not differ significantly from trees managed with cooperating growers' conventional fungicide schedules in 16 of 28 site-years. The on-site warning system was more consistently successful in Illinois and Iowa than it was in Wisconsin in both replicated experiments and in cooperating commercial orchards. The reduced-risk fungicides kresoxim-methyl and trifloxystrobin provided control of SBFS equal to conventional fungicides (benomyl or thiophanate-methyl) in all trials. Potassium bicarbonate controlled SBFS less effectively than either conventional fungicides on a calendar-based or disease-warning schedule, or treatments incorporating reduced-risk fungicides.

Sooty blotch (SB) of apple is a disease complex caused by the fungi *Peltaster fructicola* Johnson, *Leptodontium elatius* (G. Mangenot) De Hoog, *Geastrumia polystigmatis* Balista & M.L. Farr, and other fungi (Johnson et al., 1996; Williamson and Sutton, 2000). Flyspeck (FS) is caused by the fungus *Schizothyrium pomi* (Mont. & Fr.) Arx. (anamorph: *Zygophiala jamaicensis* E. Mason) (Williamson and Sutton, 2000). SB and FS are the most common summer diseases of apple (*Malus* ×*domestica* Borkh) in the midwestern United States (Bessin et al., 1998) and commonly occur together on apple fruit (Williamson and Sutton, 2000). The fungi blemish the fruit cuticle, which can result in up to 100% of the crop being unmarketable as fresh fruit and increase desiccation of fruit during storage (Rosenberger, 1994).

Most growers in the midwestern U.S. apply three to eight calendar-based protectant fungicide sprays per season to control SBFS (Weinzierl et al., 2002). The application of conventional fungicides on a calendar-based spray schedule is unsustainable for several reasons. First, the Food Quality Protection Act (FQPA) restrictions may impact disease management most critically during the mid- to late-season period, when SBFS is active. Pesticides applied during this period are more likely to leave residue on apples at harvest than early season sprays. As a result, older fungicides [i.e., ethylene bisdithiocarbamates (EBDCs)] that have been the mainstay of SBFS management are at higher risk of being restricted or banned, as they come up for periodic review under FQPA (Williamson and Sutton, 2000). Second, severe economic pressures are forcing apple growers to cut pest control costs (Gleason et al., 1994). A fungicide program for control of summer diseases of apple has a cost of about $15 to $25/acre ($37.06 to $61.77/ha) per spray (Gleason et al., 1994). Third, many broad-spectrum fungicides are acutely toxic to nontarget organisms (Cooley et al., 1995). Fourth, resistance development has reduced the efficacy of benzimidazole fungicides, which are commonly used to control summer diseases of apple (Cooley et al., 1995). Several alternative tactics that reduce pesticide use have been proposed, but these strategies will be adopted only if they provide acceptable fruit yield and quality (Cooley and Autio, 1997).

The incidence and severity of SB and FS are dependent on moisture conditions in the orchard. Kirby (1954) reported that the amount of SB in Pennsylvania in a given year was proportional to the amount of rainfall occurring in July and, to a lesser extent, in August and September. Hickey (1960) reported that SB symptoms appeared after 8 to 12 d on inoculated mature fruit in a moist chamber, but appeared after 20 to 24 d in the field where moisture levels fluctuated. Brown and Sutton (1995) reported that symptoms of SB and FS in North Carolina appeared after 273 leaf wetness hours (LWH) (counting only of wetness periods of ≥4 h) had accumulated following the first-cover spray (applied 10 d after petal fall). They suggested a threshold value of 200 to 250 accumulated LWH after the first-cover spray before the initiation of subsequent calendar-based fungicide sprays for control of SBFS. In Kentucky, Hartman (1995) and Smigell and Hartman (1997) applied a second-cover spray after 175 LWH had accumulated following the first-cover spray, and reported that this strategy was as effective as calendar-based timing of the second-cover spray for SBFS control. In addition, two to four fungicide applications were saved. The LWH used in disease-warning systems in North Carolina and Kentucky were measured with sensors placed 5 ft (1.5 m) high within the apple canopy.

Although on-site sensors are accurate, they can be labor-intensive and prone to mechanical failure. Recent commercialization of site-specific weather simulation (e.g., SkyBit, Inc., Bellefonte, Pa.) has potential to make disease-warning systems easier to use (Gleason et al., 1997, 2000; Russo, 2000; Russo et al., 1996). Geographical information system programs estimate weather variables to within an area of 0.4 mile^2 (1 km^2), and deliver these data daily to the end user by electronic mail or fax at a low cost. A critical step in implementing this new technology in disease-warning systems is to validate it in field trials.

Reduced-risk strobilurin fungicides, which pose relatively low hazard to humans and the environment, are an alternative to conventional fungicides currently used for SBFS management. The strobilurin fungicides have been used to effectively control SBFS in New York and North Carolina (Rosenberger et al., 2000; Sutton et al., 2000). In addition, potassium bicarbonate fungicides, which are approved for use by organic growers, have been used effectively to control several plant diseases (Bervejilo et al., 2000; Lunden and Grove, 2002). Potassium bicarbonate provided effective control of SBFS in preliminary field trials in Wisconsin (Andrews et al., 2001).

This study was conducted to evaluate the efficacy of a wetness-based disease-warning system and reduced-risk fungicides for management of SBFS in Illinois, Iowa, and Wisconsin. Also, LWH derived from sensors in apple-tree canopies was compared with LWH estimates derived from remotely sensed, site-specific (SkyBit, Inc.) data. A preliminary report of this study has been published (Gleason et al., 2002).

Materials and methods

REPLICATED EXPERIMENTS. Field trials were conducted in 2001 and 2002 at three locations: University of Illinois Pomology Research Farm in Urbana, Ill.; Iowa State University Horticulture Station in Ames, Iowa; and Oakwood Fruit Farm in Richland Center, Wis. The experimental unit in Iowa was a two-tree block in a mixed orchard of 'McIntosh', 'Red Delicious', 'Golden Delicious', and 'Jonathan' trees. In Illinois and Wisconsin, the experimental units were two-tree blocks of 'Golden Delicious' and 'Redcort', respectively.

In 2001, the experimental design was a randomized complete block with four replications (two trees each) of seven treatments. In all treatments, trees were sprayed with fungicides through the first-cover spray to control scab, rust, and powdery mildew. Trees were sprayed with 150 gal of water per acre (1406.7 L.ha^{-1}), without any wetting agent, using handgun sprayers. In four treatments, second-cover and later sprays were applied on a calendar-timed basis (about every 14 d). These included: conventional control of 2.2 oz/acre (154.1 g·ha^{-1}) a.i. benomyl [Benlate 50 WP (DuPont, Wilimington, Del.)] plus 12 oz/acre (840.6 g·ha^{-1}) a.i. captan [Captan 50 WP (Arvesta Corp., San Francisco, Calif.)]; 1.2 oz/acre (84.1 g·ha^{-1}) a.i. kresoxim-methyl [Sovran 50 WG (BASF Corp., Research Triangle Park, N.C.)] alternated every 14 d with benomyl plus captan; 1.2 oz/acre (84.1 g·ha^{-1}) a.i. trifloxystrobin [Flint 50 WG (Bayer Corp., Kansas City, Kans.)] alternated every 14 d with benomyl plus captan; and 2.5 lb/acre (2.8 kg·ha^{-1}) a.i. potassium bicarbonate [Kaligreen 82 WP (Toagosei Co., Tokyo)]. Two treatments based on warning systems were sprayed with benomyl plus captan at the first-cover spray. The second-cover spray was applied when about 175 LWH had accumulated according to the on-site sensor (of ≥4 h duration) or site-specific source (SkyBit, Inc.). On-site LWH were recorded in each orchard with Watchdog Leaf Wetness/Temperature Logger [WLWTL (Spectrum Technologies, Inc., Plainfield, Ill.)]. Starting with the second-cover spray, benomyl + captan were applied on a 14-d schedule for the reminder of the growing season, similar to other treatments. A nonsprayed control received no fungicides after the first-cover spray. In 2002, the reduced-risk strobilurin fungicides kresoxim-methyl was tested using the disease warning systems with both on-site and site-specific weather data. In addition, benomyl was replaced with thiophanate-methyl [Topsin-M 70 WSB (Cerexagri, Inc., King of Prussia, Pa.)] in the 2002 trial due to the impending withdrawal of registration of benomyl. Thiophanate-methyl was applied at the rate of 6.3 oz/acre (441.3 g·ha^{-1}) a.i.

About 2 weeks before harvest, apples were inspected independently for incidence (percent fruit infected) of SB and FS. In Iowa and Wisconsin, 50 apples selected arbitrarily on each tree (25 apples from the top half and 25 from the bottom half of the canopy) were inspected. In Illinois, 60 apples selected arbitrarily from each tree were inspected for incidence and rated for severity (percent surface area of fruit with SB or FS infection); five apples from the upper, middle, and lower canopies on each of the four sides (north, east, south, and west) of each tree were rated.

On-site wetness measurements. Hourly measurements of wetness were made from the time of the first-cover spray until accumulation of 175 LWH at all of the research sites. LWH were recorded in each orchard with the WLWTL. The WLWTL sensor measures the degree of leaf wetness on a scale from 0 (dry) to 15 (wet). An hour was considered wet when a value of ≥6 was recorded. One sensor was placed on the northern side of the canopy of one tree in each orchard about 5 ft above the ground facing north at an angle of 45° to horizontal. Data were downloaded to a computer at least once per week, and accumulated LWH were calculated.

Site-specific weather data. Site-specific estimates were provided by SkyBit, Inc. SkyBit processes data from the U.S. National Weather Service using computer programs based on a weather model called MASS (mesoscale atmospheric simulation system) (Kaplan et al., 1982). The MASS model simulates fine scale, near-surface weather data and provides a detailed representation of mesoscale phenomena. SkyBit delivered hourly estimates of leaf wetness (0 = dry, 1 = wet) for each experimental site daily by electronic mail.

Demonstration trials. The effectiveness of the on-site warning system for management of SBFS also was tested in demonstration trials at 14 cooperating commercial orchards in 2001 and 2002 (Table 4): in Illinois at Champaign, Peoria, Sidney, Sullivan, and Villa Grove; in Iowa at Cambridge, Ft. Dodge, Iowa Falls, Jefferson, and Nevada; and in Wisconsin at Cottage Grove, Fitchburg, Poynette, and Waunakee. The goal of these trials was to give growers experience with the disease-warning system and to refine and improve the system.

In each orchard, a block of eight to ten trees was used to evaluate the warning system (IPM block). One WLWTL was placed in each orchard as discussed in the field experiment. The second-cover spray (benomyl plus captan or thiophanate-methyl plus captan) was applied to the test block when 175 LWH had accumulated, whereas the rest of the orchard received the second-cover spray according to each grower's spray schedule (usually 14-d intervals). The IPM blocks received the normal spray program once the second cover-spray was initiated. At the end of the season in Iowa and Wisconsin, incidence of SB and FS were rated on 50 apples selected arbitrarily from each of the IPM trees and an equal number of trees from the same-cultivar that had received the conventional sprays. In Illinois, 60 apples selected arbitrarily from each tree were rated for incidence and severity of SB and FS using the same technique as previously described

Data analysis. In both years, data were analyzed using analysis of variance (ANOVA), general linear model (GLM), and correlation (CORR) procedures of SAS (SAS Institute, Cary, N.C.), and comparisons were made using Fisher's protected least significant difference (LSD). Although data were analyzed in the demonstration trials as though each tree was a replication, these replications were not randomized.

Results and discussion

Disease warning system. In Illinois and Iowa, use of the SBFS on-site warning system with benomyl or thiophanate-methyl plus captan saved one to four fungicide sprays compared to the conventional control calendar-based schedule (Table 1). There were no significant differences in incidence of SBFS between the two procedures (Tables 2 and 3). In 2002, using the on-site warning system with an alternation of kresoxim-methyl and thiophanate-methyl plus captan provided excellent control at all locations (Table 3). In Iowa, however, incidence of FS was significantly higher for the warning system treatment than the conventional treatment. The on-site SBFS disease warning system in Illinois and Iowa could save growers one or more sprays each year and is an effective IPM strategy for SBFS control.

In Wisconsin, using LWH measurements in the warning system saved three sprays over the conventional control in 2001 (Table 1), but apples from these trees had a significantly higher

Table 1. Hours of accumulated wetness, dates of sprays, and number of sprays saved using on-site or site-specific data in a sooty blotch/flyspeck/warning system in 2001 and 2002.[z]

State	1st Cover spray	2nd Cover spray (calendar[y])	2nd Cover spray (on-site[y])			2nd Cover spray (site-specific[y])		
			Date	LWH[x]	SS[w] (no.)	Date	LWH	SS (no.)
2001								
Illinois	17 May	1 June	22 June	178	1	5 June	248	0
Iowa	16 May	30 May	15 June	181	1	1 June	177	0
Wisconsin	28 May	11 June	24 July	169	3	25 June	233	1
2002								
Illinois	24 May	7 June	19 July	174	3	25 June	248	0
Iowa	23 May	6 June	13 Aug.	181	4	15 July	175	2
Wisconsin	12 June	26 June	27 June	199	0	27 June	220	0

[z]Trials were conducted at the University of Illinois Pomology Research Farm, Urbana; Iowa State University Horticulture Station, Ames; and Oakwood Fruit Farm, Richland Center, Wis.
[y]Second-cover spray timing was about 14 d after first-cover spray (calendar); based on leaf wetness data from Watchdog dataloggers placed in orchards (on-site); or based on leaf wetness data remotely estimated for the location of each orchard (site-specific) by SkyBit, Inc. (Bellefonte, Pa.).
[x]LWH = leaf wetness hours from the first-cover fungicide spray until application of the subsequent fungicide spray. Target threshold was 175 LWH.
[w]SS = sprays saved.

Table 2. Effect of reduced-risk fungicides and a disease warning system on the incidence and severity of sooty blotch (SB) and flyspeck (FS) of apple in replicated experiments in 2001.[z]

Treatment	Illinois[y] SB Incidence (%)	Illinois[y] SB Severity[v] (%)	Illinois[y] FS Incidence (%)	Illinois[y] FS Severity (%)	Wisconsin[x] SB Incidence (%)	Wisconsin[x] FS Incidence (%)	Iowa[x] SB/FS[w] Incidence (%)
Benomyl + captan (conventional)	0.8 a[u]	0.03 a	0.4 ab	0.01 a	0.3 a	2.3 a	0.0 a
Benomyl + captan (on-site[t])	0.8 a	0.02 a	0.1 ab	0.02 a	0.2 a	12.7 ab	0.0 a
Benomyl + captan (site-specific[t])	0.0 a	0.00 a	0.0 a	0.00 a	1.0 a	4.0 a	0.0 a
Kresoxim-methyl alternated with benomyl + captan	0.0 a	0.00 a	0.0 a	0.00 a	0.2 a	2.3 a	0.0 a
Trifloxystrobin alternated with benomyl + captan	0.0 a	0.00 a	0.2 ab	0.00 a	0.1 a	2.6 a	0.5 a
Potassium bicarbonate	1.0 a	0.03 a	1.5 b	0.01 a	2.3 a	27.8 b	7.7 a
Nontreated control	4.0 b	0.21 b	5.0 c	0.22 b	14.7 b	54.1 c	62.5 b
LSD ($P < 0.05$)	1.2	0.07	1.3	0.06	3.8	15.5	12.0

[z]Trials were conducted at the University of Illinois Pomology Research Farm, Urbana; Iowa State University Horticulture Station, Ames; and Oakwood Fruit Farm, Richland Center, Wis.
[y]Mean percent of four replications; 120 apples per replication.
[x]Mean percent of four replications; 100 apples per replication.
[w]Combined incidence of SB and FS was rated in Iowa in 2001.
[v]Severity = percent surface area of fruit with SB or FS infection.
[u]Values within each column with a letter in common are not significantly different according to Fisher's protected least significant difference ($P = 0.05$).
[t]Second-cover spray timing based on leaf wetness data from dataloggers placed in orchards (on-site) or based on leaf wetness data remotely estimated for the location of each orchard (site-specific) by SkyBit, Inc. (Bellefonte, Pa.).

incidence of FS than those from the control (Table 2). In 2002, neither the on-site nor the site-specific weather data saved sprays over the conventional control (Table 1). Possible explanations for the apparent failure of the warning system against FS in 2001 include greater susceptibility of Redcort to FS than cultivars tested in Illinois and Iowa, and poor spray coverage in these trees, and different strain of FS pathogen in Wisconsin than in Illinois and Iowa. Characterization of SB and FS isolates from orchards in Illinois, Iowa, and Wisconsin using sequence analysis of the internal transcribed spacer (ITS) region of rDNA suggested that the assemblages and relative abundance of SB and FS fungi varies considerably among the orchards (Batzer et al., 2002a). It is possible that the FS pathogen in the Wisconsin orchard has different leaf wetness requirements for apple colonization than those in Illinois and Iowa. Characterization of FS pathogen(s) in Wisconsin and adjustment of the disease warning system for these fungi may be necessary before this system can be used with confidence.

In all three states, use of the site-specific leaf wetness data in the disease-warning system resulted in acceptable control of SBFS but required more sprays than did use of on-site measurements. The difference between on-site and site-specific warning systems occurred because SkyBit, Inc. consistently overestimated LWH. The location of the apple tree canopy may account for part of this difference. In an Iowa orchard, the duration of the dew period, which is the primary source of wetness during summer in the Midwest, was much shorter at the base of the canopy of mature semi-dwarf apple trees than at the top of the canopy, due to the presence of overhanging foliage and fruit in the apple canopy (Batzer et al., 2002b). Remote estimates, while site-specific, do not account for this canopy effect. Therefore, such estimates would need to be calibrated in some manner in order to more accurately reflect leaf wetness conditions within apple tree canopies.

REDUCED-RISK FUNGICIDES. Calendar-based applications of the strobi-

Table 3. Effect of reduced-risk fungicides and a disease warning system on the incidence and severity of sooty blotch (SB) and flyspeck (FS) of apples in replicated experiments in 2002[z]

	Illinois[y]				Wisconsin[x]		Iowa[x]	
	SB		FS		SB	FS	SB	FS
Treatment	Incidence (%)	Severity[w] (%)	Incidence (%)	Severity (%)	Incidence (%)			
Thiophanate-methyl + captan (conventional)	3.3 b[v]	0.04 ab	0.8 ab	0.01 a	0.0 a	0.5 a	0.0 a	0.0 a
Thiophanate-methyl + captan (on-site[u])	4.6 b	0.05 b	2.3 ab	0.02 a	0.0 a	0.2 a	0.2 a	0.2 ab
Thiophanate-methyl + captan (site-specific[u])	0.2 a	0.01 a	0.2 a	0.01 a	0.3 a	2.0 a	0.0 a	0.0 a
Kresoxim-methyl alternated with thiophanate-methyl + captan	0.0 a	0.00 a	0.2 a	0.01 a	0.0 a	11.8 b	0.2 a	0.0 a
Kresoxim-methyl alternated with thiophanate-methyl + captan (on-site)	0.2 a	0.01 a	0.0 a	0.00 a	0.0 a	0.6 a	0.4 a	0.7 b
Kresoxim-methyl alternated with thiophanate-methyl + captan (site-specific)	0.0 a	0.00 a	0.0 a	0.00 a	0.0 a	0.5 a	0.0 a	0.0 a
Potassium bicarbonate	2.9 b	0.04 ab	2.7 b	0.03 a	2.4 b	19.4 bc	0.0 a	0.0 a
Nontreated control	43.8 c	0.65 c	44.2 c	0.54 b	6.5 b	25.6 c	0.0 a	0.2 ab
LSD ($P < 0.05$)	2.7	0.05	2.5	0.034	3.5	9.1	NS	0.51

[z]Trials were conducted at the University of Illinois Pomology Research Farm, Urbana; Iowa State University Horticulture Station, Ames; and Oakwood Fruit Farm, Richland Center, Wis.
[y]Mean percent of four replications; 120 apples per replication.
[x]Mean percent of four replications; 100 apples per replication.
[w] Severity = percent surface area of fruit with SB or FS infection.
[v]Values within each column with a letter in common are not significantly different according to Fischer's protected least significant difference ($P = 0.05$). NS = nonsignificant.
[u]Second-cover spray timing based on leaf wetness data from dataloggers placed in orchards (on-site) or based on leaf wetness data remotely estimated for the location of each orchard (site-specific) by SkyBit, Inc. (Bellefonte, Pa.).

Table 4. Location, apple cultivars, cover spray dates, and leaf wetness hours (LWH) in demonstration trials of a sooty blotch and flyspeck warning system in commercial apple orchard in Illinois, Iowa, and Wisconsin, 2001 and 2002.

			2nd Cover spray (calendar[y])		2nd Cover spray (IPM plots)[z]				Sprays saved (no.)	
					2001		2002			
State	Location	Variety	2001	2002	Date	LWH	Date	LWH	2001	2002
Illinois	Champaign	Golden Delicious	18 May	23 May	22 June	177	14 June	203	3	2
Illinois	Sidney	Golden Delicious	28 May	1 June	16 June	175	24 June	171	2	2
Illinois	Villa Grove	Golden Del/Smoothie	19 May	30 May	29 July	171	NA[x]	NA	6	7
Illinois	Sullivan	Golden Del/Smoothie	23 May	29 May	16 July	178[w]	4 July	208	4	2
Illinois	Peoria	Ozark Gold	7 June	31 May	16 June	195	12 Aug.	186	2	5
Iowa	Iowa Falls	Smoothie	1 June	28 June	17 July	175	6 Aug.	175	3	2
Iowa	Nevada	Yellow Delicious	1 June	24 June	22 June	177	5 Aug.	185	1	2
Iowa	Cambridge	Golden Delicious	12 June	12 June	15 July	94	NA[v]	NA	1	NA
Iowa	Ft. Dodge	Golden Delicious	7 June	13 June	9 July	180	31 July	169	2	2
Iowa	Jefferson	Golden Delicious	10 June	15 June	9 July	170	23 July	175	1	2
Wisconsin	Poynette	Honeygold	2 June	10 June	22 June	174	23 July	182	1	5
Wisconsin	Waunakee	Golden Delicious	8 June	11 June	11 Aug	208	26 July	149	5	3
Wisconsin	Fitchburg	Jonee	5 June	15 June	15 June[u]	140	24 July	218	1	3
Wisconsin	Cottage Grove	Golden Delicious	11 June	16 June	Never	309	22 July	135	4	3

[z]IPM = the second-cover spray was applied after 175 h of wetness following the first-cover spray.
[y]Sprays applied on a biweekly schedule following the first-cover spray.
[x]On 10 Sept., wetness hours were 164. Fruit were harvested on 25 Sept. Thus, no second-cover fungicide was applied.
[w]The data logger at Sullivan orchard stopped recording data during 27 May to 5 June. We used the data from the orchard in Villa Grove (closest orchard to Sullivan) to measure the accumulated wetness hours.
[v]The second cover spray was never applied, thus wetness hours accumulated to well over 175 by harvest.
[u]The IPM block was inadvertently sprayed along with rest of orchard [2 lb/acre (2.2 $kg \cdot ha^{-1}$) a.i. captan] on 15 June, but then not sprayed again for the rest of the season.

Table 5. Incidence and severity of sooty blotch (SB) and flyspeck (FS) in demonstration trials of a SBFS warning system in commercial apple orchards in Illinois, 2001 and 2002.

	Sooty blotch[z]						Flyspeck[z]					
	Incidence (%)			Severity[y] (%)			Incidence (%)			Severity (%)		
Location	Grower	IPM[x]	LSD[w]	Grower	IPM	LSD	Grower	IPM	LSD	Grower	IPM	LSD
2001												
Champaign	3.0 a[v]	1.5 a	NS	0.03 a	0.05 a	NS	2.3 a	5.0 b	2.1	0.03 a	0.05 b	0.02
Sidney	10.0 a	7.5 a	NS	0.15 a	0.15 a	NS	3.2 a	3.7 a	NS	0.05 a	0.07 a	NS
Villa Grove	2.8 a	11.0 b	2.9	0.07 a	0.38 b	0.12	2.2 a	8.5 b	2.5	0.04 a	0.20 b	0.07
Sullivan	32.8 a	43.0 b	5.8	0.67 a	1.77 b	0.26	36.0 a	45.8 b	5.6	1.21 a	2.54 b	0.35
Peoria	0.0 a	0.0 a	NS	0.00 a	0.00 a	NS	0.0 a	0.0 a	NS	0.00 a	0.00 a	NS
2002												
Champaign	0.0 a	4.2 b	1.6	0.00 a	0.05 b	0.02	0.0 a	0.0 a	NS	0.00 a	0.00 a	NS
Sidney	17.0 a	24.8 b	4.6	0.20 a	0.48 b	0.16	3.0 a	2.6 a	NS	0.03 a	0.03 a	NS
Villa Grove	0.0 a	0.0 a	NS	0.00 a	0.00 a	NS	0.0 a	0.0 a	NS	0.00 a	0.00 a	NS
Sullivan	0.2 a	0.8 a	NS	0.01 a	0.01 a	NS	0.0 a	0.7 b	0.65	0.00 a	0.06 a	0.06
Peoria	0.0 a	0.0 a	NS	0.00 a	0.00 a	NS	0.0 a	0.0 a	NS	0.00 a	0.00 a	NS

[z]Mean percent of 10 trees; 60 apples per tree.
[y]Severity = percent surface area of fruit with SB or FS infection.
[x]IPM = the second-cover spray was applied after 175 h of wetness following the first-cover spray.
[w]Fisher's protected least significant difference at $P < 0.05$. NS = nonsignificant.
[v]Values followed with the letter within each year, location, and disease combination are not significantly different.

Table 6. Incidence of sooty blotch (SB) and fly speck (FS) in demonstration trials of a SBFS warning system in commercial apple orchards in Iowa, 2001 and 2002.

	2001			2002					
	Incidence SBFS[z] (%)			Incidence SB[z] (%)			Incidence FS[z] (%)		
Location	Grower	IPM[y]	LSD[x]	Grower	IPM	LSD	Grower	IPM	LSD
Iowa Falls	0.5 a[w]	0.1 a	0.08	0.0 a	0.0 a	NS	0.0 a	0.0 a	NS
Nevada	5.0 a	6.6 b	0.16	1.3 a	5.2 a	NS	0.0 a	2.3 a	NS
Cambridge	0.0 a	0.0 a	NS	NA[v]	NA	NA	NA[v]	NA	NA
Ft. Dodge	0.0 a	0.0 a	NS	0.0 a	0.0 a	NS	0.0 a	0.0 a	NS
Jefferson	0.0 a	0.0 a	NS	0.0 a	0.0 a	NS	0.0 a	0.0 a	NS

[z]Mean percent of 10 trees; 50 apples per tree.
[y]IPM = the second-cover spray was applied after 175 h of wetness following the first-cover spray.
[x]Fisher's protected least significant difference at $P < 0.05$. NS = nonsignificant.
[w]Values followed by the same letter within each year, location, and disease combination are not significantly different.
[v]NA = the second cover spray was never applied at this orchard, thus wetness hours accumulated to well over 175 by harvest.

Table 7. Incidence of sooty blotch (SB) and fly speck (FS) in demonstration trials of a SBFS warning system in commercial apple orchards in Wisconsin, 2001 and 2002.

	2001						2002					
	Incidence SB[z] (%)			Incidence FS[z] (%)			Incidence SB[z] (%)			Incidence FS (%)		
Location	Grower	IPM[y]	LSD[x]	Grower	IPM	LSD	Grower	IPM	LSD	Grower	IPM	LSD
Poynette	17.6 a[w]	20.8 a	NS	4.0 a	14.0 b	5.1	23.0 a	70.6 b	14.1	70.0 a	79.8 a	NS
Waunakee	44.2 a	82.0 b	14.1	43.1 a	72.0 b	17.5	32.2 a	44.8 a	NS	20.0 a	18.6 a	NS
Fitchburg	11.8 a	25.4 b	12.2	48.0 a	48.8 a[v]	NS	0.0 a	1.2 a	NS	2.8 a	6.0 a	NS
Cottage Grove	27.8 a	90.2 b	*23.5*	19.2 a	84.6 b	12.0	4.6 a	5.4 a	NS	2.0 a	4.0 a	NS

[z]Mean percent of 10 trees; 50 apples per tree.
[y]IPM = the second-cover spray was applied after 175 h of wetness following the first-cover spray.
[x]Fisher's protected least significant difference at $P < 0.05$. NS = nonsignificant.
[w]Values followed by the same letter within each year, location, and disease combination are not significantly different.
[v]IPM block was inadvertently sprayed along with rest of orchard [2 lb/acre (2.2 $kg \cdot ha^{-1}$) a.i. captan] on 15 June but then not sprayed again for the rest of the season.

lurin fungicides kresoxim-methyl and trifloxystrobin provided control of SBFS equal to that of the conventional control (benomyl or thiophanate-methyl plus captan) at 11 of 12 site-years (Tables 2 and 3). In Wisconsin in 2002, one of the eight trees treated with kresoxim-methyl had a very high incidence of FS, which raised the mean incidence of FS at that location. When data from that tree were excluded from the analysis, FS incidence was 3.2% and not significantly different from the conventional control. Overall, when used in alternation with benomyl or thiophanate-methyl plus captan, trifloxystrobin and kresoxim-methyl reduced the incidence of SBFS to acceptable levels. Potassium bicarbonate (Kaligreen) controlled SBFS better than the unsprayed control (Tables 2 and 3), but it was clearly less effective than strobilurins or conventional fungicides. Nevertheless, potassium bicarbonate may be useful in organic orchards where use of synthetic fungicides are prohibited.

DEMONSTRATION TRIALS. The on-site warning system saved one to six (mean 2.6) and two to seven (mean 3.1) sprays per season in 2001 and 2002, respectively (Table 4). However, in 2001, three Illinois, one Iowa, and four Wisconsin orchards had higher incidence of SB and/or FS in the plots sprayed according to the warning system than in the plots that received the growers' typical spray schedules (Tables 5, 6, and 7). Also, in 2002, SB and/or FS incidence was significantly higher in the IPM plots at three Illinois and one Wisconsin orchards (Tables 5 and 7). Overall, the incidence of SB and/or FS was higher in IPM plots than conventional plots in 12 of 28 site-years. In nine out of these 12 cases, the second-cover spray was applied after the 175-h threshold. Therefore, it appears that delayed application of the second-cover spray has been the main reason for the higher incidence of SB or FS in the warning-system plots. Other possible reasons for higher incidence of SB or FS in the IPM plots could be poor spray coverage in inadequately pruned trees. Because our wetness-based spray program was effective in replicated trials in research orchards in Illinois and Iowa (Tables 2 and 3), we suspect that poor pruning may have caused the failures at commercial orchards in these states. Likewise, in Wisconsin, failure in IPM plots (e.g., FS at Waunakee in 2001) was associated with dense tree canopies. The extra fungicide sprays on conventional calendar-based system may have compensated for poor pruning. Although incidence of SBFS was higher in the IPM plots than the conventional control calendar-based plots in some of the orchards, severity of disease was very low (mostly <1%) which should not have a significant negative impact on the value of fruit.

Overall, growers in Illinois and Iowa were very pleased with the success of the disease prediction system. Several growers have purchased their own sensors, and many others are interested in cooperating in future trials of the system. In Wisconsin, despite mixed success, some growers intend to use the system, with the understanding that adequate pruning is essential, especially in upper canopies where wetness duration is longer and spray coverage tends to be incomplete. Saving sprays by using the disease prediction system and integrating reduced-risk fungicides for control of SBFS will be economical and reduce exposure of workers, consumers, and the environment to fungicides.

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