Fungicide control of apple scab: 2007 trial results

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I. Introduction

Apple scab, caused by the pathogen *Venturia inequalis*, is the most important disease involved in apple production across the world (MacHardy 1996). In California, the disease impacts orchards in coastal regions, in the Central Valley, and in the foothills of the Sierra Nevada (Ohlendorf 1999). Leaf and fruit infection occurs as *V. inequalis* ascospores are released from leaf litter (or conidia are dispersed from tree branches and budscales) in the course of spring rains (MacHardy 1996).

A field trial was conducted to evaluate fungicide control of apple scab at an orchard near Camino, El Dorado Co., California, in the spring of 2007. The fungicides Procure, Dithane, Sovran, Evito, Endorse, Flint, the organic Champion + Kumulus rotating to JMS Stylet Oil, and the experimental materials A7402 (difenoconazole), Topguard (flutriafol), and LEM17 (penthiopyrad) were compared to an unsprayed control in a completely randomized design. We examined product effects on foliar and fruit scab lesions and evidence for phytotoxicity/russeting on fruit.

Location	Camino, El Dorado Co., California
Cooperators	Mike and Jean Gastaldi
Crop	Apple (*Malus* x *domestica*), “Red Delicious” variety
Diseases	Apple scab (*Venturia inaequalis*)

II. Materials and Methods

A. Trial layout

Experimental design	Complete randomized design with 5 replicates per treatment.
Experimental unit	1 tree = 1 plot
Row and tree spacing	18 ft (row) and 18 ft (tree) — Plot unit area: 324 ft^2
Area/treatment	1620 ft^2 or 0.372 acre/treatment (5 replicate trees = 1 treatment)
Fungicide applications (at roughly 7 day intervals)	A ¾ inch leaves Tu 20 March 2007 150 gallons/acre 5.6 gallons/5 replicates B pink bud W 28 March 150 gallons/acre 5.6 gallons/5 reps C bloom W 4 April 200 gallons/acre 7.4 gallons/5 reps D bloom Tu 10 April 250 gallons/acre 9.3 gallons/5 reps E post-bloom W 18 April 250 gallons/acre 9.3 gallons/5 reps F post-bloom W 25 April 300 gallons/acre 11.2 gallons/5 reps
Application method	Tank sprayers (25 or 50 gallon capacity). Backpack sprayers for several early applications.
Disease evaluation	Disease on fruits was evaluated in the field on 8 June 2007. Scab incidence in each plot was estimated as the proportion of apples evaluated per tree (usually 50) that were infected by at least one lesion. Scab severity was estimated as the mean number of scab lesions on all fruits evaluated per tree. Disease severity (number of lesions) was also determined on 12 randomly-collected leaves from each tree on 8 June.
Other data collection	Daily rainfall and mean temperatures were obtained for the nearby Camino weather station (station 13 at wwwcimis.water.ca.gov). Phytotoxicity/russeting was estimated in the field by observation of up to 50 fruits per plot; incidence calculated as the proportion of fruit exhibiting at least some (>0%) damage. All Phytotoxicity data were based on 5 plots, except for KD, RKS and PC (n=4) and BKS (n=3).
Data transformation	*Fruit and leaf disease data:* Severity data for fruit and leaves was square-root transformed and incidence was inverse sine transformed to improve the distribution of residuals. *Fruit phytotoxicity data:* Incidence data was arcsine transformed to improve variance inequality.
Statistical analysis	Type III, single factor ANOVAs were used to test treatment effects on scab incidence, scab severity and phytotoxicity/russeting incidence. *A posteriori* comparisons of treatment means were conducted with Tukey's HSD tests at α=0.05. Effect sizes of fungicide treatments relative to the unsprayed control (unit-less, standardized measures of the magnitude of treatment effects) were calculated for fruit data using the following equations: 1. For incidence data, $h = \| \varphi_f - \varphi_c \|$ where φ_f and φ_c represent the arcsine transformation ($\varphi = 2\sin^{-1}(\sqrt{p})$) of fungicide and control proportions (p) respectively (Cohen 1988). 2. For severity data, $g = \| (M_f - M_c)/SD_c \|$ where M_f = fungicide treatment mean, M_c = unsprayed control mean, and SD_c = the standard deviation of unsprayed control plot data (Tatsuoka 1993).

B. Experimental treatments

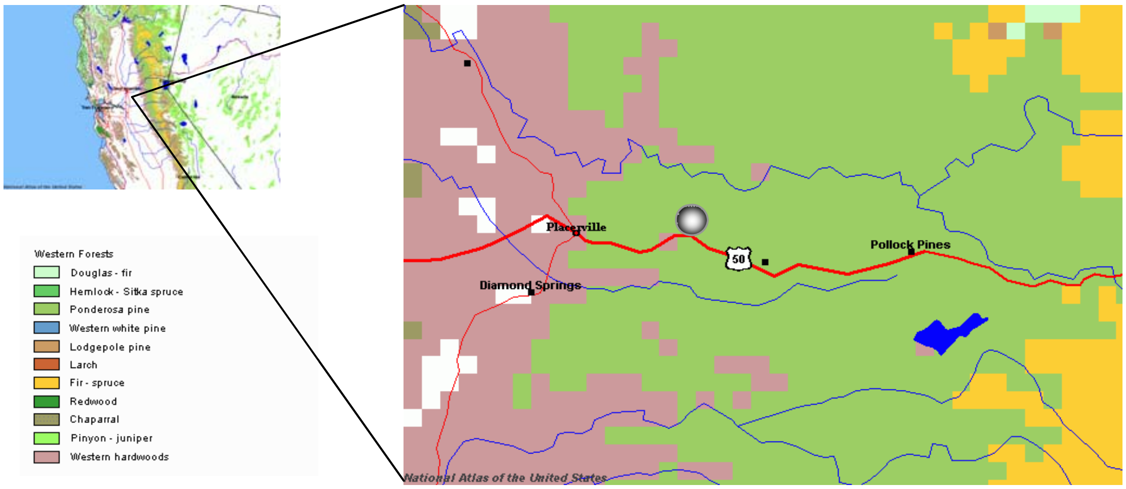
Trt no.	Flag	Product(s)	Applications	FP/Acre	FP/Treatment
1	RC	Unsprayed control	none	none	none
2	BD	Procure	ACE	12 fl oz	13.2 ml
3	YKS	Procure alternated with Sovran	AE C	12 fl oz alt 4 oz	13.2 ml alt 4.2 g
4	BKS	Sovran	ACE	4 oz	4.2 g
5	PKD	Dithane + Topguard	ACE	3 lb + 13 fl oz	51 g + 14.3 ml
6	RD	Dithane + Topguard	ACE	3 lb + 26 fl oz	51 g + 28.6 ml
7	YS	Dithane then Flint	AB CDEF	6 lb then 2 oz	101 g then then 2.1 g
8	RKS	Dithane then Dithane + A7402 then A7402	A B CDEF	6 lb then 3 lb + 4 fl oz then 4 fl oz	101 g then 51 g + 4.4 ml then 4.4 ml
9	GKC	Dithane then Dithane + A7402	A BCDEF	6 lb then 3 lb + 3 fl oz	101 g then 51 g + 3.3 ml
10	KD	Dithane then A7402 + Vangard	AB CDEF	6 lb then 2.5 fl oz + 2.5 oz	101 g then 2.8 ml + 2.6 g
11	TS	Dithane then A7402 +Vangard	AB CDEF	6 lb then 3 fl oz + 3 oz	101 g then 3.3 ml + 3.2 g
12	LG	LEM17	ABCDEF	4.3 oz ai	22.7 ml
13	GS	LEM17 + Flint alternated with LEM17	ACE BDF	2 oz ai + 1 oz alt 2 oz ai	10.5 ml + 1.1 g alt 10.5 ml
14	KS	LEM17 + Dithane	ABCDEF	2 oz ai 3 lb	10.5 ml + 51 g
15	RS	LEM17 alternated with Dithane	ACE BDF	3 oz ai 3 lb	15.8 ml alt 51 g
16	KC	LEM17 alternated with Dithane	ACE BDF	4.3 oz ai 3 lb	22.7 ml alt 51 g
17	G	Champion then Kumulus then JMS Stylet Oil JMS Stylet Oil (organic treatment)	AB C DE F	12 lb 15 lb 0.5 % 2.0 %	202 g then 253 g 176 ml (250 gal) 845 ml (300 gal)
18	PC	Dithane then Evito + Endorse	A BCDEF	6 lb then 5 fl oz + 8 oz	101 g then 5.5 ml + 8.4 g
19	OKD	Dithane then Dithane + Evito then Evito	A B CDEF	6 lb then 3 lb + 6 fl oz then 6 fl oz	101 g then 51 g + 6.6 ml then 6.6 ml

Notes: FP=formulated product; ai=active ingredient. Manzate was used in place of Dithane for some treatments during application B.

C. Fungicide application history

A	Tu 20 March 2007	Leaves about ¾ inch 	150 gallons/acre (=5.6 gallons/5 trees)	Applications made to treatments 2-19. CIMIS weather data for Camino indicated that 2 mm rain fell during the 18:00 hour; another 1 mm fell about midnight.
B	W 28 March 2007	Pink bud 	150 gallons/acre (=5.6 gallons/5 trees)	Applications made to treatments 7-19. About 67% of trees observed for phytotoxicity; substantial brownish leaf spots observed in each of the 5 replicates of treatment 17. Only 8.0 g of Endorse fungicide applied to PC plots.
C	W 4 April 2007		200 gallons/acre (=7.4 gallons/5 trees)	Applications made to treatments 2-19.
D	Tu 10 April 2007	Petal fall 	250 gallons/acre (=9.3 gallons/5 trees)	Applications made to treatments 7-19.
E	W 18 April 2007		250 gallons/acre (=9.3 gallons/5 trees)	Applications made to all treatments in morning. Weather conditions variable at that time: mostly cloudy but including snow, very light rain, and sunshine.
F	W 25 April 2007	Mostly post-bloom 	300 gallons/acre (=11.2 gallons/5 trees)	Applications made to treatments 7-19.

D. Site map



E. Map of the experimental plots

54 feet

				●	●	●	●	●	●	●	●	●	●
				●	●	LG	G	BD	GS	YKS	LG	G	●
			●	●	YS	BD	RD	RS	OKD	RS	YKS	OKD	
			●	●	RS	PKD	LG	PC	KD	RKS	KS	RC	●
		●	●	●	RC	YS	G	BD	●	●		●	
	●	●	●	PKD	●	TS	RKS	OKD	YS	RD	GKC	●	●
		●	●	TS	RS	YKS	BKS	PKD	GKC	KC	GS	●	●
	●	●	●	KS	KD	GS	GKC	G	KD	YS	OKD	●	●
	●	●	●	BKS	KS	YKS	YS	GKC	GS	G	RD	●	
	●		BD	OKD	PKD	TS	KD	KC	PC	KS	●	●	
	●	LG	RKS	RC	RS	KS	RD	RC	RKS	KC			
	●	PC	TS	RC	GS	PC	BKS						
	●	TS	KD	BD	LG	KC							
	●	KC	PC	BKS	YKS								
●	●	RD	PKD	RKS									
●	●	GKC	BKS										
●	●												

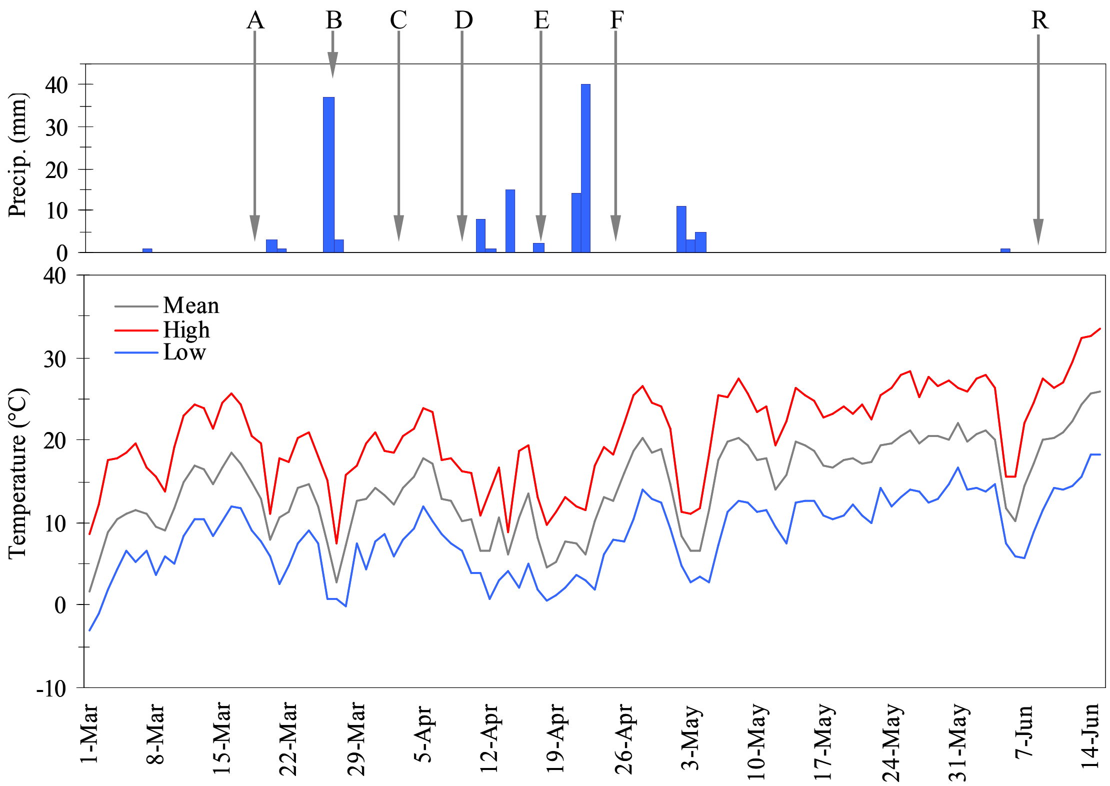
Private road

Apple trial, 2007. W.D. Gubler lab, Department of Plant Pathology, University of California, Davis.

III. Results and discussion

Climate data. Four significant rainfall events occurred between March and May 2007 with potential *Venturia* ascospore release from leaf litter and subsequent infection of trees (Figure 1). Fungicide applications A, D, E and F occurred prior to each of these rainfall events.

Figure 1. Variability in daily (a) precipitation and (b) mean, maximum, and minimum temperatures at Camino (data from California Irrigation Management Information System). Capital letters above the precipitation data indicate the timing of the six fungicide applications (A-F) and the evaluation of disease (R).



Scab incidence and severity. Scab lesions were common on untreated fruits at the time of disease evaluation in early June (Figure 2a,b). Fruit on untreated controls trees had a mean of 8.34 lesions, but mean disease occurrence in all fungicide treatments was less than 0.7 lesions per fruit (one-factor ANOVA, $F_{18,76} = 42.3$, $P < 0.0001$, Power = 0.999; Table 1). *A posteriori* comparison of means with a Tukey HSD test showed that fruit on untreated trees had significantly more disease than in any of the 18 fungicide treatments. Twelve treatments, including all LEM17 treatments, the organic treatment, and Procure alternated with Sovran were significantly better than Procure used alone, but no difference was seen between these top performing spray regimes and the remaining 5 treatments (Dithane then Dithane + A7402, Sovran, both Dithane + Topguard treatments, and Dithane then Evito + Endorse). Marginally-improved statistical separation of fungicide treatments was achieved by analysis of incidence data (one-factor ANOVA, $F_{18,76} = 24.1$, $P < 0.0001$, Power = 0.999). Again, all treatments significantly reduced disease incidence relative to unsprayed controls and, similarly, the top eight products showed better disease control than Procure alone or Dithane followed by Evito and Endorse. By both measures (colony number and disease incidence), Procure alternated with Sovran controlled disease development better than Procure used alone (neither treatment was significantly different from Sovran used alone). No difference in disease level could be detected between the two Topguard concentrations used (13 and 26 fl oz/acre).

Fungicide treatments were also effective at controlling disease on leaves. Leaf colony numbers were highest for the untreated control (mean = 8.33), at a level more than five times greater than the least performing fungicide (one-factor ANOVA, $F_{18,76} = 10.9$, $P < 0.0001$, Power = 0.999). Differences between fungicide protocols were difficult to detect statistically. The best products, LEM17 + Flint alternated with LEM17, Dithane then Flint, Dithane then Dithane + A7402, and LEM17 alone (at 4.3 oz ai/acre) showed less disease than Procure alternated with Sovran (the poorest treatment) but were statistically equivalent to all other fungicide regimes (Tukey HSD, Table 2). Slightly better statistical separation between products was evident with leaf incidence data. Control trees showed leaf infection rates of 88%, and fungicide treated plot disease incidence ranged from 0-41% (one-factor ANOVA, $F_{18,76} = 10.7$, $P < 0.0001$, Power = 0.999). The eight best treatments showed significantly lower disease incidence than Procure or Procure alternated with Sovran (Table 2): LEM17, LEM17 + Flint alt LEM17, Dithane then Flint, Dithane then Dithane + A7402, both LEM17 alt Dithane treatments, Dithane then Dithane +A7402 then A7402 and Dithane + Topguard at 13 fl oz/acre.

Figure 2. *Venturia* lesions on untreated fruits (a-b), and fruit and leaves from a tree treated with one of the top performing treatments, LEM + Flint alternated with LEM (c). Photos taken on 8 June.

Table 1. Incidence and severity of scab lesions on fruit (means ± S.E.). "alt" = alternated with. Means are grouped statistically with Tukey's HSD test.

Flag	Product(s)	Scab incidence (%)	Tukey group	No. scab lesions	Tukey group
GS	LEM17 + Flint alt LEM17	0.8 ± 0.5	d	0.01 ± 0.01	c
RKS	Dithane then Dithane + A7402	1.2 ± 0.8	d	0.01 ± 0.01	c
RS	LEM17 (3 oz ai/acre) alt Dithane	1.6 ± 0.7	d	0.02 ± 0.01	c
LG	LEM17	2.4 ± 0.7	d	0.02 ± 0.01	c
KS	LEM17 + Dithane	2.4 ± 1.2	d	0.02 ± 0.01	c
YS	Dithane then Flint	2.8 ± 1.0	d	0.03 ± 0.01	c
GKC	Dithane then Dithane + A7402	2.8 ± 0.8	d	0.10 ± 0.04	bc
G	Organic treatment	3.2 ± 1.5	d	0.05 ± 0.02	c
TS	Dithane then A7402 + Vangard (3 oz/acre)	3.6 ± 0.7	cd	0.04 ± 0.01	c
KD	Dithane then A7402 + Vangard (2.5 oz/acre)	3.6 ± 1.2	cd	0.04 ± 0.02	c
OKD	Dithane then Dithane + Evito then Evito	4.8 ± 2.2	cd	0.05 ± 0.02	c
KC	LEM17 (4.3 oz ai/acre) alt Dithane	5.2 ± 1.9	cd	0.06 ± 0.03	c
YKS	Procure alt Sovran	5.4 ± 3.0	cd	0.07 ± 0.03	c
BKS	Sovran	6.4 ± 1.9	cd	0.08 ± 0.02	bc
RD	Dithane + Topguard (26 fl oz/acre)	7.6 ± 1.6	cd	0.09 ± 0.02	bc
PKD	Dithane + Topguard (13 fl oz/acre)	8.8 ± 2.6	cd	0.11 ± 0.04	bc
PC	Dithane then Evito + Endorse	19.6 ± 2.8	bc	0.23 ± 0.04	bc
BD	Procure	31.6 ± 8.7	b	0.61 ± 0.29	b
RC	Unsprayed control	87.2 ± 8.2	a	8.34 ± 1.58	a

Table 2. Effect sizes (ES) of each fungicide treatment on fruit disease. ES indices were calculated for incidence (h) and for the number of lesions per fruit (severity, g) and represent the magnitude of treatment effects on fruit disease. ES are standardized unit-less numbers: h ranges from 0 (no effect) to a theoretical maximum difference between treatments of 3.14 (π); g' expresses the difference between means in standard deviation units and ranges from 0 (no effect) to a theoretical maximum of infinity. All effect sizes here are very large, showing substantial reductions in disease for treated trees versus control trees.

Flag	Product(s)	Treatment effect sizes	
		Incidence (h)	**Severity (g)**
GS	LEM17 + Flint alt LEM17	2.23	2.35
RKS	Dithane then Dithane + A7402 then A7402	2.19	2.35
RS	LEM17 (3 oz ai/acre) alt Dithane	2.16	2.35
LG	LEM17	2.10	2.35
KS	LEM17 + Dithane	2.10	2.35
YS	Dithane then Flint	2.07	2.35
GKC	Dithane then Dithane + A7402	2.07	2.33
G	Organic treatment	2.05	2.34
TS	Dithane then A7402 + Vangard (3 oz/acre)	2.03	2.35
KD	Dithane then A7402 + Vangard (2.5 oz/acre)	2.03	2.34
OKD	Dithane then Dithane + Evito then Evito	1.97	2.34
KC	LEM17 (4.3 oz ai/acre) alt Dithane	1.95	2.34
YKS	Procure alt Sovran	1.94	2.34
BKS	Sovran	1.90	2.34
RD	Dithane + Topguard (26 fl oz/acre)	1.85	2.33
PKD	Dithane + Topguard (13 fl oz/acre)	1.81	2.33
PC	Dithane then Evito + Endorse	1.49	2.29
BD	Procure	1.22	2.18

Table 3. Scab incidence and severity on leaves. Means to be followed by upper and lower 95% confidence intervals respectively. "alt" = alternated with.

Flag	Product(s)	Scab incidence	Tukey group	No. scab lesions	Tukey group
GS	LEM17 + Flint alt LEM17	0.0 ± 0.0	d	0.00 ± 0.00	c
LG	LEM17	0.0 ± 0.0	d	0.00 ± 0.00	c
YS	Dithane then Flint	0.0 ± 0.0	d	0.00 ± 0.00	c
GKC	Dithane then Dithane + A7402	0.0 ± 0.0	d	0.00 ± 0.00	c
RS	LEM17 (3 oz ai/acre) alt Dithane	1.7 ± 1.7	d	0.02 ± 0.02	bc
KC	LEM17 (4.3 oz ai/acre) alt Dithane	3.3 ± 2.0	d	0.05 ± 0.03	bc
RKS	Dithane then Dithane + A7402 then A7402	3.3 ± 3.3	d	0.05 ± 0.05	bc
PKD	Dithane + Topguard (13 fl oz/acre)	3.3 ± 3.3	d	0.05 ± 0.05	bc
OKD	Dithane then Dithane + Evito then Evito	5.0 ± 3.3	cd	0.07 ± 0.05	bc
TS	Dithane then A7402 + Vangard (3 oz/acre)	5.0 ± 3.3	cd	0.13 ± 0.11	bc
KD	Dithane then A7402 + Vangard (2.5 oz/acre)	6.7 ± 3.1	bcd	0.08 ± 0.04	bc
BKS	Sovran	8.3 ± 3.7	bcd	0.08 ± 0.04	bc
G	Organic treatment	8.3 ± 4.6	bcd	0.10 ± 0.06	bc
KS	LEM17 + Dithane	8.3 ± 8.3	cd	0.57 ± 0.57	bc
RD	Dithane + Topguard (26 fl oz/acre)	10.0 ± 4.9	bcd	0.80 ± 0.72	bc
PC	Dithane then Evito + Endorse	13.6 ± 6.3	bcd	0.99 ± 0.64	bc
YKS	Procure alt Sovran	36.7 ± 12.0	bc	1.50 ± 0.77	b
BD	Procure	41.1 ± 11.5	b	0.98 ± 0.45	bc
RC	Unsprayed control	87.9 ± 4.6	a	8.33 ± 1.86	a

Host plant phytotoxicity/russeting. Evidence of phytotoxicity in the organic treatment was first observed on 28 March 2007. On that date, leaves in approximately two thirds of plots in the trial were observed. Organic treatment plots consistently showed a relatively large concentration of brownish spots on leaves (concentrated on leaf margins; Figure 3), whereas all other trees only showed relatively minor evidence of foliar spots.

Phytotoxicity/russeting effects were also evident on fruit at the time of disease evaluation in early June. Control fruits and apples on most fungicide treatments showed a relatively low incidence of damage (≤5%). However, damage to fruits treated with Sovran and with the organic products was higher (6% and 38% respectively; one-factor ANOVA: $F_{18,71} = 2.9$, $P = 0.0007$, Power = 0.996; Table 4).

Figure 3. Evidence of phytotoxicity in the organic treatment. (a) Photo taken on 28 March following application of Champion. (b) Photo taken of fruit collected on 8 June.

Table 4. Incidence of phytotoxicity/russeting in fruit, showing high phytotoxicity effects in the organic treatment.

Flag	Product(s)	Incidence of phytotoxicity/russeting (%)	Tukey group
GKC	Dithane then Dithane + A7402	0.8 ± 0.8	a
PKD	Dithane + Topguard (13 fl oz/acre)	0.8 ± 0.8	a
RC	Unsprayed control	0.8 ± 0.8	a
KC	LEM17 (4.3 oz ai/acre) alt Dithane	1.6 ± 0.7	a
KS	LEM17 + Dithane	1.6 ± 1.0	a
LG	LEM17	1.6 ± 1.6	a
YKS	Procure alt Sovran	1.6 ± 1.6	a
GS	LEM17 + Flint alt LEM17	2.0 ± 1.5	a
RKS	Dithane then Dithane + A7402 then A7402	2.0 ± 2.0	a
YS	Dithane then Flint	2.4 ± 1.6	a
OKD	Dithane then Dithane + Evito then Evito	2.4 ± 2.4	a
PC	Dithane then Evito + Endorse	3.0 ± 2.4	a
BD	Procure	3.2 ± 3.2	a
KD	Dithane then A7402 + Vangard (2.5 oz/acre)	3.5 ± 2.4	a
TS	Dithane then A7402 + Vangard (3 oz/acre)	3.6 ± 3.1	a
RD	Dithane + Topguard (26 fl oz/acre)	4.4 ± 4.0	a
RS	LEM17 (3 oz ai/acre) alt Dithane	4.8 ± 3.2	a
BKS	Sovran	6.0 ± 1.2	ab
G	Organic treatment	37.6 ± 11.8	b

Conclusions. Scab data suggest that most fungicide treatments were highly effective at reducing both the severity (number) of lesions on fruit and leaves and the incidence of infected fruits and foliage on trees. Thirteen of eighteen fungicide treatments reduced the incidence of disease on fruit to 5% or less, suggesting that these products may result in the largest marketable yield at the end of a growing season. The experimental materials LEM17 and A7402 were consistently among the treatments exhibiting the lowest disease incidence on fruit. Leaf data also showed that all fungicides had lower disease incidence and severity than unsprayed controls, but the ordering of products from best to worst differed somewhat from fruit results.

The organic treatment performed as well as non-organic fungicides with respect to disease management, but more than one third of fruits from these plots showed evidence of at least some phytotoxicity and/or russeting. Reduction of copper rates early in the spray period and/or use of only sulfur and JMS Stylet Oil should be tested to determine if good disease control can be still be achieved with less damage to fruits and leaves.

Several fungicides were tested at different concentrations or as part of treatments with or without additional products. Because of good disease control by virtually all materials and modest replication (n=5) in the experiment however, statistical separation of these treatments was difficult. Application rates for Topguard varied by a factor of two in the trial, but there was no statistically significant improvement in disease management at the higher rate and differences in effect size were trivial. Similarly, there was no statistical difference (and only small effect size differences) between the various LEM treatments (e.g., with or without Dithane and Flint) and the four different treatments containing A7402. There was some evidence (fruit data) that Procure (a DMI) alternated with Sovran (a strobilurin) had better disease management than Procure used alone. Incidence data (both in terms of Tukey's HSD results and effect size indices) elucidated treatment differences better than severity results. Depending on the performance of Topguard, A7402, and LEM17 at other sites and during other growing seasons, future work might focus on testing these experimental products towards the lower end of the concentrations used here.

IV. Acknowledgements

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V. References

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VI. Appendix 1

Product	Active ingredient(s) and concentration	Chemical class
A7402T	difenoconazole (25%)	DMI-Triazole
Champion WP	copper hydroxide (77%)	Inorganic
Dithane DF Rainshield 75WG	mancozeb (75%)	Carbamate
Endorse 11.3DF	polyoxin D zinc salt (11.3%)	
Evito 480SC	fluoxastrobin	Strobilurin
Flint 50WG	trifloxystrobin (50%)	Strobilurin
JMS Stylet Oil	various hydrocarbons (97.1%)	Oil
LEM17 SC 200G/L	penthiopyrad (20%)	Pyrazole carboxamide
Manzate 200DF (75WG)	mancozeb (75%)	Carbamate
Procure 480SC	triflumizole (42.14%)	DMI-Imidazole
Sovran	kresoxim methyl, 50%	Strobilurin
Kumulus DF	wettable sulfur (80%)	Inorganic
Topguard	flutriafol (125g/L or 12%)	
Vangard 75WG	cyprodinil (75%)	Anilinopyrimidine

Note: Chemical class data from Adaskaveg et al. (2007).