Epidemiology and Control of Almond Scab and Alternaria Leaf Spot

Project No.: **12-PATH3-Adaskaveg**

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Objectives:

I. Etiology
   A. Identify pathogenic species of *Alternaria* using molecular methods.
   B. Determine the *Alternaria* species composition within selected orchards. This objective is contingent on the development of molecular methods for identification of the pathogens.
   C. Determine the *F. carpophilum* population composition within selected orchards and determine if sexual reproduction occurs within orchard populations using molecular methods.

II. Management
   A. Evaluate new and registered fungicides for their efficacy in managing scab, Alternaria leaf spot, and leaf blight. Fungicides to be evaluated include fluopyram (Luna Privilege), fluxapyroxad (Xemium), penthiopyrad (Fontelis), difenoconazole (component of Inspire Super), metconazole (Quash), polyoxin-D (Ph-D, Tavano), chlorothalonil (Bravo, Echo), and dodine (Syllit).
      i. Single-fungicide programs
      ii. Rotation programs of different fungicide chemistries
   B. For scab management, evaluate the effect of dormant applications (new formulations of copper or Bravo used with oil) on sporulation of infected twig lesions, as well as registered (Bravo, Manzate/Dithane, Ziram) and new fungicides (see above) for in-season use. The focus will be on chlorothalonil for extended springtime usage for disease control - i.e., 60 day PHI. Currently, the IR-4 program is conducting fungicide residue studies on almond.
   C. Establish and expand baseline sensitivities and monitor for shifts in sensitivity in populations of *Alternaria* and *Fusicladium* spp. to sub-groups of the SDHIs: pyridine-carboxamides (boscalid), pyrazole-carboxamide (fluxapyroxad), and pyridinyl-ethyl-benzamides (fluxopyroxad), DMIs, polyoxin-D, and QoIs.
   D. Develop and use a modified DSV model based on dew point (instead of leaf wetness) and temperature (i.e., onset of dew formation and rising temperatures during mid-spring) with a goal for countywide forecasts for the first in-season fungicide application. Time additional applications in 2- to 3- week intervals under low-rainfall conditions.

Interpretive Summary (Note-This report is mainly based on our 2012 data because our 2013 project is ongoing)**.**

Scab (caused by *Fusicladium carpophilum;* formerly *Cladosporium carpophilum*) and Alternaria leaf spot (caused by three very closely related species in the *Alternaria alternata* complex) have become of increasing importance in recent years in many growing areas in California. Recently, Alternaria twig infections were identified on cv. Wood Colony and thus, both diseases include twig infections. Both diseases are summer diseases that especially occur in locations with high humidity and where air circulation is poor, such in high-density plantings, or in orchards with soils with inadequate drainage, or where trees require frequent and extended irrigations throughout the summer. Because Alternaria leaf spot is greatly influenced by microclimatic conditions such as temperature and wetness within orchards, we previously successfully modified the Disease Severity Value (DSV) model to predict infection periods and to time fungicide treatments. For the last two seasons (2012 and 2013), measures of Alternaria leaf spot were correlated to accumulated days with dew, temperature thresholds and total precipitation data from CIMIS stations in Kern and Colusa Co. Total disease was related to the number of dew periods. Orchards with a lower number of days with wetness from dew had lower disease levels at the end of the season. The distribution of days with dew over the spring season varied widely and initiation of management programs based on dew period alone was not indicative of a successful program. Research is ongoing to determine new indices based on dew periods and temperature levels.

In our field trials we continued to collaborate with growers, the agrochemical industry, and regulatory agencies to develop and design sustainable treatment programs where several classes of fungicides are mixed or rotated, so that no single class is over-used. Our research on the management of these diseases demonstrates that in the presence of QoI resistance (and boscalid-resistance in *Alternaria* spp.) low disease levels can be obtained with properly timed applications with currently registered fungicides. Moreover, two- or three-spray rotation programs that use three or four FRAC groups are an excellent strategy to minimize fungicide resistance development and spread. For Alternaria leaf spot, the highly effective polyoxin-D (Ph-D), several DMI fungicides (e.g., Quash, Inspire), as well as pre-mixtures (e.g., Luna Sensation, Luna Experience, Quadris Top, Inspire Super, Merivon – pending registration) have been registered through our research. These fungicides also fit well into a scab management program, especially since treatment timings are overlapping for the two diseases when a delayed dormant treatment suppresses sporulation of scab twig infections until May-June.

The multi-site mode of action chlorothalonil that is effective against both diseases potentially will have a critical role in preventing the over-use of SDHI and DMI fungicides, thus, reducing the potential for selecting resistant pathogen populations. The proposed label changes for chlorothalonil will allow for a shortening in the preharvest interval on almond from 155 days to 60 days PHI. Additionally, in 2013 again, delayed dormant applications with chlorothalonil (Bravo)/oil demonstrated to be outstanding as inoculum reduction treatments by delaying the sporulation of twig cankers in the springtime. With a prolonged delay in sporulation, these treatments potentially can minimize the need for additional springtime fungicide applications and allow fungicide usage in the management of other diseases (e.g., hull rot).

Laboratory evaluations on sensitivity of *Alternaria* and *Fusicladium* spp. to SDHI fungicides indicated that for both pathogens resistant sub-populations exist to all of these fungicides, but there was no strict cross-resistance among the sub-groups or even within a sub-group. This indicates that field rotations between fungicides of this FRAC 7 group can provide a resistance management strategy, even when using compounds within the same sub-group (e.g., fluxapyroxad and penthiopyrad).

Materials and Methods:

Etiology of scab and Alternaria leaf spot and scab. Populations of *F. carpophilum* are being evaluated by AFLP analyses. Fragment patterns are scored on computer-generated gels. Possible evidence for sexual recombination will be provided through multilocus genotypic analysis. The etiology of *Alternaria* spp. populations is also done by AFLP analyses. Fragment patterns are analyzed, compared to reference isolates, and data are presented using tree-building programs that visualize relationships among isolates. Alternaria species groups are being identified for a current taxonomic understanding of the species on almond.

Fungicide evaluations for management of scab in 2012 and 2013. Data for evaluation of dormant treatments are presented for 2013 and for in-season treatments for 2012. Dormant treatments were applied in a commercial orchard in January 2013 (cv. Carmel in Butte Co.). Treatments included Kocide 3000 5 lb/4% oil and Bravo WeatherStik (4 and 6 pts/A)/4% oil. Samples of last fall's twigs growth were collected on April 18 and May 22, 2013, and evaluated in the laboratory for sporulation of overwintering scab lesions. Sporulation was expressed as incidence of sporulating lesions and as severity using a rating scale with 0=no sporulation, 1=very little sporulation, 2=lesion partially covered with sporulation, and 3=lesion completely covered with sporulation or a full concentric ring of sporulation.

In-season treatments were initiated after petal fall after the onset of twig sporulation at three locations in Butte (cv. Carmel) and Colusa (cvs. Carmel and Monterey) Co. Fungicides used in three applications included Koverall (FRAC M3), Bravo (FRAC M15), Quash, Topguard, Tilt, and Bumper (FRAC 3), Fontelis (FRAC 7), Ph-D (FRAC 19), S2200 (FRAC unknown), Syllit (FRAC U12), and the pre-mixtures Luna Sensation, Pristine, Merivon (FRAC 7+11), Luna Experience (FRAC 3+7), Inspire Super (FRAC 3+9), Quadris Top (FRAC 3+11), LBG-61 (potassium phosphite + tebuconazole – FRAC 33+3), and Catamaran (chlorothalonil + potassium phosphite – FRAC M5 + 33). Some of the above fungicides were only used in mixtures (i.e., Tilt, Ph-D, Syllit, S2200, Bravo, Koverall) or rotations (i.e., Syllit, Bumper). In the Butte Co. trial, two application timings were compared (see results). Disease was evaluated based on incidence of fruit with scab lesions and on the number of lesions per fruit (disease severity).

Fungicide evaluations for management of Alternaria leaf spot of almond in 2012. The modified DSV model was used to determine initiation times of spray programs. Two trials were established in Kern Co. (cvs. Monterey and Fritz); two trials in Butte Co. (cv. Carmel); and two trials in Colusa Co. (cvs. Carmel and Monterey). Each site received two or three applications between mid-April and mid-June. Treatments included Bravo (FRAC M15), Topguard, Bumper, and Quash (FRAC 3), Fontelis (FRAC 7), YT669 (picoxysrobin, FRAC 11), Ph-D (FRAC 19), Syllit (FRAC U12), S2200 (FRAC unknown), and the pre-mixtures Luna Sensation, Merivon,

Pristine, and Q8Y78 (penthiopyrad + picoxystrobin; FRAC 7+11), Luna Experience (FRAC 3+7), Inspire Super (FRAC 3+9), Quadris Top (FRAC 3+11), LBG-61 (potassium phosphite + tebuconazole – FRAC 33+3), as well as selected mixtures and one rotation. Evaluations were done late August. For disease incidence 30-40 leaves per single-tree replication were evaluated for the presence of disease. For disease severity (lesions/leaf), a rating was used with a scale from 0 to 4. Trees were also rated for defoliation based on a scale from 0 (= no defoliation) to 4 (= more than 75% of the leaves fallen). Trials were repeated in 2013.

In vitro sensitivity of *Fusicladium carpophilum* and *Alternaria* spp. to selected SDHI fungicides – 2012-2013 Research. Isolates from orchards in Kern, Butte, Colusa, and Stanislaus Co. were evaluated for their sensitivity against several SDHI fungicides (i.e., boscalid, fluopyram, fluxapyroxad, penthiopyrad) using the spiral gradient dilution method. In addition to several sensitive isolates, isolates were selected that showed a reduced sensitivity against boscalid in previous screenings. Inhibition of mycelial growth was measured after 3 to 4 days of incubation, and EC_{50} values were determined.

Development of a modified DSV model for initiating Alternaria leaf spot management practices based on precipitation, dew point (instead of leaf wetness) and threshold temperatures during the spring season. In the last two years, wide ranges of environmental factors have been observed in our Alternaria management plots in southern and northern California. Optimal timing for the initiation of fungicide applications and of subsequent applications is critical for obtaining high levels of disease management. Thus, we evaluated daily temperatures (mean, min/max), daily incidence of dew periods (based on temperatures below dew point), and daily precipitation as indicators of wetness periods at temperatures conducive for disease based on the DSV model that we previously utilized for describing disease progress curves of Alternaria leaf spot of almond. Regional environmental data sets were downloaded from the CIMIS database for parameters described above. Numbers of days with dew periods, total precipitation, and minimum temperatures were graphed over time (Julian days) from April through June. Timing of fungicides and disease incidence, severity, and intensity (incidence*severity) were determined for the two locations for both 2012 and 2013. Data was evaluated and disease was correlated to accumulated days with dew, temperature thresholds and total precipitation.

Statistical analysis of data. Experiments were designed with treatments in randomized blocks. Data for the large scab field trial were analyzed using split-plot procedures. All data were analyzed using analysis of variance and least significant difference (LSD) mean separation procedures ($P > 0.05$).

Results and Discussion:

Etiology of scab and Alternaria leaf spot and scab. *Alternaria* spp. populations are currently being evaluated by AFLP analyses and results are pending. We are currently assigning species names in molecular groups to over 80 isolates in collaboration with an *Alternaria* systematics researcher. This information will help us to solve the species complexity for almond leaf spot. In both 2012 and 2013, Alternaria twig infections were identified on young green shoots of cv. Wood Colony where severe epidemics occurred resulting in tree defoliation. Twig infections are well known for scab but this is a new report for Alternaria on

almond. Thus, disease cycles of both diseases include twig infections but the role of Alternaria twig lesions needs to be further studied.

Scab management – 2012 and 2013 Research. Dormant treatments to reduce the production of primary inoculum in the springtime from overwintering twig lesions were evaluated in a trial on cv. Carmel in Butte Co. Kocide 3000/4% oil treatments were compared to Bravo/4% oil treatments using 2 rates of Bravo. At the first evaluation in mid-April, 65.7% of lesions of untreated trees sporulated and this was significantly and similarly reduced using copper (12.0% incidence) or the 4-pt rate of Bravo (19.1% incidence) (**Table 1**). No sporulation was observed with the 6-pt Bravo treatment. In a May 22 sampling, 79.9% of the copper-treated lesions sporulated, whereas 10.5 and 2.1% of the lesions sporulated for the low and high rates

Table 1. Efficacy of dormant treatments on sporulation of overwintering scab lesions on cv. Carmel almond - Butte Co. 2013

	Samples collected 4-18-13				Samples collected 5-22-13			
	Twig sporulation**				Twig sporulation			
Treatment*	Inc. (%)	LSD^	Rating	LSD	Inc. (%)	LSD	Rating	LSD
Control	65.7	a	1.1	a	97.4	a	2.0	a
Kocide 3000 5 lb + Oil 4 gal	12.0	b	0.2	bc	79.9	a	1.4	c
Bravo WeatherStick 4 pts + Oil 4 gal	19.1	b	0.3	b	10.5	b	0.2	c
Bravo WeatherStick 6 pts + Oil 4 gal	0.0	c	0.0	c	2.1	c	0.0	c

* Treatments were applied using an air-blast sprayer at 100 gal/A in January 2013.

** Lesions were evaluated using a rating scale: 0=no sporulation, 1=very little, 2=lesion partially covered with dark sporulation, 3=lesion completely covered with sporulation, or full concentric ring sporulating.

^ Values followed by the same letter are not significantly different based on an analysis of variance and LSD mean separation (P > 0.05) procedures.

of Bravo, respectively (the lower sporulation for the 4-pt rate of Bravo in this second sampling is likely due to sampling errors in this large trial). Thus, as in 2011 and 2012, Bravo/oil performed exceptionally well and had a long-lasting effect on the suppression of twig sporulation. The 6-pt rate of Bravo has the potential of suppressing inoculum production throughout late spring, and under less favorable disease conditions, spring-time fungicide applications may not be needed. We previously established that this performance is only obtained when Bravo is tank-mixed with oil, and oil should not be used with in-season applications. Bravo WeatherStik received a Section 2(ee) registration for dormant application between Dec. 1, 2012 and Jan. 10, 2013 using the 4-pt rate. Full registration is being pursued through the IR-4 program to change the PHI to 60 days.

Table 2. Efficacy of springtime fungicide treatments for management of scab cv. Carmel almond – Butte Co. 2012

						Applic. 4-18 and 5-22-12**		Applic. 5-22 and 6-12-12***	
		Product	Applications*			Dis. Incid. on fruit****		Dis. Incid. on fruit	
No.	Treatment*	Rate (/A)	4-18	5-22	6-12	(%)	LSD^	(%)	LSD^
1	Control	---	---	---	---	63.1	a	48.7	a
2	Bravo	4 pts/A	@	@	@	15.5	bc	54.7	a
3	Fontelis	14 fl oz	@	@	@	20.7	bc	32.7	ab
4	Quash + Ph-D	3.5 oz + 6.2 oz	@	@	@	5.5	cd	5.1	c
5	Luna Sensation	5 fl oz	@	@	@	28.1	b	56.7	a
6	Inspire Super + Surf.	20 fl oz	@	@	@	0.9	d	11.2	bc
7	Quadris Top	14 fl oz	@	@	@	6.9	cd	5.1	c
8	Merivon	6.5 fl oz	@	@	@	17.8	bcd	33.0	a
9	Syllit	32 oz	@	---	---	4.6	cd	32.3	ab
	Bumper	4 fl oz	---	@	@				

* Treatments were applied using an air-blast sprayer at a rate of 100 gal/A
** In the Quash + Ph-D application on 5-22-12, Quash was replaced by 14 fl oz Topguard
*** In the Quash + Ph-D application on 5-22-12, Quash was used at 2 oz.
**** For evaluation of scab on 8-28-12, 25-35 fruit were scored and a scale was used from 0=no disease, 1=<25% 2=26-50%, 3=51-75%, 4=>75% of fruit surface covered with lesions
^ Values followed by the same letter are not significantly different based on an analysis of variance and least significant difference (LSD) mean separation (P > 0.05) procedures.

Table 3. Efficacy of fungicide treatments for management of scab of almond cv. Monterey - Colusa Co. 2012

			Application			Dis. Incid. on fruit**		Dis. Sev. on fruit	
No.	Treatment*	Rate (/A)	4/19	5/22	6/13	(%)	LSD^	Lesions	LSD
1	Control	-----	-----	-----	-----	99.4	a	2.9	a
2	Syllit	24 oz	@	@	@	83.9	abc	1.3	bc
3	Quash 50WG	3.5 oz	@	@	@	25.7	h	0.4	fgh
4	Topguard	7 fl oz	@	@	@	82.7	abc	1.1	bcd
5	Topguard	14 fl oz	@	@	@	79.6	bcd	1.1	bcd
6	Syllit + Tilt	24 oz + 4 fl oz	@	@	@	59.3	cdefg	0.8	cdefg
7	Quash + S2200	2 oz + 2 oz	@	@	@	59.1	bcdef	1.0	cde
8	Quash + S2200	3 oz + 3 oz	@	@	@	21.9	hi	0.2	gh
9	Chlorothalonil + Ph-D	32 fl oz + 6.2 oz	@	@	@	51.0	defgh	0.7	defg
10	Luna Sensation	5 fl oz	@	@	@	27.6	fgh	0.3	gh
11	Luna Experience	6 fl oz	@	@	@	46.0	efgh	0.6	defgh
12	Quadris Top	14 fl oz	@	@	@	3.9	i	0.0	h
13	Inspire Super + surf.	20 fl oz	@	@	@	32.1	gh	0.4	efgh
14	Pristine 38WG	14.5 oz	@	@	@	79.3	ab	1.6	b
15	Merivon	6.8 fl oz	@	@	@	39.8	efgh	0.5	efgh
16	LBG-61	40 fl oz	@	@	@	30.0	fgh	0.4	fgh
17	Catamaran	64 fl oz	@	@	@	48.3	defgh	0.6	defg
18	Topguard + Koverall	7 fl oz + 48 oz	@	---	---	70.9	bcde	1.1	bcd
	Topguard + Ph-D	7 fl oz + 6.2 oz	---	@	@				
19	Topguard + Koverall	14 fl oz + 48 oz	@	---	---	61.4	bcde	0.9	cdef
	Topguard + Ph-D	14 fl oz + 6.2 oz	---	@	@				

* Treatments were applied using an air-blast sprayer at a rate of 100 gal/A
** For evaluation of scab on 8-15-12, 25-35 fruit were scored and a scale was used from 0=no disease, 1=<25%, 2=26-50%, 3=51-75%, 4=>75% of fruit surface covered with lesion.
^ Values followed by the same letter are not significantly different based on an analysis of variance and least

Table 4 A & B. Efficacy of fungicide treatments for management of Alternaria leaf spot and scab on almond cvs. Monterey and Fritz – Kern Co. 2012

A. cv. Monterey

						Alternaria*** cv. Monterey			
		Product	Timings			Dis. Incid. on leaves		Tree Defoliation	
No.	Treatment*	Rate (/A)	5/8	5/30	6/20	(%)	LSD^	Rating	LSD
1	Control	---	---	---	---	90.9	a	2.1	a
2	Ph-D 11.2DF + NF-P	6.2 oz/8 fl oz	@	@	@	34.7	bcd	0.8	cd
3	Quash 50WG	3 oz	@	@	@	25.0	cde	0.4	cdef
4	Topguard	10 fl oz	@	@	@	27.8	cde	0.3	cdef
5	Topguard	14 fl oz	@	@	@	64.9	b	0.8	cde
6	S-2200	3 oz	@	@	@	60.9	b	1.7	ab
7	YT669 2.08SC + NF-P	12 fl oz/8 fl oz	@	@	@	47.5	bc	0.8	cd
8	Fontelis (DPX LEM 17-090) + NF-P	20 fl oz/8 fl oz	@	@	@	34.7	bcd	0.6	def
9	Ph-D + Quash 50WG + NF-P	6.2 oz + 3 oz/8 fl oz	@	@	@	16.3	def	0.0	f
10	S-2200 + Quash	2 oz + 2 oz	@	@	@	26.0	cde	0.5	cdef
11	S-2200 + Quash	3 oz + 3 oz	@	@	@	36.6	bcd	1.0	bc
12	Luna Experience	6 fl oz	@	@	@	26.7	cde	0.4	cde
13	Luna Sensation	5 fl oz	@	@	@	5.1	f	0.2	ef
14	Inspire Super SC+ NF-P	20 fl oz/8 fl oz	@	@	@	10.1	ef	0.4	cdef
15	Quadris Top	14 fl oz	@	@	@	19.6	cde	0.6	cdef
16	Q8Y78 240SC	24 fl oz	@	@	@	39.1	bcd	0.5	cdef
17	LBG-61	2.5 pts = 40 fl oz	@	@	@	46.5	bc	0.7	cdef
18	PW38DD	6 lb	@	---	---	20.4	cde	0.2	def
	Merivon	6.5 fl oz	---	@	@				
19	Merivon	4 fl oz	@	---	@	19.8	def	0.3	def
	Ph-D + Quash 50WG + NF-P	6.2 oz + 3 oz/8 fl oz	---	@	---				
20	Merivon	6.5 fl oz	@	---	@	15.0	def	0.1	ef
	Ph-D + Quash 50WG + NF-P	6.2 oz + 3 oz/8 fl oz	---	@	---				
21	Pristine	14.5 fl oz	@	---	@	37.4	bcd	0.3	def
	Ph-D + Quash 50WG + NF-P	6.2 oz + 3 oz/8 fl oz	---	@	---				

B. cv. Fritz

		Product	Timings			Dis. Incid. on leaves		Tree Defoliation	
No.	Treatment*	Rate (/A)	5/8	5/30	6/20	(%)	LSD^	Rating	LSD
1	Control	---	---	---	---	46.3	a	1.2	a
2	Ph-D 11.2DF + NF-P	6.2 oz/8 fl oz	@	@	@	5.1	cde	0.2	bc
3	Quash 50WG	3 oz	@	@	@	4.2	cde	0.0	c
4	Topguard	10 fl oz	@	@	@	2.0	de	0.2	bc
5	Topguard	14 fl oz	@	@	@	1.1	de	0.2	bc
6	S-2200	3 oz	@	@	@	10.1	bcd	0.3	bc
7	YT669 2.08SC + NF-P	12 fl oz/8 fl oz	@	@	@	26.2	b	0.3	bc
8	Fontelis (DPX LEM 17-090) + NF-P	20 fl oz/8 fl oz	@	@	@	9.0	cde	0.2	bc
9	Ph-D + Quash 50WG + NF-P	6.2 oz + 3 oz/8 fl oz	@	@	@	5.0	cde	0.2	bc
10	S-2200 + Quash	2 oz + 2 oz	@	@	@	16.8	bc	0.5	b
11	S-2200 + Quash	3 oz + 3 oz	@	@	@	1.0	e	0.0	c
12	Luna Experience	6 fl oz	@	@	@	7.1	cde	0.3	bc
13	Luna Sensation	5 fl oz	@	@	@	0.9	e	0.2	bc
14	Inspire Super SC+ NF-P	20 fl oz/8 fl oz	@	@	@	3.9	cde	0.3	bc
15	Quadris Top	14 fl oz	@	@	@	2.0	de	0.2	bc
16	Q8Y78 240SC	24 fl oz	@	@	@	8.1	cde	0.3	bc
17	LBG-61	2.5 pts = 40 fl oz	@	@	@	4.9	cde	0.1	bc
18	PW38DD	6 lb	@	---	---	1.1	e	0.3	bc
	Merivon	6.5 fl oz	---	@	@				
19	Merivon	4 fl oz	@	---	@	2.0	de	0.1	bc
	Ph-D + Quash 50WG + NF-P	6.2 oz + 3 oz/8 fl oz	---	@	---				
20	Merivon	6.5 fl oz	@	---	@	2.0	de	0.1	bc
	Ph-D + Quash 50WG + NF-P	6.2 oz + 3 oz/8 fl oz	---	@	---				
21	Pristine	14.5 fl oz	@	---	@	8.6	bcde	0.1	bc
	Ph-D + Quash 50WG + NF-P	6.2 oz + 3 oz/8 fl oz	---	@	---				

* - Treatments were applied using an air-blast sprayer at a rate of 100 gal/A and there were 3 single-tree replications for each treatment. NF-P = NuFilm P surfactant.

***- Evaluations were doen on 8-23-12. For Alternaria disease incidence on leaves, 30-40 leaves from each of the 3 single-tree replications were evaluated for the presence of disease. For evaluation of disease severity, a rating was used with 0=healthy, 1= 1 lesion/leaf, 2= <50% leaf area diseased, no sporulation, 3= 75% of leaf area diseased, 4= >75% area diseased, sporulation For evaluation of tree defoliation, trees were rated based on a scale from 0= full canopy, 1= <10%, 2= 10-25%, 3= 25-50%, and 4=>50% defoliation.

^ - Values followed by the same letter are not significantly different based on an analysis of variance and least significant difference (LSD) mean separation (P > 0.05) procedures.

Spring-time applications for the management of scab were evaluated in several field trials in 2012 (data not available for 2013) and data for two trial sites are presented here. In a comparison of two timings, applications done on April 18 and May 22 were more effective for most fungicides that when done on May 22 and June 12 (**Table 2**). Quadris Top and Quash/Topguard+Ph-D, however, were similarly highly effective at both timings. We previously demonstrated the benefit of early application timings for scab (starting at the onset of twig sporulation) for the best disease control. All treatments evaluated at this timing effectively reduced the incidence of scab on almond fruit. Disease was reduced from 63.1% in the control to between 0.9% (i.e., Inspire Super) and 28.1% (i.e., Luna Sensation). In the trial on cv. Monterey in Colusa Co., 18 three-spray programs were compared (**Table 3**). Based on the reduction of disease incidence (99.4% in the control), Quadris Top was the best treatment with 3.9%, followed by treatments containing the 3- or 3.5-oz rate of Quash. Disease severity was reduced by >50% by all treatments evaluated.

Our data on scab management indicate that the disease can be effectively managed with currently available fungicides. A highly effective, three-spray program should include dormant applications with chlorothalonil-oil and two petal-fall applications based on twig sporulation. Dormant applications result in a reduced amount of inoculum and this will reduce the risk for selection of fungicide resistance. Large-scale trials may establish if dormant treatments with Bravo-oil alone can manage the disease. Effective petal fall treatments are chlorothalonil, DMI fungicides such as Quash or Inspire Super, Syllit, compounds containing SDHIs, QoIs (at locations where the pathogen population has not developed resistance), or Ph-D. Treatments containing a DMI compound were very effective, although the incidence of natural resistance against DMIs in *F. carpophilum* is high at some locations (see 2011 Annual Report). Thus, this class of chemicals, as well as others, can be effectively used, but they should be rotated with other classes or FRAC Groups (representing different modes of action) to prevent further selection of insensitivity.

Fungicide evaluations for management of Alternaria leaf spot of almond in 2012. Our research in 2013 is ongoing. We are planning to evaluate our Alternaria field plots in Aug./Sept. Thus, information is presented here for 2012 trials using three-spray programs in Kern and two-spray programs in Butte Co. with single-fungicides, mixtures, pre-mixtures, and rotations. In Kern Co., the same treatments were evaluated on cv. Monterey with a high disease incidence in the control and on cv. Fritz where disease pressure was half as high (**Table 4A, B**). On both cultivars, all treatments significantly reduced the disease incidence on leaves and tree defoliation was also reduced. Many treatments, however, were more effective on cv. Fritz. Luna Sensation with 5.1% incidence (as compared to the control with 90.9%) was most effective on cv. Monterey, followed numerically by Inspire Super (10.1%), and a rotation of Merivon with Ph-D+Quash (15%) (**Table 4A**). Tree defoliation was at low levels using all treatments, except for the experimental S2200. On cv. Fritz, Luna Sensation, was again among the best treatments, but several others were also highly effective (**Table 4B**). In the Butte Co. trial, Luna Sensation was also among the best treatments with a similar disease incidence as Quadris Top (**Table 5**). Several rotation programs were evaluated in the Kern and Colusa Co. trials, most with very good efficacy. In the Kern Co. trial three to four fungicide classes were included in the rotations and thus, these are excellent examples for resistance management programs using fungicide classes currently available.

Table 5. Efficacy of fungicide treatments for management of Alternaria leaf spot and scab on Almond cv Carmel in Butte Co, 2012

						Alternaria Leaf Spot **					
						Dis. Incid on leaves		Dis. Sev. on Leaves		Tree Defoliation	
No.	Treatment *	Product Rate (/A)	Applications 4/18	5/22	6/12	(%)	LSD	Rating	LSD	Rating	LSD
1	Control	- - -	- - -	- - -	- - -	47.4	a	1.1	a	0.8	a
2	Bravo	4 pts/A	@	@	@	3.6	bc	0.1	b	0.4	b
3	Ph-D 11.2DF	6.2 oz	@	@	@	11.4	b	0.2	b	0.3	b
4	Luna Sensation	5 fl oz	@	@	@	0	c	0	b	0.3	b
5	Quadris Top	14 fl oz	@	@	@	2.4	bc	0	b	0.3	b
6	Syllit	32 oz	@	- - -	- - -	10.3	bc	0.2	b	0.4	b
	Propiconazole	4 fl oz	- - -	@	@						
7	Fontelis	14 fl oz	@	- - -	- - -	4.2	bc	0.1	b	0.3	b
	Topguard +Ph-D	14 fl oz + 6.2 oz	- - -	@	- - -						
	Fontelis +Ph-D	15 fl oz + 6.2 oz	- - -	- - -	@						

* Treatments were applied using an air-blast sprayer at a rate of 100 gal/A and there were 4 single-tree replications for each treatment.

** For Alternaria disease incidence on leaves, 30-40 leaves from each of the 3 single-tree replications were evaluated for the presence of disease. For evaluation of disease severity, a rating was used with 0=healthy, 1 = 1 lesion/leaf, 2 = < 50% leaf area diseased, 3 = 75% of leaf area diseased, and 4 = > 75% area diseased. For evaluation of tree defoliation, trees were rated based on a scale from 0 = full canopy, 1 = < 10%, 2 = 10-25%, 3 = 25% - 50%, and 4 = > 50% defoliation.

^ Values followed by the same letter are not significantly different based on analyses or variance and least significant difference (LSD) mean separation (P>0.05) procedures.

Our data indicate that Alternaria leaf spot can be effectively managed with currently available fungicides in an integrated program with cultural practices. Boscalid resistance in the pathogen populations can be controlled using the newer SDHI sub-groups. These especially include Luna Sensation because no high-resistance and only moderate-resistance to fluoropyram has been found to date and Merivon where EC_{50} values for fluxapyroxad are in a lower range for resistant isolates that for boscalid or penthiopyrad (see below). Due to widespread resistance to QoIs, these SDHI pre-mixtures should be used in rotation with other FRAC classes such as DMIs (FRAC 3) or Ph-D (FRAC 19). For an overview on the management of scab and Alternaria leaf spot with currently registered fungicides we refer to the guidelines presented our 2012 report or at http://www.ipm.ucdavis.edu.

In vitro sensitivity of *Fusicladium carpophilum* and *Alternaria* spp. to selected SDHI fungicides – 2012-2013 Research. Isolates of *Alternaria* spp. were rated as sensitive, moderately resistant, or highly resistant against the four fungicides (i.e., boscalid, fluxapyroxad, penthiopyrad, and fluopyram) belonging to three SDHI sub-groups. EC_{50} values for sensitive isolates were all between 0.01 and 0.2 ppm (**Table 6**). Different ranges were defined for moderate or high resistance for each of the four fungicides. Isolates moderately or highly resistant to the pyridine carboxamide boscalid had EC_{50} values of 0.2-15 ppm and >20 ppm, respectively. Moderately or highly resistant isolates to the pyrazole-carboxamide fluxapyroxad had EC_{50} values of 0.1-0.8 ppm and >0.8 ppm, respectively. Moderately or highly resistant isolates to the pyrazole-carboxamide penthiopyrad had EC_{50} values of 0.2-6 ppm and >6 ppm, respectively. For the pyridinyl-ethyl-benzamide fluopyram, moderately resistant isolates had EC_{50} values between 0.15 and 0.5 ppm.

Table 6. In vitro sensitivity of isolates of *Alternaria* spp. from almond against four SDHI fungicides

isolate ID	Cross resis. group	EC50 mycelial growth (ppm)*			
		Boscalid	Fluxapyroxad	Penthiopyrad	Fluopyram
3286	---	0.054	0.02	0.045	0.024
3723	---	0.027	S	S	0.03
3775	---	0.026	S	S	0.097
4288	---	0.042	S	S	S
4260	---	0.030	S	S	S
4767	1	5.05	1.53	4.97	0.457
3772	1	5.98	1.53	5.95	0.431
4775	1	>20	2.30	>20	0.279
4776	1	>20	1.62	>20	0.276
4780	1	>20	1.52	>20	0.458
4773	1	>20	1.19	17.0	0.177
4779	1	>20	1.60	>20	0.215
4772	1	>20	0.85	>20	0.218
4778	1	>20	0.94	>20	0.211
3734	2	1.67	0.206	0.379	0.023
3779	2	3.60	0.139	0.427	0.019
3785	2	3.50	0.123	0.734	0.034
3790	2	5.46	0.164	0.576	0.037
4777	---	12.87	0.34	9.2	0.082
3784	---	3.20	0.025	0.033	0.017
4781	---	>20	0.19	0.308	0.012
3708	---	R	0.185	0.140	0.163
3287	---	12.2	0.70	4.0	0.194
4771	---	>20	0.37	>20	0.238
4774	---	>20	0.34	>20	0.302
S**		0.02 - 0.2 ppm	0.01 - 0.1 ppm	0.02 - 0.2 ppm	0.019 - 0.15 ppm
MR		0.2 - 15 ppm	0.1 - 0.8 ppm	0.2 - 6 ppm	0.15 - 0.5 ppm
HR		>20 ppm	>0.8 ppm	>5 ppm	---

* Sensitivities were determined using the spiral gradient dilution method.
** Sensitivity ranges for S (sensitive), MR (moderately resistant), and HR (highly resistant) isolates.

Isolates with moderate or high resistance against boscalid showed differential sensitivity to the other three SDHI fungicides and most isolates could be placed into one of two groupings (**Table 6**). The first group contained isolates moderately or highly resistant to boscalid, highly resistant to fluxapyroxad and penthiopyrad, and moderately resistant to fluopyram. The second group contained isolates moderately resistant to boscalid, fluxapyroxad, and penthiopyrad, and sensitive to fluopyram. Six additional isolates showed various sensitivity levels against the four fungicides and could not be placed into distinct groups.

Overall there was no strict cross-resistance among the sub-groups or even within a subgroup (i.e., fluxapyroxad and penthiopyrad). Sequencing of the succinate dehydrogenase gene is currently being concluded for these isolates. This was done to find out if the cross-resistance groupings could be associated with particular mutations in the *sdhB*, *sdhC*, or *sdhD* subunits of

the gene. Several mutations were identified and preliminary analyses indicate that there is some correlation between type of mutation and cross-resistance phenotype.

Table 7. In vitro sensitivity of isolates of *Fusicladium carpophilum* from almond against four SDHI fungicides

Isolate ID	Cross resis. group	EC50 mycelial growth (ppm)*			
		Boscalid	Fluxapyroxad	Penthiopyrad	Fluopyram
4792	---	0.38	0.59	19.8	2.76
4793	---	0.26	0.56	11.5	3.98
4790	---	0.42	0.90	15.6	1.70
4782	1	>40	26.9	>40	>40
4786	1	>40	30.3	>40	>40
4783	2	>40	7.53	>40	>40
4784	2	>40	3.64	>40	>40
4785	2	>40	2.86	>40	>40
4787	2	>40	2.02	>40	>40
4788	---	24.2	34.4	11.8	1.50
4791	---	2.68	30.3	>40	>40
4789	---	0.72	5.91	>40	26.0
S*		<3 ppm	<10 ppm	<20 ppm	<10 ppm
R		>10 ppm	>20 ppm	>50 ppm	>20 ppm

* Sensitivities were determined using the spiral gradient dilution method.
** Sensitivity ranges for S (sensitive) and R (resistant) isolates
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In vitro sensitivities for *F. carpophilum* against the four fungicides were much lower than those for *Alternaria* spp. EC_{50} values for isolates considered sensitive were <3 ppm (range 0.26-2.68 ppm) for boscalid, <13 ppm for fluxapyroxad (range 0.56-13 ppm), <20 ppm (range 10.7-19.7 ppm) for penthiopyrad, and <10 ppm (range 1.5-9.5 ppm) for fluopyram. Isolates considered resistant had values of >10 ppm, >20 ppm, >50 ppm, and >20 ppm, respectively. These threshold values were established from a screening of 42 isolates from different locations that were collected between 2006 and 2012. The low in vitro sensitivity of *F. carpophilum* against SDHIs correlates with some inconsistencies in efficacy trials in the field. Perhaps, the combination of SDHI-QoI mixtures provides activity in genetically heterogenous populations. It is also interesting to note that boscalid and fluxapyroxad were more active against this pathogen than penthiopyrad or fluopyram.

Cross resistance among SDHIs was studied for nine isolates of *F. carpophilum* and two groups were identified: group 1 with isolates resistant to all four SDHIs and group 2 with isolates resistant to boscalid, penthiopyrad, and fluopyram and sensitive to fluxapyroxad (**Table 7**). Sequence analysis of the *sdh* gene subunits is pending.

These cross-resistance studies among SDHI fungicides provide some information for their field use. Thus, rotations between fungicides of this FRAC 7 group can provide a resistance management strategy, even using compounds within the same sub-group (e.g., fluxapyroxad and penthiopyrad). For *Alternaria* spp., no isolates highly resistant to fluopyram have been identified and this is in agreement with studies by others that indicate a distinct binding site for

this fungicide that makes resistance development less likely. High resistance to fluopyram, however, was found for *F. carpophilum*. Possibly, as indicated in **Table 7**, fluxapyroxad may be more effective in the field against this pathogen.

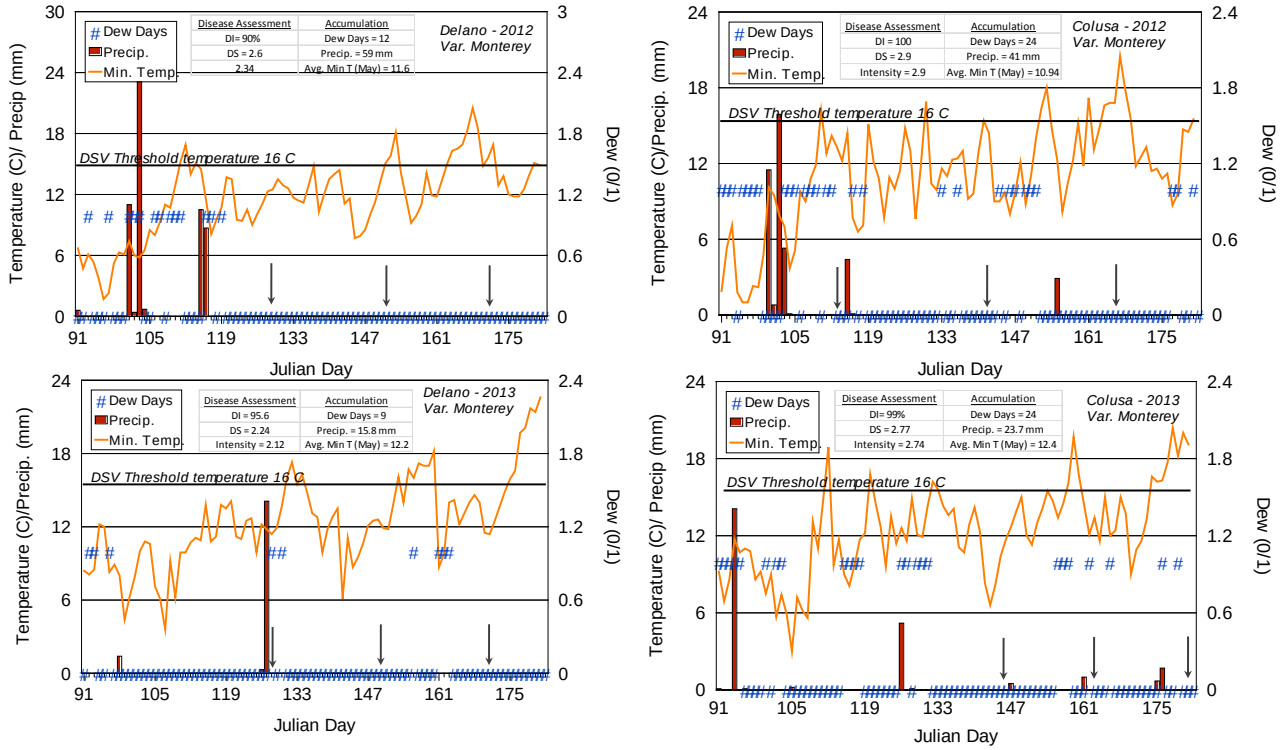

Figure 1. Threshold temperature, precipitation, and dew as possible initiation predictors of Alternaria leaf spot management practices. Vertical black arrows indicate fungicide application dates.

Development of a modified DSV model for initiating Alternaria leaf spot management practices based on precipitation, dew point (instead of leaf wetness) and threshold temperatures during the spring season. We evaluated daily temperatures (mean, min/max), daily incidence of dew periods (based on temperatures below dew point), and daily precipitation as indicators of wetness periods at temperatures conducive for disease based on the DSV model that we previously utilized for describing disease progress curves of Alternaria leaf spot of almond. Measures of disease were correlated to accumulated days with dew, temperature thresholds and total precipitation in the two locations in Kern and Colusa Co. in 2012 and 2013. Total disease was related to the number of dew periods. In other words, locations with fewer days with wetness from dew had lower disease levels at the end of the season (**Figure 1**). The distribution of days with dew over the spring season varied widely and different timings of fungicides during May and June still provided very good disease control (Delano 2012 and 2013). Precipitation levels also varied widely in Delano from 15.8 mm (2013) to 59 mm (2012) and in Colusa from 23.7 mm (2013) to 41 mm (2012) and were associated with both higher and lower disease levels. Warm minimum temperatures above 16 C and warm June temperatures were also related to total disease (**Figure 1**). Optimal timing of the initiation of fungicide applications and of subsequent applications is critical for obtaining high levels of disease management. The data is inconclusive for determining imitation times of management programs based on dew periods from regional weather station databases and

additional research is needed. Still, the wetness and temperature DSV model is functioning to describe disease progress and infection periods when data is collected from individual orchards. Fungicide applications beginning in May and subsequently applied into late June (early July) in approximately three week intervals continue to provide a high level of disease control (see **Table 3** and **Table 4** for 2012 efficacy data). Efficacy data for 2013 is currently being summarized. Research is ongoing to determine if new indices based on dew periods (instead of leaf wetness) and temperature levels can be used for modifying the DSV model.