Yield Reduction in Almond Related to Incidence of Shot-Hole Disease

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ABSTRACT

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The effect of shot-hole disease, caused by *Stigmina carpophila*, on yield of Nonpareil almond was studied in two commercial almond orchards. Differences in disease severity among plots were obtained when various fungicides were applied over several years. Higher yields were obtained from treatments that significantly reduced disease severity. In a Merced County field plot where various fungicide treatments had been applied, disease severity in 1982 was 89 and 90% lower and yields were 283 and 240% higher, respectively, for the ziram and captan petal-fall spray treatments than for the untreated control. Similarly, in a Kern County field plot, a 2-yr treatment consisting of three bloom-time ziram spray applications resulted in 59% lower disease severity in 1982 and 36% higher yield than for the untreated control. Differences in kernel size and weight between treatments were not observed. Higher yields can be maintained with fungicide applications that significantly reduce disease incidence.

Additional key words: *Coryneum beyerinckii*

Shot-hole disease of stone fruit caused by the fungus *Stigmina carpophila* (Lév.) M. B. Ellis (=*Coryneum beyerinckii* Oud.) has been reported on *Prunus* species throughout the temperate regions of the world, including North and South America, Africa, Australia, and New Zealand. In the United States, shot-hole disease is serious on stone fruit cultivated in the Pacific Coast states, although it also is found in other parts of the country. In California, annual applications of protective fungicide sprays on almond, apricot, nectarine, and peach for shot-hole disease control are a standard orchard practice.

Increased costs of fungicide application and decreased returns to almond growers in recent years have resulted in the need for careful evaluation of the costs and returns associated with disease control programs. Demonstration of yield loss caused by shot-hole disease severity is a critical factor in such analyses, because shot-hole infection does not appear to result in almond yield loss through blemished fruit, bud blight, or twig dieback (1,3–7). Despite the absence of yield loss by such direct means, studies by Wilson (6) established the efficacy of fungicide applications for reducing shot-hole disease severity in almonds and also suggested concomitant yield increases. Wilson's data presented to support this contention, however, were inconclusive.

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In this study, shot-hole disease severity and crop yield comparisons were made between unsprayed trees and trees sprayed with various protective fungicides in two naturally infected almond orchards in an attempt to document and quantify crop loss associated with shot-hole disease incidence.

MATERIALS AND METHODS

To study the association between shot-hole disease severity and crop yield in Nonpareil almond, two field plots in Merced and Kern counties (San Joaquin Valley) were maintained over a 4- and 2-yr period, respectively. Comparisons of shot-hole disease severity and crop yields were made between trees that received various fungicide applications and trees that were not sprayed.

Merced County field plot. The Merced County field plot was in a 23-yr-old almond orchard with alternating rows of Nonpareil/Mission/Nonpareil/Merced cultivars planted on a 7.63-m-square planting design (173 trees per hectare). The orchard was sprinkle-irrigated and had a sandy loam soil. Trees within the field plot were differentially treated with various fungicides and timings of application over a 4-yr period (Table 1), using a randomized complete-block (RCB) design with six treatments replicated three times. Treatments consisted of five trees in each of four adjacent cultivar rows (Nonpareil/Mission/Nonpareil/Merced).

The 1982 season treatments consisted of single spray applications of protective fungicides at pink bud (PB) or petal fall (PF). The various fungicides, timings, and rates of application are summarized in Table 2. Ziram (76%) and captan (50W) were applied as either PB or PF sprays, and chlorothalonil (40.4%) was applied as a PF spray. Dates of application for the PB and PF sprays were 27 February and 28 March, respectively. Control trees did not receive protective fungicide applications. Benomyl (0.9 g a.i./L) was applied to all trees at full bloom for control of brown rot blossom blight, and dormant oil was applied in

Table 1. Three-year fungicide application histories of 1982 treatments in Merced County[a]

	Chemical and timing[b]		
1982	1981	1980	1979
Ziram (PF)	Copper (DD) Ziram (PB) Ziram (PF)	Ziram (PB) Ziram (PF)	Copper (D) Copper (DD) Ziram (PB)
Captan (PF)	Copper (DD) Captan (PB) Captan (PF)	Copper (DD) Captan (PB) Captan (PF)	Copper (DD) Ziram (PB) Ziram (PF)
Captan (PB)	Copper (DD) Captan (PB)	Captan (PB)	Copper (DD) Captan (PB) Captan (PF)
Chlorothalonil (PF)	Copper (DD) Chlorothalonil (PF)	Copper (DD)	Copper (D) Copper (DD)
Ziram (PB)	Copper (DD) Ziram (PB)	Ziram (PB)	Copper (DD) Ziram (PF)
Untreated control	Copper (DD) (control)	Untreated control	Copper (DD) (control)

[a] Fungicides were applied with a semiconcentrate airblast sprayer at 935 L/ha: ziram at 7.28 g a.i./L, captan at 4.79 g a.i./L, and chlorothalonil at 3.03 ml a.i./L. Annual applications of benomyl were included in all treatments, at full bloom for brown rot blossom blight and at dormant oil for mites and aphids.

[b] Timings of fungicide applications: D = dormant, DD = delayed dormant, PB = pink bud, and PF = petal fall.

January to control mites and aphids. Fungicide applications were made with a semiconcentrate airblast sprayer traveling at 3.54 km/hr and delivering 935 L/ha.

Data on disease levels were obtained from three representative Nonpareil trees in each treatment over the 4-yr period 1979–1982. In 1979, disease levels were evaluated in terms of percent infected leaves and percent infected fruit (i.e., one or more lesions present) after spring rains. In subsequent years, disease data were obtained by rating either leaf or fruit infection. Disease levels in 1982 treatments were evaluated in terms of percent infected fruit, average number of lesions per infected fruit, and total number of lesions per treatment for 60 fruits collected from the lower limbs of representative trees on 12 May. Maximum disease levels were present at the time of fruit collection. Disease ratings were analyzed by analysis of variance (ANOVA) and means were separated by Duncan's multiple range test at $P = 0.05$.

Crop yield in 1982 was measured by mechanical harvesting of Nonpariel trees on 16 September. Gross field weights of hulls, shells, kernels, and debris for each treatment sample were obtained, and subsamples (1,814 g) were removed. Nuts in each subsample were counted, hulled, and shelled, then kernels were dried to constant weight (130–145 C for 72 hr) and final subsample kernel dry weights were obtained. Gross field weights for each treatment were adjusted to a kernel dry weight basis for subsequent statistical analysis. Data on the number, weight, and size (volume) of kernels were also obtained for each treatment. Yield and kernel data were analyzed by ANOVA and means were separated by Duncan's multiple range test at $P = 0.05$.

Kern County field plot. The second field plot was in Kern County in an 8-yr-old almond orchard with alternating rows of Merced/Nonpareil/Nonpareil/Mission cultivars planted on a 7.32-m offset planting design (185 trees per hectare). The orchard was sprinkle-irrigated and had a sandy loam soil. The 2-yr field plot was arranged as a RCB design with two treatments (a ziram treatment and an untreated control treatment) and two replicates, each consisting of two adjacent 107-tree Nonpareil rows. Trees within the ziram treatment received applications at PB, PF, and 5 wk after PF. All applications were made at a rate of 7.28 g a.i./L with a semiconcentrate airblast sprayer traveling at 3.54 km/hr and delivering 935 L/ha. Before the 2-yr study, all trees within the field plot had identical fungicide application histories.

Disease levels were assessed in 1982 by rating the level of fruit infection on 100 fruits per replicate collected from the lower portions of treatment trees. Yield data for 1982 treatments were obtained by total plot harvest. Nuts from Nonpareil trees within treatments were mechanically harvested and gross field weights were obtained. Field weights were adjusted to a kernel dry weight basis, as previously described, and the data were analyzed by ANOVA as RCB with two treatments.

Table 2. Effects of various fungicides and application timings on disease severity and yield of Nonpareil almond, Merced County, 1982

Treatment			Disease ratings[u]			
Fungicide[v]	Timing[w]	Rate (g a.i./L)	Fruit infected (%)	Total lesions (no.)	Av. lesions per infected fruit (no.)	Kernel yield[x] (kg/ha)
Ziram (76%)	PF	7.28	11 a[y]	24 a	4 a	2,203.6 a
Captan 50W	PF	4.79	10 a	27 a	5 a	1,961.5 a
Captan 50W	PB	4.79	95 c	822 c	14 bc	1,161.0 b
Chlorothalonil (40.4%)	PF	3.03[z]	77 b	507 b	11 b	1,130.7 bc
Ziram (76%)	PB	7.28	99 c	832 c	14 bc	1,025.2 bc
Untreated control	···	···	100 c	1,141 cd	19 d	575.2 c

[u] Based on 60 fruits per replicate collected 12 May 1982.
[v] Fungicides were applied with a semiconcentrate airblast sprayer at 935 L/ha.
[w] Dates of application for delayed dormant (DD), pink bud (PB), and petal fall (PF) spray treatments were 25 January, 27 February, and 28 March 1982, respectively.
[x] Based on adjusted kernel weights for three trees per replicate in a planting containing 173 trees per hectare.
[y] In each column, values followed by the same letter do not differ significantly ($P = 0.05$) according to Duncan's multiple range test.
[z] Milliliters (a.i.) per liter.

Table 3. Disease ratings on Nonpareil almonds, Merced County, for 1979 and 1982

	1979		1982
1982 Treatment	Leaves infected (%)	Fruit infected (%)	Fruit infected (%)
Ziram PF[y]	22.6 b[z]	3.3 a	11 a
Captan PF	8.9 a	1.0 a	10 a
Captan PB	17.1 ab	0.7 a	95 c
Chlorothalonil PF	22.8 b	55.3 bc	77 b
Ziram PB	16.5 ab	14.7 a	99 c
Control	49.5 c	67.7 c	100 c

[y] PF = petal fall and PB = pink bud.
[z] In each column, values followed by the same letter do not differ significantly ($P = 0.05$) according to Duncan's multiple range test.

RESULTS

Merced County field plot. Disease data obtained for the Merced County field plot in 1979 and 1982 treatments are shown in Table 3. In 1979, significant ($P = 0.05$) differences in disease levels existed between the various fungicide treatments and the untreated control trees; fruit and leaf infection differences were similar for a given treatment.

Severe leaf drop in late spring of 1980 and 1981 made leaf infection ratings difficult during these two seasons. Data obtained from fallen leaves collected from underneath trees, however, showed leaf infection differences between fungicide-treated and untreated control trees similar to that in 1979. Because similar disease level differences were detected in 1979 with leaf infection and fruit infection data, fruit data were collected for disease evaluation in 1982 treatments to avoid complications resulting from premature leaf drop.

Regardless of the method used in 1982 to evaluate fruit infection levels, trees within the 1982 ziram and captan PF treatments had significantly lower disease severity levels ($P = 0.05$) than those within the chlorothalonil PF, ziram PB, captan PB, or control treatments (Table 2). Although significantly greater than in ziram or captan PF treatments, disease severity within the chlorothalonil PF treatment was significantly lower ($P = 0.05$) than in ziram PB, captan PB, or control treatments. Disease severity was not significantly different for the remaining treatments.

Yield data collected in 1982 showed trees within ziram or captan PF treatments had significantly greater yield than trees within the remaining treatments (Table 2). Yield of trees within the captan PB treatment, although significantly lower than in ziram or captan PF treatments, was significantly greater ($P = 0.05$) than in the control treatment. Yields for the remaining treatments were not statistically different.

Regression analysis of 1982 Merced County data showed a negative correlation ($P = 0.01$) between yield and disease severity. The regression equation obtained for the model was $y = 85.00 - 0.522x$, and the coefficient of correlation was $r = 0.9117$.

Comparisons of kernels obtained from the various treatments revealed no significant differences in the average size of kernels or the weight of 100 kernels per subsample (Table 4). Only kernel numbers per subsample differed significantly; the captan PF treatment had the greatest number of kernels per subsample.

Kern County field plot. Results obtained from the Kern County plot in 1982 revealed that fruit infection was significantly ($P = 0.05$) reduced by the ziram treatment (Table 5). Both percent infected fruit and number of lesions per infected fruit were significantly reduced by the ziram treatment. Sixty-four percent of the fruit in the ziram treatment compared with 12% in the control were uninfected (zero lesions per fruit). Similarly, only 6% of the diseased fruit in the ziram treatment compared with 48% in the control had more than 15 lesions per fruit.

Yield data for the Kern County plot in 1982 revealed that the ziram treatment resulted in a 36% increase in yield over the control (Table 5). No significant differences in average kernel size, number of kernels per subsample, or weight of 100 kernels per subsample (Table 6) were associated with the treatments in the Kern County plot.

DISCUSSION

Results of studies conducted in 1982 on the effect of shot-hole disease on almond yield show a significant correlation ($P = 0.01$) between yield and disease severity and support an earlier contention that higher yields are obtained where protective fungicide applications effectively control the disease (7). In the Merced County plot, highest yields and lowest disease levels were obtained in 1982 from trees that had received ziram or captan PF applications. These trees received two bloom-time spray applications of ziram or captan per year in 1979, 1980, and 1981. In contrast, a slight increase in yield and reductions in disease level resulted when trees received ziram or captan PB applications in 1982 and single bloom-time fungicide applications per year in 1979, 1980, and 1981.

The mechanisms by which shot-hole disease reduces almond yield are not known. As previously stated, shot-hole infections apparently do not result in direct yield loss through blemished fruit, bud blight, or twig dieback as is seen in other stone fruit crops (1,3–7), and they do not cause reduction in kernel size or kernel weight, as shown in this study.

Despite the lack of direct yield loss, several workers have reported premature defoliation (with or without an associated nut drop) resulting from shot-hole leaf infections (1–7). Wilson (6) presented data on the amount of defoliation within various fungicide treatments, as well as leaf infections and nut yield, and concluded that defoliation contributes to crop reduction and economic loss. However, he expressed caution in interpreting the data, stating that a severe and uneven infestation of red spider mites may have influenced defoliation and crop yield. In a later paper (7), Wilson again suggested an association between defoliation and shot-hole infections and stated that young, newly formed leaves will drop with only a few lesions per leaf, whereas older leaves remain on the tree despite larger numbers of lesions per leaf.

If leaf infections cause early defoliation (with greater defoliation where disease levels are greater) and if early defoliation adversely affects tree growth or vigor (2), then defoliation over several years could stress the trees or reduce the amount of fruiting wood. This argument would explain the apparent connection between 1982 yields and fungicide application histories in our Merced County study. The extremely low yield obtained in the control (575.5 kg/ha in the Merced County plot compared with the state average of 1,105 kg/ha for cultivar Nonpareil) possibly reflect tree stress or decline over the 4-yr period resulting from extremely high disease levels. In contrast, trees receiving single bloom-time fungicide applications over the 4-yr period had less disease and possibly more vigor than control trees. Trees treated with ziram or captan at PF, with disease

Table 4. Effects of various fungicide application timings on kernel characteristics of Nonpareil almonds, Merced County, 1982

Treatment			Kernel measurements[v]		
Fungicide	Timing	Rate (g a.i./L)	Av. kernel size[w] (ml)	Av. kernel no. per subsample	Weight of 100 kernels per subsample (g)
Captan 50W	PF[x]	4.79	109 a[y]	300 a	111 a
Ziram (76%)	PF	7.28	121 a	266 ab	122 a
Chlorothalonil (40.4%)	PF	3.03[z]	112 a	243 bc	177 a
Ziram (76%)	PB	7.28	115 a	239 bc	118 a
Captan 50W	PB	4.79	113 a	241 bc	115 a
Untreated control	···	···	107 a	216 bc	111 a

[v] Based on 1,814-g subsamples from each replicate. Nuts were hulled, shelled, and dried to constant weight before measurements were recorded.
[w] Based on the amount of water displacement (ml) of 100 kernels.
[x] PF = petal fall and PB = pink bud.
[y] In each column, values followed by the same letter do not differ significantly ($P = 0.05$) according to Duncan's multiple range test.
[z] Milliliters (a.i.) per liter.

Table 5. Effects of three ziram applications on disease severity and yield of Nonpareil almonds, Kern County, 1982

Treatment	Fruit infected (%)	Percentage of infected fruit[w] (lesions per fruit)			Kernel yield[x] (kg/ha)
		1–5	6–15	>15	
Ziram (76%)[y]	36 a[z]	76	19	6	2,838 a
Untreated control	88 b	27	25	48	2,082 b

[w] Based on reading of 100 fruit per replicate collected from lower 6 ft of trees by Tejon Farming Company.
[x] Nuts were harvested from all trees within treatment replicates (214 trees per replicate).
[y] Applied in pink bud, petal fall, and 5 wk after petal fall with a semiconcentrate sprayer at 935 L/ha. Treatments were applied to the same trees for two consecutive years (1981 and 1982).
[z] In each column, values followed by the same letter do not differ significantly ($P = 0.05$) according to Duncan's multiple range test.

Table 6. Effects of three ziram applications on kernel characteristics of Nonpareil almonds, Kern County, 1982

Treatment	Kernel measurements[w]		
	Av. kernel size[x] (ml)	Av. kernel no. per subsample	Weight of 100 kernels per subsample (g)
Ziram (67%)[y]	114 a[z]	427 a	118 a
Untreated control	120 a	2383 a	121 a

[w] Based on 1,814-g subsamples from each replicate. Nuts were hulled, shelled, and dried to constant weight before measurements were recorded.
[x] Based on the amount of water displacemnt (ml) of 100 kernels.
[y] Applied in pink bud, petal fall, and 5 wk after petal fall with a semiconcentrate sprayer at 935 L/ha. Treatments were applied to the same trees for two consecutive years (1981 and 1982).
[z] In each column, values followed by the same letter do not differ significantly ($P = 0.05$) according to Duncan's multiple range test.

kept at low levels by two bloom-time spray applications annually over the 4-yr period, were distinctly more vigorous than control trees.

Indirect evidence of tree stress or decline in the Merced County study was apparent in subsamples collected after mechanical harvesting of the various treatment plots. Subsamples obtained from trees where shot-hole disease levels were high contained significant amounts of tree debris along with kernels. In these subsamples, debris probably accounted for a significant proportion of the subsample weight. However, in subsamples collected from trees where disease levels were low (ziram and captan PF plots), the amount of tree debris collected along with kernels was minimal and kernels alone probably accounted for the bulk of the subsample weight. As would be expected, these subsamples contained significantly greater numbers of kernels. During mechanical harvesting, greater amounts of debris would be expected to fall from stressed trees, because weakened and dead limbs would be more abundant. Results from the Kern County study illustrate how quickly shot hole can affect yield of Nonpareil almond trees; after only 2 yr, significant yield increases were obtained for trees receiving three ziram applications over trees in the control.

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LITERATURE CITED

1. Aldrich, T., Moller, W. J., and Schulbach, H. 1974. Shot hole disease control in almonds—by injecting fungicides into overhead sprinklers. Calif. Agric. 28(10):11.
2. Anonymous. 1930. Shot-hole disease of almond trees in farming in South Africa. Union S. Afr. Dep. Agric. Reprint 37. 2 pp.
3. Luepschen, N. S., Rohrback, R. G., Core, C. M., and Gilbert, H. A. 1968. Coryneum blight infection and control studies. Colo. State Univ. Exp. Stn. Prog. Rep. 68-2. 2 pp
4. Ogawa, J. M., English, H., Yates, W. E., and O'Reilly, H. J. 1959. Chemical control of Corynemum blight. Almond Facts 23:4.
5. Ogawa, J. M., Teviotdale, B. L., and Rough, D. 1983. Shot hole of stone fruits. Univ. Calif. Div. Agric. Sci. Leafl. 21363. 4 pp.
6. Wilson, E. E. 1937. The shot-hole disease of stone-fruit trees. Calif. Univ. Agric. Exp. Stn. Bull. 608:3-40.
7. Wilson, E. E. 1953. Coryneum blight of stone fruits. Pages 705-710 in: USDA Yearbook of Agricultural Plant Diseases. Government Printing Office, Washington, DC.