The Influence of European Red Mites on Intensity of Alternaria Blotch of Apple and Fruit Quality and Yield

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ABSTRACT

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Two levels of Alternaria blotch (*Alternaria mali*) intensity and three levels of European red mite (*Panonychus ulmi*) populations were established to study the possible effect of an interaction between mite feeding and fungal infection on disease intensity and fruit quality and yield of apples (*Malus* × *domestica* cv. Delicious). The effect of mite feeding on disease and yield was most apparent in 1991, when disease severity and levels of mite infestations were higher than in 1992 and 1993. Disease severity was increased with increased mite densities in more instances than it was with defoliation and fruit drop. Fruit quality characteristics such as diameter, weight, firmness, commercial color, and soluble solids content were not affected to a great extent by increased mite densities although soluble solids content was reduced in about one-half of the tests with a high intensity of Alternaria blotch.

Alternaria blotch has become a serious disease of strains of Delicious apples (*Malus* × *domestica* Borkh.) in the southeastern United States. The disease is caused by *Alternaria mali* Roberts, which was first identified in 1924 in the United States (11) but was not considered to be a pathogen at that time. Currently, Alternaria blotch is the most important disease of apple in Japan and other Asian countries (6). After the disease was first confirmed in North Carolina in 1988, a survey of major apple-growing regions in the western part of the state was conducted to determine the distribution, incidence, and severity of the disease (6). High populations of European red mites, *Panonychus ulmi* (Koch), also were observed in many orchards severely affected by Alternaria blotch. Based on this observation, and a recent study that found that feeding of leaf miners (*Lyriomyza trifolii* Burgess, Diptera: Agromyzidae) increased infection of muskmelon by *Alternaria cucumerina* (Ellis & Everh.) J. A. Elliot (5), we hypothesized that mite populations may be affecting the intensity (severity and defoliation) of Alternaria blotch on apple leaves.

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Other studies have investigated the effect of European red mite on apple leaves, vegetative growth, flowering, and yield (2, 3,4,7,9). Beers and Hull (3) reported that shoot length, leaf number, and trunk girth were not affected greatly by mite damage but defoliation was increased in Golden Delicious. Flowering was reduced in Golden Delicious and Stayman but not in Delicious. According to Avery and Briggs (2), mites feed on both upper and lower leaf surfaces and damage mesophyll and bundle sheath cells, resulting in bronzing of leaves.

The objective of this study was to determine if there is an interaction between *A. mali* and *P. ulmi*, and, if so, to quantify its influence on disease intensity, fruit quality, and yield parameters. A preliminary report has been published (7).

MATERIALS AND METHODS

Locations of experimental plots. Experimental plots were established in two orchards in Henderson County in western North Carolina (McKay and Staton orchards). The McKay orchard had a 5-year history (1989 to 1993) of severe Alternaria blotch, with defoliation up to 60% (N. Filajdić and T. B. Sutton, *unpublished*). The European red mite population was very high during the same period, averaging more than 3,000 cumulative mite days (CMD), (J. F. Walgenbach, *unpublished*). Alternaria blotch intensity in the Staton orchard was moderate from 1990 to 1992 and severe in 1993 (N. Filajdić and T. B. Sutton, *unpublished*), and the European red mite population was moderate from 1990 to 1993 (<2,000 CMD, J. W. Walgenbach, *unpublished*).

In the summer of 1991, 24 trees in a single row were used in the McKay orchard to establish two levels of Alternaria blotch intensity and three levels of European red mite density with four replications. Trees were of the cultivar Oregon Spur Delicious and were 12 years old at the initiation of the study. In 1992, the same trees were used in McKay (block 1), and the study was expanded to 24 additional trees in the same orchard (block 2). The same number of trees was used in the Staton orchard. Trees at the Staton orchard were of the cultivar Oregon Spur Delicious and were 8 years old.

1991 experiment. High and low levels of Alternaria blotch were established in the McKay orchard (block 1) with iprodione sprays (Rovral 4F, Rhone-Poulence Ag Company, Research Triangle Park, N.C.). One half of all assigned trees were sprayed with a high pressure handgun sprayer at 0.6 g a.i. per liter on a 2-week schedule beginning 28 May to 15 August. Three levels of European red mite populations were achieved using propargite (Omite 30WP, Uniroyal Chemical Company, Inc., Middlebury, Conn.) at 0.72 g a.i. per liter. The eight trees where a low mite density was intended were sprayed at 2-week intervals beginning on 28 May. Trees where a moderate mite density was desired were sprayed only when the motile mite population exceeded 25 per leaf (in weekly counts). If propargite was needed, it was applied on the same date as the propargite in the low mite density treatment. The last eight-tree group (high mite density) was not treated with propargite. Propargite was applied with a handgun sprayer in the same manner as iprodione. The experimental design was a randomized complete block with six treatments and four single-tree replications receiving the same sprays. Ten arbitrarily selected leaves per tree were taken to the laboratory, brushed with a mite-brushing machine onto the surface of greased circular glass plates and mites were counted with a dissecting scope. Mite numbers were expressed as cumulative mite days (CMD) = Σ $(((a + b) / 2) \times c) + d$ (equation 1), in which a = number of mites on a count date 1, b = number of mites on count date 2, c = the number of days between count days, and d = CMD on the previous sampling date.

Alternaria blotch severity was assessed every 3 weeks beginning 31 May and continuing through 22 August, on all leaves from 10 arbitrarily selected terminals per tree, using the lower portion of the Horsfall-Barratt scale of 0 to 5, in which 0 = no symptoms, 1 = 1 to 3% leaf area covered with lesions, 2 = 4 to 6%, 3 = 7 to 12%, 4 = 13 to 25%, and 5 = 26 to 50%. Defoliation was assessed on 4 and 24 July and 22 August by counting the number of nodes where leaves abscised and relating that number to a total number of nodes on each terminal. Percent fruit drop was assessed five times in September 1991.

Fruit quality and quantity characteristics were determined on 20 arbitrarily collected fruit from each tree at harvest on 10 September 1991. Fruit were stored at 0°C for 6 to 8 weeks before quality and quantity parameters were assessed. Fruit diameter was measured using a handheld band-size diameter (Cranston Machinery Co., Oak Grove, Oreg.) and soluble solids content was assessed with a refractometer (American Optical, Scientific Instrument Division, Buffalo, N.Y.).

1992 and 1993 experiments. The same 24 trees from the 1991 experiment were used at the McKay orchard (block 1), and the same treatments were assigned to each tree with iprodione and propargite being applied as described previously. On 21 July 1992, all trees received one application of propargite at the same rate as in the previous year. Iprodione was applied on 28 May and applications continued at 2-week intervals until 31 July 1992. Ten arbitrarily selected leaves were examined with a magnifying visor (Optivisor magnifier, Donegan Optical Company Inc., Lenexa, Kans.), and the total number of motile

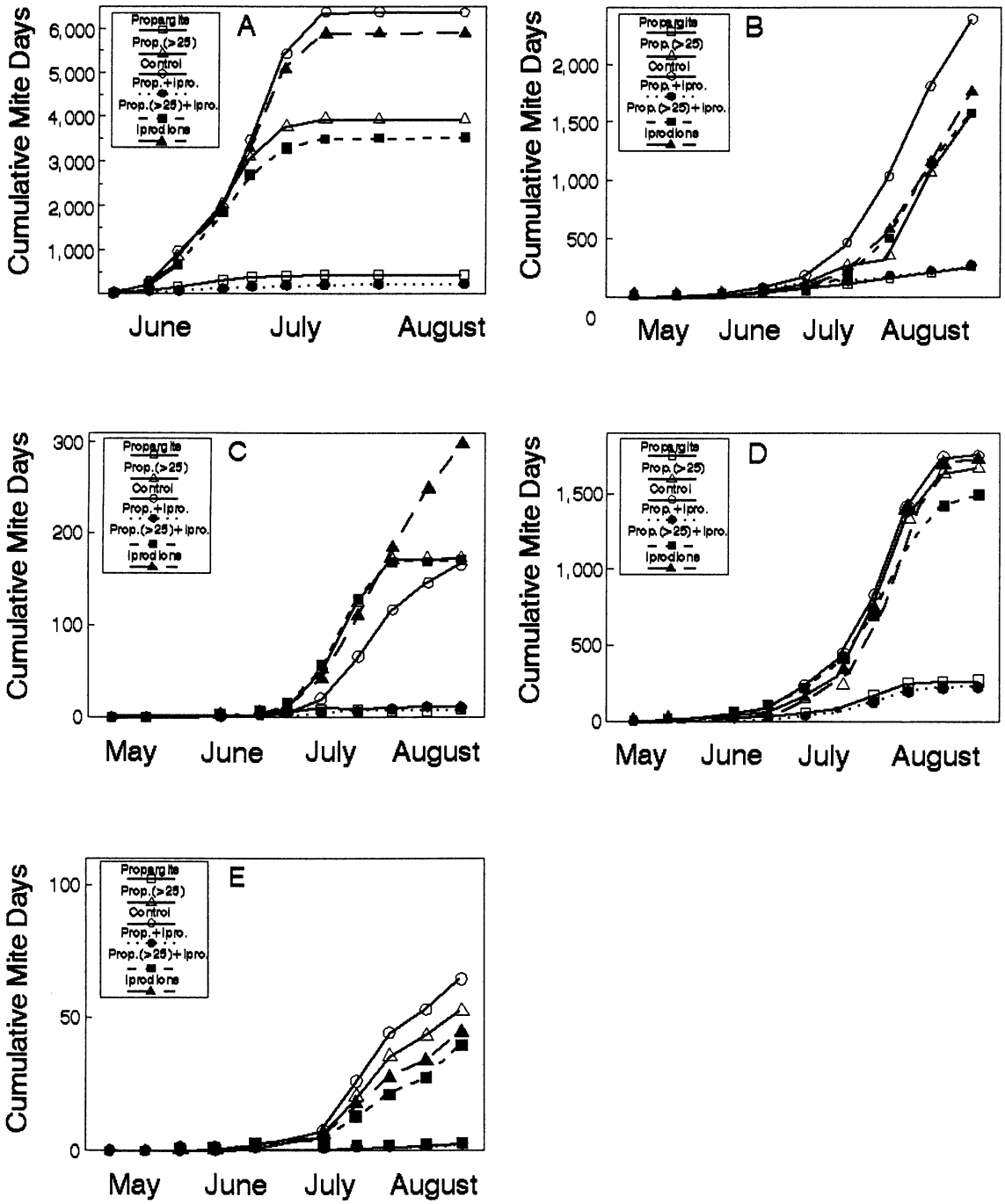

Fig. 1. Cumulative mite days (CMD) calculated by summing the product of mean number of motile European red mites per leaf between two sampling dates with number of days between those two sampling dates. **(A)** McKay 1991 (block 1), **(B)** McKay 1992 (block 2), **(C)** McKay 1993 (block 2), **(D)** Staton 1992, **(E)** Staton 1993.

mites was recorded. Mite counts were made on 5, 23, and 30 June, 15 and 23 July, and 7 and 13 August. Disease severity and defoliation were assessed on all leaves from 10 arbitrarily selected terminals/tree on 7 September 1992 and on four arbitrarily selected terminals on 14 September 1993; fruit drop was recorded on 9 September 1992, and 21 September 1993. Twenty fruit were collected arbitrarily from each tree at harvest on 10 September 1992 and 21 September 1993 for quality evaluations.

In block 2 and the Staton orchard, iprodione and propargite were applied at the same rate as in the previous year with a Swanson DA 500 speed sprayer (Durand Wayland, LaGrange, Ga.) driven at 4 km per h and with 1,379-kPa manifold pressure. Iprodione applications were made on the same 2-week schedule as in block 1. Propargite was applied on 10 June and 7 and 21 July 1992, and 2 and 21 July 1993 in the treatment where a low mite density was desired. No propargite sprays were applied in other treatments (except in the moderate mite density treatment on 28 July 1993) because the mite population was always lower than 25 mites per leaf. In the Staton orchard, propargite was applied on 6 and 16 June and 7 and 21 July only in the treatment where the low mite density was desired. The experimental design in block 2 at the McKay orchard and at the Staton orchard was a randomized split-plot.

Mite counts were made weekly beginning 29 April and continuing until 10 August as described for block 1. The mite population was expressed in the same manner as in the previous year. Alternaria blotch severity was assessed on all leaves from 10 arbitrarily selected terminals per tree on: 19 May, 2, 15, and 29 June, 14 and 30 July, 18 August, and 4 September 1992 and on all leaves from four arbitrarily selected terminals per tree on 20 May, 10 and 24 June, 8 and 22 July, 12 and 26 August, and 14 September 1993. Defoliation was assessed on the same 10 and four branches in 1992 and 1993, respectively, on the last four sampling dates in each year by counting the number of nodes where leaves were present and relating that number to the total number of leaf nodes. Defoliation was expressed in percentages. Because mite populations did not increase until late in the season, data on severity and defoliation are presented only for the last three sampling dates of each year. Fruit drop was assessed at both locations on 10 September 1992 and 21 September 1993 by counting the number of fruit on

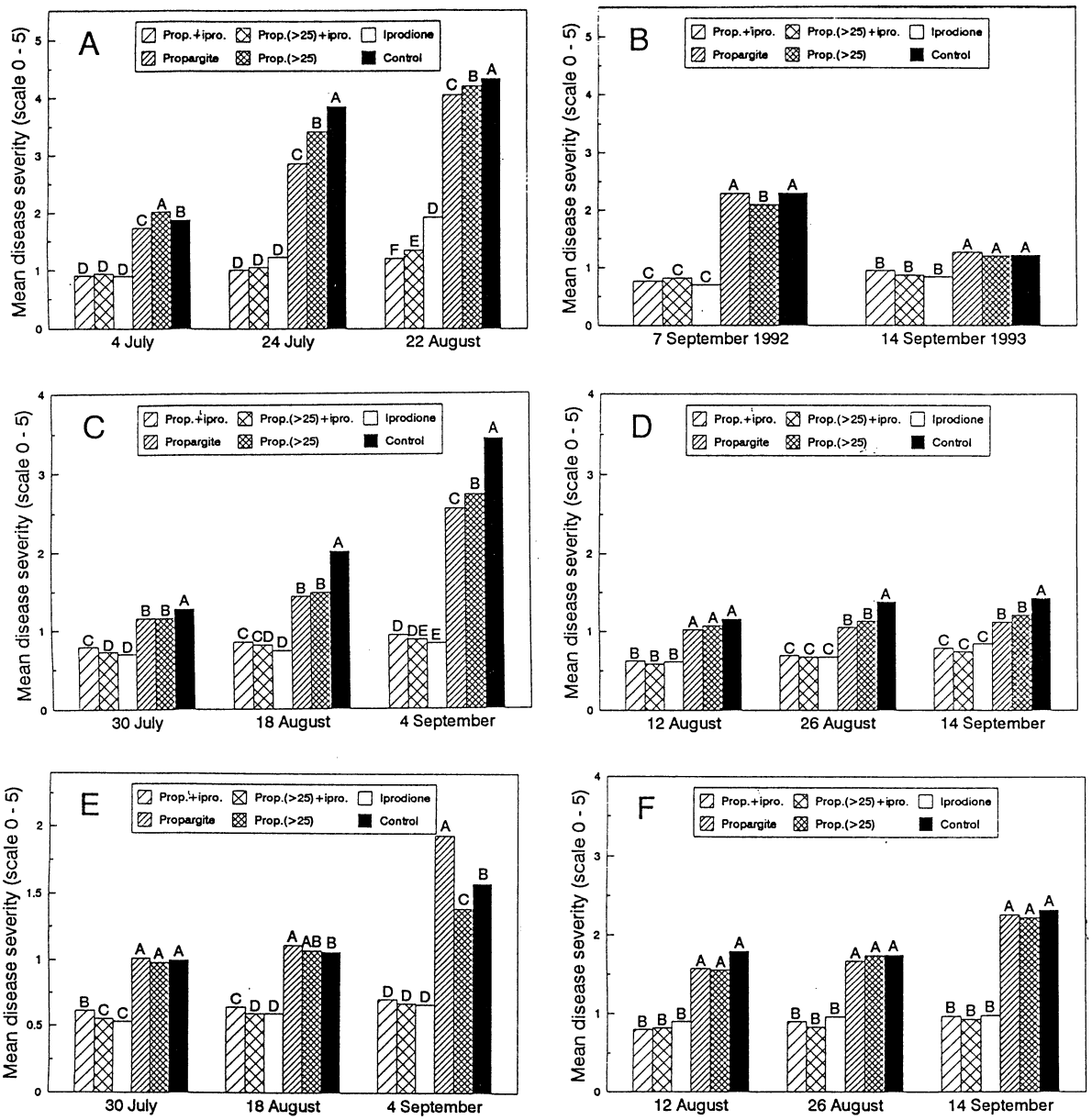

Fig. 2. Mean disease severity obtained using a lower portion of the Horsfall-Barratt scale of 0 to 5, for six treatments on three last sampling dates. **(A)** McKay 1991 (block 1), **(B)** McKay 1992 and 1993 (block 1), **(C)** McKay (block 2), 1992, **(D)** McKay (block 2), 1993, **(E)** Staton 1992, **(F)** Staton 1993.

the ground and relating that number to the total number of fruit remaining on tree. Fruit drop was also expressed as a percentage. Fruit quality and quantity characteristics again were assessed on 20 arbitrarily collected fruit at harvest on 10 September 1992 and 21 September 1993. In addition, firmness was measured with a handheld pressure tester (McKormick Co., Yakima, Wash.), and commercial color was calculated from a visual assessment of percent fruit area with any coloration (total color) and red color, using the formula CC = RC + ((TC – RC) / 2) (equation 2), in which CC = commercial color, RC = percent red color, and TC = percent total color. All fruit were weighed, and mean fruit weight (g) was calculated.

Synergistic effect of European red mites and Alternaria blotch. To measure possible synergistic effects between European red mites and *A. mali* on disease intensity, Abbott's (8) formulae were used: $E(\text{exp}) = a + b - ab$ (equation 3) and $SF = E(\text{obs}) / E(\text{exp})$ (equation 4).

These formulae were used to calculate the action of mixtures of two pesticides with independent joint action; $E(\text{exp})$ = expected control efficacy of a pesticide mixture, a and b = proportion of the population controlled by pesticides a and b, respectively, ab = proportion of the population controlled by two pesticides together, SF = synergy factor between the observed experimental efficacy of the mixture ($E(\text{obs})$) and the expected efficacy of the mixture (value of $SF > 1$ indicates synergism, $SF < 1$ indicates antagonism). In our case, $E(\text{exp})$ was defined as the expected mean disease severity and/or defoliation in the treatment with a high mite density and a high disease level, a = the mean disease severity and/or defoliation attributed to mites (severity and/or defoliation in the treatment with a high mite density and a low disease level expressed as the proportion of severity and/or defoliation recorded in the treatment with a high mite density and a high disease level), b = mean disease severity and/or defoliation attributed to *A. mali* (mean disease severity and/or defoliation in the treatment with a low mite density and a high disease level expressed as the proportion of severity and/or defoliation recorded in the treatment with a high mite density and a high disease level), and $E(\text{obs})$ = actual mean disease severity and/or defoliation in the treatment with a high mite density and a high disease level.

Statistical analysis. Disease severity and defoliation, arthropod data, and fruit quality and yield were analyzed using the

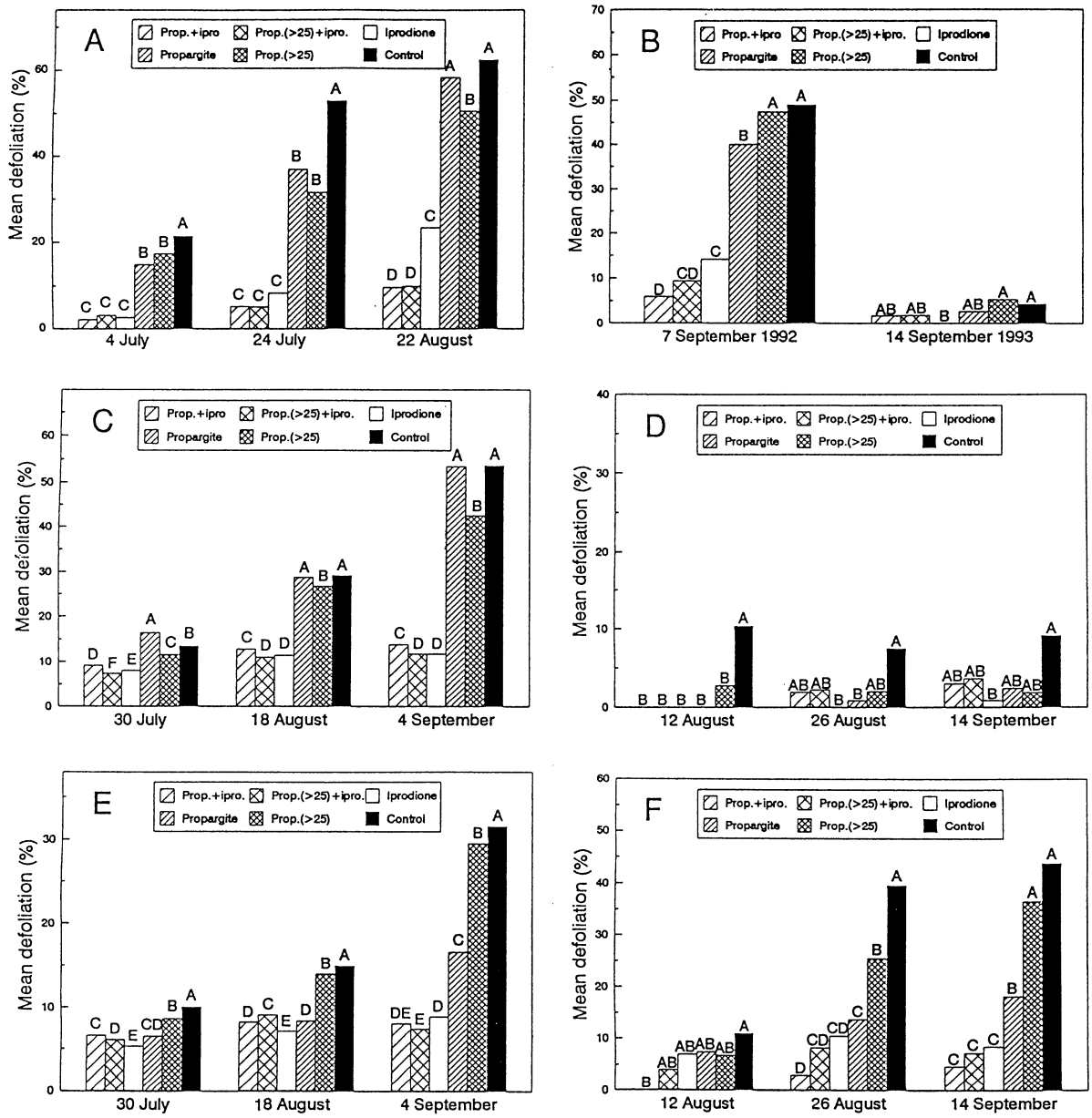

Fig. 3. Mean percent defoliation for six treatments on three last sampling dates. **(A)** McKay 1991 (block 1), **(B)** McKay 1992 and 1993 (block 1), **(C)** McKay (block 2), 1992, **(D)** McKay (block 2), 1993, **(E)** Staton 1992, **(F)** Staton 1993.

PROC GLM procedure with SAS (SAS Institute Inc., Cary, N.C.). The effect of mite densities on disease intensity and fruit quality and yield was not examined with regression analysis because mite numbers were recorded on dates different from those for disease assessment and mite sampling ended approximately 1 month before disease intensity assessment.

RESULTS

European red mite populations. Mite populations in control plots were high at McKay in 1991 but moderate or low in other years and locations (Fig. 1). At McKay in 1991, mite populations increased from 5 June to a peak on 27 June in the low mite density treatments (14.8 mites per leaf), and 3 July in the high mite density treatments (328.1 mites per leaf).

In 1992, there were no differences among treatments in number of European red mites on any sampling date at the McKay orchard in block 1. In block 2, the number of mites in the treatment with low disease level where a high mite density was desired, did not differ significantly from treatments with a moderate mite density (Fig. 1B). Mite populations steadily increased from 29 June, to a peak on 27 July (12.6 mites per leaf) in the high mite density treatments, and 1 mite per leaf in the low mite density treatments. At Staton, there was no significant difference between treatments in which moderate and high mite densities were desired (Fig. 1D). The peak density was reached on 20 July with 10.5 mites per leaf in the high density treatments, and two mites per leaf in the low density treatments.

In 1993 there were no differences among treatments in number of European red mites on any sampling date at the McKay orchard in block 1. Mite populations in block 2 and at Staton were significantly lower compared with the previous year (Fig. 1C,E). Number of mites in the treatment with high disease level in which the high mite density was desired did not differ from treatments with moderate mite densities. Mite populations increased at both locations at approximately the same time as in 1992 (Fig. 1C,E).

Disease severity. Disease severity in treatments with low disease levels was not affected greatly by increasing mite densities during the 3-year study. In 1991, disease severity increased with increasing mite densities only on the last sampling date at McKay (block 1), (Fig. 2A). In 1992 and 1993, there was either no effect—Staton, 4 September 1992, (Fig. 2E), McKay, block 2 and Staton 1993, (Fig. 2D,F)—or there was a slight decrease in severity with increasing mite densities among certain treatments: McKay, block 2, 1992, (Fig. 2C), and Staton, 30 July, 18 August 1992, (Fig. 2E).

In treatments with a high disease level, severity of disease increased with increasing mite densities at McKay block 1, 1991 (24 July, 22 August) and McKay block 2 (4 September, 1992), (Fig. 2A,C). At McKay block 2 in 1992 on 30 July and 18 August, and McKay block 2 in 1993 on 26 August and 14 September, severity was increased only at the high mite density treatments (Fig. 2C,D). On other dates there was either no effect or a slight decrease in severity in some treatments compared with the treatments with low mite densities.

Defoliation. Defoliation also was not affected greatly with increasing mite densities in treatments with low disease. There was either no effect (McKay block 1, 4 and 24 July 1991, [Fig. 3A], McKay block 2, 1993 [Fig. 3D], Staton 1993, [Fig. 3F]), or there was a slight decrease in defoliation with increasing mite densities (McKay block 2 1992 [Fig. 3C], Staton 30 July 1992 [Fig. 3E]).

In treatments with a high disease, defoliation increased with increasing mite densities at Staton 1992 (Fig. 3E), and Staton 1993 on 26 August and 14 September (Fig. 3F). At McKay block 1 on 4 and 24 July 1991 (Fig. 3A), and McKay on 12 August 1993 (Fig. 3D) defoliation increased only in the treatment with a high mite density. On other sampling dates, there was either no effect or a slight decrease in defoliation in treatments with moderate mite densities (McKay, block 2 in 1992 and 14 September 1993, and Staton on 12 August 1993).

Table 1. Percent fruit drop associated with three levels of mite densities and two levels of Alternaria blotch at different locations and years

Location	Year	Treatment	Percent fruit drop[x]
McKay (block 1)	1991	LD-LM[y]	6.3 c[z]
		LD-MM	11.3 bc
		LD-HM	18.8 b
		HD-LM	34.8 a
		HD-MM	36.2 a
		HD-HM	35.3 a
McKay (block 1)	1992	LD-LM	3.5 ns
		LD-MM	3.2
		LD-HM	3.3
		HD-LM	3.0
		HD-MM	3.9
		HD-HM	6.5
McKay (block 1)	1993	LD-LM	10.9 ns
		LD-MM	8.7
		LD-HM	9.9
		HD-LM	10.9
		HD-MM	10.2
		HD-HM	8.7
McKay (block 2)	1992	LD-LM	6.3 c
		LD-MM	4.9 c
		LD-HM	15.1 bc
		HD-LM	22.1 b
		HD-MM	23.3 ab
		HD-HM	38.6 a
McKay (block 2)	1993	LD-LM	7.6 ns
		LD-MM	9.6
		LD-HM	7.2
		HD-LM	8.9
		HD-MM	10.9
		HD-HM	9.7
Staton	1992	LD-LM	9.0 c
		LD-MM	8.4 c
		LD-HM	25.8 bc
		HD-LM	23.3 bc
		HD-MM	46.5 ab
		HD-HM	57.0 a
Staton	1993	LD-LM	28.5 ns
		LD-MM	21.3
		LD-HM	22.9
		HD-LM	41.3
		HD-MM	45.5
		HD-HM	43.2

[x] Percent fruit drop recorded on 9 September 1991, 9 September 1992 at McKay (block 1), and 21 September 1992 at McKay (block 2) and Staton, and 21 September 1993 at McKay (blocks 1 and 2) and Staton.

[y] The abbreviations in treatment column mean: LD = low disease level, LM = low mite density, MM = moderate mite density, HM = high mite density, and HD = high disease level.

[z] Numbers followed by different letters are significantly different ($P = 0.05$), according to the Waller-Duncan k-ratio t test.

Fruit drop at harvest. In 1991, there was no difference in the amount of fruit drop among treatments with a high disease level. Among treatments with low disease, fruit drop increased with increasing mite densities; fruit drop in the treatments with a high mite density was significantly greater than that in treatments with a low mite density (Table 1).

In 1992, at McKay in block 1, there were no significant differences among treatments (Table 1). In block 2, greater fruit drop was recorded in the treatment with a high mite density than in the treatment with a low mite density among treatments with high disease. In treatments with low disease, fruit drop was greater in the treatment with the high mite density, but it was not significantly different from treatments with other mite densities (P = 0.05). Results were similar at the Staton orchard. In 1993, no differences were found among treatments in either of the two locations.

Fruit quality. There were some differences in fruit quality variables among treatments that were not associated with significant differences in mite levels during the season (Fig. 1, Table 2). For example, at McKay 1992 (block 1), there were no differences in mite levels, but there were significant differences among treatments at each disease level for all quality variables. Only those differences in quality variables associated with significant differences in mite levels are reported in the text below.

Firmness. There was no consistent effect on fruit firmness in most years and locations at either disease level except there was a slight decrease with increased mite densities at the high disease level at McKay block 2, 1992.

Commercial color. In treatments with low disease, commercial color was increased in the treatment with a moderate or high mite density compared with the treatment with a low mite density at McKay block 2 in 1992 but was decreased at high mite levels in block 2 in 1993. In treatments with high disease, commercial color decreased at the moderate and high mite densities at McKay block 2 in 1992. In other years and locations, there was no effect on commercial color.

Soluble solids content. Among treatments with low disease, soluble solids content decreased at the high mite densities at McKay 1991 and Staton in 1992. In other years and locations there was no effect. In treatments with high disease, soluble solids content decreased with increasing mite densities at McKay block 1 in 1991 and Staton in 1992. In other years and locations, soluble solids content was not affected or was less in the treatment with a low mite density (Staton 1993).

Fruit diameter. There was no effect of mite density on diameter in treatments with low disease. In treatments with high disease, fruit diameter decreased with increasing mite densities at McKay block 1 in 1991. In 1992, diameter was increased in the treatment with a moderate mite density at McKay block 2, but was decreased in the treatment with a high mite density compared with the treatment with a low mite density at McKay block 2 in 1993.

Fruit weight. There was no effect of mite density on fruit weight at low disease levels. In treatments with high disease there was either no effect or fruit weight decreased with increasing mite densities (McKay block 1 in 1991). At McKay block 2 in 1993, fruit weight was less in the treatment with a high mite density than in the treatment with a low mite density. There was no effect on fruit weight in other years or locations.

Yield. Yield was not affected by mite feeding in either year or location at low disease levels. In treatments with high disease, yield decreased with increasing mite densities at McKay block 1 in 1991 and block 2 in 1993 (Fig. 4A,C). At Staton in 1993, there was a decrease in yield with increasing mite densities, but differences were not significant (Fig. 4E).

Synergistic effect of European red mites and Alternaria blotch. The synergy factor for disease severity was slightly greater than 1, in four of five cases, and less than 1 in one instance (Table 3). In four of five cases, the synergy factor for defoliation was greater than one.

Table 2. Fruit quality and yield characteristics associated with three levels of mite densities and two levels of Alternaria blotch at different locations and years

	Treatment[y]					
Fruit characteristics	**LM-LD**	**MM-LD**	**HM-LD**	**LM-HD**	**MM-HD**	**HM-HD**
McKay 1991						
Diameter (cm)	7.0 a[z]	7.0 a	6.7 ab	6.9 a	6.4 bc	6.3 c
Soluble solids (%)	11.4 a	11.5 a	10.7 b	11.4 a	10.2 b	9.1 c
Weight (g)	154.0 a	149.5 a	131.8 ab	141.0 a	116.3 b	108.3 c
McKay 1992 (block 1)						
Diameter (cm)	7.1 a	7.1 a	6.8 b	7.1 a	6.6 c	6.2 d
Firmness (N/cm^2)	75.1 c	74.6 c	81.7 a	73.0 c	78.9 b	81.2 ab
Commercial color	45.5 c	47.2 b	47.8 ab	47.4 ab	48.3 a	48.2 ab
Soluble solids (%)	13.5 ab	13.3 c	13.0 d	13.0 d	13.6 a	13.3 bc
Weight (g)	171.4 a	166.9 a	145.5 bc	166.3 ab	133.8 cd	113.7 d
McKay 1992 (block 2)						
Diameter (cm)	6.7 a	6.6 a	6.7 a	6.3 b	6.6 a	6.4 b
Firmness (N/cm^2)	78.2 a	78.8 a	75.5 b	74.6 b	70.2 c	70.9 c
Commercial color	41.3 d	47.0 ab	47.3 ab	47.8 a	45.8 bc	44.6 c
Soluble solids (%)	12.9 a	12.4 b	12.9 a	13.0 a	11.9 c	11.8 c
Weight (g)	131.1 ns	133.3	143.0	119.2	129.3	120.1
McKay 1993 (block 2)						
Diameter (cm)	6.7 ab	6.6 ab	6.6 ab	6.6 ab	6.5 bc	6.4 c
Firmness (N/cm^2)	68.4 a	70.1 a	68.3 a	69.0 a	65.2 b	69.7 a
Commercial color	46.1 ab	47.9 a	43.8 cd	45.7 bc	43.6 d	44.1 bcd
Soluble solids (%)	12.3 b	12.1 b	12.2 b	12.2 b	11.8 c	12.7 a
Weight (g)	124.4 a	116.7 abc	120.6 ab	120.2 ab	114.4 bc	112.0 c
Staton 1992						
Diameter (cm)	7.1	7.2	7.0	7.0	7.0	7.0 ns
Firmness (N/cm^2)	74.5 a	71.4 bc	73.4 a	72.9 ab	70.4 c	73.9 a
Commercial color	51.5 a	48.8 c	50.5 ab	49.3 bc	49.3 bc	48.6 c
Soluble solids (%)	13.0 a	12.4 b	12.5 b	13.0 a	11.7 c	12.4 b
Weight (g)	159.3	172.5	156.6	161.2	175.4	156.5 ns
Staton 1993						
Diameter (cm)	7.0	7.0	7.0	7.3	7.1	7.1 ns
Firmness (N/cm^2)	68.5 a	66.9 ab	67.7 ab	66.3 b	66.7 ab	68.0 ab
Commercial color	47.9	48.0	47.8	47.1	48.4	47.8 ns
Soluble solids (%)	12.8 a	12.7 a	12.8 a	12.3 b	12.6 ab	12.7 a
Weight (g)	150.4	159.3	159.1	155.4	161.0	159.5 ns

[y] The abbreviations in treatment column: LD = low disease level, LM = low mite density, MM = moderate mite density, HM = high mite density, and HD = high disease level.

[z] Numbers followed by different letters in rows are significantly different (P = 0.05), according to the Waller-Duncan k-ratio t test.

Table 3. Synergistic effect of European red mites and Alternaria blotch on disease level as calculated from Abbott's formula

Location/year	**Disease component**	***SF*[z]**
McKay 1991 (block 1)	Severity	1.02
	Defoliation	1.04
McKay 1992 (block 2)	Severity	1.19
	Defoliation	1.00
McKay 1993 (block 2)	Severity	1.10
	Defoliation	2.94
Staton 1992	Severity	0.88
	Defoliation	1.52
Staton 1993	Severity	1.04
	Defoliation	1.92

[z] Synergy factor between observed experimental efficacy and expected efficacy. Values of SF > 1 indicate synergism, < 1 = no effect, 0 = antagonism.

DISCUSSION

In this study, the severity of Alternaria blotch and defoliation generally increased with increasing mite populations. Yield also was reduced at McKay in 1991 and 1993, years when there was a full crop. In addition, some fruit quality parameters were affected negatively. Premature fruit drop was more closely associated with high disease than with increasing mite populations.

Our study also provides evidence that mites act synergistically with *A. mali* to increase defoliation. Abbott's formula (8), adapted to help us investigate this possibility, indicated that effects of mites in the presence of Alternaria blotch on defoliation were greater than just additive effects. If *P. ulmi* interacts synergistically with *A. mali*, mite populations will need to be maintained at a lower level than if effects of *P. ulmi* and *A. mali* are independent of each other.

The synergistic effect of *A. mali* and *P. ulmi* on yield and fruit quality characteristics was more apparent in 1991 than in 1992 and 1993. One possible reason is that the overall disease and level of mite populations were higher in 1991 than in 1992 and 1993. The mite population increased earlier in 1991 and was approximately three times as high as in 1992, and 20 times as high as in 1993. Light and Ludlam (9) found that feeding by European red mites affected yield only when there was an early-season peak of infestation. An additional factor that contributed to a minimal effect of disease and mites on yield in 1992 was the early season freeze that greatly reduced the crop load. Ames et al. (1) reported that with light fruit loads, heavy mite feeding had a negligible effect on fruit quality, but the effect increased with increasing fruit load. With a greatly reduced crop in 1992, and low disease and mite populations early in the 1992 and 1993 growing seasons in our study, trees were probably able to produce sufficient energy for normal development of fruit. These results are not unusual, i.e., Light and Ludlam (9) found yield decreases caused by *P. ulmi* in only 2 out of 5 years, which also coincided with peak mite populations before mid-July.

In 1992 and 1993, at both locations, there was a greater effect of the interaction on disease severity and defoliation in treatments with high than in treatments with low disease levels. This indicates that, possibly, a stress threshold needs to be attained before fruit quality characteristics and yield are affected. This threshold probably was not achieved in treatments with low disease.

Most fruit quality characteristics were not affected strongly in this study. Soluble solids content, an important horticultural

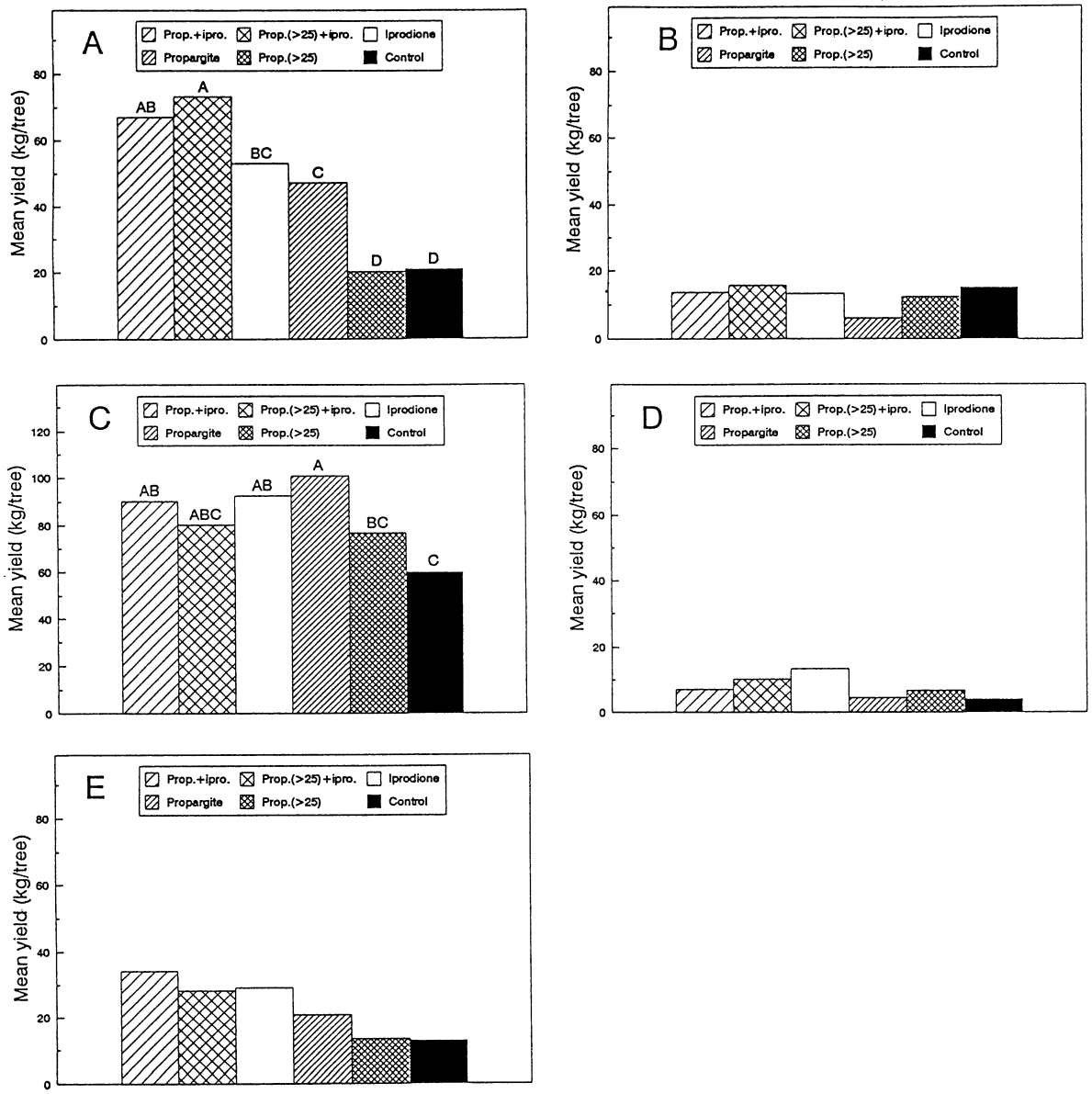

Fig. 4. Yield calculated by multiplying the mean number of fruit on a tree at harvest by mean fruit weight. **(A)** McKay (block 1), 1991, **(B)** McKay (block 2), 1992, **(C)** McKay (block 2) 1993, **(D)** Staton 1992, **(E)** Staton 1993.

characteristic that determines the flavor and marketability of the fruit, was reduced in treatments with moderate and high mite densities in about one-half of the tests with high disease intensity; this is a potentially serious consequence because less flavorful fruit from affected orchards in North Carolina or other states would result in consumers avoiding fruit from those areas in preference to those from areas without the disease.

Although mite populations were much lower in 1992 than 1991 at McKay block 1, some differences were still observed in fruit quality characteristics between treatments with a low mite density and those with moderate or high densities at McKay (Table 2). Although there was no significant difference among mite levels in 1992, fruit diameter, soluable solids, and fruit weight were reduced in treatments at both disease levels that had moderate or high mite levels in 1991. This suggests that stress induced by high mite levels, disease intensity, and defoliation may have multi-year effects.

In this study we did not attempt to investigate the nature of the interaction between European red mites and *A. mali*. However, work by McKenzie et al. (10) suggests that increased penetration of conidia of *Alternaria porri* into leaves of onions occurs through areas damaged by *Thrips tabaci*. It is possible that conidia of *A. mali* penetrate through wounds on leaves caused by European red mites.

Currently there are no fungicides registered for control of *A. mali*. Consequently, many affected orchards will have disease levels similar to those in our treatments without iprodione. Based on the results of our study, it is very important to maintain low mite populations in those orchards. Although we cannot establish a specific threshold based on our studies, we believe the threshold currently used (10 mites per leaf) should not be exceeded in orchards with severe disease. This may necessitate greater attention to mite management practices during periods favorable for mite buildup. Conversely, the failure of mites to significantly affect disease severity, incidence, or fruit quality characteristics and yield when iprodione was applied, indicates that mite populations may be allowed to increase to higher levels when iprodione is used. In orchards with light to moderate disease, the current threshold should provide acceptable control.

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