Effect of Chemical Thinning Sprays on Apple Fruit Set

R.E. Byers¹ and

D.H. Carbaugh²

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Summary. Apple growers of different regions need different chemical fruit-thinning responses for thinning trees of different tree ages, cultural conditions, rootstocks, climates, and amounts of fruit removal desired. In this research, a range of chemical thinning responses was achieved by combinations of thinning materials or addition of potentiating agents. Superior oil, certain organic phosphates, and a light-absorbing agent (ferbam, a fungicide) increased the thinning of carbaryl. In addition, combinations of 50 or 200 ml 6-BA/liter + carbaryl + oil defruited 'Campbell Redchief Delicious'/M.111 trees, and 50 ml 6-BA/liter alone over-thinned in one year (however, oil or 6-BA has been shown previously to cause russet in 'Golden Delicious'). Carbaryl 50 WP and the 4L carbaryl formulations were equally effective for thinning 'Golden Delicious', 'Stayman', and 'Redspur Delicious', and did not affect fruit russet. Three days of cloudy weather is typical at least once in most seasons in the eastern United States during the fruit set period. Two days of artificial polypropylene shading (92%) (which was nearly equivalent to 3 days of cloudy weather) caused more thinning of 'Golden Delicious' and 'Stayman' than carbaryl or 10 mg NAA/liter + Tween. Shading reduced viable seed numbers about 50% for 'Golden Delicious' in fruit remaining at harvest, but chemical thinning agents (NAA or carbaryl) did not affect viable seed number.

¹*Professor of Horticulture.*

²*Agricultural Manager.*

Department of Horticulture, Agricultural Experiment Station, Virginia Polytechnic Institute and State University, Winchester, VA 22601.

Superior 'Delicious' strains of apple normally set heavy crops and are difficult to thin adequately with carbaryl (Herrera-Aguirre and Unrath, 1980; Rogers and Williams, 1977). The effectiveness of carbaryl was increased by the addition of superior spray oil (Byers, 1978; Byers et al., 1982). Rates of naphthaleneacetic acid (NAA) above 5 mg·liter⁻¹ or naphthaleneacetamide (NAD) at 50 mg·liter⁻¹ can cause high percentages of dwarfed fruit in some years (Rogers and Williams, 1977). Carbaryl plus lower rates of NAA (2 to 5 mg·liter⁻¹) gave excellent thinning in some years, but caused serious overthinning and/or dwarfed fruit in others (Rogers and Williams, 1977). Combinations of ethephon and carbaryl have been used

under a state label in North Carolina and Virginia, but no federal label exists. Ethephon has been considered very dose- and temperature-dependent; however, in Virginia, the ethephon + carbaryl combination has given good thinning in most tests (Byers et al., 1990a). Oxamyl (a systemic carbamate) at its highest insecticidal rate has given mild thinning similar to that of carbaryl (Byers et al., 1982), but no federal label exists for its use as a thinner. Carbaryl increases mite populations, probably due to the killing of mite predators. Oxamyl used as a thinner did not affect mite populations (Byers et al., 1982). Preliminary studies showed that the addition of superior oil (2.5, 5, and 10 mg·liter⁻¹) to carbaryl reduced mite populations (Horsburgh and Cobb, unpublished

data). Terbacil, a photosynthetic inhibitor, applied to the foliage at very low rates, or artificially shading (2%) the tree for 2 days, caused thinning (Byers et al., 1990a, 1990b). However, since terbacil is a very persistent herbicide, overthinning and injury were more serious than with other thinning chemicals in one test (Byers et al., 1990a).

Since certain pesticides labeled for use on apples reduce photosynthesis of apple leaves by 20% to 30% in multiple applications in the laboratory [superior oil (Ayers and Barden, 1975; Ferree and Hall, 1975; Ferree et al., 1976; Wood and Payne, 1984), ethion (Heinicke and Foott, 1966), dicofol (Sharma et al., 1977), fenvalerate (Wood and Payne, 1984), diazinon

Table 1. Effect of various chemicals on 'Campbell Redchief Delicious' apple fruit set and photosynthesis (1987).

Treatment ^{a,y}	Active ingredient (per liter)	Fruit/cm ² of limb cross-sectional area (+52 days AFB)	Photosynthesis (mg CO ₂ /dm per h, days after application)		Spur shoot length (cm)	No. spurs/cm length of shoot	Return bloom 1988 (% spurs flowering) ^w
			+1	+5			
1) Control		2.59 a ^x	21 a	24 a	2.47 c	0.29 a	9.2 c
2) Hand-thinned (+52 days AFB)		1.84 ab			2.64 c	0.27 a	9.8 c
3) Oil	2.5 ml	2.56 a					24.3
4) Oil	10.0 ml	2.45 a	21 a	25 a			7.2 c
5) Carbaryl 50 WP	900 mg	0.95 cd					76.7 a
6) Carbaryl 50 WP + oil	900 mg 2.5 ml	0.90 cd			2.92 c	0.30 a	69.2 a
7) Carbaryl 50 WP + oil	900 mg 10.0 ml	0.78 de					49.2 ab
8) Carbaryl 50 WP + Ethion 4 EC	900 mg 1160 mg	0.58 e			3.97 c	0.28 a	72.5 a
9) Carbaryl 50 WP + Ethion 4 EC + oil	900 mg 1160 mg 10.0 ml	0.56 e	21 a	24 a			81.3 a
10) Carbaryl 50 WP + oil + Ethion 4 EC + Vapor Gard	900 mg 10.0 ml 1160 mg 20.0 ml	0.40 e					59.2 ab
11) Carbaryl 50 WP + Diazinon 50WP	900 mg 1250 mg	0.69 e					77.5 a
12) Terbacil 80 WP + X-77	50 mg 1.25 ml	0.28 e	1 b	13 b			63.3 a
13) 6-BA + X-77	50 mg 1.25 ml	1.64 bc			3.66 c	0.32 a	25.8 c
14) 6-BA + X-77	200 mg 1.25 ml	0.20 e			9.95 b	0.31 a	32.5 bc
15) 6-BA + oil	50 mg 10.0 ml	0.06 e			10.47 ab	0.30 a	11.3 c
16) 6-BA + Carbaryl 50 WP + oil	200 mg 900 mg 10.0 ml	0.01 e			12.71 a	0.29 a	31.7 bc

^aFull bloom occurred 1 May 1987.

^yFruit size was 8.98 ± 0.35 mm on 13 May 1987 (FB + 12 days).

^xMean separation within columns by Duncan's multiple range test, 5% level.

^wReturn bloom was a visual estimate of the percentage of spurs flowering at bloom. Data were transformed to arcsin of the square root of the percentage before analysis.

(Heinicke and Foott, 1966), and other organic phosphates (Ayers and Barden, 1975; Ferree and Hall, 1978, Pickett et al., 1952)], combinations of these could potentiate thinning by carbaryl.

The general objective of this research was to identify combinations of chemicals that would give a range of thinning responses from no thinning to defruiting young spur 'Delicious' trees so that a grower could choose a combination to fit a particular thinning need. The specific objectives were to: 1) screen certain pesticides that inhibit photosynthesis for their potentiation of carbaryl for thinning, 2) evaluate 6-BA and its combinations with carbaryl and/or 70-sec superior oil for thinning, 3) compare the 50 WP and 4L formulations of carbaryl, and 4) evaluate other chemicals as potential thinning agents.

Materials and Methods

Experiment 1. In 1987, 96 six-year-old 'Campbell Redchief Delicious'/MM.111 trees were selected for uniform flowering at bloom and were blocked according to row and terrain into six blocks for the 16 treatments listed in Table 1. Chemicals were applied with a hand-held pressurized sprayer using ≈ 2.5 liter/tree. Two limbs per tree were tagged near the trunk before treatment. At the point where limbs were tagged, limb circumference was measured. Fruit numbers per tree were recorded after fruit drop [+52 days after full bloom (AFB)] and expressed as fruit/cm² of limb cross-sectional area (LCSA) using methods described previously (Byers et al., 1990a, 1990b, 1991).

Net photosynthesis (Pn) was measured in the field with a portable ADC LCA-2 infrared CO₂ analyzer equipped with a Parkinson leafchamber (Analytical Development Co., Ltd., supplied by P.K. Morgan Instruments, Inc., 2 Dundee PK 'Level 1', Andover, Mass.) that exposed 6.25 cm² of leaf to sunlight. Only bright, cloudless days were chosen for Pn measurements (Byers et al., 1990b). Measurements were recorded between 10:00 AM and 1:00 PM consecutively by block. Photosynthesis of three leaves on each of two trees for each treatment was measured 1 and 5 days after treatment (+13 and +17 days AFB).

The following spring, two 2-year-old scaffold limbs on each tree were selected for measuring spur numbers

and spur lengths. In 1988, return bloom was estimated visually as the percentage of spurs flowering at full bloom for each tree.

Experiment 2. In 1988, 96 seven-year-old 'Campbell Redchief Delicious'/M.111 trees were selected for uniform flowering at bloom and were blocked according to row and terrain into six blocks for the 16 treatments listed in Table 2. Chemicals were applied and data collected as in Expt. 1, except fruit numbers per tree were recorded +49 days AFB.

Experiment 3. In 1989, 96 five-year-old 'Redspur Delicious'/M.26 trees were selected for uniform flowering and were blocked according to row

and terrain into six blocks for the 15 treatments listed in Table 3. Chemicals were applied with a hand-held pressurized sprayer using ≈ 2 liter/tree. Trees were tagged on the trunk before treatment. Fruit numbers per tree were recorded after fruit drop (+55 days AFB) and expressed as fruit/cm² of trunk cross-sectional area (TCSA) using methods described previously (Byers et al., 1990a, 1990b, 1991). Near harvest, a representative lo-fruit sample was harvested from each tree. For each fruit, fruit diameter was measured with a band sizer, red color was estimated visually as the percentage of the fruit surface showing red, and firmness of each fruit was measured

Table 2. *Effect of various chemicals on 'Campbell Redchief Delicious'/M.111 apple fruit set (1988).*

Treatment ^a	Active ingredient (per liter)	Fruit/cm ² of limb cross-sectional area (+49 days AFB)
1) Control		6.11 b [*]
2) Hand-thinned (+49 days AFB)		3.57 cd
3) Carbaryl 50 WP	900 mg	3.09 c-e
4) Carbaryl 50 WP + oil	900 mg 2.5 ml	2.07 ef
5) Carbaryl 50 WP + oil	900 mg 10.0 ml	1.41 f-h
6) Carbaryl 50 WP + Ethion 4 EC + oil	900 mg 2.5 ml 10.0 ml	1.48 f-h
7) Carbaryl 50 WP + Ethion 4 EC + oil	900 mg 2.5 ml 10.0 ml	1.43 f-h
8) Carbaryl 50 WP + ferbam 50 WP + oil	900 mg 12,550 mg 10.0 ml	0.46 hi
9) Ferbam 50 WP	12,550 mg	3.83 cd
10) Carbaryl 50 WP + oil	900 mg 10.0 ml	1.66 fg
11) 6-BA	50 mg	4.16 c
12) 6-BA + oil	50 mg 10.0 ml	2.87 de
13) 6-BA + Carbaryl 50 WP + oil	50 mg 900 mg 10.0 ml	0.42 hi
14) 6-BA + Carbaryl 50 WP + oil	100 mg 900 mg 10.0 ml	0.16 i
15) 6-BA + Carbaryl 50 WP + Tween	50 mg 900 mg 1.3 ml	0.84 g-i
16) 6-BA + GA ₄₊₇ (Promalin)	200 mg 200 mg	8.42 a

^aFull bloom occurred 22 Apr. 1988.

^bFruit size was 11 mm on 13 May 1988 (FB + 21 days).

^cMean separation within columns by Duncan's multiple range test, 5% level.

Table 3. *Effect of various chemicals on fruit thinning of 'Redspur Delicious'/M.26 (1989).*

Treatment ^{a,y}	Active ingredient (per liter)	Fruit/cm ² of trunk cross-sectional area (+55 days AFB)	Fruit diam (cm)	Percent red color	Side russet rating ^x	Firmness (N)	Return bloom (% spurs flowering) ^w
1) Control	---	8.13 ab ^y	6.45 hi	73 a	0.8 de	83 a	0 f
2) Carbaryl 50 WP	900 mg	5.32 c	7.24 b-e	68 ab	1.5 c	78 b	62 cd
3) Carbaryl 4L	900 mg	4.92 c	7.11 c-f	73 a	1.3 c-e	79 b	63 cd
4) Carbaryl 50 WP + oil	900 mg 10 ml	1.85 ef	7.54 bc	67 ab	1.5 c		86 ab
5) Carbaryl 4L + oil	900 mg 10 ml	2.29 de	7.19 b-f	60 a-c	0.7 e		80 cb
6) Carbaryl 50 WP + 6-BA + oil	900 mg 50 mg 10 ml	1.37 ef	7.62 b	53 b-d	1.3 cd		93 a
7) Carbaryl 4L + 6-BA + oil	900 mg 50 mg 10 ml	1.83 ef	7.48 b-d	56 a-c	0.4 e		92 ab
8) 6-BA	50 mg	7.71 b	6.78 e-h	48 cd	0.8 de	82 a	1 f
9) 6-BA + oil	50 mg 10 ml	3.85 cd	7.26 b-d	55 bc	0.8 de	79 b	45 de
10) Vydate 2L	600 mg	4.96 c	7.00 d-g	57 a-c	1.3 cd	82 a	45 de
11) Vydate 2L + 6-BA + oil	600 mg 50 mg 10 ml	0.98 ef	7.41 b-d	37 d	2.7 b		91 ab
12) Harmony	10 mg	7.42 b	6.72 g-i	50 cd	0.8 de		8 f
13) RPA 86177 + Exp 80033A	2.4 g 1.25 ml	0.28 f	8.05 a	43 cd	1.6 c		42 e
14) RPA 86177 + Exp 80033A + Carbaryl + oil	2.4 g 1.25 ml 900 mg 10 ml	0.04 f	7.19 b-f	45 cd	5.0 a		48 de
15) Hand-thinned (+55 days AFB)		5.63 c	6.62 g-i	53 b-d	0.7 e	83 a	0 f

^aFull bloom occurred 25 Apr. 1989.^yTreatment were applied 25 May 1989-30 days AFB, when fruit diameter was 15 mm.^xSide russet rating: 0 = lenticel enlargement; 2 = lenticel enlargement and some russet between lenticels; 3 = lenticel enlargement and slightly raised to touch, moderate to heavy russet between lenticels; 4 = lenticel enlargement and moderately raised to touch and moderate to heavy russet between lenticels; 5 = lenticel enlargement and heavily raised to touch and heavy russet between lenticels.^wReturn bloom was a visual estimate of the percentage of spurs flowering at bloom. Data were transformed to arcsin of the square root of the percentage before analysis.^yMean separation within columns by Duncan's multiple range test, 5% level.

on two sides with a McCormick penetrometer (Yakima, Wash.) with a 11.1-mm tip. Fruit finish was rated from 0 to 5 as follows: 0 = no lenticel enlargement; 1 = lenticel enlargement; 2 = lenticel enlargement and some russet between lenticels; 3 = lenticel enlargement and slightly raised to touch, moderate to heavy russet between lenticels; 4 = lenticel enlargement and moderately raised to touch and moderate to heavy russet between lenticels; 5 = lenticel enlargement and heavily raised to touch and heavy russet between lenticels. In 1990, return bloom was estimated visually as the percentage of spurs flowering at full bloom for each tree.

Experiment 4. In 1989, 60 five-year-old 'Golden Delicious'/M.26 trees trained to a three-wire trellis were se-

lected for uniform flowering and were blocked according to row and terrain into six blocks for the 10 treatments listed in Table 4. Trees were tagged, chemicals and/or artificial shade were applied, and data taken as in Expt. 3, except fruit numbers were taken +50 days AFB. Fruit finish was rated from 0 to 5 as follows: 0 = no lenticel enlargement; 1 = small lenticel enlargement; 2 = lenticels rough and raised to touch; 3 = some russet between lenticels; 4 = considerable russet between lenticels; 5 = severe russet.

At harvest, the numbers of viable and aborted seeds were counted in each fruit of the 10-fruit sample from each tree. In 1990, return bloom was estimated visually as the percentage of spurs flowering at full bloom for each tree.

Experiment 5. In 1989, 42 five-

year-old 'Stayman'/M.9 trees were selected for uniform flowering and were blocked according to row and terrain into six blocks for the seven treatments listed in Table 5. Trees were tagged, chemicals and/or artificial shade were applied, and data taken as in Expt. 3, except fruit numbers per tree were taken +51 days AFB.

At harvest, the number of viable and aborted seeds were counted in each fruit of the 10-fruit sample from each tree. In 1990, return bloom was estimated visually as the percentage of spurs flowering at full bloom for each tree.

Experiment 6. In 1989, eight 14-year-old 'Golden Delicious'/M.9 trees were selected for uniform crop load. At 13 days AFB, four limbs on each tree were tagged and the number of

fruit on each limb was recorded. Two applications of the antitranspirant RPA 86177 treatments listed in Table 6 were applied to one limb on each tree and compared to an untreated control. The number of fruit on each limb was recounted 72 days AFB. Fruit russet was evaluated as described previously in Expt. 4.

Experiment 7. In 1990, 102 five-year-old 'Nured Delicious'/M.7 trees

were selected for uniform flowering and were blocked according to row and terrain into six blocks for the 17 treatments listed in Table 7. Trees were tagged, chemicals were applied, and data taken as in Expt. 3, except fruit numbers per tree were taken after fruit drop +53 days AFB. Photosynthesis was measured as described in Expt. 1.

In 1991, return bloom was esti-

mated visually as 1) the percentage of spurs (2 years old and older) flowering at full bloom and 2) the percentage of nodes flowering on 1-year-old wood.

Results and Discussion

Natural fruit set and chemical thinning results may be quite variable from year to year. For this reason, a control, a hand-thinned treatment, carbaryl 50 WP, and carbaryl 50 WP +

Table 4. *Effect of artificial shade and chemical thinning materials on 'Golden Delicious' /M.26 fruit set (1989).*

Treatment ^a	Active ingredient (per liter)	Fruit/cm ² of trunk cross-sectional area (+50 days AFB)	Russet rating ^b	Stem end russet ^c	Percent U.S. Grade ^d				No. viable seeds/fruit	Total (viable + aborted) seeds/fruit	Percent viable seeds	Fruit diam (cm)	Return bloom (% spurs flowering) ^e
					Extra fancy	Fancy	No. 1	Utility					
1) Control		8.65 a ^f	1.81 a	1.25 a	13 a	69 a	17 a	0 a	5.4 a	5.7 a	94 a	7.52 b	3 d
2) Shade (2 days)		3.22 de							2.5 b	6.2 a	41 b	8.08 a	84 b
3) Shade (3 days)		1.01 f											80 b
4) NAA	10 mg	4.36 cd	1.87 a	1.39 a	7 a	70 a	22 a	0 a	5.1 a	6.0 a	84 a	7.98 a	43 c
+ Tween 20	1.25 ml												
5) NAA	10 mg	0.75 f											83 b
+ Tween 20	1.25 ml												
+ shade (2 days)													
6) Carbaryl 50 WP	900 mg	5.50 b	1.73 a	1.22 a	12 a	74 a	12 a	1 a					95 ab
7) Carbaryl 50 WP	900 mg	2.14 ef											100 a
+ shade (2 days)													
8) Carbaryl 4L	900 mg	4.99 bc	1.85 a	1.47 a	10 a	68 a	22 a	0 a	5.1 a	5.8 a	86 a	8.00 a	95 ab
9) Carbaryl 4L	900 mg	1.50 f											100 a
+ shade (2 days)													
10) Hand-thinned (+50 days AFB)		6.35 b	1.74 a	1.15 a	11 a	74 a	14 a	0 a					2 d

^aFull bloom occurred on 27 Apr. 1989.

^bSpray and shade treatments began 24 May 1989–27 days AFB when fruit diameter was 15 mm.

^cMean separation within columns by Duncan's multiple range test, 5% level.

^dRating scale: 0 = no lenticel development; 1 = small lenticel enlargement; 2 = lenticel rough and raised to touch; 3 = some russet between lenticels; 4 = considerable russetting other than lenticels; 5 = severe russet.

^eRating scale: 0 = no stem end russet; 5 = severe stem end russet.

^fU.S. grade standards were equivalent to russet scale: extra fancy = 0 to 1.49; fancy = 1.50 to 2.49; U.S. no. 1 = 2.50 to 3.49; utility = 3.5 to 5.50.

^gReturn bloom was a visual estimate of the percentage of spurs flowering at bloom. Data were transferred to arcsin of the square root of the percentage before analysis

Table 5. *Effect of artificial shade and chemical thinning material on 'Stayman/M.9 fruit set (1989).*

Treatment ^a	Active ingredient (per liter)	Fruit/cm ² of trunk cross-sectional area (+51 days AFB)	Side russet rating ^b	No. viable seeds/fruit	Total (viable + aborted) seeds/fruit	Percent viable seeds/fruit	Fruit diam (cm)	Return bloom (% spurs flowering) ^c
1) Control		5.64 a ^w	1.17 b	5.6 a	5.8 a	97 a	7.70 c	51 c
2) Shade (2 days)		0.03 d						97 a
3) Shade (3 days)		0.01 d						84 ab
4) NAA	10 mg	1.62 c	1.65 a	5.5 a	6.0 a	92 a	8.43 ab	88 ab
+ Tween 20	1.25 ml							
5) Carbaryl 50 WP	900 mg	1.64 c	1.75 a	5.6 a	6.1 a	92 a	8.38 ab	95 a
6) Carbaryl 4L	900 mg	1.55 c	1.68 a	5.4 a	5.8 a	93 a	8.59 a	95 a
7) Hand-thinned (+51 days AFB)		4.16 b	1.32 b	5.9 a	6.4 a	94 a	8.26 b	79 b

^aFull bloom occurred on 25 Apr. 1989.

^bSpray and shade treatments began 24 May 1989 - 29 days AFB when fruit diameter was 14 mm.

^cSide russet rating: 0 = lenticel enlargement; 2 = lenticel enlargement and some russet between lenticel; 3 = lenticel enlargement and slightly raised to touch, moderate to heavy russet between lenticels; 4 = lenticel enlargement and moderately raised to touch and moderate to heavy russet between lenticels; 5 = lenticel enlargement and heavily raised to touch and heavy russet between lenticels.

^dMean separation within columns by Duncan+ multiple range test, 5% level.

^eReturn bloom was a visual estimate of the percentage of spurs flowering at bloom. Data were transformed to arcsin of the square root of the percentage before analysis.

Table 6. Effect of various chemicals on russet development of 'Golden Delicious' apple fruit (1989).

Treatment	Rate (per liter)	Application (days AFB)	Russet rating ^a	Stem end russet ^b	Percent U.S. Grade ^c				Percent fruit set
					Extra fancy	Fancy	No. 1	Utility	
1) Control			3.08 b ^w	2.95 b	0 a	10 a	55 bc	35 ab	52 a
2) RPA 86177	2400 mg	13, 20	2.95 b	3.05 b	0 a	7 a	69 ab	24 bc	43 a
3) RPA 86177	600 mg	13, 20	3.03 b	2.90 b	0 a	3 a	78 a	19 c	51 a
4) RPA 86177 + surfactant (Exp 80033 A)	2400 mg 1.25 ml	13, 20	3.39 a	3.33 a	0 a	0 a	45 c	55 a	9 b

^aRating scale: 0 = no lenticel development; 1 = small lenticel enlargement; 2 = lenticels rough and raised to touch; 3 = some russet between lenticels; 4 = considerable russetting other than lenticels; 5 = severe russet.

^bRating scale: 0 = no stem end russet; 5 = severe stem end russet.

^cU.S. grade standards were equivalent to russet scale: extra fancy = 0 to 1.49; fancy = 1.50 to 2.49; U.S. No. 1 = 2.50 to 3.49; utility = 3.5 to 5.0.

^wMean separation within columns by Duncan's multiple range test, 5% level.

superior oil was included in most of the experiments on spur 'Red Delicious' (Tables 1-3 and 7). For example, in 1987, natural fruit set was poor and carbaryl overthinned in relation to the control (Table 1), but in 1988 (Table 2), 1989 (Table 3), and 1990 (Table 7), fruit set was good and carbaryl was less effective as a thinner. The data from several years indicate the superior oil usually increased the effectiveness of carbaryl, 6-BA, or other chemicals (RPA 86117) better than surfactants (Tables 2, 3, and 7). The growth regulators 6-BA and ethephon appear to be very powerful, rate-dependent chemical thinners (Tables 1-3 and 7) that, when used in combination with carbaryl + oil, might be used to thin very difficult-to-thin cultivars, or spur strains of 'Red Delicious'.

Since previous work has shown the great influence of low light on fruit abscission (Byers et al., 1990a, 1990b), several treatments were included to demonstrate the potential use of photosynthetic inhibition as a mode of action alone or in combination with other thinners such as terbacil (Table 1), ferbam (Table 2), RPA 86117 (Tables 3, 6, and 7), and shading (Tables 4-7). However, it should be noted that photosynthetic inhibition is not required for a chemical thinner to induce fruit abscission.

The results of each experiment are discussed in detail below by experiment because each year's results may be different.

Experiment 1. The application of superior oil alone at 2.5 or 10 ml-liter⁻¹ (treatments 3 and 4) did not cause thinning (Table 1). The combinations of carbaryl 50 WP + ethion or + diazinon appeared to increase the thinning (treatments 5, 8, and 11) compared to carbaryl alone. Superior

oil did not appear to potentiate carbaryl 50 WP (treatments 6 and 7), as it does in most of our experiments. Terbacil 80 WP + X-77 caused fruit-thinning by inhibiting photosynthesis (treatment 12), as has been determined previously (Byers et al., 1990b). Superior oil or carbaryl + ethion + oil did not appear to cause photosynthetic inhibition, but the combination caused severe thinning. The 200 mg 6-BA/liter + X-77 treatment was more effective than 50 mg-liter⁻¹ (treatments 13 and 14), and thus the thinning response was considered rate-dependent. Superior oil was more effective than X-77 for potentiating 6-BA (treatments 13 and 15). The combinations of 200 mg 6-BA/liter + X-77 (treatment 14), 50 mg 6-BA/liter + oil (treatment 15), or 200 mg 6-BA/liter + carbaryl + oil (treatment 16) were very effective for defruiting young trees and initiating side branches on annual growth. The 50 mg 6-BA/liter + X-77 did not induce the initiation of side branches and was less effective as a thinner than 200 mg 6-BA/liter + X-77 or 50 mg 6-BA/liter + oil.

Treatments that thinned caused a better return bloom in 1988. However, treatments that contained 6-BA did not appear to induce as good a return bloom as expected (treatments 13-16), considering that the trees were thinned more than other carbaryl-sprayed trees.

Experiment 2. The addition of 10 ml superior oil/liter to carbaryl increased thinning (treatments 3 and 5); however, no further increase in thinning occurred with the addition of ethion, ethion + CaCl₂, or CaCl₂ (treatments 6, 7, and 10) (Table 2). Ferbam (ferbam sprayed on a glass plate absorbed five times more photosynthetic active radiation than carbon black) caused fruit

thinning (treatment 9) and appeared to increase the thinning by carbaryl + oil (treatments 4 and 8). The addition of superior oil to 50 mg 6-BA/liter (treatments 11 and 12) increased the thinning, and the addition of carbaryl (treatment 13) to this combination increased thinning further. The addition of Tween 20 was as effective as oil for potentiating 6-BA (treatments 13 and 15). The combination of 100 mg 6-BA/liter + carbaryl + oil nearly defruited these trees (treatment 14). Although the combination of 100 mg 6-BA/liter + 100 mg GA₄₊₇/liter was reported to cause thinning when applied in bloom (Stembridge and Morrell, 1972), 200 mg 6-BA/liter + 200 mg GA₄₊₇/liter applied at this timing increased fruit set (treatment 16). Since GA₄₊₇ is known to increase fruit set, the use of promalin as a thinner does not make much sense. Since an extreme drought in 1988 caused very poor return bloom in 1989, even on defruited trees, bloom data are not presented.

Experiment 3. Carbaryl 50 WP and carbaryl 4L thinned when used alone (treatments 2 and 3), when combined with superior oil (treatments 4 and 5), or when combined with 6-BA + oil (treatments 6 and 7) (Table 3). Superior oil potentiated 6-BA (treatments 8 and 9). Oxamyl was potentiated by 6-BA + oil (treatments 10 and 11); however, this combination (treatment 11) reduced red color and increased opalescence. Oxamyl alone increased opalescence only slightly. The antitranspirant RPA 86117 + surfactant (Exp 890033A) caused overthinning with no injury to leaves or fruit (treatment 13). However, in Expt. 6 on 'Golden Delicious', RPA 86117 + surfactant (Exp 890033A) increased russet, which may have been a result of the surfactant. If

carbaryl + oil were added to the RPA + surfactant, 'Redspur' trees were defruited and ≈30% of the leaves dropped (treatment 14). None of the other treatments caused fruit color or fruit finish differences. Fruit firmness did not appear to be affected by the material used and small differences were probably related to crop load.

Treatments that did not thin did not induce adequate return bloom for a crop in 1990 (treatments 1, 8, 12, and 15). Even though RPA (treatments 13 and 14) defruited trees, the return bloom was not as good as would be expected (42% and 48% spurs flowering).

Experiment 4. Two days of artificial shade (92%) caused more thinning than carbaryl 50 WP, carbaryl 4L, or 10 mg NAA/liter + Tween 20 (treatments 2, 4, 6, and 8) (Table 4). The

addition of 2 days of artificial shade to any of these chemical thinning combinations increased thinning. These data demonstrate the possible interaction between chemical thinning applications and environmentally induced "June drop," as reported previously (Byers et al., 1990a, 1990b, 1991). Fruit russet was not affected by the three chemical formulations. Shading induced seed abortion; however, neither NAA nor carbaryl had an effect on seed numbers. Fruit diameter was increased by shade-thinning of trees, and the reduced seed numbers caused by shading did not appear to affect fruit size. Return bloom of carbaryl-thinned trees (treatments 6-9) was superior to those thinned by NAA + Tween 20 (treatments 4 and 5).

Experiment 5. Two days of artificial shade caused more thinning of

'Stayman' trees than carbaryl 50 WP, carbaryl 4L, or 10 mg NAA/liter + Tween (Table 5). Fruit russet was not different among the three chemical formulations, but all three had more russet than the control or the hand-thinned treatments. Fruit russet was probably a function of crop load and fruit size and not a direct effect of the chemicals. The number of viable seeds was not affected by the chemical thinners. There was an inadequate number of fruit on the shaded trees, as exhibited by a representative sample. Return bloom of 'Stayman' was affected by crop load, but not as much as were 'Golden Delicious' (Table 4) and 'Delicious' (Table 6).

Experiment 6. Two applications of RPA 86117 at 2400 mg·liter⁻¹ did not cause thinning or affect fruit russet; however, the combination of RPA

Table 7. Effect of various chemicals on fruit-thinning of 'Nured Delicious'/M.7 (1990).

Treatment ^{xy}	Active ingredient (per liter)	Fruit/cm ² of trunk cross-sectional area (+51 days AFB)	Photosynthesis (mg CO ₂ /dm ² per h) + 2 days after treatment	Fruit diam (cm) 24 Aug.	No. viable seeds/fruit	Total (viable + aborted) seeds/fruit	Percent viable seeds/fruit	Russet rating (0-5) ^z	Percent spurs flowering (19 Apr. 1991)	Percent nodes flowering (19 Apr. 1991)
1) Control		8.06 ab ^w	17.4 a	6.62 c	2.27 def	3.40 c	63.8 cdef	0.28 f	85 cde	5c
2) Carbaryl 80 WP	900 mg	6.90 abc		6.78 de	1.65 f	3.50 c	47.3 fgh	0.43 ef	96 abc	10 c
3) Carbaryl 4L	900 mg	5.95 bc		6.75 de	1.92 ef	3.65 bc	52.2 efg	0.59 def	90 bcde	14 de
4) Carbaryl 80 WP + oil	900 mg 10 ml	5.42 c		7.08 abc	1.37 f	3.96 abc	35.1 gh	0.71 cde	95 abc	17 cde
5) Carbaryl 4L + oil	900 mg 10 ml	5.03 c		6.95 bcd	1.5 f	4.73 a	31.7 h	0.43 ef	93 bcd	30 bcd
6) Ethephon + Carbaryl 80 WP	500 mg 900 mg	0.55 d		7.18 ab	2.72 cde	4.02 abc	71.8 bcd	0.50 def	100 a	38 bc
7) Ethephon	500 mg	2.36 d		7.18 ab	3.38 bc	4.85 a	70.7 bcd	0.74 cde	100 a	33 bc
8) Ethephon (early + oil 16 May)	500 mg 10 ml	1.09 d		7.28 a	3.37 bc	4.4 abc	78.2 abc	0.67 cde	100 a	49 b
9) Ethephon (late + oil 5 June)	1500 mg 10 ml	0.60 d		7.62 a	3.91 ab	4.28 abc	91.7 a	0.97 bc	100 a	90 a
10) Carzol 92%	275 mg	8.47 a		6.68 de	3.53 abc	4.18 abc	83.8 ab	0.39 ef	75 de	8 c
11) Carzol 92% + oil	275 mg 10 ml	7.60 ab		6.68 de	2.60 cde	4.55 ab	57.4 def	0.56 def	73 c	5 c
12) Oil	10 ml	8.40 a		6.62 c	3.13 bcd	4.72 a	67.1 bcde	0.59 def	79 de	8 c
13) RPA 86117	2.4 g	7.78 ab	15.8 a	6.75 de	3.42 bc	4.12 abc	82.2 abc	0.48 def	83 bcde	9 c
14) RPA 86117 + surfactant 80033A	2.4 g 1.25 ml	5.43 c	10.8 b	6.80 cde	3.42 bc	4.30 abc	79.9 abc	0.81 cd	88 bcde	20 cde
15) RPA 86117 + Tween 20	2.4 g 1.25 ml	5.01 c	12.4 b	6.93 bcde	3.25 bc	4.05 abc	80.0 abc	1.14 b	85 bcde	13 de
16) RPA 86117 + oil	2.4 g 10 ml	0.60 d	10.0 b	7.36 a	4.44 a	4.8 a	91.8 a	4.39 a	85 bcde	29 bcd
17) Hand-thinned (+ 53 days AFB)		5.31 c		7.28 a	3.95 ab	4.25 abc	92.9 a	0.48 def	95 ab	19 cde

^xFull bloom occurred on 26 Apr. 1990.

^yTreatments were applied 16 May - 20 days AFB when fruit diameter was 16 mm ± 0.72 mm, except treatment 9, which was applied 5 June - 40 days AFB when fruit diameter was 30.5 ± 0.63 mm, which was = 10 days after starch started accumulating in the fruit.

^zSide russet rating: 1 = lenticel enlargement; 2 = lenticel enlargement and some russet between lenticel; 3 = lenticel enlargement and slightly raised to touch, moderate to heavy russet between lenticel; 4 = lenticel enlargement and moderately raised to touch and moderate to heavy russet between lenticels; 5 = lenticel enlargement and heavily raised to touch and heavy russet between lenticels.

^wMean separation within columns by Duncan's multiple range test, 5% level.

86117 + a surfactant (Exp 80033A) caused fruit thinning and increased russet. Further tests are required to determine if a change in the surfactant would eliminate the effect on fruit finish.

Experiment 7. Carbaryl 50 WP and 4L were equally effective for thinning alone (treatments 2 and 3) or when combined with superior oil (treatments 4 and 5) (Table 7). The number of viable seeds was not statistically different from the control. Carzol alone or with superior oil did not thin, nor did oil alone. At 500 mg ethephon/liter + oil overthinned when fruits were 16 mm; when fruits were 30 mm in diameter, which was about 10 days after starch had started to accumulate in the fruit, 1500 mg ethephon/liter + oil almost completely defruited trees. The anti-transpirant RPA 86177 alone did not thin, but the addition of Exp 80033A surfactant or Tween 20 to the RPA 86117 increased thinning to the same extent. The addition of superior oil to RPA 86117, however, caused leaf injury, some defoliation, fruit russet, and defruiting of trees.

Photosynthesis was reduced by those RPA 86117 treatments that included a surfactant or superior oil (Table 7).

The return bloom on all trees was adequate for a full crop in 1991. Just 40% to 50% of the spurs flowering would have been adequate for a 111 crop. The check trees had 85% of the spurs flowering. Treatments that contained higher rates of ethephon and/or treatments that greatly thinned fruit from the trees caused more flower buds to develop on annual growth. These buds usually bloom later than spur flowers and may not be damaged by early frosts; however, they usually produce smaller fruit than those borne on spurs.

Summary

A range of thinning responses was achieved by combinations of certain thinners and adjuvants. Chemical thinning also increased return bloom.

The use of superior oil as an adjuvant for carbaryl was effective 2 of 3 years, and it has the advantage of suppressing mite populations (Horsburgh and Cobb, unpublished data). However, oil increased russet in 'Golden Delicious' (unpublished data),

but this was not a problem with 'Red Delicious'. Two formulations of carbaryl had similar thinning activity, whether applied alone or in combinations with artificial shade (92%).

Our data suggest that 2 days of artificial shade (92%) (equivalent to about 3 days of a typical cloudy period in the eastern United States) reduced viable seed numbers by 50%, caused fruit thinning, and increased fruit size. Chemical thinners in these experiments did not affect seed numbers.

The amount of fruit removal desired from one or more chemical thinning sprays is a major management decision for fruit growers. In addition, the response from chemical thinning can be quite variable between years due to many factors (fruit set, cultivar or strain, rootstock, tree age, climate, site, culture, etc.). The experiments reported here were intended to give the grower a range of chemical thinning possibilities from no thinning to defruiting trees. Since a grower will likely make last-minute decisions to increase or decrease the amount of thinning desired (based on previous season's results, current season's weather, fruit set), the relative thinning level of various combinations of thinners or the addition of adjuvants in these experiments can be useful for estimating the relative contribution of them to fruit thinning.

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