Chemically Thinning Spur 'Delicious' Apples with Carbaryl, NAA, and Ethephon at Various Stages of Fruit Development

Richard P. Marini¹

Additional index words. *Malus × domestica*, fruit diameter

Summary. Chemical fruit thinners were applied to limbs or whole trees of spur 'Delicious' at various stages of fruit development as indicated by fruit diameter. Carbaryl, naphthalene acetic acid (NAA), and ethephon all reduced fruit set when applied at a fruit diameter of ≈ 4 to 15 mm. Fruit thinning for NAA and carbaryl, alone or combined, generally was greater when applied at an average fruit diameter of 8 mm, rather than at 4 mm. Repeated applications of NAA or carbaryl were no more effective than single applications. NAA + carbaryl applied at 9 mm was more effective than NAA applied at 4 mm followed by carbaryl at 8 mm. Applied when fruit diameter averaged 17 to 22 mm, ethephon and ethephon + carbaryl were effective fruit thinners. When applied at full bloom to ≈ 10 and 20 mm, the insecticides ethion and oxamyl, respectively, were effective fruit thinners.

Spur strains of 'Delicious' apple (*Malus × domestica* Borkh.) grown in the mid-Atlantic region are difficult to thin adequately with currently registered materials. Carbaryl and carbaryl + superior oil usually does not thin adequately (Byers, 1978; Byers et al., 1982). Naphtha-

lene acetic acid (NAA) and naphthaleneacetamide (NADm) have caused unacceptable numbers of pigmy fruit when used at concentrations required for adequate thinning (Rogers and Williams, 1977). Carbaryl combined with low rates of NAA (2 to 5 mg·L⁻¹) thinned acceptably in some years but underthinned (Herrera-Aguirre and Unrath, 1980) or overthinned (Rogers and Williams, 1977) in other years. Ethephon is registered as an apple thinner in North Carolina and Virginia. When used alone or with NAA, ethephon produced variable results, depending on location and season (Byers and Carbaugh, 1991; Herrera-Aguirre and Unrath, 1980).

The insecticides ethion (not registered as an apple thinner) and oxamyl (registered in Virginia and Pennsylvania) are similar to carbaryl for thinning spur 'Delicious' (Byers, 1978; Byers and Carbaugh, 1991; Byers et al., 1982). Benzyladenine (BA), an ingredient in Accel, which was registered as an apple thinner, inadequately thinned 'Redspur Delicious' when applied at 50 mg·L⁻¹ (Byers and Carbaugh, 1991).

The effect of application time relative to fruit development has not been reported for many thinning materials, especially for combinations of materials that are used to thin apples. My objective was to document the efficacy of different chemical apple thinners, alone or combined, applied to spur 'Delicious' at various stages of fruit development.

Materials and methods

Limb treatments, 1991. On 23 Apr. 1991, during full bloom, twenty-seven 9-year-old 'Campbell Redchief Delicious' /MM.111 trees growing at the Virginia Tech Horticultural Research Farm, Blacksburg, were selected. Trees were grouped into three blocks of nine trees with similar visual bloom ratings. Five scaffold limbs per tree were assigned randomly to one of the five following thinning treatments (a.i. in mg·L⁻¹): 1) control (water), 2) BA at 100, 3) carbaryl (Sevin 50w) at 900, 4) ethephon (Ethrel) at 400, and 5) NAA (Fruitone N) at 2.5. Tween 20 (1.25 ml·L⁻¹) of solution was added to all treatments. One tree per block was assigned randomly to one of the nine treatment dates listed in Table 1. Treatment limbs were sprayed to runoff with a hand-sprayer. On 1 Sept.,

the number of fruit per limb and the limb circumference were recorded, and crop density (CD), the number of fruit per square centimeter of branch cross-sectional area, was calculated. Treatments were arranged as a 5 × 9 factorial in a randomized complete-block design with three replicates per treatment. Data were analyzed by SAS's (Cary, N.C.) analysis of variance (ANOVA), which indicated a significant ($P < 0.01$) treatment × treatment date interaction. Data then were analyzed by ANOVA by treatment date. Means within date were compared with Duncan's new multiple range test ($P = 0.05$).

Limb treatments, 1993. On 30 Apr. 1993, during full bloom, thirty-two 11-year-old 'Campbell Redchief Delicious' /MM.111 trees growing at the Virginia Tech Horticultural Research Farm were selected. Trees were grouped into four blocks of eight trees according to a visual bloom rating. Limb circumference and blossom clusters per limb were recorded. Four scaffold limbs per tree were assigned randomly to one of the four following thinning treatments (a.i. in mg·L⁻¹): 1) control (water), 2) carbaryl at 900, 3) Ethion (Ethion E-4) at 50, and 4) Oxamyl (Vydate L) at 600. Tween 20 was added to all treatments at 1.25 ml·L⁻¹ of solution. One tree per block was assigned randomly to one of the eight treatment dates listed in Table 2. Treatment limbs were sprayed to runoff with a hand-sprayer. On 3 Sept., the number of fruit per limb was recorded. Fruit set per 100 blossom clusters and CD were calculated. Treatments were arranged as a 4 × 8 factorial in a randomized complete-block design. Because an ANOVA for the 32 treatment combinations indicated a significant treatment × treatment date interaction ($P < 0.01$), data were analyzed by treatment date by ANOVA, and means were compared with Duncan's new multiple range test ($P = 0.05$).

Whole-tree treatments, 1992. On 18 Apr. 1992, during full bloom, fifty-seven 9-year-old 'Campbell Redchief Delicious' /MM.111 trees growing in Stuart, Va., were selected for uniformity of bloom. Three trees were assigned randomly to each of 19 groups representing the treatments listed in Table 3. Three scaffold limbs (8 to 10 cm in diameter) per tree were tagged. Treatments were applied at

¹Department of Horticulture, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0327.

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Table 1. The influence of chemical thinning treatments on crop density (fruit per square centimeter of branch cross-sectional area) of 'Redchief Delicious' trees growing in Blacksburg, Va., in 1991. Treatments were applied to single branches on nine dates

Chemical ^y	Concn (mg a.i./L)	Treatment date								
		30 Apr. ^z	3 May	6 May	10 May	13 May	15 May	17 May	22 May	24 May
		Mean fruit diam (mm)								
		4.0	6.0	8.0	10.0	13.0	17.0	18.5	22.6	24.3
<i>Crop density (fruit/cm²)</i>										
Control	---	10.7 a ^x	11.2 a	10.4 a	7.5 a	8.1 ab	8.7 a	8.6 ab	9.1 a	9.4 a
6-BA	100	10.5 a	8.3 a	6.2 b	6.7 a	10.9 a	7.2 ab	9.7 a	8.2 a	10.3 a
Carbaryl	900	5.1 b	6.7 ab	3.7 b	4.1 b	5.3 bc	4.4 cd	3.4 cd	6.5 ab	6.8 a
Ethephon	400	3.6 b	3.5 b	5.5 b	0.8 c	4.4 c	3.0 d	0.5 d	4.0 b	2.1 b
NAA	2.5	1.0 c	2.8 b	5.2 b	3.9 b	5.7 bc	5.8 bc	5.5 bc	8.6 a	9.8 a
<i>P</i> > <i>F</i>		0.001	0.007	0.003	0.001	0.003	0.001	0.001	0.012	0.001

²Trees were at petal fall on 30 Apr. 1991.

¹Tween 20 was added to all treatments at 1.25 ml·L⁻¹.

^xMean separation within columns by Duncan's new multiple range test at P = 0.05. Each value is the mean of three observations.

Table 2. The influence of chemical thinning treatments on fruit set and crop density of 'Redchief Delicious' branches in Blacksburg, Va., in 1993. Treatments were applied on nine dates.

		Treatment date							
		28 Apr. ^z	7 May ^z	14 May	18 May	21 May	30 May	2 June	6 June
	Concn	Mean fruit diam (mm)							
Chemical	(mg a.i./L)	FB	3.6	7.0	10.3	14.4	19.7	23.7	25.5
Fruit/100 blossom clusters									
Control	---	96 a ^y	97 a	118 a	102 a	98 a	100 a	91	128 a
Carbaryl	900	81 ab	52 b	51 b	56 bc	49 ab	106 a	88	100 ab
Ethion	50	61 b	42 b	52 b	74 b	66 ab	97 a	91	88 b
Oxamyl	600	67 b	73 ab	67 b	42 c	37 b	65 b	82	84 b
P > F		0.07	0.03	0.01	0.01	0.01	0.05	0.88	0.04
Crop density (fruit/cnr ² branch cross-sectional area)									
Control	---	11.6	11.0 a	11.1 a	13.2 a	9.8 a	10.2	13.6	11.3
Carbaryl	900	8.6	6.1 b	5.9 b	6.9 b	5.2 ab	11.2	11.7	8.8
Ethion	50	7.3	4.8 b	8.1 ab	7.2 b	5.1 ab	8.3	9.4	9.4
Oxamyl	600	8.1	7.5 ab	5.8 b	4.8 b	4.6 b	8.1	9.9	8.7
P > F		0.37	0.05	0.02	0.01	0.05	0.39	0.21	0.24

²Full bloom occurred on 28 Apr. and petal fall occurred on 7 May.

^yMean separation within columns and variables by Duncan's new multiple range test at P = 0.05. Each value is the mean of four observations.

three stages of fruit development. Mean fruit diameter on each treatment date was assessed by randomly selecting two fruit clusters from each of 30 trees; the diameters of the largest three fruit in each cluster were recorded. Thinning treatments were applied by spraying the trees to runoff with a handgun. Tween 20 (1.3 ml·L⁻¹) was added to all treatments. On 27 Aug., the crop load for each tree was estimated visually to the nearest 10% (100% is an ideal crop load). The experiment was a completely randomized design, and data were analyzed by ANOVA using SAS's general linear models procedure. Because there was some structure to the treatments, single degree-of-freedom contrasts were used to test the significance of main effects and inter-

actions. Variances for percentage data were stabilized using the complementary log-log transformation (Llewelyn, 1968) before analysis.

Whole-tree treatments, 1993.

On 22 Apr. 1993, during full bloom, fifty-two 8-year-old 'Oregon Spur Delicious' /MM.111 trees growing in Stuart were selected for uniformity of bloom. Four trees were assigned randomly to each of 13 groups representing the treatments listed in Table 4. Treatments were applied at three stages of fruit development. On each treatment date, mean fruit diameter was determined as previously described. Thinning treatments were applied with an air-blast sprayer calibrated to deliver 2521 L·ha⁻¹ (175% tree row volume). Tween 20 (1.3 ml·L⁻¹) was

added to all treatments. The experiment was a completely randomized design with four replicates. Crop load data were analyzed with single degree-of-freedom contrasts as previously described. On 15 Apr. 1994, the quantity of bloom was rated on each tree as 1 = none, 4 = moderate, or 7 = very heavy. Bloom ratings were analyzed with Kruskal-Wallis test.

(experimentwise error rate = 5%) (Hollander and Wolfe, 1973).

Whole-tree treatments, 1994.

Forty 9-year-old 'Oregonspur II Delicious' trees on MM.111 rootstock growing in Stuart were selected for uniformity of bloom on 15 Apr. during bloom. The experimental design was completely randomized with eight single-tree replicates per treatment. The five treatments are explained in Table 5. During bloom, one representative branch per tree was selected, and 100 blossom clusters were counted from the terminal end toward the base of the branch. The branch was marked so the same section could be evaluated later for fruit set.

Treatments were applied with an air-blast sprayer calibrated to deliver

2257 L·ha⁻¹ (175% tree row volume). Tween 20 (1.3 ml·L⁻¹) was added to each treatment. On each application date, 60 fruit were measured as previously described.

At harvest, 145 d after bloom, the number of fruit on the previously marked branches was recorded to calculate fruit per 100 blossom clusters. We also visually evaluated the percent-

age of crop on each tree (where 100% = an ideal crop). Ten consecutive fruit on each of two branches were harvested, and fruit weight and number of live and aborted seeds per fruit were recorded. During full bloom in 1995, the amount of bloom per tree was rated on a scale of 1 to 7, where 1 = no bloom, 4 = moderate bloom, and 7 = very heavy. Bloom ratings were ana-

lyzed with a distribution-free multiple comparison based on Kruskal-Wallis rank sums (Hollander and Wolfe, 1973). Other data were analyzed by ANOVA, and means were compared with Duncan's new multiple range test using SAS's general linear models procedure.

An additional 36 trees growing in the same block for the previous experi-

Table 3. Crop load on 'Campbell Redchief Delicious' whole trees treated with carbaryl, NAA, or ethephon on different dates in 1992 in Stuart, Va. Treatments were applied with a hand-gun.

Treatment	Mean fruit diam (mm)							Crop load ^b (%)
	4		9		18			
	Treatment date							
	23 Apr. ^z		30 Apr.			14 May		
	Chemical (mg a.i./L)		Chemical (mg a.i./L)			Chemical (mg a.i./L)		
	Carbaryl	NAA	Carbaryl	NAA	Ethephon	Carbaryl	Ethephon	
1	0	0	0	0	0	0	0	125 ^x
2	0	2.5	0	0	0	0	0	109
3	0	5.0	0	0	0	0	0	78
4	900	0	0	0	0	0	0	108
5	900	2.5	0	0	0	0	0	116
6	0	2.5	900	0	0	0	0	84
7	0	0	0	0	0	0	0	131
8	0	0	900	0	0	0	0	89
9	0	0	0	5.0	0	0	0	108
10	0	0	900	5.0	0	0	0	102
11	0	0	0	0	400	0	0	108
12	0	0	900	0	400	0	0	78
13	0	0	0	0	0	0	0	128
14	0	0	0	0	0	900	0	95
15	900	0	900	0	0	900	0	86
16	0	0	900	0	0	0	200	55
17	0	0	0	0	0	0	200	38
18	0	0	0	0	0	0	400	41
19	0	0	0	0	0	900	200	7
Contrast (P > F)								
Carbaryl, 4 mm (1 + 2 vs. 4 + 5)								0.350
NAA _p , 4 mm (1, 2, 3)								0.312
NAA _q , 4 mm (1, 2, 3)								0.006
NAA, 4 vs. 9 mm (3 vs. 5)								0.065
Carbaryl, 4 vs. 9 mm (4 vs. 8)								0.244
Carbaryl, 9 vs. 18 mm (8 vs. 14)								0.696
Carbaryl × NAA, 4 mm (1 + 5 vs. 2 + 4)								0.272
Carbaryl, 9 mm (7 + 9 + 11 vs. 8 + 10 + 12)								0.007
5 vs. 6								0.046
Carbaryl × NAA, 9 mm (7 + 10 vs. 8 + 9)								0.102
Ethephon, 9 mm (7 + 8 vs. 11 + 12)								0.126
Carbaryl × ethephon, 9 mm (8 + 11 vs. 7 + 12)								0.536
Ethephon _p , 18 mm (13, 17, 18)								0.001
Ethephon _q , 18 mm (13, 17, 18)								0.001
Carbaryl, 18 mm (13 + 17 vs. 14 + 19)								0.007
16 vs. 19								0.004
Ethephon, 9 mm vs. 18 mm (11 vs. 18)								0.001
Carbaryl × ethephon 18 mm (13 + 19 vs. 15 + 16)								0.930
Carbaryl, 4 mm vs. 4 + 9 + 16 mm (4 vs. 15)								0.189
Carbaryl, 9 mm vs. 4 + 9 + 16 mm (8 vs. 15)								0.880
Carbaryl, 18 mm vs. 4 + 9 + 16 mm (14 vs. 15)								0.587

^zPetal fall occurred on 23 Apr.

^yData collected on 23 Aug. 1992.

^xEach value is the mean of three trees. Data were transformed with the complementary log-log transformation.

Table 4. Crop load and return bloom on 'Oregon Spur Delicious' whole trees treated with carbaryl (900 mg a.i./L) and ethephon on different dates in 1993 in Stuart, Va. Treatments were applied with an air-blast sprayer.

Treatment	Treatment date			Crop load (%)	Bloom rating ^y
	29 Apr. ^z	6 May	20 May		
	Mean fruit diam (mm)				
	4.3	8.7	22.1		
	Chemical (mg a.i./L)	Chemical (mg a.i./L)	Chemical (mg a.i./L)		
1	---	---	---	134 ^x	3.5 d
2	NAA, 5	---	---	85	4.0 d
3	NAA, 10	---	---	94	3.2 d
4	NAA, 5	Carbaryl	---	80	5.8 ab
5	---	Carbaryl	---	63	5.5 bc
6	---	NAA, 5	---	65	5.5 bc
7	---	NAA, 5 + Carbaryl	---	79	6.2 ab
8	---	---	Ethephon, 200	98	4.5 cd
9	---	---	Ethephon, 400	75	5.5 bc
10	---	---	Ethephon, 600	91	5.5 bc
11	---	Carbaryl	Ethephon, 400	68	6.8 a
12	---	---	Carbaryl + ethephon, 400	74	6.5 ab
13	---	---	Carbaryl	103	4.0 d
Contrasts (P > F)					
NAA _i (1, 2, 3)				0.02	
NAA _q (1, 2, 3)				0.05	
2 vs. 6				0.24	
2 vs. 4				0.77	
4 vs. 7				0.94	
Ethephon _i (1, 8, 9, 10)				0.03	
Ethephon _q (1, 8, 9, 10)				0.01	
5 vs. 13				0.03	
11 vs. 12				0.67	
9 vs. 12				0.97	

^zPetal fall occurred on 29 Apr.

^yBloom was rated as 1 = none, 4 = moderate, and 7 = very heavy. Mean separation within columns by Kruskal-Wallis test, experimentwise error rate = 5%.

^xEach value is the mean of four trees. Data were transformed with the complementary log-log transformation.

ment were assigned randomly to the 12 treatments described in Table 6. Application method and data collection, number of fruit per 100 blossom clusters, percentage of crop, and return bloom were the same as described in the previous experiment. The design was completely randomized, and there were three replicates per treatment. Data were analyzed by ANOVA, and, to compare certain treatments, sums of squares were partitioned into single degree-of-freedom contrasts.

In all experiments, we assumed that all natural fruit drop occurred uniformly across treatments, and crop load was evaluated in late summer before the onset of preharvest drop.

Results and discussion

Limb treatments. Single limbs were used to test the efficacy of chemicals that induce (Byers and Lyons, 1985) or delay (Marini et al., 1989) peach and apple fruit abscission, re-

spectively. Single limbs may not respond exactly as whole trees, because mobile chemicals may be translocated out of the treatment limb (Marini et al., 1993). However, single limbs offer researchers the opportunity to test many treatments in a single season. Promising treatments then can be tested later on whole trees.

BA was the least effective material used in this study and differed significantly from the nontreated control only when applied when the fruit diameter was 8 mm (Table 1). Greene and Autio (1989) reported that thinning on 'McIntosh' trees with BA was dose-related and was most effective when applied 8 to 18 d after bloom. However, BA did not thin 'Delicious' trees when applied at 100 mg·L⁻¹ (Greene and Autio, 1989) and was less effective than carbaryl when applied at 50 mg·L⁻¹ (Byers and Carbaugh, 1991). Carbaryl thinned significantly when applied to single limbs when the

fruit diameter was 4 to 18.5 mm in 1991 (Table 1) and 3.6 to 10.3 mm in 1993 (Table 2). Carbaryl usually is used as a thinner when fruit diameter averages 10 to 12 mm (Pfeiffer et al., 1993), but my study indicates that carbaryl may be effective from petal fall through 18.5 mm. Ethephon at 400 mg·L⁻¹ was the only material that reduced fruit set on all fruit sizes tested (Table 1). Byers and Carbaugh (1991) also reported that ethephon applied at 16 mm at 500 mg·L⁻¹ with a hand-gun overthinned 'Nured Delicious' trees. NAA thinned significantly when applied to fruit ≤10 mm but was most effective at petal fall (Table 1). Ethion thinned when applied from full bloom until fruit diameter averaged ≈10 mm (Table 2). Oxamyl thinned some when applied from full bloom until fruit diameter was ≈19.0 mm (Table 2).

Whole-tree treatments. Results for the three seasons sometimes conflicted (Tables 3–6). The discrepancies

may be due to 1) year-to-year variation in environmental conditions and tree status as previously described by Herrera-Aguirre and Unrath (1980) and Byers (1978), 2) differences in the

strains of 'Delicious' treated, or 3) differences in application method (e.g., results may vary with the amount of water applied) (Herrera-Aguirre and Unrath, 1980).

In 1992 and 1993, crop load declined nonlinearly with increasing NAA concentration applied at petal fall (Tables 3 and 4). When applied at petal fall or when fruit diameter aver-

Table 5. Influence of applying carbaryl (Sevin XLR-Plus) at different times in 1994 on fruit set, fruit weight, seeds per fruit and return bloom of 'Redchief Delicious' in Stuart, Va.^{z,y}

Carbaryl concn (mg a.i./L)										
Treatment date										
19 Apr.	25 Apr.	5 May								
Fruit diam (mm)			Fruit/ 100 clusters	Crop load (%)	Fruit wt (g)	Seeds/fruit			Return bloom rating 1995 ^x	
4.2	7.1	17.2				Live	Aborted	Total		
0	0	0	51 a ^w	138 a	150 b	5.5 a	1.3 c	6.9 a	2.6 c ^v	
600	0	0	45 a	115 ab	159 a	5.0 ab	1.7 bc	6.7 ab	4.2 b	
0	600	0	32 a	81 c	164 a	4.1 c	2.2 ab	6.3 b	4.7 a	
0	0	600	52 a	134 a	139 c	3.8 c	2.4 a	6.2 b	2.8 c	
600	0	600	42 a	91 bc	160 a	4.3 bc	2.2 ab	6.5 ab	4.7 a	

^zFull bloom and petal fall occurred on 15 and 19 Apr., respectively.

^ySevin XLR-Plus was applied with an air-blast sprayer at 175% tree row volume.

^xBloom was rated as 1 = no bloom, 4 = moderate bloom, and 7 = very heavy.

^wMean separation within columns by Duncan's new multiple range test at P = 0.05. Data were collected 1 Sept. 1994.

^vMean separation within columns by Kruskal-Wallis test, experimentwise error rate = 5%.

Table 6. Influence of carbaryl (C) at 600 mg a.i./L, NAA (N) at 5 mg a.i./L, and ethephon (E) at 400 mg a.i./L applied at different times in 1994 on fruit set and crop load on 'Redchief Delicious' in Stuart, Va. Treatments were applied with an air-blast sprayer.

Treatment	Chemical applied			Fruit/ 100 clusters	Crop load (%)	Return bloom 1995 ^y
	Application date					
	19 Apr. ^z	25 Apr.	5 May			
	Fruit diam (mm)					
	4.2	7.1	17.2			
1	---	---	---	73	128	2.7 d
2	C	---	---	53	92	5.0 ab
3	N	---	---	47	92	3.3 d
4	C + N	---	---	41	95	4.3 c
5	---	C	---	37	53	5.3 ab
6	---	N	---	4	13	5.1 ab
7	---	C + N	---	6	22	4.7 b
8	N	C	---	37	53	4.3 b
9	N	N	---	14	48	4.3 b
10	N	C + N	---	12	15	5.3 ab
11	---	---	E	25	32	5.3 ab
12	---	---	C + E	10	13	5.3 ab
Contrasts (P > F)						
Control vs. C (1 vs. 2)				0.40	0.046	
Control vs. N (1 vs. 3)				0.265	0.046	
C vs. N interaction (1 + 4 vs. 2 + 3)				0.752	1.000	
C vs. N interaction (1 + 4 vs. 2 + 3)				0.655	0.117	
Control vs. C (1 vs. 5)				0.132	0.001	
Control vs. N (1 vs. 6)				0.006	0.001	
C vs. N (5 vs. 6)				0.124	0.031	
Carbaryl NAA interaction (1 + 7 vs. 5 + 6)				0.233	0.003	
C time (2 vs. 5)				0.438	0.038	
N time (3 vs. 6)				0.050	0.001	
Combination time (4 vs. 7)				0.103	0.001	
Combination time (3 vs. 8)				0.658	0.038	
Combination time (7 vs. 8)				0.140	0.082	
Combination time (3 vs. 9)				0.129	0.020	

^zPetal fall occurred on 19 Apr.

^yBloom was rated as 1 = none, 4 = moderate, and 7 = very heavy. Mean separation within column by Kruskal-Wallis test, experimentwise error rate = 5%.

aged 9 mm, NAA at 5 mg·L⁻¹ thinned similarly (treatment 3 vs. 9 in 1992). In 1992, carbaryl thinned similarly when applied at fruit diameters of 4, 9, 18, or 4 + 9 + 18 mm (treatments 4, 8, 14, and 15) (Table 3). Byers et al (1982) also reported that carbaryl thinned similarly when applied at a fruit diameter of 8, 10, or 6 + 8 + 10 mm. Compared to the nontreated control, carbaryl significantly reduced crop load when applied at a fruit diameter of 9 or 18 mm but not 4 mm (Table 3). However, in 1994, carbaryl applied when fruit diameter was 4.2-mm reduced crop load (Table 6). Carbaryl in the new formulation (Sevin XLR-Plus) significantly thinned fruit in 1994 when applied at a mean fruit diameter of 7.1 mm but not 4.2 or 17.2 mm (Table 5). Applying carbaryl at 4.2 + 17.2 mm was no more effective than applying it only at 7.1 mm. Although thinning response was not significant ($P < 0.05$), fruit weight increased when carbaryl was applied when fruit diameter was at 4.2, 7.1, or 4.2 + 17.2 mm. Fruit from trees treated with carbaryl at 7.1 or 17.2 mm had fewer live and more aborted seeds than fruit from the control trees. Return bloom was enhanced by applying carbaryl at a fruit diameter of ≤ 7.1 mm. Carbaryl + NAA was no more effective than either material applied alone, and the carbaryl $\times$ NAA interaction was not significant in all 3 years (Tables 3, 4, and 6). Applying carbaryl or NAA at petal fall with additional treatments at 9 mm was no more effective than applying carbaryl or NAA at 9 mm.

Ethephon was more effective when applied at a fruit diameter of 18 rather than 9 mm (treatment 11 vs. 18) (Table 3), and crop load declined nonlinearly with increasing ethephon concentration (Tables 3 and 4). Adding carbaryl to ethephon resulted in improved thinning in 1992 (treatments 11 vs. 12 and 16 vs. 17) and 1994 (treatment 11 vs. 12) (Tables 3 and 6) and confirms a previous report by Byers and Carbaugh (1991).

Return bloom generally increased when carbaryl, but not NAA, was applied at petal fall or when either carbaryl or NAA was applied when fruit diameter averaged 7 to 9 mm (Tables 4–6). Return bloom was greatest when ethephon was applied alone or with carbaryl in 1993 and 1994 (Tables 4 and 6).

Many of the treatments in my

study provided commercially acceptable levels of fruit thinning. There were three windows of opportunity for thinning spur 'Delicious' trees.

- 1) Near petal fall, carbaryl was a mild thinner, and NAA at 5 to 10 mg·L⁻¹ was a stronger thinner than carbaryl.
- 2) When fruit diameter averaged 8 to 9 mm, NAA and carbaryl alone or combined were effective. However, NAA applied at a mean fruit diameter > 9 mm caused excessive development of pigmy fruit (unpublished data).
- 3) When mean fruit diameter averaged 16 to 22 mm, ethephon and ethephon + carbaryl were effective.

Apple producers can vary timing, materials, and concentration of materials to obtain various levels of thinning. Additional work is needed to evaluate some of these combinations over several years and to determine the influence of environmental factors, such as light and temperature, on thinning response.

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