Flower Bud Thinning and Winter Survival of 'Redhaven' and 'Cresthaven' Peach in Response to GA₃ Sprays

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ABSTRACT. The timing and concentration of dilute foliar sprays of gibberellic acid (GA₃) were tested for their flower bud thinning effect during three consecutive years on two common cultivars of peach [*Prunus persica* (L.) Batsch.] grown in commercial culture under midwestern conditions. There was a strong trend for June sprays to minimize the total flower bud density (buds/cm shoot) of unbranched shoots on mature 'Redhaven' and 'Cresthaven' trees. The GA₃ treatments applied between early July and late October did not reduce the total flower bud density. Increasing the concentration from 25 or 50 mg·L⁻¹ to 200 mg·L⁻¹ tended to decrease total flower bud density, especially when applied May through July. During the same period the GA₃ treatments reduced total flower bud density of short shoots (<10 cm), but only about two-thirds as effectively as on long shoots. The 'Redhaven' live flower density on trees treated in May, June or September was up to 2 times greater than the control in March following exposure to extreme fluctuations in winter temperatures to near critical lows in 1988 and 1989. Although 50 mg·L⁻¹ GA₃ applied in June 1989 reduced total flower bud density by 70%, it resulted in a live flower density only 35% lower than the control. The treatment induced 2.3 times greater survival of the total flower buds existing after thinning when winter temperatures gradually declined to critical levels. The increased live flower density caused by the GA₃ sprays translated to a cropload 1.3 to 2.25 times greater than control. The length of neither fruiting quality shoots in the bearing canopy nor 1-year-old upright branched shoots in the top of trees (watersprouts) was appreciably affected by the GA₃ applications. GA₃ treatments at 100 and 200 mg·L⁻¹ in late July and early August slightly delayed time of full bloom. Defoliation was delayed slightly by treatments applied in September and late July. Moderate doses of appropriately timed GA₃ sprays reduced flower bud densities without adverse effects on winter survival, yield, defoliation or bloom time. Our results support the use of GA₃ as a reliable peach thinning tool.

Growers could increase the economic efficiency of peach production if reliable chemical thinning agents were available (Daniel, 1988). Hand thinning is the single most expensive task in preharvest culture (Mizelle and Westberry, 1989). Thinning agents could also optimize the physiological efficiency of peach trees by reducing flower and fruit density early, when fruit size is increased the most by thinning with the least reduction of tonnage (Havis, 1962).

Gibberellin sprays reduce flower bud density of peach trees when applied to trees the previous season (Hull and Lewis, 1959; Edgerton, 1966; Painter and Stembridge, 1972; Clanet et al., 1979). The GA₃ sprays even reduced flower bud density when the tendency for peach shoots to develop flower buds was intensified with paclobutrazol (Casper and Taylor, 1989). Although this research spans 3 decades, adoption of this technology has not occurred due to concerns about the reliability of the flower bud thinning response and the risk of reducing the crop potential by overthinning in advance of winter or spring frost injury (Clanet et al., 1979, Martin, 1988). Recent reports from California have shown favorable response in areas generally without adverse winter and spring weather stress (Southwick et al., 1995).

Recently increased market pressures to maximize fruit size and

minimize labor costs have dramatically increased the need for a chemical thinning agent for peaches. The experiments reported here were conducted to determine peach flower bud response to concentrations and timings of GA₃ sprays over a 3-year period under adverse winter/spring weather conditions.

Materials and Methods

Over three consecutive years the experiments were conducted on full sized (306 and 348 trees/ha, respectively), mature (18- and 8-year-old, respectively) 'Redhaven' and 'Cresthaven' peach trees located in a commercial wholesale orchard in southern Illinois. All trees were carefully managed with commercial care. Each treatment was applied to whole, single-tree plots arranged in a randomized complete-block design (RCBD) with six to eight replications as indicated.

The GA₃ treatments were delivered as dilute, full coverage foliar sprays (2432 L·ha⁻¹) applied just to the point of runoff with a high pressure handgun. Tween 20 (polyoxyethylene-20 sorbitan monolaurate, Sigma Chem. Co., St. Louis) surfactant was added to each spray treatment at 0.02% (v/v). Shoots were subsequently evaluated in late winter and early spring for effects on shoot growth in the current season and flowering and fruiting in the next season.

1987 TREATMENTS. Ten treatments were applied to investigate concentration effects and the effect of date of application from late June to late October during a typical midwestern growing season beginning with full bloom on 25 Mar. In March 1988, 18 long (>10 cm) and 18 short (<10 cm) unbranched extensions shoots produced in the previous season each oriented at 30 to 60° from vertical were randomly selected from around the cropping mantle of the open center trees at a height of 2 to 3 m. Shoot lengths and total flower bud numbers were measured. The shoots were similarly sampled

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for live flowers in April 1988. Total flower bud density and live flower density (buds/cm shoot length) were then calculated on an individual shoot basis.

Just before harvest, individual tree yield was assessed by a visual rating of 1 (100 fruit) to 5 (500 fruit per tree) calibrated by actual counts made on each control tree.

1988 TREATMENTS. Twelve treatments were applied to trees previously not treated with GA₃ in 1987 but located adjacently in the same orchard. A range of GA₃ concentrations were applied on four dates at ≈3-week intervals from late spring to midsummer (full bloom occurred on 4 Apr.). Shoot length, total flower bud number and number of live flowers were measured in Spring 1989. Yield was measured just before harvest 1989 by counting all fruit on each tree.

1989 TREATMENTS. On 23 June, four concentrations of GA₃ were applied to 'Redhaven' and 'Cresthaven' peach trees not previously treated with GA₃ in 1987 and 1988, but located in the same orchard (full bloom occurred on 1 Apr.). Only unbranched, long shoots were sampled for flower bud effects. The impact of the 1989 treatments on the 1990 fruit yields was not measurable because a spring freeze at full bloom eliminated the crop.

WATERSPROUTS. Upright, 1-year-old, branched watersprouts originating 2.5 m above ground on the inside of open center scaffolds on the 1988 treated 'Cresthaven' trees were evaluated in March 1989. Primary, secondary and tertiary shoot length and numbers of secondary and tertiary shoots per primary shoot were measured.

TIME OF BLOOM. In Spring 1988 and 1989, a visual rating of the stage of bloom development was made for each tree just before or at bloom independently by each author.

DEFOLIATION. Visual ratings of defoliation on each tree were made at the end of October 1987 by the authors.

DATA ANALYSIS. Standard RCBD ANOVAs were performed. Treatment differences were then tested for polynomial trends (for linear effects and where appropriate, for quadratic effects) across treatment dates when the same GA₃ concentration was used. The responses to GA₃ concentration (including the control) were tested for polynomial trends at each treatment date. Standard error of the difference of means was calculated as $\sqrt{2 \text{ MSE}/n}$, where MSE is the mean square for error in the ANOVA and n is the number of observations in the means. These analyses were conducted using the General Linear Models procedure (SAS Institute, Cary, N.C.).

Table 1. Density of total and live flower buds (sampled in Spring 1988) and fruit yield (1988) of mature 'Redhaven' and 'Cresthaven' peach trees in response to dilute GA₃ applications in 1987.

Application date	GA ₃ concn mg·L ⁻¹	Long shoots (>10 cm) ^z				Short shoots (<10 cm) ^y				Yield rating ^x	
		Redhaven		Cresthaven		Redhaven		Cresthaven			
		Flower buds/cm	Live flowers/cm	Flower buds/cm	Live flowers/cm	Flower buds/cm	Live flowers/cm	Flower buds/cm	Live flowers/cm		
1987										Redhaven	Cresthaven
Control	0	0.38	0.05	0.60	0.04	0.95	0.10	1.37	0.10	2.85	3.15
Date of application trends											
30 June	100	0.22	0.08	0.27	0.06	0.68	0.20	0.87	0.34	4.40	3.90
31 July	100	0.37	0.02	0.59	0.04	0.89	0.11	1.40	0.11	1.69	0.60
12 Sept.	100	0.43	0.06	0.62	0.10	0.90	0.16	1.78	0.25	4.30	3.20
14 Oct.	100	0.39	0.04	0.61	0.03	0.99	0.12	1.69	0.12	3.65	1.75
Standard error		0.02	0.01	0.03	0.01	0.06	0.03	0.12	0.05	0.75	0.79
Significance											
Linear		**	†	**	NS	**	NS	**	*	NS	NS
Quadratic		**	NS	**	**	NS	NS	*	NS	NS	NS
Concentration trends											
31 July	50	0.36	0.04	0.56	0.04	0.88	0.10	1.43	0.08	1.62	1.65
	100	0.37	0.02	0.59	0.04	0.89	0.11	1.40	0.11	1.67	0.60
	200	0.34	0.04	0.45	0.04	0.84	0.11	1.28	0.10	2.05	1.75
Standard error		0.02	0.01	0.03	0.01	0.05	0.03	0.11	0.03	0.73	0.84
Significance											
Linear		NS	NS	**	NS	NS	NS	NS	NS	NS	NS
Quadratic		NS	*	NS	NS	NS	NS	NS	NS	†	NS
12 Sept.	50	0.39	0.07	0.60	0.08	1.09	0.20	1.58	0.21	4.20	3.05
	100	0.43	0.06	0.62	0.10	0.90	0.16	1.78	0.25	4.30	3.20
	200	0.40	0.05	0.56	0.09	0.88	0.10	1.38	0.30	4.25	3.50
Standard error		0.02	0.01	0.03	0.01	0.07	0.03	0.11	0.05	0.56	1.05
Significance											
Linear		NS	NS	NS	**	NS	*	NS	*	*	NS
Quadratic		†	NS	NS	**	NS	NS	**	NS	†	NS
29 Oct.	200	0.42	0.08	0.62	0.05	0.98	0.14	1.61	0.10	5.00	1.30
	400	0.37	0.04	0.59	0.04	0.89	0.10	1.47	0.08	3.15	1.50
Standard error		0.02	0.01	0.03	0.01	0.06	0.03	0.10	0.03	0.82	0.72
Significance											
Linear		NS	NS	NS	NS	NS	NS	NS	NS	NS	*

^aMeans of 89 or 90 observations of unbranched current season extension shoots (>10 cm).

^bMeans of 90 observations of current season spurs (<10 cm).

^cMeans of ratings of four to five individual whole trees by two independent raters.

NS, †, *, ** Nonsignificant or significant at *P* = 0.1, 0.05, or 0.01, respectively, across concentration or date of application.

Results

1987 TREATMENTS. The GA₃ applied on 30 June reduced total flower bud density (FBD) 42% and 55% from the untreated control, respectively on 'Redhaven' and 'Cresthaven' long shoots (Table 1). The 30 June GA₃ treatment also reduced short shoot

FBD, about two-thirds as effectively as it reduced long shoot FBD. On 31 July only the 'Cresthaven' long shoot FBD was reduced (25%) by the highest concentration of GA₃ applied. Short shoots were not affected by treatments in July, September, or October.

The 30 June and 12 Sept. GA₃ treatments increased the live flower density (LFD) of the long shoots of 'Redhaven' and

Table 2. Density of total and live flower buds (sampled in spring 1989), and fruit yield (1989) of mature 'Redhaven' and 'Cresthaven' peach trees in response to dilute GA₃ applications in 1988.

Application date	GA ₃ concn mg·L ⁻¹	Long shoots ^a (>10 cm)				Short shoots (<10 cm) ^b				Crop load ^x (fruit/tree)	
		Redhaven		Cresthaven		Redhaven		Cresthaven		Redhaven	Cresthaven
		Flower buds/cm	Live flowers/cm	Flower buds/cm	Live flowers/cm	Flower buds/cm	Live flowers/cm	Flower buds/cm	Live flowers/cm		
1988 Control	0	0.47	0.06	0.66	0.08	0.78	0.08	1.85	0.40	109	116
Date of application trends											
26 May	100	0.15	0.06	0.37	0.07	0.52	0.13	1.05	0.46	176	107
18 June	100	0.14	0.08	0.20	0.07	0.53	0.20	0.65	0.32	170	83
9 July	100	0.22	0.02	0.35	0.11	0.65	0.02	0.90	0.54	22	126
6 Aug.	100	0.38	0.05	0.53	0.04	0.80	0.06	1.27	0.39	32	52
Standard error		0.03	0.01	0.04	0.01	0.05	0.03	0.18	0.18	29	41
Significance											
Linear		**	*	*	NS	**	**	NS	NS	**	NS
Quadratic		**	NS	**	†	†	NS	†	NS	NS	NS
18 June	200	0.06	0.05	0.14	0.06	0.26	0.17	0.53	0.51	81	78
9 July	200	0.11	0.02	0.28	0.08	0.40	0.01	0.48	0.24	19	101
6 Aug.	200	0.30	0.05	0.41	0.03	0.66	0.05	1.10	0.20	54	38
12 Oct.	200	0.43	0.09	0.72	0.15	0.71	0.16	2.10	0.44	241	102
Standard error		0.03	0.01	0.04	0.02	0.05	0.05	0.29	0.13	59	50
Significance											
Linear		**	†	**	NS	†	NS	**	NS	*	NS
Quadratic		†	†	NS	NS	**	**	*	*	*	NS
Concentration trends											
26 May	25	0.32	0.11	0.64	0.15	0.77	0.22	1.56	0.87	238	169
	50	0.26	0.12	0.46	0.09	0.54	0.22	1.26	0.73	245	129
	100	0.15	0.06	0.37	0.07	0.52	0.13	1.05	0.46	176	107
Standard error		0.02	0.01	0.03	0.01	0.06	0.04	0.25	0.20	53	50
Significance											
Linear		**	NS	**	NS	**	NS	*	NS	NS	NS
Quadratic		*	**	NS	NS	NS	**	NS	NS	*	NS
18 June	50	0.24	0.09	0.39	0.16	0.63	0.13	1.16	1.00	240	152
	100	0.14	0.08	0.20	0.07	0.53	0.20	0.65	0.32	170	83
	200	0.06	0.05	0.14	0.06	0.26	0.17	0.53	0.51	81	78
Standard error		0.02	0.01	0.03	0.02	0.06	0.05	0.19	0.15	36	36
Significance											
Linear		**	†	**	NS	**	NS	**	NS	†	NS
Quadratic		**	**	**	NS	NS	NS	*	NS	**	NS
9 July	50	0.35	0.02	0.64	0.11	0.78	0.06	1.70	0.26	50	88
	100	0.22	0.02	0.35	0.11	0.65	0.02	0.95	0.54	22	126
	200	0.11	0.02	0.28	0.08	0.40	0.00	0.48	0.24	19	101
Standard error		0.03	0.01	0.04	0.02	0.06	0.03	0.29	0.13	16	58
Significance											
Linear		**	**	**	NS	**	**	**	NS	**	NS
Quadratic		†	**	NS	NS	NS	NS	NS	NS	**	NS
6 Aug.	100	0.38	0.05	0.53	0.04	0.80	0.06	1.27	0.39	32	53
	200	0.30	0.05	0.41	0.03	0.66	0.05	1.10	0.20	54	38
Standard error		0.04	0.01	0.04	0.01	0.06	0.02	0.23	0.17	18	20
Significance											
Linear		**	NS	*	*	†	NS	*	NS	†	*

^aMeans of 72 to 90 observations of unbranched current season extension shoots (>10 cm).

^bMeans of 72 to 90 observations of current season spurs (<10 cm).

^xMeans of counts of five individual, whole trees made before harvest.

NS, †, *, ** Nonsignificant or significant at $P = 0.1$, 0.05, or 0.01, respectively, across concentration or date of application.

'Cresthaven' compared to the untreated controls. This increased LFD translated to a yield rating 1.5 times greater than control for 'Redhaven' trees and a 1.25 times greater yield rating on the June treated 'Cresthaven'. Several near critical winter temperature extremes had killed 87% and 93% of the flower buds present on long shoots of 'Redhaven' and 'Cresthaven' controls respectively. The June and September treatments also increased the LFD of 'Cresthaven' short shoots.

The 31 July application generally produced the lowest LFD of any GA₃ application date (Table 1). In the worst case the 50 and 100 mg·L⁻¹ treatments reduced live flowers of 'Redhaven' long shoots to ≈60% below that of the control, which reduced the yield rating of 'Redhaven' by 43%. Increased GA₃ concentrations in September had little effect on LFD of 'Redhaven' long shoots, but all the GA₃ treatments more than doubled the long shoot LFD on 'Cresthaven' compared to the control as demonstrated by the strong quadratic trend.

1988 TREATMENTS. The GA₃ (100 mg·L⁻¹) applied on 26 May and 18 June reduced the total FBD of 'Redhaven' long shoots by ≈70% (Table 2). The 18 June treatment resulted in minimum long shoot FBD (70% reduction) on 'Cresthaven', while the 26 May and 9 July treatments were only about two-thirds as effective in reducing flower buds. The short shoot flower buds on 'Redhaven' and 'Cresthaven' trees were also reduced by the May and June treatments similarly to their long shoot counter parts but to a lesser extent.

Increasing the GA₃ concentration generally increased the thinning response of flower buds (Table 2). The increasing GA₃ concentrations applied in May, June, or July to 'Redhaven' induced virtually identical shape and slope of trend response, but the intercept was lowest on 18 June and highest on 9 July. The long shoot flower bud density response to concentration of sprays applied on 18 June to 'Cresthaven' was very similar to the 'Redhaven' trends, except for a slightly higher intercept. As a

result the 50 and 100 mg·L⁻¹ treatments to 'Cresthaven' on 18 June produced a 40% and 60%, respectively greater efficacy in FBD reduction as compared to the sprays applied on 26 May. 'Cresthaven' long shoot flower buds were much less sensitive to increasing GA₃ concentration than 'Redhaven' on 26 May and 9 July.

The FBD of short shoots on 'Redhaven' and 'Cresthaven' trees was generally reduced linearly with increasing GA₃ concentrations. The flower buds were thinned more on 18 June and 9 July than on 26 May or 6 Aug. On 9 July, the 50 mg·L⁻¹ GA₃ treatment had little effect on FBD of short shoots of both cultivars. But doubling the concentration to 100 mg·L⁻¹ substantially reduced the short shoot FBD by 17% and 44% on 'Redhaven' and 'Cresthaven', respectively. This concentration effect was less evident on 18 June and minimal on 26 May and 6 Aug.

The LFD of 'Redhaven' long shoots was increased 33% by GA₃ treatments on 18 June compared to the untreated control. The 'Cresthaven' LFD was also increased 38% over the control, but not until 9 July, 3 weeks after 'Redhaven'. The long shoot flower buds on the 'Redhaven' and 'Cresthaven' controls had both sustained ≈88% mortality from low winter temperatures. The late season GA₃ treatments applied on 12 Oct. also increased long shoot LFD by ≈50% on both cultivars.

The two earliest season GA₃ (100 mg·L⁻¹) applications increased short shoot LFD of 'Redhaven' and later applications decreased it. Applying 200 mg·L⁻¹ GA₃ in July or August reduced LFD of short shoots by 38% to 88% of control on both cultivars. In contrast, the 12 Oct. treatment doubled LFD of short shoots of 'Redhaven', but had no effect on 'Cresthaven'.

The LFD of long and short 'Redhaven' shoots treated with 25 or 50 mg·L⁻¹ GA₃ on 26 May was 2 to 3 times greater than the LFD of the respective control. There was little treatment effect when the concentration exceeded 50 mg·L⁻¹ as demonstrated by the strong quadratic trend. On 18 June the 50 and 100 mg·L⁻¹ GA₃ treatments produced a similar (≈40%) increase in LFD on the 'Redhaven'

Table 3. Density of flower and shoot buds and node condition on long shoots (sampled in March 1990) of mature 'Redhaven' and 'Cresthaven' peach trees in response to dilute GA₃ applications on 23 June 1989.

GA ₃ concn mg·L ⁻¹	Flower buds/cm	Live flowers/cm	Vegetative buds/cm	Nodes/ cm	Flower buds/node	Flower buds/ vegetative bud	Total ² buds/node
Redhaven³							
0	0.34	0.049	0.242	0.482	0.72	1.62	1.23
50	0.10	0.032	0.304	0.471	0.22	0.43	0.87
65	0.05	0.018	0.306	0.451	0.14	0.28	0.83
100	0.04	0.011	0.294	0.444	0.10	0.17	0.76
Standard error	0.02	0.007	0.018	0.019	0.03	0.11	0.05
Significance							
Linear	**	**	*	NS	**	**	**
Quadratic	**	NS	†	NS	**	**	†
Cresthaven⁴							
0	0.52	0.074	0.310	0.504	1.03	1.94	1.68
50	0.18	0.050	0.368	0.463	0.40	0.58	1.21
65	0.16	0.044	0.377	0.466	0.36	0.47	1.18
100	0.16	0.036	0.379	0.500	0.30	0.42	1.05
Standard error	0.02	0.007	0.016	0.014	0.04	0.11	0.06
Significance							
Linear	**	**	*	NS	**	**	**
Quadratic	**	NS	NS	*	**	**	*

²Total buds = flower + vegetative buds.

³Means of 56 to 60 observations.

⁴Means of 116 to 120 observations.

NS, †, *, ** Nonsignificant or significant at *P* = 0.1, 0.05, or 0.01, respectively, across concentration or date of application.

long shoots. But on this date there was minimal treatment effect on LFD with the highest (200 mg·L⁻¹) concentration in a trend pattern similar to that of 26 May. The LFD on 'Redhaven' short shoots and 'Cresthaven' long and short shoots did not show a clear concentration trend response.

All GA₃ concentrations applied on 9 July uniformly reduced

'Redhaven' long shoot LFD by 65%. The 'Redhaven' short shoots responded similarly but only to the 100 and 200 mg·L⁻¹ GA₃ treatments. The 'Cresthaven' long shoot LFD was only reduced below control by the August treatment.

The GA₃ effect on cropload of 'Redhaven' and 'Cresthaven' trees paralleled its effect of increasing LFD with the response more

Table 4. Length of unbranched current season shoots and upright, branched watersprouts in response to GA₃ applied as a dilute, handgun spray to mature 'Redhaven' and 'Cresthaven' peach trees in 1988.

Application date (1988)	GA ₃ concn mg·L ⁻¹	Current season shoot length (cm) ²				Watersprouts ³					
		Redhaven Shoots		Cresthaven Shoots		Avg length (cm)			Lateral shoot no./primary		Cumulative length of laterals (cm)
		Long	Short	Long	Short	Primary	Secondary	Tertiary	Secondary	Tertiary	
Control	0	26	5.5	28	4.7	142	28.2	11.3	18.8	0.40	540
Date of application trends											
26 May	100	27	5.8	32	5.3	130	29.8	10.7	13.3	0.33	406
18 June	100	29	6.1	29	5.4	146	29.9	10.8	19.5	0.57	600
9 July	100	28	5.3	28	5.3	139	27.9	7.7	17.4	1.29	494
6 Aug.	100	27	6.0	30	5.5	143	28.6	13.6	17.2	0.53	506
Standard error		2	0.4	2	0.4	6	1.4	2.4	1.4	0.32	57
Significance											
Linear		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Quadratic		NS	NS	NS	NS	NS	NS	NS	*	NS	†
18 June	200	28	6.1	29	5.9	127	30.4	12.0	14.6	0.37	461
9 July	200	31	5.7	28	6.0	142	32.4	11.0	18.6	1.40	629
6 Aug.	200	27	5.9	28	5.0	146	32.1	15.3	18.9	0.53	634
12 Oct.	200	28	6.0	28	5.3	132	28.3	13.7	16.6	0.38	484
Standard error		2	0.4	2	0.4	6	1.6	2.3	1.6	0.38	69
Significance											
Linear		NS	NS	NS	†	*	NS	NS	NS	NS	NS
Quadratic		NS	NS	NS	NS	**	*	NS	†	*	**
Concentration trends											
26 May	25	30	5.8	31	5.3	129	26.0	16.2	15.6	0.23	424
	50	30	6.2	30	5.1	132	27.7	13.8	13.9	0.60	390
	100	27	5.8	32	5.3	130	29.8	10.7	13.3	0.33	406
Standard error		2	0.4	2	0.5	5	1.2	3.5	1.1	0.23	41
Significance											
Linear		NS	NS	†	NS	NS	†	NS	†	NS	NS
Quadratic		NS	NS	NS	NS	NS	†	NS	NS	NS	NS
18 June	50	30	6.3	30	4.5	135	28.0	15.4	17.7	0.77	512
	100	29	6.1	29	5.4	146	29.9	10.8	19.5	0.57	600
	200	28	6.1	29	5.9	127	30.4	12.0	14.6	0.37	461
Standard error		2	0.4	2	0.4	6	1.5	1.4	1.5	0.42	58
Significance											
Linear		NS	NS	NS	*	NS	†	NS	†	NS	NS
Quadratic		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
9 July	50	28	6.7	28	5.6	124	27.9	12.4	17.2	0.80	517
	100	28	5.3	28	5.3	139	27.9	7.7	17.4	1.29	494
	200	31	5.7	28	6.0	142	32.4	11.0	18.6	1.40	629
Standard error		2	0.4	2	0.4	6	1.4	2.0	1.5	0.46	67
Significance											
Linear		**	NS	NS	*	NS	*	NS	NS	*	NS
Quadratic		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
6 Aug.	100	27	6.0	30	5.5	143	28.6	13.6	17.2	0.53	506
	200	27	5.9	28	5.0	146	32.1	15.3	18.9	0.53	634
Standard error		2	0.4	1	0.4	6	1.3	3.8	1.6	0.30	65
Significance											
Linear		NS	NS	NS	NS	NS	*	†	NS	NS	†

²Length of fruiting quality shoots in the bearing canopy. Means of 72 to 90 observations.

³Growth of 1-year-old, upright, branched shoots in the top of trees. Means of 24 to 30 observations except for the average length of tertiary shoots where the number of observations equals the number of tertiary shoots/primary.

NS, †, *, ** Nonsignificant or significant at $P = 0.1$, 0.05, or 0.01, respectively, across concentration or date of application.

obvious on 'Redhaven' trees (Table 2). The 'Redhaven' cropload was increased over control by as much as 2.2 times by the lower GA₃ concentrations applied on 26 May and 18 June. 'Redhaven' cropload was decreased below control by 54% with the 50 mg·L⁻¹ treatment on 9 July. Increasing the GA₃ concentration to 100 mg·L⁻¹ at this time halved the cropload again. Delaying the GA₃ spray (100 mg·L⁻¹) until 6 Aug. reduced the cropload of 'Cresthaven' and 'Redhaven' by 54% to 70%, respectively. The mid-October GA₃ treatment increased 'Redhaven' cropload 2.2 times, which was similar to its having increased the LFD (50% and 100% increase on long and short shoots, respectively).

1989 TREATMENTS. The 50 mg·L⁻¹ GA₃ treatment applied on 23 June reduced FBD of long shoots by ≈70% on 'Redhaven' and 'Cresthaven' (Table 3). Increasing the concentration resulted in FBD trend patterns for the two cultivars almost identical to those induced by the 1988 sprays.

After sustaining 86% flower bud winter mortality on both cultivars, the 'Cresthaven' and 'Redhaven' untreated controls carried a higher LFD than any GA₃ treated trees. However a greater

proportion of the flower buds remaining on the shoots after GA₃-induced thinning survived the low temperature (-25 °C) extreme on the GA₃ treated trees than on the controls: 50 mg·L⁻¹ GA₃ reduced total FBD by 70%, but resulted in a live flower density only 35% lower than control. Increasing the GA₃ concentration reduced the LFD to the point that there was little or no increase in winter survival of the flower buds remaining after the GA₃ treatment on 'Cresthaven' and 'Redhaven', respectively.

Although GA₃ treatment increased the vegetative bud density, the proportion of the increase could account for only about one-fourth of the decrease in flower bud number elicited by GA₃ on both cultivars (Table 3). The primary means of reduction was through decreasing flower bud number per node with these sites becoming blind in the majority of cases. The number of flower buds per vegetative bud as well as the total number of buds per node were also reduced with increasing GA₃ concentration on both cultivars. The number of nodes per cm shoot length remained constant on 'Redhaven', but was slightly reduced by 50 or 65 mg·L⁻¹ GA₃ on 'Cresthaven' trees.

Table 5. Defoliation and time of flowering response to date and concentration of GA₃ sprays applied to peach trees in 1987.

Application date	GA ₃ concn mg·L ⁻¹	Defoliation ² (%) 29 Oct. 1987		Flower buds still pink ² (%) 9 Apr. 1988	
		Redhaven	Cresthaven	Redhaven	Cresthaven
Control	0	91	77	0.0	0.0
Date of application trends					
30 June	100	82	60	0.0	0.0
31 July	100	76	58	30.0	15.0
12 Sept.	100	63	38	0.1	4.8
14 Oct.	100	78	74	0.0	0.2
Standard error		7	15	4.6	4.9
Significance					
Linear		NS	NS	†	NS
Quadratic		†	†	**	*
31 July	200	56	40	58.0	21.0
12 Sept.	200	49	18	0.3	10.4
29 Oct.	200	92	68	0.0	0.0
Standard error		11	11	2.0	11.8
Significance					
Linear		**	**	**	NS
Concentrations trends					
31 July	50	73	59	14.0	0.6
	100	76	58	30.0	15.0
	200	56	40	58.0	21.0
Standard error		10	10	5.8	10.2
Significance					
Linear		**	**	**	*
Quadratic		NS	NS	NS	NS
12 Sept.	50	66	34	0.0	2.3
	100	63	38	0.1	4.8
	200	49	18	0.3	10.4
Standard error		8	7	0.2	4.3
Significance					
Linear		**	**	†	*
Quadratic		NS	**	NS	NS
29 Oct.	200	92	68	0.0	0.0
	400	89	82	0.0	0.2
Standard error		2	8	0.0	0.1
Significance					
Linear		NS	NS	NS	†

²Means of ratings of five individual whole trees by two independent raters.

NS, †, *, ** Nonsignificant or significant at *P* = 0.1, 0.05, or 0.01, respectively, across concentration or date of application.

SHOOT LENGTH. In 1987 the long shoots of 'Redhaven' and 'Cresthaven' controls both averaged 31 cm. When GA₃ treatments were applied 31 July and 12 Sept., 'Redhaven' long shoot length was suppressed by 6% and 12%, respectively (data not presented). The effect increased with concentration. All other treatments had no effect on shoot length.

In 1988 'Redhaven' long shoot length was increased slightly by some GA₃ treatments (Table 4). The 'Cresthaven' long shoot

length was also very little affected and only slightly increased by increasing concentrations of the GA₃ spray applied on 26 May. However, the same 26 May GA₃ treatments decreased the cumulative shoot length of watersprouts growing in the tree top. Length of 'Redhaven' short shoots was not affected. 'Cresthaven' short shoot length tended to be a little higher on all treated trees than on controls. Primary watersprout length and number of lateral shoots were reduced by the GA₃ treatment in May. Secondary and tertiary shoot length was minimally affected. But when treatments were applied on 9 July, the number of tertiary lateral shoots was increased linearly with increasing concentration. In midsummer (July and August) the highest concentration of GA₃ (200 mg·L⁻¹) increased the cumulative lateral shoot length of watersprouts.

In 1989 the 50 and 65 mg·L⁻¹ GA₃ treatments applied on 23 June increased the 'Redhaven' long shoot length by 4.8% on average of control ($\bar{X}_{\text{control}} = 43.9$ cm, data not presented). But the 100 mg·L⁻¹ spray actually decreased the 'Redhaven' long shoot length by 3.0% of control (Quadratic trend significance = 0.09). The 'Cresthaven' long shoots ($\bar{X}_{\text{control}} = 43.1$ cm) appeared to exhibit a concentration response (quadratic trend significance = 0.13) very similar to the 'Redhaven' shoots.

DEFOLIATION. The 12 Sept. 1987 GA₃ treatments (100 and 200 mg·L⁻¹) delayed leaf fall of 'Redhaven' and more dramatically of 'Cresthaven' trees (Table 5). The June and October treatments had minimal effect on autumn defoliation. Increasing the GA₃ concentration in July and September generally increased the delay in defoliation on both cultivars, but had no effect on trees treated in October.

TIME OF BLOOM. The 31 July and 12 Sept. 1987 GA₃ treatments delayed flower bud development in comparison to other dates of spray (Table 5). On 9 Apr. 1988, essentially all flower buds were past pink on controls while there was a positive linear increase in percentage of buds remaining in pink with increasing GA₃ concentration applied on 31 July and 12 Sept. The bloom delay response of the 12 Sept. treatments was less than that of the 31 July treatments, especially on 'Redhaven'.

Only the 6 Aug. 1988 treatments delayed the bloom of 'Redhaven' on 1 Apr. 1989 (Table 6). There were 25% fewer buds that had progressed to full bloom on the 100 mg·L⁻¹ trees compared to all other treatments. Doubling the GA₃ concentration to 200 mg·L⁻¹ reduced the number of flower buds that had reached full bloom stage on 1 Apr. by two-thirds of that on the 100 mg·L⁻¹ treatment. Delay of bloom was less pronounced on 'Cresthaven' trees. In both years, GA₃-induced bloom delay did not last longer than a couple of days after sampling because of generally warm temperatures immediately before and after the date of bloom rating.

Discussion

Timing of the GA₃ treatment was critical for inducing maximum reduction in flower bud density (Tables 1 and 2). Although 'Redhaven' long shoots were thinned to about the same FBD by the 26 May and 18 June 1988 50 mg·L⁻¹ treatment, the 'Cresthaven' FBD was clearly reduced more by the 18 June spray as compared to 26 May (Table 2). However the FBD of both cultivars was reduced much less by the July treatments as compared to their respective late June sprays. Li et al. (1989) showed a diminished flower bud thinning effect from GA₃ applied to 'Redwing', 'Suncrest', and 'Redskin' peach trees in the Rhone valley on either 5 July or 15 July as compared to treatments applied just 6 to 11 d earlier. Byers et al. (1990) reported an increased GA₃ induced thinning effect on 'Redhaven' as application date progressed from

Table 6. Time of flowering response to date and concentration of GA₃ sprays applied to peach trees in 1988.

Application date	GA ₃ concn mg·L ⁻¹	Flowers at full bloom ² (%)	
		1 Apr. 1989	
		Redhaven	Cresthaven
Control	0	92	79
Date of application trends			
26 May	100	89	84
18 June	100	85	90
9 July	100	88	78
6 Aug.	100	67	71
Standard error		8	14
Significance ³			
Linear		*	NS
Quadratic		NS	NS
18 June	200	76	74
9 July	200	92	61
6 Aug.	200	26	62
12 Oct.	200	91	60
Standard error		9	14
Significance			
Linear		NS	NS
Quadratic		**	NS
Concentration trends			
26 May	25	92	79
	50	95	82
	100	89	84
Standard error		5	10
Significance			
Linear		NS	NS
Quadratic		NS	NS
18 June	50	92	81
	100	85	90
	200	76	74
Standard error		9	10
Significance			
Linear		†	NS
Quadratic		NS	NS
9 July	50	87	59
	100	88	78
	200	92	61
Standard error		5	18
Significance			
Linear		NS	NS
Quadratic		NS	NS
6 Aug.	100	67	71
	200	26	62
Standard error		10	12
Significance			
Linear		**	NS

²Means of ratings of five individual whole trees by two independent raters.

NS, †, *, ** Nonsignificant or significant at $P = 0.1$, 0.05, or 0.01, respectively, across concentration or date of application.

≈27 Apr. to 31 May but later dates of application were not tested.

The GA₃ treatments generally resulted in much less thinning on short shoots on the date of maximum thinning efficacy for long shoots of 'Redhaven'. The flower buds on short shoots of 'Redhaven' and 'Cresthaven' (Table 1 and 2) were less sensitive to GA₃ thinning than flower buds on long shoots when a high concentration (100 mg·L⁻¹) was used. At moderate concentrations (50 mg·L⁻¹), the flower buds on 'Redhaven' short shoots were much less sensitive to GA₃ induced thinning on 18 June than on 26 May—in contrast, flower bud thinning on long shoots was greater in June than in May. The flower buds of 'Cresthaven' short shoots were thinned by about the same proportion as on long shoots. Byers et al. (1990) reported that flower buds were inhibited more strongly on short shoots, but they did not apply GA₃ at the time of maximum efficacy for long shoot thinning (mid- to late June). Our results supported by those of Byers et al. (1990) suggest that early season GA₃ sprays could be used to selectively thin flower buds from short shoots on cultivars where fruits on short shoots are difficult to handthin or have poor size potential as in 'Cresthaven'.

The thinning response of 'Cresthaven' long shoots to 100 mg·L⁻¹ GA₃ treatments in June 1987, 1988 and 1989 was very uniform: respectively 70%, 66%, and 69% reduction in FBD. The reduction in long shoot FBD on 'Redhaven' treated with 100 mg·L⁻¹ GA₃ in June 1988 and 1989 (70% and 88%, respectively) increased with increasing vegetative vigor of trees (extension shoots of controls averaged respectively 26 and 43 cm in length). Cumulative rainfall for April, May, and June of 1989 (348 mm) was more than twice that of 1988 (162 mm). Vigorously growing young trees have been previously reported to be more sensitive to GA₃-induced flower bud thinning than less vigorous mature trees (Taylor and Geisler-Taylor, 1990). The 42% reduction in flower buds on trees treated with 100 mg·L⁻¹ GA₃ on 30 June 1987 is consistent with reduced thinning efficacy found with treatments made after 18 June 1988 (Table 2). The spray date for optimal thinning efficacy of 'Redhaven' long shoots had passed.

The 50 mg·L⁻¹ treatment applied in June of each year provided a more moderate thinning response from year to year: 50% (1988) and 70% (1989) reduction in 'Redhaven' and 41% (1988) and 65% (1989) reduction in 'Cresthaven'. Dilute sprays of 50 mg·L⁻¹ GA₃ from a wide range in locations were reported to reduce FBD 43% to 72% (Brown et al., 1968, Edgerton, 1966).

The live flower density response to GA₃ treatments following Winters 1987–88 and 1988–89 was very different from that of the flower bud thinning response (Tables 1 and 2). There was high flower bud mortality on control trees. The June and especially the May treatments increased LFD, but the July spray decreased it. The 1987 experiment was subjected to sudden drops in temperature from highs around 16.1 °C to lows of -13.9 to -17.8 °C within 2 to 5 d in early January and again in early February 1988. The trees treated with GA₃ in 1988 experienced similar fluctuations in late December and early February 1989.

In the winter of '89/'90 there was 85% winter mortality of total flower buds on the controls, but only 66% mortality (of buds present after thinning) occurred on trees previously treated with 50 or 65 mg·L⁻¹ GA₃ (Table 3). Although the LFD was decreased at concentrations above 50 mg·L⁻¹, the winter survival of flower buds was always higher than on controls. Edgerton (1965) found increased 'Redhaven' LFD on trees treated with 50 mg·L⁻¹ GA₃ in July despite a reduced FBD. Edgerton (1966) and Corgan and Widmoyer (1971) reported midsummer GA₃ treatments delayed flower bud development in early fall and increased hardiness in mid-November and late February. A GA₃-induced delay in peach flower bud development before winter is consistent with increased

bud survival because of the increased ability to supercool (Ashworth et al., 1989).

The September/October GA₃ treatments in 1987 and 1988 also increased LFD causing higher yields (Tables 1 and 2). Proebsting and Mills (1964) reported late summer GA₃ treatments increased LFD following low temperatures in January, which caused a 73% increase in yield as compared to the winter damaged control. Unfortunately our late season applications caused little or no reduction in total FBD. (Tables 1 and 2).

In contrast late July (Table 1) and early August (Table 2) treatments tended to reduce LFD. Stembridge and LaRue (1969) also found that 100 to 150 mg·L⁻¹ GA₃ treatments caused excessive flower bud thinning (by increased bud mortality). Byers et al. (1990) concluded the danger of "overdosing" with late summer/fall GA₃ treatments precluded using these sprays to thin flower buds. However low GA₃ concentrations (50 mg·L⁻¹) in September (Table 1; Corgan and Widmoyer, 1971) or October (Stembridge and LaRue, 1969) caused little reduction in FBD.

Early hopes of using GA₃ to delay peach bloom (Stembridge and LaRue, 1969; Corgan and Widmoyer, 1971) appear unachievable because: 1) climates where spring freezes often occur also push blossoming during warm periods so that little (Table 5 and 6) or no (Proebsting and Mills, 1964) delay in bloom was seen; 2) the most consistent delay was associated with late July (Table 5) or August treatments (Table 6; Corgan and Widmoyer, 1971), at times which also induced great flower bud mortality and reduced yield (Table 1 and 2); 3) the greatest bloom delay occurred at 200, 240 or 250 mg·L⁻¹ GA₃ concentrations (Table 5 and 6; Proebsting and Mills, 1964; Corgan and Widmoyer, 1971), which resulted in poor flower bud survival and subsequent poor yield (Table 1 and 2; Proebsting and Mills, 1964).

The results presented in this paper added to the previous literature indicate that GA₃ can be a useful tool for managing peach trees. Its use could be adapted to local individual conditions. In areas exposed to little danger of flower bud loss to abiotic or biotic stress, bud thinning could be as much as 80 to 90% without affecting cropping potential (Dorsey and McMunn, 1944) on cultivars or in orchards that carry high bud densities. Where spring frost at flowering is a major hazard to peach cropping, growers would want to treat only a portion of acreage with the lower rates to thin perhaps 30% to 50% of the total FBD. Where winter temperature fluctuations predispose flower buds to winter mortality, moderate concentrations applied May through June or September/October may provide some protection but they could not be expected to save the entire crop every year, especially when temperatures decline to levels critical even for well acclimated buds.

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