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Effect of a Late Spring Application of Hydrogen Cyanamide on High-Chill Peaches

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Abstract: Due to a record low chilling accumulation in the winter of 2016–2017, many high-chill peach cultivars displayed almost no budbreak by mid-April of 2017 in central Georgia, USA, where budbreak usually occurs around mid-March. In this study, nine of these peach cultivars were used to study the effect of a late spring Dormex spray application (April 13, 2017) on subsequent budbreak, year-end cumulative vegetative growth, and following-season yield. Dormex was found to have strong stimulating effects on lateral budbreak, but little effect on terminal and floral budbreak. It also had apparent phytotoxic effects on lateral, terminal and floral buds, and growth. The effects varied among genotypes, tree ages, and shoot types. The peak of the effects occurred two weeks post-application. Most floral buds abscised before they swelled. Between Dormex-sprayed trees and unsprayed controls, there was no significant difference in the number and average length of the new lateral shoots by the end of 2017, nor in the number and weight of the fruit harvested in 2018. In conclusion, our data showed a late spring Dormex spray application stimulated earlier lateral budbreak and caused some level of phytotoxicity to all types of buds and new growth, but had little impact on flower budbreak, fruit set, year-end vegetative growth, or following-season yield. These findings provide useful information for growers, considering the need for spraying dormancy-breaking compounds when faced with insufficient chilling.

Keywords: *Prunus persica* (L.) Batsch; chilling requirement; hydrogen cyanamide; Dormex

1. Introduction

Peach (*Prunus persica* [L.] Batsch) is produced in temperate, subtropical, and Mediterranean climate zones. Minimal chilling requirement (CR) must be satisfied for peach cultivars to complete foliar and floral bud differentiation and start budbreak on time [1]. Inadequate chilling, depending on the level of adequacy or percent to cultivar's CR, can cause budbreak delay or varying degrees of failure up to complete crop loss. For example, only 466 chill hours (CH) were received by February 15, 1989 at Southeastern Agricultural Weather Service Center, National Weather Service, Auburn, Alabama, USA, and all cultivars that had a CR of 750 CH or over failed to bloom and foliate in mid-April [2]. CH have been commonly used to monitor and estimate CR [1], which are calculated as the sum of accumulated hours below 7.2 °C (~45 °F) between October 1st and the following February 15th in the Northern Hemisphere. In addition, modified approaches or models have been developed with adjustment of the chilling efficacy at different temperature ranges, such as chill units [3], negated chill units [4], or chilling portions [5].

Hydrogen cyanamide (CH_2N_2) is a registered plant growth regulator and an active ingredient of Dormex® (AlzChem, Trostberg, Germany). Application of hydrogen cyanamide at appropriate concentrations and timing may induce budbreak from dormancy and stimulate earlier budbreak in order to advance a more uniform bloom and harvest and/or help break inadequately chilled buds [2].

It may also cause phytotoxicity. Hydrogen cyanamide has been tested on various fruit and nut crops, such as grape [6], pistachio [7], peach [2], pecan [8], blueberry [9], and sweet cherry [10], to name a few. For example, Dormex effectively induced vegetative budbreak and reduced shoot dieback in seventeen insufficiently chilled peach and nectarine cultivars in 1989 in a linear fashion as the concentration of Dormex was increased at a rate from 0% to 2%. The 2% rate was the most effective in the induction of vegetative budbreak and the reduction in shoot dieback in most cases [2]. Insufficient chill caused abnormality and substantial delay in development of sweet cherry ovules and embryo sacs, compared to their adequately chilled counterparts. The abnormality and delay were eliminated by application of hydrogen cyanamide, suggesting hydrogen cyanamide could be used as an agent to compensate CR for some insufficiently chilled sweet cherry cultivars, and allows them to be grown in warm winter regions [10]. Under normal chilling accumulation, Dormex advanced the mean harvest time by 10 days at one location in subtropical Australia when applied to 'Flordaprince' peach early to mid-June (endodormancy). But the trends between dates of harvests and sprays were inconsistent at another location and the spray with the lowest concentration (10 mL/L) reduced yield by up to 40.8% [11]. A comparison of four concentrations of hydrogen cyanamide (0.125, 0.25, 0.5, and 1.0 M) applied to normally chilled 'Redhaven' peach on 1 and 15 October, 1 and 15 November, and 1 and 15 December 1990, revealed all concentrations promoted budbreak and caused phytotoxicity, varying with concentrations and timing of applications. Hydrogen cyanamide at 0.125 M had the greatest budbreak and lowest phytotoxicity of all treatment dates [12]. These results have demonstrated that hydrogen cyanamide is capable of changing the natural course of budbreak and affecting plant vegetative and reproductive growth routine in the applied year. However, there is little information regarding whether the effect varies among different bud types or whether Dormex impacts tree health and yield in the following growing season(s), especially when the treated trees were inadequately chilled in the year treated.

Warm winters appear to be occurring with increasing frequency, according to Georgia Weather Station Network. The average at the USDA Byron Weather Station over the last 80 years is 1055 CH. Due to a record low chilling accumulation (520 CH) in the winter of 2016–2017, many high-chill peach cultivars (i.e., those requiring 850 CH and above) displayed almost no budbreak by mid-April in central Georgia (where budbreak of such cultivars usually occurs around mid-March). These cultivars appeared to still be essentially dormant as there was almost no floral or lateral budbreak but limited terminal and adventitious budbreak. This late spring Dormex spray application was an attempt to stimulate lateral budbreak and hopefully save these extremely abnormal peach trees from suffering branch dieback and possible tree death due to lack of leaves. It also was an opportunity to study the effect of a late spring Dormex spray application on all three bud types (lateral, floral, and terminal). We are not aware of any reports on the impact of such an application on vegetative growth at the end of the applied year and fruit yield in the following year in high-chill peach cultivars.

2. Materials and Methods

2.1. Peach Materials and Spray Treatment

Nine high-chill peach cultivars (abbreviations and tree ages in year in the parentheses), 'Black Boy' (BB, 8), 'Contender' (CO, 4, 8, and 14), 'Cresthaven' (CH, 5 and 14), 'Elberta' (EL, 4), 'Julyprince' (JP, 8), 'Julyprince' nectarine mutant (JN, 5); 'Red Bird Cling' (RB, 5), 'Redhaven' (RH, 4), 'Ta Qiao' (TQ, 10), were used in this study. All were located in the variety blocks at the Southeastern Tree Fruit and Nut Research Laboratory, Byron, Georgia, USA, where the coordinates are latitude 32° 39′ 54″ N, longitude 83° 44′ 31″ W, and elevation 155 m (~509 ft). There were four trees of each cultivar and tree age, comprising 12 sets of four trees (i.e., 48 trees in total). Two of the four trees in each set were sprayed with 2% Dormex® on April 13, 2017, following the product label and a previous recommendation [2]. The spray was applied at a 6.8 L per minute rate (converted from 1.8 g pm) using an AG 25th sprayer (AG Spray Equipment Inc., North Sioux City, SD, USA), ensuring a uniform coverage of all tree surfaces to run off. Each application took approximately half to one minute per tree, varying by tree size. The other two trees in each set, not sprayed, were used as controls. All cultivars were grafted on 'Guardian' rootstock and subjected to standard orchard management.

2.2. Data Collection.

Prior to the spray application, five long shoots (>35 cm, an average of 48 cm) and five short shoots (<30 cm, an average of 22 cm) were flagged on each tree for various measurements and counts on the day before the spray application and six more times on a weekly basis afterward. Unlike some species, peach does not have mixed (compound) buds; reproductive and vegetative buds are separate, although both may be present at an axillary node. The shoots used in this study were fruiting shoots. For brevity, axillary reproductive and vegetative buds were called floral (or flower) buds and lateral buds, respectively. The shoot length (cm) was measured and the total number of unbroken lateral buds, unopened flower buds, nodes with buds, and blind nodes (i.e., nodes with no vegetative or reproductive buds) were counted on each shoot, respectively, only on Apr 13, 2017 (prior to the Dormex spray application). The number of breaking lateral buds (cumulatively), newly opened flowers (removed after every count), and abscised buds (collected by gentle hand-stripping of each shoot) were counted and the status of terminal buds was noted on each shoot weekly on the following days in 2017: 4/13 (prior to the Dormex spray application), 4/20, 4/27, 5/4, 5/11, 5/18, and 5/25. The total number of opened flowers and abscised buds were a sum of the 6 weekly counts from 4/20 to 5/25 (after the Dormex spray applications). At each data collection date, the status of each terminal bud was determined and assigned to one of four classes: yes breaking into a terminal shoot (Y), not breaking into a terminal shoot (N), breaking into a terminal shoot but dying (D), and blind terminal bud (not present) (B). Percentage of each class per shoot type (long vs. short) and per spray treatment were calculated by the count on the date divided by 120 (the total number of terminals), which was also the number of flagged shoots of each shoot type and spray treatment (one terminal each shoot). At the end of the 2017 season (October 26), the number of new lateral shoots that developed on each flagged shoot was counted, and the length of each new lateral shoot, along with the length of each newly extended terminal shoot, was measured. In the 2018 season, the number and weight (kg) of the fruit were recorded from each harvested tree that were unthinned (i.e., no flowers or fruit removed intentionally), which was an attempt to assess whether the Dormex application could benefit the yield in the following year. All data were entered into EXCEL (Microsoft, Seattle, WA, USA) for management, reporting, drawing, and subsequent statistical analysis.

2.3. Statistical Analysis

Data from the Dormex experiment was analyzed using the generalized linear model (GLM) procedure with Tukey's honestly significant difference (HSD) test in SAS 9.4 (SAS Institute Inc., Cary, NC, USA). Type III F values and P values indicated the probability that the F values for the effect of main factors and their interactions for the null hypothesis was not significant. Means separation was based on Tukey's HSD (α = 0.05).

3. Results

3.1. Effect of Dormex on Budbreak

Stimulating and phytotoxic effects of Dormex on lateral, floral, and terminal buds were observed at different levels, and there were some differences between long and short shoots, based on the averages of counts on new lateral shoots developed and flowers opened from these buds in all the cultivars (Figure 1A–F; Table 1; Table S1). Almost no lateral buds (average of 0.14 per long shoot and 0.01 per short shoot) had developed into new shoots before the Dormex application on 4/13/2017 (Figure S1). The stimulating effect of Dormex on lateral buds started showing on 4/20 and reached a peak on 4/27 (Figure 1A; Figure S2). By 4/27 the average number of breaking lateral buds on sprayed long and short shoots was 10.90 and 2.63, respectively, approximately four times greater than their unsprayed counterparts. There were also differences in percent breaking lateral and floral buds among the cultivars, tree ages, shoot types, and treatments (Table 1; Table S1). There were some differences in the changes of average cumulative breaking laterals per shoot among the cultivars (examples in Figure 2A–F).

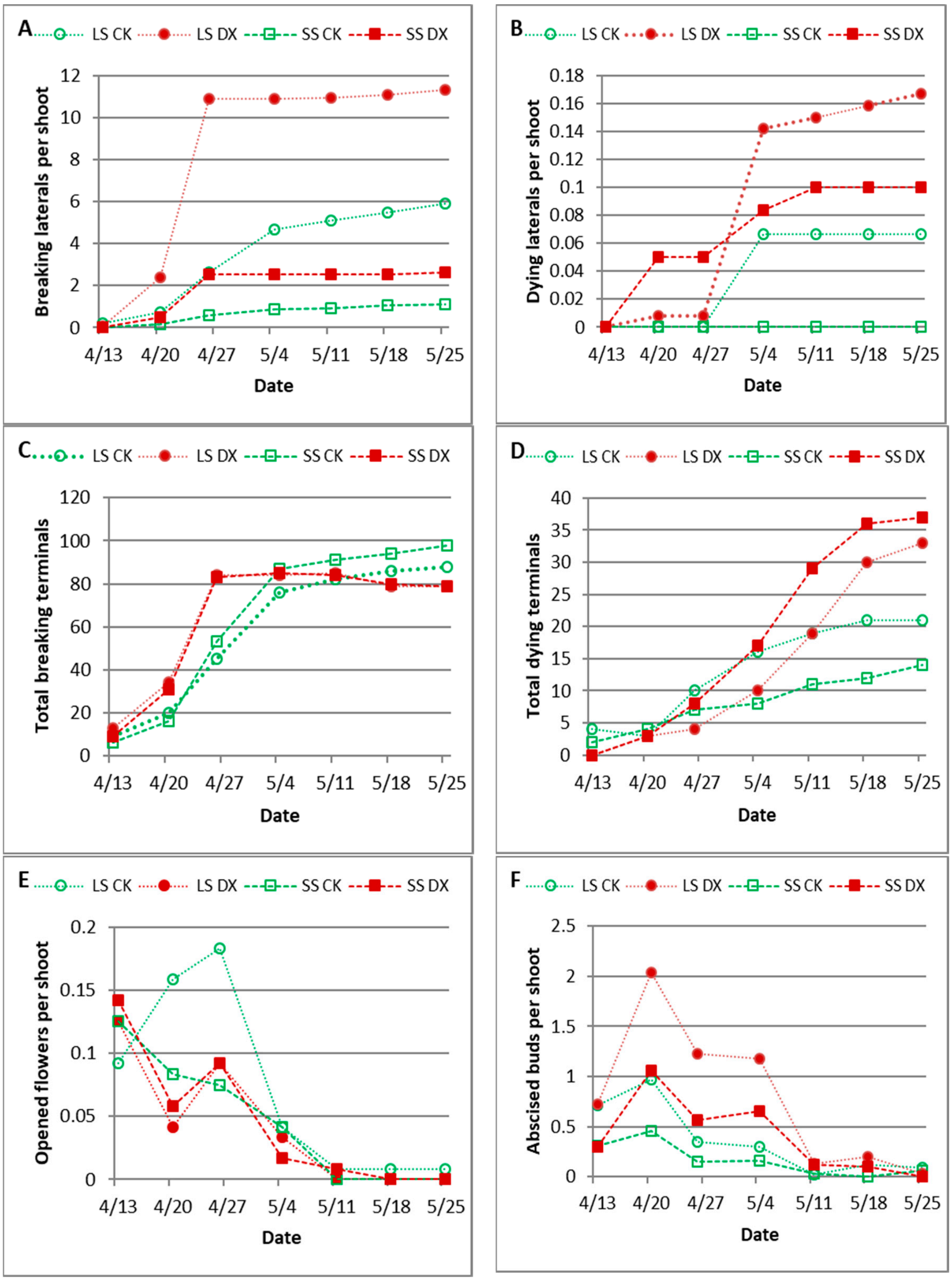

Figure 1. Averages of counts from all cultivars on the seven sampling days. Cumulative breaking laterals per shoot (**A**), cumulative breaking but dying laterals per shoot (**B**), total breaking terminals of all shoots (**C**), total breaking but dying terminals of all shoots (**D**), weekly opened flowers per shoot (**E**), and weekly abscised buds per shoot (**F**). Nearly zero breaking lateral bud (**A**) or opened flower (**E**) was observed on Apr 13, 2017 (4/13 on the x axis) when Dormex was sprayed. LS—long shoot; SS—short shoot; CK—unsprayed control; DX—Dormex sprayed.

Table 1. Statistical analysis of bud counts on 4/13 (unopened) and 5/25 (breaking) and their respective ratios [z].

	LB									**FB**								
	4/13			**5/25**			**Ratio**			**4/13**			**5/25**			**Ratio**		
	Mean	**SE**		**Mean**	**SE**		**Mean**	**SE**		**Mean**	**SE**		**Mean**	**SE**		**Total**	**SE**	
TT																		
DX	9.11	0.40	a	7.00	0.41	a	0.71	0.04	a	14.21	0.54	a	1.20	0.11	a	0.10	0.01	A
CK	7.56	0.36	b	3.51	0.27	b	0.43	0.03	b	13.66	0.49	a	0.66	0.08	b	0.06	0.01	B
ST																		
LS	12.55	0.34	a	8.57	0.38	a	0.70	0.03	a	17.45	0.56	a	1.18	0.11	a	0.08	0.01	A
SS	4.13	0.16	b	1.86	0.15	b	0.44	0.04	b	10.43	0.33	b	0.68	0.08	b	0.09	0.01	A
CV																		
BB	9.75	0.82	ab	4.23	0.84	bc	0.37	0.05	bc	16.13	0.86	b	0.93	0.19	bc	0.06	0.01	B
CO	6.81	0.48	cd	4.85	0.48	b	0.62	0.06	ab	12.78	0.81	cd	0.93	0.14	bc	0.11	0.02	Ab
CH	6.90	0.56	cd	5.14	0.60	b	0.63	0.05	ab	15.53	0.73	bc	1.39	0.19	ab	0.11	0.02	Ab
EL	9.85	1.20	ab	4.50	0.96	b	0.70	0.20	a	9.18	0.72	e	0.18	0.07	c	0.02	0.01	B
JP	10.35	0.86	a	7.78	0.89	a	0.65	0.05	ab	13.50	0.97	bcd	1.83	0.31	a	0.18	0.05	A
JN	8.03	0.73	bc	5.93	0.76	ab	0.71	0.05	a	12.48	0.76	d	0.83	0.21	bc	0.06	0.01	B
RB	5.33	0.77	d	2.10	0.51	c	0.29	0.06	c	6.78	0.39	e	0.15	0.06	c	0.02	0.01	B
RH	11.85	1.18	a	7.90	1.20	a	0.59	0.06	abc	14.78	1.04	bcd	0.55	0.12	bc	0.04	0.01	B
TQ	10.65	0.94	a	5.18	0.81	b	0.43	0.06	abc	25.00	1.36	a	1.15	0.29	ab	0.05	0.01	B
Age																		
4	10.40	0.65	a	6.49	0.64	ab	0.64	0.07	a	9.22	0.60	d	0.58	0.10	b	0.10	0.02	B
5	7.03	0.46	bc	4.75	0.45	c	0.57	0.04	a	11.15	0.53	d	0.89	0.14	b	0.08	0.01	B
7	10.35	0.86	a	7.78	0.89	a	0.65	0.05	a	13.50	0.97	c	1.83	0.31	a	0.18	0.05	A
8	7.63	0.57	b	4.03	0.54	c	0.47	0.04	a	16.75	0.73	b	0.95	0.17	b	0.05	0.01	B
10	10.65	0.94	a	5.18	0.81	bc	0.43	0.06	a	25.00	1.36	a	1.15	0.29	b	0.05	0.01	B
14	5.75	0.50	c	4.10	0.54	c	0.59	0.07	a	17.06	0.76	b	0.95	0.15	b	0.07	0.01	B

[z] Statistical output and F values indicating probability of significance were in Table S1. The counts of unopened lateral buds (LB) and flower buds (FB) (4/13) were done on 4/13/2017 prior to treatment. The count of breaking LB (5/25) was last done cumulatively on 5/25/2017, and the count of total breaking FB (5/25) was summed from the six weekly counts during 4/20-5/25/2017. The ratios were calculated as the number of breaking buds (5/25) divided by the number of unopened buds (4/13), lateral and floral, respectively. Means with the same letter are not significantly different ($\alpha = 0.05$). TT = treatment; DX = Dormex sprayed; CK = unsprayed control; ST = shoot type; LS = long shoot; SS = short shoot; CV = cultivar; BB = 'Black Boy'; CO = 'Contender'; CH = 'Cresthaven'; EL = 'Elberta'; JP = 'Julyprince'; JN = 'Julyprince' nectarine mutant; RB = 'Red Bird Cling'; RH = 'Redhaven'; TQ = 'Ta Qiao'; Age=age of trees (year), SE = standard error.

The count of newly breaking but dying lateral buds increased in the sprayed long and short shoots, compared to their unsprayed controls (Figure 1B). For example, on 5/25 the average count of breaking but dying lateral buds in sprayed long and short shoots was 0.17 and 0.10, whereas those in unsprayed long and short shoots were 0.07 and zero, respectively (Figure 1B). This suggests that there was some phytotoxicity of Dormex on the new shoots growing from the lateral buds.

As showed in Table 2 and Table S2, except for the B class, the percentage and count of terminal buds of the other three classes changed when N shifted to Y or D during the seven evaluation weeks. The average count of Y was slightly higher in sprayed long and short shoots in the first two weeks, compared to their unsprayed controls (Table S2). On 5/25 the total number of Dormex treated and surviving terminal shoots was fewer than in unsprayed controls (79 vs. 88 for long shoots and 79 vs. 98 for short shoots, treated vs. untreated, respectively) (Figure 1C; Table S2), likely due to more Dormex-induced death of new terminal shoots. A total of 33 and 37 breaking terminals were dead on 5/25 in the sprayed long and short shoots, compared to 21 and 14 in the unsprayed controls, respectively (Figure 1D, Table 2). This suggests that most unbroken terminal buds might have eventually developed into new terminal shoots without the Dormex treatment and that Dormex had some level of phytotoxic effect on dormant terminal buds.

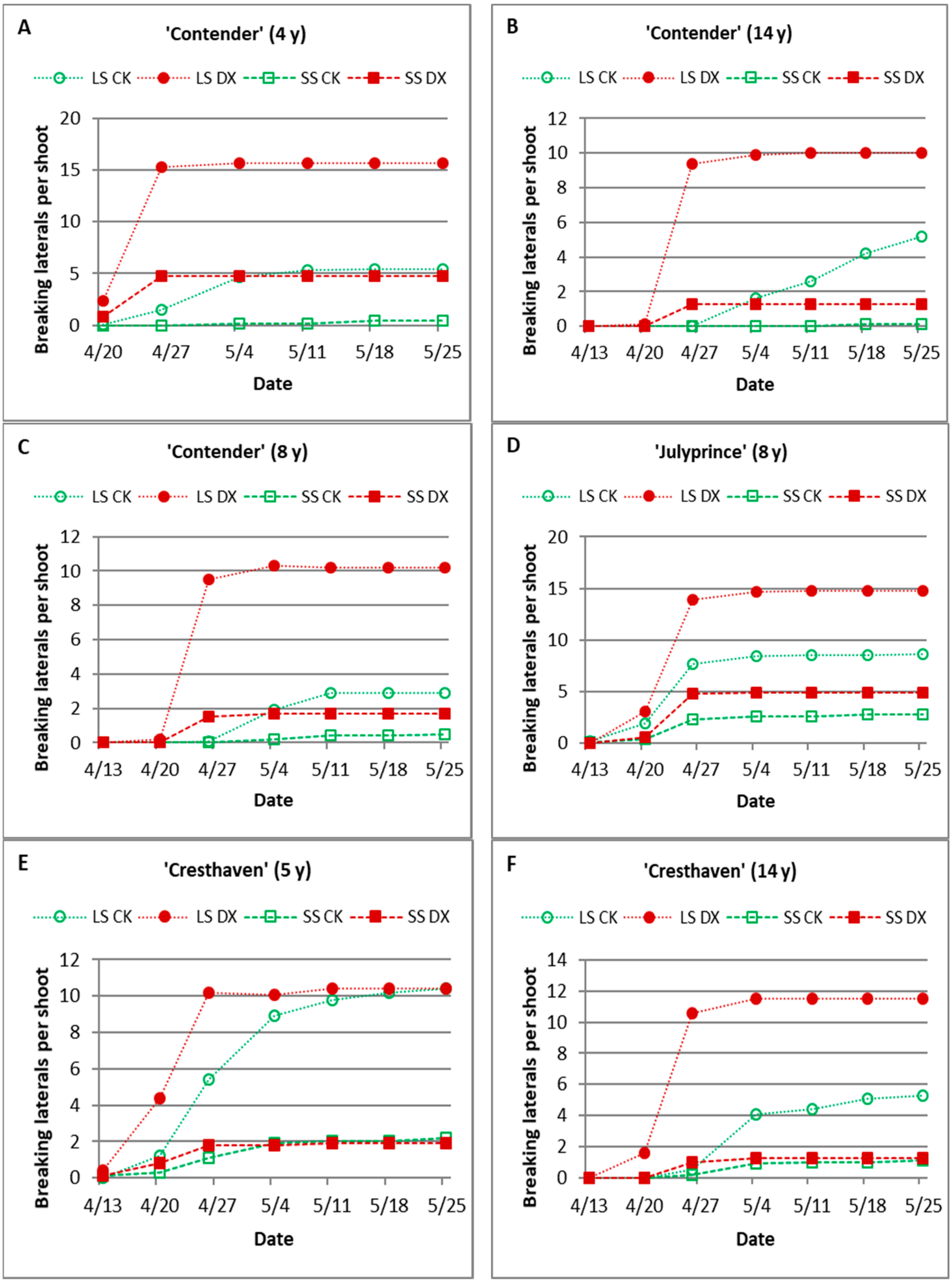

Figure 2. Averages of cumulative breaking laterals per shoot in 'Contender' (4 year old, 1050 chill hours) (**A**), 'Contender' (14 y) (**B**), 'Contender' (8 y) (**C**), 'Julyprince' (8 y, 850) (**D**), 'Cresthaven' (5 y, 950) (**E**), and 'Cresthaven' (14 y) (**F**) on the seven sampling days. Almost no breaking lateral buds or opened flowers were observed on Apr 13, 2017 (4/13 on the x axis) when Dormex was sprayed. LS—long shoot; SS—short shoot; CK—unsprayed control; DX—Dormex sprayed.

Table 2. Changes of weekly percentage (%) of the four terminal bud classes on seven dates [z].

Shoot Type	Treatment	Terminal Bud Class	4/13	4/20	4/27	5/4	5/11	5/18	5/25
LS	DX	N	83.33	63.33	20.83	15.83	7.50	3.33	0.83
		Y	10.83	28.33	70.00	70.00	70.83	65.83	65.83
		D	0.00	2.50	3.33	8.33	15.83	25.00	27.50
		B	5.83	5.83	5.83	5.83	5.83	5.83	5.83
	CK	N	84.17	74.17	48.33	17.50	10.00	5.00	3.33
		Y	7.50	16.67	37.50	63.33	68.33	71.67	73.33
		D	2.50	3.33	8.33	13.33	15.83	17.50	17.50
		B	5.83	5.83	5.83	5.83	5.83	5.83	5.83
SS	DX	N	91.67	70.83	23.33	14.17	5.00	2.50	2.50
		Y	7.50	25.83	69.17	70.83	70.00	66.67	65.83
		D	0.00	2.50	6.67	14.17	24.17	30.00	30.83
		B	0.83	0.83	0.83	0.83	0.83	0.83	0.83
	CK	N	90.00	80.00	46.67	17.50	11.67	8.33	3.33
		Y	5.00	13.33	44.17	72.50	75.83	78.33	81.67
		D	1.67	3.33	5.83	6.67	9.17	10.00	11.67
		B	3.33	3.33	3.33	3.33	3.33	3.33	3.33

[z] The four classes of terminal buds were: N = not breaking into a terminal shoot, Y = yes, breaking into a terminal shoot, D = breaking a terminal shoot but dying, and B = blind terminal bud. Percentage under each status was calculated by the count on the date divided by 120 (the total number of terminals), which was also the number of flagged shoots of each shoot type and spray treatment (one terminal each shoot). LS = long shoot; SS = short shoot; DX = Dormex-sprayed trees; CK = unsprayed control trees.

A very limited number of floral buds opened on both the sprayed and unsprayed shoots (Figure 1E), suggesting late-sprayed Dormex had little effect on blooming of floral buds of these high-chill peach cultivars when they fell well short, i.e., nearly 50%, of their required CH. Failing to swell and break, most floral buds appeared to have desiccated and abscised (Figure 1F). Consequently, no differences were observed on floral budbreak in spray treatments, indicating that the late spring Dormex spray application provided little help for fruit set on these under-chilled high-chill peach cultivars.

3.2. Effect of Dormex on Year-End Vegetative Growth

The number and average length of the new lateral shoots grown on each flagged shoot (data collected on October 26, 2017) were statistically analyzed to compare the effect of Dormex on the year-end vegetative growth (Table 3; Table S3). Both the number and average length showed significant differences among some genotypes and/or tree ages. However, there were no significant differences between the long and short shoot types, nor between Dormex sprayed trees and unsprayed controls (Table 3; Table S3; Figure S3), suggesting that Dormex had little effect on vegetative growth in terms of new shoot number or average length at the end of the year treated.

3.3. Effects of Dormex on Fruit Number and Yield in Following Season

The number and yield of the fruit harvested from test trees in the unthinned 2018 season were also analyzed to compare the effect of the late spring Dormex spray application on the following-season reproductive growth (Table 3; Table S3). Similar to the effect on the year-end vegetative growth, both the fruit number and yield showed significant differences among some genotypes and/or tree ages. However, there was no significant difference between Dormex-sprayed trees and unsprayed controls (Table 3; Table S3), suggesting Dormex had little effect on yield in the following season after treatment.

Table 3. Statistical analysis of year-end (10/26/2017) count and average length (cm) of new lateral shoots and of following-season (2018) fruit number and yield (kg) [z].

	Shoots						Fruit					
	Count			Length (cm)			Number			Yield (kg)		
	Mean	SE		Mean	SE		Mean	SE		Mean	SE	
TT												
DX	1.90	0.20	a	9.51	0.94	a	91.00	10.33	a	16.75	1.48	a
CK	2.31	0.20	a	8.08	0.70	a	115.31	19.83	a	16.90	2.76	a
ST												
LS	2.01	0.19	a	9.09	0.79	a	-			-		
SS	2.23	0.21	a	8.4	0.86	a	-			-		
CV												
BB	2.13	0.45	a	7.36	2.8	b	-			-		
CO	2.23	0.28	a	8.39	0.87	b	134.55	10.47	a	20.41	1.59	ab
CH	1.40	0.25	a	3.71	0.73	b	31.50	14.20	c	8.66	3.37	ab
EL	2.89	0.63	a	8.63	1.54	b	-			-		
JP	1.81	0.39	a	8.77	2.13	b	132.75	33.51	ab	26.88	6.26	a
JN	1.43	0.40	a	7.43	2.05	b	38.75	29.65	bc	3.22	2.30	b
RB	1.93	0.56	a	10.58	2.14	b	-			-		
RH	2.70	0.53	a	9.85	1.66	b	-			-		
TQ	2.71	0.49	a	18.83	3.00	a	150.00	13.74	a	20.71	1.52	ab
Age												
4	2.74	0.32	a	8.85	0.89	b	134.50	22.19	a	22.16	3.89	ab
5	1.59	0.28	a	7.69	1.16	b	43.71	22.64	b	7.06	3.83	ab
7	1.81	0.39	a	8.77	2.13	b	132.75	33.51	a	26.88	6.26	a
8	1.71	0.28	a	6.97	1.53	b	80.71	5.03	b	13.50	1.12	b
10	2.71	0.49	a	18.83	3.00	a	150.00	13.74	a	20.71	1.52	ab
14	2.13	0.33	a	6.97	1.01	b	136.14	11.37	a	22.79	1.30	a

[z] Statistical output and F values indicating probability of significance were in Table S3. The count and average length (cm) of the year-end new shoots grown on flagged shoots were performed on Oct 26, 2017. The fruit number and yield (kg) from unthinned Dormex-sprayed and unsprayed trees were collected in the following season (2018). Means with the same letter are not significantly different (α = 0.05). TT = treatment; DX = Dormex sprayed; CK = unsprayed control; ST = shoot type; LS = long shoot; SS = short shoot; CV = cultivar; BB = 'Black Boy'; CO = 'Contender'; CH = 'Cresthaven'; EL = 'Elberta'; JP = 'Julyprince'; JN = 'Julyprince' nectarine mutant; RB = 'Red Bird Cling'; RH = 'Redhaven'; TQ = 'Ta Qiao'; Age = age of trees (year); SE = standard error. "-" indicated no or missing data.

4. Discussion

In recent episodes of insufficient chill accumulation, a new low chill record, 520 CH, was set in the middle Georgia peach production area in 2016–2017 and impacted in varying degrees almost every commercial peach cultivar typically utilized there (600–1200 CH). Nine high-chill cultivars (≥850 CH) that received substantially less than their CR and which had displayed little floral and lateral budbreak by mid-April were chosen for this late spring Dormex spray study. At that time, most of these cultivars appeared to be essentially dormant. Dormex is typically used to promote floral budbreak and to advance the harvest time of fruit and nut trees [8,11,12], but little attention has been paid to its effect on vegetative buds [2]. In this study, Dormex had a much stronger effect on peach lateral vegetative (leaf) buds than on floral buds, compared to the unsprayed controls, although both effects peaked at the second week after spray. Dormex also caused varying levels of phytotoxicity for breaking buds in this study, similarly to in previous reports [2,12]. However, phytotoxicity appeared limited and did not affect the overall health and growth/production capacity of the entire trees, as demonstrated by year-end new shoot and following season yield data in this study.

Similar to phytotoxicity, in spite of early budbreak stimulated by the Dormex application, we saw no correlated improvement in year-end vegetative growth nor following-season yield. This is in agreement with previous studies in which hydrogen cyanamide treatment resulted only in bloom advancement and various levels of phytotoxicity in normally chilled crops [7,8,12] and under-chilled stone fruit cultivars as well [2,10]. In this study, we observed a similar advance in budbreak. However, by the end of the season we saw no differences between the spray treatments in new shoot counts and lengths. Moreover, trees were so insufficiently chilled that no fruit was observed on either spray treatment. Hence, there was no possibility of any beneficial impact on fruit set and maturity.

Although the number of all abscising buds was difficult to monitor, we observed that almost all of them were floral buds. They failed to swell and break and eventually abscised, regardless of spray treatment. We might speculate that the biological underdevelopment of these buds (due to significant under-chill) probably was the primary reason for their failure to develop normally and bloom. Unseasonably high daytime temperatures in April and May likely were also a factor worsening this situation. There were some variations in bud response to the Dormex application, year-end new growth, and following season yield among the tested cultivars and their tree ages. For example, compared to the other cultivars, JP and RH had the highest lateral budbreak count on 5/25 (statistically significant compared to the other cultivars tested, Table 1). TQ had the average longest year-end new shoot and JP had the highest following season yield (statistically significant compared to the other cultivars tested, Table 3). It is well known that genotypes or genes always are important factors contributing to cultivars' different responses or horticultural performances, but additional data is needed for validation of consistency or correlation among these observations. In addition, CR is a quantitative trait in peach [13]. How insufficiently chilled trees compensate at the gene expression and regulation level is another subject of interest, as several candidate genes and expression patterns related to bud dormancy were previously characterized in peach and other stone fruit [14,15]. This area would appear worthy of research efforts, as it would be of potentially great value for breeders in the development of cultivars that are less vulnerable or less sensitive to insufficient chill.

5. Conclusions

In this study, Dormex was found to have strong stimulating effects on lateral budbreak, but little stimulating effect on terminal and floral budbreak. It had evident phytotoxic effects on all the three types of buds. The effects varied among genotypes, tree ages, and shoot types and the peak of the effects occurred on the second week after treatment. Most floral buds abscised before they swelled, regardless of spray treatment. There was no statistical difference between Dormex-sprayed trees and unsprayed controls in the number and average length of new lateral shoots at the end of 2017, nor in the number and yield of fruit harvested in 2018. In this study, Dormex had little beneficial impact, making it difficult to justify the expense of a late spring spray application to severely under-chilled peach trees. These new findings may encourage growers to reconsider whether to spray Dormex (or not) when insufficient chill occurs in the future.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4395/9/11/726/s1, Table S1. Type I and III statistical output for unopened (4/13) and opened (4/25) bud counts and their ratio; Table S2. Weekly counts of the four terminal bud classes on seven dates; Table S3. Type I and III statistical output for year-end new shoot count and average length (10/26/2017), and fruit number and weight (2018); Figure S1. Leafless, flowerless, dormant appearing peach trees on 04/12/2017 (taken by Chunxian Chen). From left to right: "Contender' (8 years old, 1050 CH), 'Cresthaven' (5, 950), and 'Julyprince' (8, 850); Figure S2. Dormex-sprayed vs unsprayed budbreak status on 4/27/2017 (taken by Chunxian Chen). Top row: 'Julyprince' (8 years old, 850 chill hours), (a) sprayed, (b) control. Bottom row, 'Ta Qiao' (10, 1200), (c) sprayed, (d) control; Figure S3. Dormex-sprayed vs unsprayed budbreak status on 9/7/2017 (taken by Chunxian Chen). Top row: 'Julyprince' (8 years old, 850 chill hours), (a) sprayed, (b) control. Bottom row, 'Ta Qiao' (10, 1200), (c) sprayed, (d) control.

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Conflicts of Interest: The authors declare no conflict of interest. This article reports the results of research only. Mention of a trademark or proprietary product is solely for the purpose of providing specific information and does not constitute a guarantee or warranty of the product by the United States Department of Agriculture and does not imply its approval to the exclusion of other products that may also be suitable.

References

1. Weinberger, J.H. Chilling requirement of peach varieties. *Proc. Am. Soc. Hortic. Sci.* **1950**, *56*, 122–128.
2. Dozier, W.A.; Powell, A.A.; Caylor, A.W.; Mcdaniel, N.R.; Carden, E.L.; Mcguire, J.A. Hydrogen cyanamide induces budbreak of peaches and nectarines following inadequate chilling. *HortScience* **1990**, *25*, 1573–1575. [CrossRef]
3. Richardson, E.A.; Seeley, S.D.; Walker, D.R. A model for estimating the completion of rest for 'Redhaven' and 'Elberta' peach trees. *HortScience* **1974**, *9*, 331–332.
4. Anderson, J.L.; Richardson, E.A. The Utah chill unit/flower bud phenology models for deciduous fruit: Their implication for production in subtropical areas. *Acta Hortic.* **1987**, *199*, 45–50. [CrossRef]
5. Erez, A.; Fishman, S.; Linsley-Noakes, G.C.; Allan, P. The dynamic model for rest completion in peach buds. *Acta Hortic.* **1990**, *276*, 165–174. [CrossRef]
6. Mayles, K.M.; Kilby, M.W. Chemical regulation of budbreak of flame seedless table grapes following dormant applications of hydrogen cyanamide in a low desert climate. *HortScience* **1987**, *22*, 1039.
7. Pontikis, C.A. Effects of hydrogen cyanamide on bloom advancement in female pistachio (*P. vera* L). *Fruit Var. J.* **1989**, *43*, 125–128.
8. Wood, B.W. Hydrogen cyanamide advances pecan budbreak and harvesting. *J. Am. Soc. Hortic. Sci.* **1993**, *118*, 690–693. [CrossRef]
9. Williamson, J.G.; Maust, B.E.; NeSmith, D.S. Timing and concentration of hydrogen cyanamide affect blueberry bud development and flower mortality. *HortScience* **2001**, *36*, 922–924. [CrossRef]
10. Wang, L.; Zhang, L.; Ma, C.; Xu, W.P.; Liu, Z.R.; Zhang, C.X.; Matthew, W.D.; Wang, S.P. Impact of chilling accumulation and hydrogen cyanamide on floral organ development of sweet cherry in a warm region. *J. Integr. Agric.* **2016**, *15*, 2529–2538. [CrossRef]
11. George, A.P.; Lloyd, J.; Nissen, R.J. Effects of hydrogen cyanamide, paclobutrazol and pruning date on dormancy release of the low chill peach cultivar Flordaprince in subtropical Australia. *Aust. J. Exp. Agric.* **1992**, *32*, 89–95. [CrossRef]
12. Sillercepeda, J.H.; Fuchigami, L.H.; Chen, T.H.H. Hydrogen cyanamide-Induced budbreak and phytotoxicity in Redhaven peach buds. *HortScience* **1992**, *27*, 874–876. [CrossRef]
13. Fan, S.; Bielenberg, D.G.; Zhebentyayeva, T.N.; Reighard, G.L.; Okie, W.R.; Holland, D.; Abbott, A.G. Mapping quantitative trait loci associated with chilling requirement, heat requirement and bloom date in peach (*Prunus persica*). *New Phytol.* **2010**, *185*, 917–930. [CrossRef] [PubMed]
14. Yamane, H. Regulation of bud dormancy and bud break in Japanese apricot (*Prunus mume* Siebold & Zucc.) and Peach [*Prunus persica* (L.) Batsch]: A summary of recent studies. *J. Jpn. Soc. Hortic. Sci.* **2014**, *83*, 187–202.
15. Li, Z.G.; Reighard, G.L.; Abbott, A.G.; Bielenberg, D.G. Dormancy-associated MADS genes from the EVG locus of peach [*Prunus persica* (L.) Batsch] have distinct seasonal and photoperiodic expression patterns. *J. Exp. Bot.* **2009**, *60*, 3521–3530. [PubMed]