Using the Dynamic Model to Time Sprays of Rest Breaking Agents In California Prune Production, 2005-2007

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Problem and Its Significance:

Consistent cropping is essential for economically sustainable prune production. Virtually all commercial prune production in California is limited to a single variety (‘Improved French’), and the full bloom “window” throughout the state can be limited to a single week. Consequently, the entire California prune industry is at risk of serious crop damage from even a short spike of extreme weather (cold or hot) at bloom.

Bloom temperatures above 80^{o}F severely limited prune fruit set in the southern Sacramento Valley in two of the last three years (2005 and 2007) and in the entire state in 2004. Low production in those years negatively impacted the entire industry, and raised doubts about the future of commercial prune production in this state.

California prune growers need a strategy to implement in existing orchards to reduce production risk from extreme weather at bloom. High rates of horticultural oil (4-5 gallons/acre) in the dormant spray have long been used to advance or tighten prune bloom, with a general window of late December through the middle of January targeted to advance bloom. This timing window was identified empirically over time, with no published research or experience-based information available to validate this practice and/or fine-tune it.

Research-based practices from other orchard crops in California and other fruit growing regions could help California prune growers maximize benefit from sprays applied to manipulate bloom timing. Defoliation prior to dormancy is a technique used experimentally (California, cherries and pears; Glozer, industry reports) and in sub-tropical and tropical temperate tree fruit culture to enhance dormancy induction or avoid dormancy altogether, respectively. California sweet cherry growers routinely apply dormant sprays to “break” dormancy, advance and ‘tighten’ bloom and harvest maturity for logistics and marketing purposes (Glozer, unpublished data). Dormant timing sprays of horticultural oil, fertilizer, or plant growth regulators applied as Rest Breaking Agents (RBAs) are timed after a certain amount of chilling has accumulated. Chilling accumulation is measured using the ‘Dynamic Model’ (Fishman, et al., 1987). This model was developed to track chilling accumulation in regions with warmer winters and warm-cold cycling in the dormant season (Mediterranean climates) and has been extensively tested in Israel, Australia and South Africa (Erez, et al, 1990; Erez, et al., 1998; P. Allan, 2004; A. Sheard, 2006 personal communication).

Advancing prune bloom may affect harvest date, which is closely related to the Growing Degree Days in the first 30 calendar days following 50% bloom (DeJong, et al., 2006). Extending prune harvest should allow growers and dryers to more effectively manage existing equipment and labor resources and, perhaps, reduce harvest/drying costs.

Objectives:

1. Test the response of ‘Improved French’ prune to rest-breaking chemicals (CAN17, horticultural oil) to obtain improved bloom, fruit set and fruit maturity advance.

2. Test the Dynamic Model for assessing when to apply defoliants, dormant oil and RBAs for bloom and harvest advance.

Plans and Procedures:

Chill hours (CH; Weinberger, 1956) and chill portions (CP; using the Dynamic Model; Fishman et al., 1987; Erez et al., 1998, 1990) were calculated from temperature data recorded by a datalogger placed at our treatment sites. In 2005, horticultural oil (Wilbur-Ellis Superior oil: 4% v/v or CAN17 (25% v/v) +2% v/v N-Ter® surfactant/adjuvant; Wilbur-Ellis) was applied at 55-66 CP; earlier treatments were not attempted. N-Ter has been tested in California tree fruit crops for rest-breaking and thinning under various trade names since 1994; the label names have included: Armobreak, Armothin, Entry and N-Ter. The first 2 label names were under the manufacturer's name (Akzo-Nobel), the last two label names have been under the current distributor's name (Wilbur-Ellis). For uniformity considerations, we have used 'N-Ter' throughout this document. In 2006 and 2007, horticultural oil (Wilbur-Ellis Superior oil or Gavicide 90, respectively; 4% v/v) or CAN17 (25% v/v) +Activator 90® (2% v/v non-ionic surfactant/penetrant; UAP), were applied at approximately 30, 40, 50, and 60 chill portions. In 2006, fall defoliation was enhanced by three different spray timings of 20lb/A each zinc sulfate and fertilizer-grade urea at approximately 0, 3 and 6 chill portions. These treatments were designed to test their ability to slightly advance bloom, as indicated by research in sweet cherries (Glozer, industry reports).

Different study sites in commercial orchards were identified and used each year. Oil was eliminated from commercial dormant sprays by arrangement with the grower. All treatments were applied with a Stihl mistblower at a calculated volume of 100 gallons per acre to single replicate trees in a complete randomized block design, using four single tree replicates per treatment chemical/date combination.

In 2005 and 2006, three limbs from each replicate tree were randomly chosen prior to flower bud opening, at three equidistant sides of the tree and in mid-canopy; buds were counted prior to flowering. Rate of bud opening was evaluated from sequential data taken over time, starting at first flower open and ending with petal fall (dates dependent on year). Dead floral buds were counted during this time period. Fruit set was determined in June, after small fruit drop. Fruit maturity (firmness and soluble solids) was evaluated just prior to commercial harvest.

In 2007, bloom variability within trees following the large 2006 crop made representative limb selection difficult, thus whole tree bloom density was used as an indicator of treatment effect. Bloom was tracked using night-time photography (Canon Powershot SD550 camera with Canon HF-DC1 external flash) followed by digital image analysis, which measured the area of white pixels in the images (Scion Image for Windows; Frederick, MD). All trees were topped to similar height (12') and similarly sized trees were selected for use in the study, thus minimizing differences in flower area between trees due to different sized trees. The camera was held at the same height and distance from the subject tree for each photograph. Because of variable yield and cropload, harvest data were not measured in 2007.

In 2005 and 2006, analyses of variance were performed with Proc GLM in SAS (SAS Institute Inc., Cary, NC) and mean separations tested by Duncan's Multiple Range Test, $P = 0.05$. In 2007, analysis of variance was tested using a General Linear Model using a repeated measures strategy (Statgraphics Centurion XV; Statgraphics, Inc.). Mean separation between treatments for each date was determined from 95% Confidence Interval for the Least Squared Mean for each *treatment x date* interaction.

Results and Discussion:

2005: CAN17 + N-Ter applied at 59 and 63 CP on January 17 and 21, respectively, advanced bloom significantly compared to all other treatments (Table 1). On March 7 the untreated control had 4.3% open flowers, while the CAN + N-Ter treatment at 59 CP was at 70% open flowers and CAN + N-Ter at 63 CP was at 63% open flowers. The most advanced oil treatment on this date was at 29% open flowers, which was also significantly more advanced than the control. CAN + N-Ter applied at 66 CP was at 47.6% open flowers, thus, all but the earliest CAN + N-Ter treatment significantly advanced bloom. Two days later, March 9, the best CAN + N-Ter treatments were at 94-95% of full bloom while the control was at 39% of full bloom. On this date, all rest-breaking treatments had bloom that was significantly more advanced than that of the control and the percentages of full bloom ranged from 66% to 95% among experimental treatments. All experimental treatments had reached 99-100% full bloom on March 11 and the control was then at 96.5% of full bloom.

Use of rest breaking sprays advanced bloom and improved fruit set, significantly in some cases (Table 2). Trees sprayed in January, in general, bloomed ahead of the peak heat experience in the region on March 10-12, 2005. Trees sprayed with CAN17 and NIS generally showed more fruit set than those sprayed with oil (Table 1).

Fruit firmness was equal among rest-breaking treatments and less than the untreated control (Table 1), therefore maturity was advanced equally by rest-breaking treatments. Advance in maturity by 1-1.4 lb pressure, as observed in this trial, may allow earlier harvest by 1-2 weeks, potentially allowing growers to spread-out harvest and help dryer managers extend the drying season.

2006: Flower opening was accelerated by trees sprayed with oil or CAN17 at 27 or 38 CP (Table 2). Oil applied on February 23 (68 CP) delayed bloom, while CAN17 applied on Feb 6 (59 CP) and 23 (68 CP) delayed bloom opening; the last CAN17 treatment killed >50% of flowers. Fruit set was reduced in trees treated with CAN17, regardless of timing, but for different reasons (Table 3). Figure 1 shows the minimum and maximum daily temperatures during the month prior to bloom, with an early warm period followed by a late freeze. Rest-breaking treatments that reduced the level of dormancy and advanced bloom (with the added 'push' by early warming) also increased susceptibility to the late freeze; most affected was the earliest-treated CAN17 trees. The bloom period for the earliest CAN17-treated trees (March 8-31), was a cool and very rainy period; rain totals for that bloom period are also found in Table 2. We believe that the reduced set for trees with bloom advanced by CAN17 applied at 27-38 CP is primarily due to these unseasonably cool temperatures (almost all well below the optimum for pollen tube growth, based on recent research by Polito and DeCeault, 2006, 2007; industry reports) and rainy conditions. Both of these weather conditions would have discouraged bee activity. The late CAN17 treatments at 59 and 68 CP delayed bloom, increasing the negative influence of high temperatures experienced at bloom April 7-10. The last CAN17 treatment was too close to bud expansion, thus phytotoxicity was the reason for high bud death. It has been observed in some trials in other crops, including on sweet cherry and pear, that RBAs such as CAN17 and Dormex (hydrogen cyanamide), when applied 'too late' have increased risk of phytotoxicity, however, the most effective application timing, i.e. the timing that advances bloom most, can also make buds more susceptible to late frost. Order of risk for either is the same as order of 'strength' for RBAs: Dormex > CAN17 > KNO_3 > oil. Type and concentration of adjuvant, especially in the case of 'penetrants', can also affect strength of response. Fruit set in oil-treated trees was not significantly different from the untreated control in 3 out of 4 timings.

Branches cut from untreated trees in the study orchard on January 6 (38 CP and 506 CH) and January 23 (50 CP and 642 CH) and the cut ends placed in water in a warm room under continuous light showed first green tissue at 17 and 10 days, respectively after cutting. Both flower and vegetative buds showed good bud break patterns.

Maturity, and presumably harvest, was advanced by oil applied 16 Dec, 6 Jan and 6 Feb (Table 3), compared to the untreated control. Although soluble solids were numerically less in the two later oil treatments compared to the control, they were not statistically different. Differences in fruit firmness in trees treated with oil at 27, 38, or 59 CP did not appear to be related to differences in crop load between oil-treated and control trees, as there was no difference in crop set (Table 3). CAN17 treatments did not to affect fruit maturity in this test, as measured by either soluble solids or firmness, compared to the control. As bloom dates were advanced for oil and CAN17 treatments applied at 27 or 38 CP, the lack of treatment affect on CAN17 treated trees may have been due to cropload differences.

The defoliation treatments did not affect any measured indices of bloom, fruit set or fruit maturity, compared to the control. Defoliation treatments such as these have not had as strong an effect as the RBAs applied in the dormant season, with respect to bloom advance, however, there is sufficient evidence from trials in other crops to indicate an improvement in bud strength due to fall N application, and probably an enhanced entrance into dormancy due to defoliation. There is evidence also for improved frost tolerance in some tree crops due to similar treatments.

2007: Bloom was observed to be highly variable within and between treatment trees, and a clear, statistically significant pattern was not visible throughout the bloom period. However, there was a visible trend (but no statistical difference), of an advance in bloom timing as of March 12, with earlier (30-50 CP) spray timings (Table 4). Late (March 1) oil application resulted in delayed/extended bloom timing compared with CAN17 applied at 60 CP, as expected from very late RBA treatments, in these and other trials. Fruit maturity measurements were not attempted, as cropload differed dramatically between and within study trees.

Summary: It is difficult to draw strong conclusions from three years of study when orchard conditions and annual weather patterns during the dormant season, bloom time and early fruit growth period differ dramatically; this is not unusual under California conditions. The three years of this study were characterized by opposites in extreme weather. The years 2005 and 2007 had excellent or good chilling accumulation, respectively, and very warm weather before and during bloom, resulting in a fast, "snowball" bloom in the study orchards in the south Sacramento Valley. Just the opposite occurred in 2006, when a warm winter and cool spring resulted in 'strung out' or 'straggly' bloom. Frequent rain events during the advanced bloom period on 2006, following an early warm period (early February) and a late freeze (mid-February) further exacerbated these conditions. Similar materials and timings produced very different results based on the year, probably due largely to the weather differences.

Is the Dynamic Model (Chilling Portions) a better way to measure chilling and time rest breaking sprays than accumulation of hours at or below 45^{o}F in 'French' prune? We cannot say one way or the other at this point. We must identify an effective rest breaking agent and continue our bud forcing work. It is interesting to note, however, that while Chilling Portions and Chilling Hours accumulation in a given year may be very well correlated, the relationship (the ratio of CH to CP accumulation differs from year to year (Table 5). CH accumulation appears to fluctuate more widely from year to year, while CP accumulation is more consistent (Tables 1,3, and 4). In sweet cherry culture in California, in which rest-breaking and chill model research and application have been continuous since 1994, we have found that the Dynamic Model most closely enables 'best timing' for RBAs and best explains bloom behavior and response to RBAs. Even without identifying what chill accumulation requirement exists for a given cultivar as defined <u>in chill portions</u>, we have been able to develop an effective technology for rest-breaking and partial 'chill replacement' in sweet cherry using this model.

What do we think we have we learned in the 3 years of this study?

- Rest breaking agents (RBAs) can accelerate prune bloom and improve prune fruit set, but results are not consistent across years.
- Use of RBAs to accelerate bloom also can advance fruit maturity. The advance in fruit maturity is affected by the number of days advance and the heat (GDH 30) during that time period.
    - The best "window" advancing bloom with any RBA is not yet definite. Additional testing will be required to optimize materials and application timing to advance prune bloom.
- Optimal timings for oil and CAN17 were the same in 2005 and 2006 (both RBAs were most effective when applied in the same range of timings)
    - 2005: 59-63 CP (Jan 17-21)
        - <u>we can't say at this time if earlier treatments would have been beneficial as they were not attempted</u>
    - 2006: 27-38 CP (Dec 16-Jan 6); CAN17 advanced bloom ~3 weeks ahead of the control with these timings
    - 2007: 31-42 CP (Dec 23-Jan 8) timing showed a trend in advancing bloom by 1-2 days

(no statistical significance).

- This range of effective timings appears to be much earlier in the dormant period than what is effective for sweet cherry, for the same RBAs. This can be explained by a lower chill requirement for ‘French’ prune than ‘Bing’ cherry, the cultivar most extensively tested.
- In general, it appears that 70-75% of chill required should be obtained naturally, prior to application of RBAs for maximum benefit.
- CAN17 applied at 59 and 68 CP (Feb 6-23) in 2006 delayed bloom and/or was phytotoxic. Based on these data, we are not recommending use of CAN17+NOI at the rate used in this study in February and/or warm weather (max temperatures of 60^{o}F or higher) is expected.

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Table 1. Treatment effect on bloom progression by horticultural oil and CAN17 applied to >French= prune, 2005. Chill portions (CP)[z] and chill hours (CH)[y] are based on temperatures recorded hourly on site in trial orchard.

Treatment (applied @ 100 gallons/acre)	Applied on	CP	CH	Bloom progression (%flower buds open on flowering shoot)				%Dead buds	%Fruit set	Firmness (lb)
				2 Mar	7 Mar	9 Mar	11 Mar			
Control				0.0 [x]	4.3 d	39.2 d	96.5 b	3.5 a	2.6 d	4.0 a
25% CAN17 + 2% N-Ter	12 Jan	56	555	0	20.2 cd	74.1 bc	99.9 a	0.1 b	11.4 bc	2.9 b
	17 Jan	59	681	0.9	70.0 a	94.9 a	100.0 a	0.0 b	21.6 a	2.8 b
	21 Jan	63	760	0.7	63.0 ab	94.0 a	99.8 a	0.2 b	21.6 a	2.6 b
	24 Jan	66	821	0	47.6 b	93.9 a	100.0 a	0.0 b	15.3 ab	3.0 b
4% Wilber-Ellis Superior oil	12 Jan	56	555	0	14.4 cd	66.2 c	98.0 ab	2.0 ab	5.2 cd	2.8 b
	17 Jan	59	681	0.4	29.1 c	86.2 ab	99.2 a	0.8 b	19.5 a	3.1 b
	21 Jan	63	760	0	21.1 cd	80.9 abc	99.1 a	0.9 b	10.3 bcd	2.6 b
	24 Jan	66	821	0.0ns	9.9 cd	69.4 bc	99.7 a	0.3 b	9.4 bcd	3.0 b

[x] Mean separation within columns by Tukey=s, *P* = 0.05; ns = non significant. Percentages transformed by arcsine; actual means are shown.
[y] 1 hour ≤ 45°F.
[z] Fishman et al., 1987.

Table 2. Treatment effect on bloom progression by defoliation, horticultural oil and CAN17 applied to 'French' prune, 2006. Chill portions (CP)[z] and chill hours (CH)[y] are based on temperatures recorded hourly on site in trial orchard.

Treatment (applied @ 100 gallons/acre)	Applied	CP	CH	Bloom progression (%flower buds open on flowering shoot)									
				8 Mar	13 Mar	15 Mar	17 Mar	20 Mar	23 Mar	27 Mar	31 Mar	7 Apr	10 Apr
Control				0.0 c [x]	0.0 c	0.0 c	0.0 c	0.0 c	0.8 c	12.4 cd	60.1 b	96.0 abc	98.5 a
Defoliation 20# each zinc sulfate & urea	30 Oct	1	8	0.0 c	0.0 c	0.0 c	0.0 c	0.0 c	0.1 c	17.4 c	31.9 d	88.7 abc	97.2 a
	4 Nov	3	36	0.0 c	0.0 c	0.0 c	0.0 c	0.0 c	0.4 c	7.8 cd	34.3 d	86.2 bc	94.1 a
	16 Nov	8	82	0.6 c	0.6 c	0.6 c	0.6 d	0.6 c	0.7 c	13.0 cd	57.6 b	97.5 abc	99.7 a
25% CAN17 + 2% Activator 90	16 Dec	27	443	24.0 a	26.0 b	16.2 b	33.4 c	44.5 b	67.4 b	48.7 b	95.1 a	100.0 a	100.0 a
	6 Jan	38	506	14.7 b	38.3 a	47.5 a	58.0 a	68.9 a	80.0 a	91.4 a	97.8 a	100.0 a	100.0 a
	6 Feb	59	723	0.0 c	0.0 c	0.0 c	0.0 c	0.0 c	0.1 c	2.5 d	40.9 d	91.8 abc	99.6 a
	23 Feb	68	911	0.0 c	0.0 c	0.0 c	0.0 c	0.0 c	0.0 c	0.0 d	0.0 e	43.2 d	38.3 b
4% Wilber-Ellis Superior oil	16 Dec	27	443	17.9 ab	33.0 ab	40.9 a	46.1 b	54.6 b	68.2 b	87.0 a	96.0 a	99.8 a	100.0 a
	6 Jan	38	506	0.1 c	7.9 c	17.3 b	32.8 c	51.0 b	75.0 ab	89.3 a	96.2 a	99.9 a	100.0 a
	6 Feb	59	723	0.0 c	0.0 c	0.0 c	0.0 c	0.0 c	0.2 c	8.2 cd	55.2 bc	97.8 ab	99.6 a
	23 Feb	68	911	0.0 c	0.0 c	0.0 c	0.0 c	0.0 c	0.2 c	7.8 cd	42.1 cd	85.6 c	97.1 a
Date (rainfall inches)				**Mar 6-8 (2.1)**	**Mar 14-15 (0.7)**			**Mar 23-25 (1.7)**		**Mar 27(0.6)**		**Apr 1-8 (3.2)**	

[x] Mean separation within columns by Duncan's Multiple Range Test, P = 0.05.

[y] 1 hour ≤ 45°F.

[z] Fishman et al., 1987.

Table 3. Treatment effect floral bud death, fruit set, and maturity (firmness & soluble solids, 1 Sept) by defoliation, horticultural oil and CAN17 applied to 'French' prune, 2006. Chill portions (CP)[z] and chill hours (CH)[y] are based on temperatures recorded hourly on site in trial orchard.

Treatment (applied @ 100 gallons/acre)	Applied	CP	CH	%Dead floral buds	%Fruit set (29 June)	Firmness (lb)	%Soluble solids
Control				1.5 b	26.1 ab	5.3 ab	19.2 ab
Defoliation 20# each zinc sulfate & urea	30 Oct	1	8	2.8 b	27.1 ab	4.8 bcd	17.4 ab
	4 Nov	3	36	5.9 b	25.2 abc	5.2 abc	15.8 b
	16 Nov	8	82	0.3 b	23.7 bc	5.3 abc	18.7 ab
25% CAN17 + 2% Activator 90	16 Dec	27	443	5.9 b	11.2 d	4.7 b-e	20.3 ab
	6 Jan	38	506	0.0 b	7.8 d	5.2 abc	19.7 ab
	6 Feb	59	723	0.4 b	8.8 d	5.4 ab	15.7 b
	23 Feb	68	911	53.4 a	8.8 d	5.7 a	23.2 a
4% Wilber-Ellis Superior oil	16 Dec	27	443	0.0 b	18.6 c	4.1 de	20.7 ab
	6 Jan	38	506	0.0 b	26.1 ab	4.0 e	20.0 ab
	6 Feb	59	723	0.4 b	31.2 a	4.5 cde	17.8 ab
	23 Feb	68	911	2.9 b	25.9 ab	4.9 bc	16.4 ab

[x] Mean separation within columns by Duncan's Multiple Range Test, P = 0.05.
[y] 1 hour ≤ 45°F.; [z] Fishman et al., 1987.

Table 4. Effect of horticultural oil (4% v/v Gavicide 90) or CAN17 (25% v/v CAN17 + 2% v/v Activator 90 surfactant/penetrant) at different chilling accumulation intervals on bloom progression of 'French' prune, 2007. Chill accumulation calculated from CIMIS station at Nicolaus up to Nov 13, 2006 and then from weather station at the study site.

Treatment material (applied @ 100 gallons/acre)	Treatment date (2006-2007)	Chill accumulated between 9/1/06 and treatment application		Visible bloom (cm^2 of visible bloom/tree)		
		Chill portions [z]	Chill hours [y]	March 12	March 15	March 21 (petal fall)
4% oil	December 23	31	521	2.00 [x]	16.8 ab	4.25 ab
CAN17 + NIS				1.00	23.8 bcd	4.50 ab
4% oil	January 8	40	725	5.25	31.0 bcd	4.75 ab
CAN17 + NIS				2.25	19.8 abc	3.50 ab
4% oil	January 22	52	946	2.00	31.5 bcd	4.50 ab
CAN17 + NIS				9.25	25.5 bcd	3.50 ab
4% oil	February 5	60	1135	2.00	24.0 bcd	4.75 ab
CAN17 + NIS				0.25	17.0 ab	1.50 a
4% oil	March 1	74	1277	0.25	26.0 bcd	13.25 b
Untreated control	--	--	--	0.00 ns	9.5 a	10.25 ab

[x] Mean separation within columns from 95% confidence intervals of Least Squared Means; ns = non-significant differences.
[y] Hours ≤ 45°F.
[z] Fishman et al., 1987.

Table 5. The ratio (slope) of the accumulation of hours at or below 45°F (CH) vs Chilling Portion accumulation (CP) for study years 2005, 2006, and 2007 and the r^2 value for this relationship for each of the three years, separately. The closer the R^2 value to 1.00, the more linear the relationship between CH and CP.

Year	CH:CP	R^2
2005	27.235	0.98
2006	9.1172	0.99
2007	17.158	0.97

Figure 1. Minimum and maximum daily temperatures and chill portion accumulation (Dynamic Model) prior to bloom (March 8-April 8). Rain events during the bloom period resulted in 8.3” cumulative rainfall and further reduced fruit set after freeze-related bud damage.