Evaluation of chill models from historical rest-breaking spray experiments on 'Bing' Sweet Cherry

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Deciduous fruit trees require a certain amount of winter chilling to enter into and overcome a winter dormant period. Once buds have entered a fully-dormant state, they become tolerant to temperatures well below freezing and will not expand in response to mild-winter warm spells. If trees receive insufficient chilling, associated physiological symptoms are manifested; these may include bud death, protracted vegetative and reproductive (truss) bud break and expansion, delayed or erratic, extended bloom, poor overlap with pollenizers, reduced fruit set and cropping and uneven fruit maturation.

Moderately warm winters are common in California cherry-growing areas. Dormant temperatures must be low (7^{o}C, 45EF) for approximately 850-880 hours in 'Bing' (Richardson et al., 1986) to terminate endo-dormancy, regulated by physiological factors within the bud (Lang et al., 1987). Following endo-dormancy and during eco-dormancy, heat unit accumulation above a base temperature (the actual base temperature and required units may be species- or cultivar-dependent) affects both date of full bloom and total duration of bloom, possibly to a greater extent than chill accumulation (Gianfagna and Mehlenbacher, 1985). In cherry, chilling and heat unit accumulation may occur simultaneously (Felker and Robitaille, 1985). While specific chill accumulation requirements vary among cultivars, the magnitude of variation within the group of sweet cheery cultivars grown commercially in California appears to be relatively slight, reflecting a similar genetic background for low chill requirement.

Chemicals may help overcome inadequate chilling and enhance bud break in some pomological species (Faust, 1989; Snir and Erez, 1988). Environmental conditions during the rest period are especially important in gauging when to spray rest-breaking agents. We believe the Utah chill unit model (Richardson et al., 1974; Erez and Lavee, 1971) and the standard methods of calculating chilling hours (45EF model; Powell and Harker, 1995) may not be sufficiently accurate to maximize the effective use of rest-breaking agents. These models are used as guides for chill accumulation, although they have not been thoroughly tested under California conditions or against the rest-breaking chemicals that are in use today. We suggest that the Dynamic Model, developed in the late 1980s and early 1990s, may be a more effective tool for assessing when to spray rest-breaking agents in California sweet cherry production (see Erez references).

Materials and Methods:

The 45EF Model, Utah Chill Unit Model and Dynamic Model require recording hourly temperatures, and the point in time to begin or end recording chilling temperatures is not well-defined. Chill hours, Utah model chill units and chill portions were calculated from hourly temperature data collected daily by California Irrigation Management Information System (CIMIS) weather stations that were nearest to the orchard locations. The hourly temperatures used were from November 1 through March 30 (the accepted dormant season for California's tree fruit and nut crops) each season. We reviewed trial results from 1994-95 to 2000-2001 winters in which we treated 'Bing' cherry with various rest-breaking agents at several locations under conditions that varied with regard to chilling. We compared the amount of chilling accumulated in these locations by calculating chill hours, Utah chill units and chill portions with the appropriate models and identified spray treatment timings based upon each model where maximal response was obtained.

Calculation of chilling models:
45°F Model, 'Chill hours':
1 'chill hour' is 1 hour $\leq$ 45EF, as defined by the Pomology Department Weather Services, University of California, Davis.

Utah Chill Unit Model:

The model is defined as:

1 hour below 34EF = 0.0 chill unit
1 hour 34.01 - 36EF = 0.5 chill unit
1 hour 36.01 - 48EF = 1.0 chill unit
1 hour 48.01 - 54EF = 0.5 chill unit
1 hour 54.01 - 60EF = 0.0 chill unit
1 hour 60.01 - 65EF = -0.5 chill unit
1 hour > 65.01EF = -1.0 chill unit

The Utah model is more complex because it introduces the concept of relative chilling effectiveness and negative chilling accumulation (or chilling negation). According to Richardson et al. (1974) temperatures between 0 and 16^{o}C promote the breaking of rest, whereas temperatures > 16EC negate such effects. Maximum promotion occurs at 7EC (1 h at 7^{o}C = 1 chill unit); higher and lower temperatures within the 0-16EC range are less effective. This model has been modified as more information has become available (Seeley, 1996).

Dynamic Model:

The model of Fishman et al. (1987a,b) was developed in Israel. The model assumes that the degree of dormancy completion depends on the level of a certain dormancy-breaking factor, which accumulates in buds in a two-step process (Figure 1). The first step is assumed to be a reversible process that produces a thermally-labile precursor. Formation of the precursor is promoted by chilling temperatures (i.e. 1.5-12.4EC), while high temperatures reverse the process. Once the critical portion of the precursor is amassed, it is transformed, irreversibly, in the second step to one portion of a stable dormancy-breaking factor or Chilling Portion (CP). Once formed, subsequent high day temperatures cannot break down this chill portion. The rest completion process is assumed to be dependent on the accumulation of some chemicals (enzyme) or physical (structure) changes in plants (Allan, 1999). This complex model adds a further element of timing of exposure to temperatures in a cycle and appears to be far more accurate under warm winter conditions, such as those experienced in Israel (and, possibly, in California).

Chilling temps

PRECURSOR Ω INTERMEDIATE 6 CHILLING PORTION (Irreversibly fixed)

High temps

Figure 1. Dynamic model, a two-step process in the formation of chilling portions.

Description of the Dynamic Model principle:

Erez and Fishman (1988) gave the following description of the Dynamic Model using various temperature conditions. The model is based on experimentation with small peach plants tested for their response to chilling under strictly controlled conditions. The model's effect was verified in Israel and in other countries. It may serve both as a tool for research and as an aid for growers to evaluate the development of dormancy in their tree buds. As a result of this work, and based on the finding that chilling reversal by high temperature is limited to short cycles, a detailed model was developed named 'The Dynamic Model' based on the following elements (Fishman et al., 1987a,b).

A) The two-step system concept:

The first step builds an intermediate that is accumulated when exposed to low temperature. The intermediate level depends on following

1. The bell shape curve effect of chilling;
2. The negating of chilling by high temperatures (effect of level; effect of high temperature duration; effect of cycle);
3. The promotive effect of moderate temperatures.

B) The concept of a fixation effect:

When a critical level of the intermediate is reached, a phase transition occurs, the intermediate level drops to 0 and a quantum that is termed 'Chilling Portion' is accumulated. This transfer is automatic at temperatures above 4EC but depends on temperature >4EC.

C) The concept of a quantum:

When a portion, the size of which is a physiological measure, is accumulated, it is fixed and conserved.

D) The concept of a threshold level:

A critical level of the intermediate has to be reached for effective chilling to accumulate. As long as this threshold is not reached, no matter how close the level of intermediate is to the threshold, no chilling accumulation will occur. Differences among cultivars or species is in the total portions needed for breaking dormancy, not in model parameters. Allan (1999) has suggested that the Dynamic Model gave better results in explaining rest-breaking physiology than the Richardson unit model in area where winters were mild.

Results and Discussion:

California Irrigation Management Information System (CIMIS) weather stations' hourly temperatures recorded on a daily basis were utilized, choosing those stations closest to trials for each county and winter season (1995-2001). Chill hours and Utah chill units were calculated using models maintained by the Pomology Department Weather Services, University of California, Davis. The Dynamic Model and the calculation of chill portions was used as presented A. Erez (Erez et al., 1990).

Yearly results

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Table 1. Comparison of Entry and potassium nitrate treatment timings with chill models [z] for rest-breaking in ‘Bing’ sweet cherry; Hollister [y]; San Benito County, California, Winter, 1994-95.

Treatment (100 gal/A)	Date applied (1995)	Chill portions	Chill hours	Utah chill units

6% KNO_3 2% Entry 2% Entry + 6% KNO_3 [x] 1% Entry + 6% KNO_3	1 February	58	736	1117
6% KNO_3 2% Entry 2% Entry + 6% KNO_3 1% Entry + 6% KNO_3	February 9	62	746	1186.5
6% KNO_3 2% Entry 2% Entry + 6% KNO_3 1% Entry + 6% KNO_3	February 22	68	827	1314.5

[x] Best physiological response.
[y] Hourly temperatures recorded from CIMIS station 126, San Benito.
[z] Chill models included: Dynamic Model (chill portions; Fishman et al., 1987, chill hours (1 hour at or below 45°F) and Utah chill unit model (chilling units vary from -1 to +1, depending on hourly temperature; Richardson et al., 1974; Erez and Lavee, 1971).

Table 2a. Comparison of Entry and calcium ammonium nitrate (CAN17) treatment timings with chill models [z] for rest-breaking in 'Bing' sweet cherry; Hollister [y]; San Benito County, California, Winter, 1995-96.

Treatment (100 gal/A)	Date applied	Response	Chill portions	Chill hours	Utah chill units
2% Entry + 25% CAN17 2% Entry + 35% CAN17 2% Entry + 45% CAN17 4% Entry + 25% CAN17 4% Entry + 35% CAN17 4% Entry + 45% CAN17	December 28		21	217	341.5
2% Entry + 25% CAN17 2% Entry + 35% CAN17 2% Entry + 45% CAN17 4% Entry + 25% CAN17 4% Entry + 35% CAN17	January 11		29	299	479.0

4% Entry + 45% CAN17					
2% Entry + 25% CAN17 *					
2% Entry + 35% CAN17					
2% Entry + 45% CAN17					
4% Entry + 25% CAN17 *	February 2	Bloom was most advanced on March 11 in marked (*) treatments	43	428	756.5
4% Entry + 35% CAN17 *					
4% Entry + 45% CAN17					
2% Entry + 25% CAN17					
2% Entry + 35% CAN17					
2% Entry + 45% CAN17					
4% Entry + 25% CAN17	February 14	Bloom was most advanced on April 9 in all treatments applied this date	45	430	732.5 [x]
4% Entry + 35% CAN17					
4% Entry + 45% CAN17					

[x] Reduction in chill units from previous date due to heat accumulation.
[y] Hourly temperatures recorded from CIMIS station 126, San Benito.
[z] Chill models included: Dynamic Model (chill portions; Fishman et al., 1987, chill hours (1 hour at or below 45°F) and Utah chill unit model (chilling units vary from -1 to +1, depending on hourly temperature; Richardson et al., 1974; Erez and Lavee, 1971).

Table 2b. Comparison of Dormex, Entry and calcium ammonium nitrate (CAN17) treatment timings with chill models [x] for rest-breaking in 'Bing' sweet cherry; Linden [x y]; San Joaquin County, California, Winter, 1995-96. All treatments applied January 18.

Treatment (100 gal/A)	Response	Chill portions	Chill hours	Utah chill units
Dormex	best response			
2% Entry + 25% CAN17	best CAN17/equivalent			
2% Entry + 35% CAN17				
2% Entry + 45% CAN17				
4% Entry + 25% CAN17		43	442	775
4% Entry + 35% CAN17	best CAN17/equivalent			
4% Entry + 45% CAN17				
6% Volck oil				
6% emulsifiable oil				

[x] Hourly temperatures recorded from CIMIS station 70, Manteca.
[y] Chill models included: Dynamic Model (chill portions; Fishman et al., 1987, chill hours (1 hour at or below 45°F) and Utah chill unit model (chilling units vary from -1 to +1, depending on hourly temperature; Richardson et al., 1974; Erez and Lavee, 1971).

Table 3a. Comparison of Dormex, Entry and calcium ammonium nitrate (CAN17) treatment timings with chill models [y] for rest-breaking in 'Bing' sweet cherry; Hollister [x]; San Benito County, California, Winter, 1996-97.

Treatment (100 gal/A)	Date applied	Response	Chill portions	Chill hours	Utah chill units
Dormex		best; advanced bloom and fruit maturity (color)			
2% Entry + 5% CAN17	January 24		43	550	788.5
2% Entry + 15% CAN17					
2% Entry + 25% CAN17					
2% Entry + 5% CAN17	February 7		50	605	927
2% Entry + 15% CAN17					
2% Entry + 25% CAN17					
2% Entry + 5% CAN17	February 21	highest fruit set for all CAN17 treatments; most advanced fruit maturity after Dormex	58	695	1088.5
2% Entry + 15% CAN17					
2% Entry + 25% CAN17					

[x] Hourly temperatures recorded from CIMIS station 126, San Benito.
[y] Chill models included: Dynamic Model (chill portions; Fishman et al., 1987, chill hours (1 hour at or below 45□F) and Utah chill unit model (chilling units vary from -1 to +1, depending on hourly temperature; Richardson et al., 1974; Erez and Lavee, 1971).

Table 3b. Comparison of Dormex, Entry and calcium ammonium nitrate (CAN17) treatment timings with chill models [y] for rest-breaking in 'Bing' sweet cherry; Linden [x]; San Joaquin County, California, Winter, 1996-97.

Treatment (100 gal/A)	Date applied	Response	Chill portions	Chill hours	Utah chill units
Dormex	January 21	Best	44	666	855.5
2% Entry + 5% CAN17					
2% Entry + 15% CAN17					
2% Entry + 25% CAN17		Good			
2% Entry + 5% CAN17	February 4		52	708	986
2% Entry + 15% CAN17					
2% Entry + 25% CAN17					
2% Entry + 5% CAN17	February 18		61	790	1133
2% Entry + 15% CAN17					
2% Entry + 25% CAN17		Good			

[x] Hourly temperatures recorded from CIMIS station 70, Manteca.
[y] Chill models included: Dynamic Model (chill portions; Fishman et al., 1987, chill hours (1 hour at or below 45°F) and Utah chill unit model (chilling units vary from -1 to +1, depending on hourly temperature; Richardson et al., 1974; Erez and Lavee, 1971).

Table 4. Comparison of rest-breaking treatments with chill models [y] in 'Bing' sweet cherry; Morgan Hill [x]; Santa Clara County, California, Winter, 1997-98.

Treatment (100 gal/A)	Date applied	Response	Chill portions	Chill hours	Utah chill units
1997 defoliations: Zinc sulfate @ 10lb/A, w/v of a 36% by weight formulation + 15lb/A fertilizer grade urea	October 30		--	--	--
	November 25		8	16	28
	November 25				
Defoliation + whitewash (latex paint)	December 1				
4% Dormex	January 20	best; advanced bloom, leaf-out and fruit maturation (color); increased soluble solids, weight and fruit softening	45	367	728.5
2% Entry + 25% CAN17	February 6	good; increased fruit set	52	424	881.5
2% Agri-Dex + 25% CAN17					
2% RNA 85 + 25% CAN17					
4% Volck Supreme oil + 25% CAN17					
2% Optima oil + 25% CAN17					

[x] Hourly temperatures recorded from CIMIS station 132, Morgan Hill.
[y] Chill models included: Dynamic Model (chill portions; Fishman et al., 1987, chill hours (1 hour at or below 45□F) and Utah chill unit model (chilling units vary from -1 to +1, depending on hourly temperature; Richardson et al., 1974; Erez and Lavee, 1971).

Steve, we have the issue here of higher soluble solids, weight and softer fruit as a function of advanced maturity, not a direct effect of Dormex

Table 5. Comparison of rest-breaking treatments with chill models [y] in 'Bing' sweet cherry; Stockton [x]; San Joaquin County, California, Winter, 1998-99.

Experiment 1: Treatment (100 gal/A)	Date applied	Response	Chill portions	Chill hours	Utah chill units
4% Dormex	January 7	best; advanced flowering and maturity (color)	43	816	827
	January 14	fruit set and crop load slightly increased; fruit size = untreated	48	976	927
	January 21	advanced bloom, leaf-out, fruit maturity	53	982	970.5
	January 28	none	57	1055	1079

Experiment 2: Treatment (100 gal/A)	Date applied	Response	Chill portions	Chill hours	Utah chill units
4% Dormex + GA_3 (ProGibb24 g a.i./A @ 200 gal/A; color break, 14 May)	January 21	advanced bloom, leaf-out, fruit maturity	53	982	970.5
25% CAN17	January 28		57	1055	1079
2% Entry + 25% CAN17	January 21	best CAN17 effect; firmer fruit	53	982	970.5
	January 28	good			
7% Erger G + 10% $CaNO_3$ (w/v, 0.3 kg□l^{-1}□ha^{-1}) + 0.5%Agridex	January 21		53	982	970.5
2% Agri-Dex + 25% CAN17	January 28		57	1055	1079
2% RNA 85 + 25% CAN17		advanced maturity			
4% Volck Supreme oil + 25% CAN17					
2% Optima oil + 25% CAN17					

[x] Hourly temperatures recorded from CIMIS station 0.1P, Live Oak.
[y] Chill models included: Dynamic Model (chill portions; Fishman et al., 1987, chill hours (1 hour at or below 45□F) and Utah chill unit model (chilling units vary from -1 to +1, depending on hourly temperature; Richardson et al., 1974; Erez and Lavee, 1971).

Table 6. Comparison of rest-breaking treatments with chill models [z] in 'Bing' sweet cherry;Winters [y]; Solano County, California, Winter, 1999-2000.

Treatment [x]	Rootstock	Date applied	Response	Chill portions	Chill hours	Utah chill units
4% Dormex+ 0.5% Agri-Dex	Mahaleb	January 13	long bloom, light crop, marginal effect	38	605	692
		February 7	best bloom advance, leaf bud break and leaf-out, maturity advance; best overall but not great effect	55	713	993.5
		February 18	little effect	63	767	1126
		March 1	none	70	1031	1267
4% Dormex+ 0.5% Agri-Dex @ 200 gal/A		January 13	bloom most advanced on March 17; fruit firmness increased	38	605	692
2% Entry + 25% CAN17		February 7	effect noted	55	713	993.5
7% Erger G		February 7		55	713	993.5
		February 18		63	767	1126
4% Dormex+ 0.5% Agri-Dex	Colt	January 13		38	605	692
		February 7	best for bloom advance and compression, advanced leaf expansion	55	713	993.5
		February 18		63	767	1126
		March 1		70	1031	1267
4% Dormex+ 0.5% Agri-Dex @ 200 gal/A		January 13		38	605	692
2% Entry + 25% CAN17		February 7		55	713	993.5
7% Erger G		February 7		55	713	993.5
		February 18		63	767	1126

[x] All treatments applied at 100 gallons per acre unless noted otherwise.
[y] Hourly temperatures recorded from CIMIS station 139, Winters.
[z] Chill models included: Dynamic Model (chill portions; Fishman et al., 1987, chill hours (1 hour at or below 45□F) and Utah chill unit model (chilling units vary from -1 to +1, depending on hourly temperature; Richardson et al., 1974; Erez and Lavee, 1971).

Table 7. Comparison of rest-breaking treatments with chill models [z] in 'Bing' sweet cherry; Lodi [y]; San Joaquin County, California, Winter, 2000-2001.

Treatment [x]	Date applied	Response	Chill portions	Chill hours	Utah chill units
4% Dormex	January 25	none	58	939	1137
6.6% v/v Erger + 10% CaNO3 w/v	January 27	advanced flowering most, leaf out advanced	59	973	1172.5
6.6% v/v Erger + 10% CaNO3, 350 gal/A	February 3	advanced fruit maturity, reduced fruit size	65	1073	1272.5
6.6% v/v Erger + 10% CaNO3	February 4		66	1079	1279.5
6.6% v/v Erger + 10% CaNO3	February 8	increased percentage of dead truss buds	69	1125	1342.5

[x] All treatments applied at a volume of 100 gallons per acre, unless otherwise noted.
[y] Hourly temperatures recorded from CIMIS station 166, Lodi West.
[z] Chill models included: Dynamic Model (chill portions; Fishman et al., 1987, chill hours (1 hour at or below 45□F) and Utah chill unit model (chilling units vary from -1 to +1, depending on hourly temperature; Richardson et al., 1974; Erez and Lavee, 1971).