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COMPARISON OF MODELS FOR PREDICTING END OF REST OF FLOWER BUDS AND USE OF EVAPORATIVE COOLING TO DELAY BLOOM IN SWEET CHERRY (PRUNUS AVIUM L.)

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MICHAEL BARR MILLER

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Frank G. Dennis Jr.
Major professor

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COMPARISON OF MODELS FOR PREDICTING END OF REST OF FLOWER BUDS AND USE OF EVAPORATIVE COOLING TO DELAY BLOOM IN SWEET CHERRY (*PRUNUS AVIUM* L.)

By

Michael Barr Miller

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ABSTRACT

Comparison of Models for Predicting end of Rest of Flower Buds and use of Evaporative Cooling to Delay Bloom in Sweet Cherry (*Prunus avium* L.)

By

Michael Barr Miller

Evaluations of two mathematical chill unit models (i.e., Utah Pheno-Climatography and Robertson-Stang Ohio models) relating environmental temperatures to rest completion of sweet cherries (*Prunus avium* L.) were conducted under Michigan conditions. Accumulation of chill units began September 1, for the years 1975 and 1976, and continued until no later than February 13. Estimation of rest completion of sweet cherry was found to be more accurate using Robertson and Stang's chill unit model.

Following the completion of rest cultivars "Hedelfingen" and "Emperor Francis" were sprinkled intermittently using an overhead sprinkling system to delay bloom by evaporative cooling. Sprinkling was begun March 8, 1977 and ended April 19, 1977. Water application began when ambient temperatures rose above 7.2°C utilizing a 2 minute on - 1 minute off cycle. Sprinkling was continued until controls reached full bloom. Treated trees reached

full bloom 2 days after the controls, with slightly more delay in the tops of the treated trees.

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CHAPTER I

INTRODUCTION

Although low winter temperatures sometimes cause severe injury to sweet cherry flowers in Michigan, a more common occurrence is late spring injury during bud swell or bloom. The goal of most efforts to prevent losses during freezes has been keeping bud temperatures above damaging levels. Heaters, wind machines, and overhead sprinkling for freeze protection are among the more common methods available. However, these methods provide protection only under specific weather conditions. If wind and cloud cover are not favorable, much of the available heat is dissipated. A large water source must be available in order to effectively sprinkle for frost protection. Once sprinkling has begun, usually at slightly above $0^{\circ}C$, it must be continued until temperatures rise above freezing. Cost of operation using these methods has risen in recent years due to the rising cost of fossil fuels, water availability, and stricter anti-pollution legislation.

More recently attempts have been made to delay bud development, thereby increasing cold hardiness during spring frosts. Chemical sprays, such as ethephon, which delay opening, offer a potential method for reducing spring freeze injury in tree crops, but none has proven commercially acceptable (Dennis, 1976). The use of cryoprotectants, which increase the resistance of tissues to injury, is another possible means of reducing losses.

In 1973, a group of researchers at Utah State University (Alfaro et al., 1974) developed a method for increasing spring-time cold hardiness of flower buds by use of evaporative cooling following rest completion. Evaporation of water from the buds cools them enough to reduce the rate of growth and therefore delay bloom. Current thought (Anderson, 1977) is to use sprinklers early in the season, after rest completion, when temperatures rise above 7.2°C. Predicting the end of rest, when buds begin to swell in response to warm weather, is critical for efficient use of the system.

The amount of cooling and delay in bud break possible by this method is related to the maximum amount of evaporation possible. Since evaporation occurs faster in a warm dry atmosphere, Utah, with lower relative humidities than Michigan, would be a better location for evaporative cooling. Significant delays have been recorded in Utah (Alfaro et al., 1974) but response to this technique under Michigan's less than optimum conditions, was unknown when this study was begun.

My objectives were to 1) test the accuracy of two chill unit models (Richardson, 1974, and Robertson et al., 1976) in predicting rest completion, and 2) determine the efficacy of evaporative cooling for bloom delay of sweet cherries (Prunus avium L.) in Michigan.

LITERATURE REVIEW

LITERATURE REVIEW

Part A. Determining end of rest.

During the course of evolution, most perennials have adapted their growth cycles to survive seasonal environmental extremes of temperature, sunlight, and water availability. The necessity to withstand low temperatures during the winter season forced higher plants, including fruit trees, to form buds either in late summer or early fall, at a time when temperature and light conditions are favorable for continued growth.

Coville (1920) demonstrated that certain woody plants (e.g. blueberries), in cold climates did not require low temperature in order to resume growth, but that chilling hastened flowering and increased the number of flowers. Most deciduous fruit trees must undergo a period of chilling before "normal" growth resumes.

Chandler (1937) defined rest as the period when the plant will not grow even though temperature and moisture conditions are favorable. The rest period, however, should not be confused with dormancy. Dormancy indicates inactivity due to any cause (Weinberger, 1950). Thus a tree in its rest period is dormant, but in northern latitudes rest may have been completed, yet the tree remains dormant because of low temperatures.

Fruit trees must experience a certain number of hours of chilling temperatures in order for rest to be broken. Hutchins (1932) suggested the use of the number of hours at or below 7.2°C as a quantitative measure of chilling. Chandler (1937) noted that temperatures just above freezing are more effective in breaking rest than temperatures at or below freezing; he also established a chilling requirement for apple. More recently, Erez and Lavee (1971) reported the optimum chilling temperature to be 6°. Higher or lower temperatures were less effective. A temperature of 21°, when alternated daily with low temperature, nullified the low temperature effect; a high of 18° had no effect. Interrupting the chilling with two separate periods of 11 and 12 days at 20° had no nullifying effect, but greatly enhanced lateral leaf bud break. These facts led to their (Erez and Lavee, 1971) proposal of weighted chilling hours, with the relative value of chilling varying with temperature.

Various attempts have been made to evaluate the amount of chilling required in the orchard. One of the first such studies was conducted by Weldon (1934) who correlated the occurrence of prolonged rest in a peach orchard with the average maximum daily temperatures during December and January. The chilling requirement was satisfied when the monthly average temperature was below 9.2°C.

Weinberger (1950), following up on Hutchin's work, proposed the use of accumulated hours below 7.2°C as an index of chilling. Bennett (1950) pointed out that not all temperatures below 7.2° are equally effective, and that temperatures below the freezing point are ineffective. Most attempts to determine chilling requirements for species and varieties, however, have been carried out with the traditional computation of the number of hours below 7.2°. The authors often do not specify whether hours below the freezing point have been included or not.

Weinberger (1950) exposed peach twigs to temperatures of 7.2°C or lower for 700, 900, or 1100 hours, then brought them into a warm room. If 50% of the flower buds became green in 3 weeks, rest was considered to be broken. Various other methods for evaluating chilling requirements have been tried. Crossa-Raynaud (1955) computed chill units using daily maximum and minimum temperatures in relation to a threshold temperature of 7°C (Table 1). Bidabe (1965) likewise utilized daily maximum and minimum temperatures, but associated these values with appropriate Q_{10} coefficients to attempt to account for the varying effects of different temperatures on growth and development (Table 1).

In 1974, Richardson et al. developed a weighted chill unit system from previous observations made by Erez and Lavee. One hour of exposure at 6° represents one chill unit. Values become less than one as temperatures drop below or rise above the optimum value. A negative contribution occurs at temperatures above 15° and no contribution to chilling occurs at temperatures below 0° (Table 2). The number of chilling hours required to satisfy rest requirements is genetically determined and varies with both species and cultivar.

Table 1. Formulae for determining chill units utilizing daily maximum and minimum temperatures.

Method 1[z] Crossa-Raynaud:

$$H_f = \frac{7 - m}{M - m} \times 24$$

H_f = Daily cold units

7 = Threshold temperature ($^{\circ}C$)

M = Maximum daily temperature

m = Minimum daily temperature

Method 2[y] B. Bidabe:

$$A_f = Q_{10}\frac{-M}{10} + Q_{10}\frac{-m}{10}$$

Af = Accumulated daily cold units

Q_{10} = Coefficient representing a specific respiration-temperature ratio

M = Maximum daily temperature

m = Minimum daily temperature

[z]From Crossa-Raynaud 1955.

[y]From B. Bidabe 1965.

Some values calculated using the "Utah model" are given in Table 3.

Robertson and Stang (1977) proposed a new model based upon conditions in Ohio. It differs from the "Utah model" by first allowing for differences in effective chilling temperatures among species (e.g., apple vs. peach) and secondly in the chill unit coefficients assigned to varying temperature ranges (Table 2).

To determine the chill unit accumulation for a 24 hour period, a computer program may be used to convert each hourly temperature to the equivalent chill-unit value given in Table 2. Since hourly temperatures needed to calculate chill units are usually not available in orchards, a method was developed by Richardson et al. (1974) which synthesizes hourly temperatures using daily maximum and minimum temperatures. Tests for 2 years covering the winter season at Salt Lake City Airport gave chill-unit accumulations within 2% of the accumulation obtained using measured hourly temperatures. (Richardson et al., 1974).

In Georgia, predictions made by utilizing the daily maximum and minimum temperatures ("Utah model") were within 8.7 ($\pm$ 5.7) days of the values obtained using hourly temperatures (Chesness et al., 1976). Discrepancies might have been due to the milder winters experienced in Georgia.

Both models have been proven accurate within the environments for which they were designed. During 1974 in Utah, rest completion was observed in peach leaf bud samples on February 3. The calculated

Table 2. Conversion of selected temperatures to chill units.

Method 1[z]	Chill unit contributed per hour at indicated temperature	
Temp. (°C)		
< 1.4	0	
1.5 - 2.4	0.5	
2.5 - 9.1	1	
9.2 - 12.4	0.5	
12.5 - 15.9	0	
16 - 18	-0.5	
> 18	-1	
Method 2[y] :	Apple	Peach
< 1.4	0	0
1.5 - 2.4	1	0.5
2.5 - 9.1	1	1
9.2 - 12.4	1	0.5
12.5 - 15.9	0	0
16 - 18	-0.5	-1
18.1 - 21.0	-1	-1
> 21	0	0

[z]From Richardson et al. 1974

[y]From Robertson and Stang 1977.

Table 3. Chill units required to complete rest for various fruit trees[z].

Species	Cultivar	Chill units
Apple	'Delicious'	1234
Apricot	-	720
Cherry	'Bing'	880
Peach	'Elberta'	800
Pear	'Bartlett'	1210
Prune	'Italian'	818

[z]From Richardson et al., 1975.

date using the model was February 1, 1974.

Part B. Delaying bloom to avoid freeze injury.

Overhead sprinkler irrigation has proven effective for evaporative cooling of many fruits and vegetables grown under adverse temperature conditions. In various studies since 1963 (Miller, 1963; Van den Brink and Carolus, 1965; Chessness and Braud, 1969; Wheaton and Kidder, 1966) reductions of 2.8 to 3.9°C in ambient temperatures of various fruits and vegetables were noted. Wheaton and Kidder (1966) reported an increase in yield of snap beans which they attributed to overhead sprinkling. Gilbert (1970) and Unrath (1972) both reported an increase in fruit quality and improved fruit size in their work with grapes and apples, respectively.

Until 1973, most experimental work with overhead irrigation dealt with evaporative cooling of crops which were in full foliage, or frost control as a result of heat of fusion of ice during bloom stage (Gilbert, 1970; Gray, 1970).

Alfaro et al. (1974) departed from the classical approach to frost control. Rather than protecting open blooms, they delayed bloom by evaporative cooling of the flower buds after the completion of rest. Apple and cherry flowering was delayed 17 and 15 days respectively. This was achieved through intermittent sprinkling of the trees at a rate of 1.8 mm/hr whenever the ambient temperature was above 7.2°C.

Since this original work, similar methods have been tried throughout the United States and Canada with various species of fruit (Table 4).

Current thought is to use sprinklers for evaporative cooling early in the season, then change sprinkler heads for frost protection as bloom approaches (Anderson, 1977; Lipe, 1977). Anderson (1977) stressed that bloom delay need not be prolonged, 10 days being enough in most years to avoid injury. If a 10 day delay in bloom of sweet cherries were possible in southwest Michigan, evaporative cooling would have been beneficial in reducing frost damage in 6 of the past 10 years (Table 5). Bloom delays of more than 10 days may reduce fruit size at harvest, as reported by Lombard (1977) for pears.

Problems may occur during or following sprinkling. Excessive bud drop has been noted in peach (Buchanan, 1977; Lipe, 1977). Disease can also be a problem. Pseudomonas syringae has been severe in at least one orchard in California and Stang (1976) reported problems with fireblight and "wet feet" with his work with 'Golden Delicious' apple in Ohio. Lombard (1977) reduced frost damage to pear with evaporative cooling in 1977, but fireblight infection was increased, particularly in the Bosc cultivar. Other physiological problems which Lombard attributed to evaporative cooling cancelled any benefits gained from frost avoidance (Table 6).

Table 4. Summary of current sprinkling data.

Species	Location	Dates of sprink-ling	Total hours operated	Sprinkler type	Nozzle size	Applica-tion rate	Total water applied	Days delay in bloom	Reference
					(mm)	(mm/hr)	(mm)		
1. Apple	Utah	3/8-5/21	671	"Rainbird" 171	-	1.8	1800	17	Alfaro et al., 1974
2. Apple	Idaho	2/26-5/4	703	"Rainbird" 30 EP	3.2 2.8	2.3	1137 935	12 7	Larsen & Kochan 1974
3. Apple	British Columbia	4/16-5/16	158	-	2.8	6.1	965	17	Looney, et al 1975
4. Apple	Ohio	3/24-5/16	182	Eddy-Mist	-	5.4	907	9	Stang et al., 1976
5. Pear	Oregon	Mist 1/24-4/19	465	-	-	1.1	497	9-11	Wolfe et al. 1976
		Sprinkler 2/2-4/19	525	"Roberts"	-	1.7	548	7-1	
6. Pear	Oregon	Mist-sprinkler-Feb., March, April		-	-	-	-	11-15 14	Lombard et al. 1976
7. Peach	Georgia	2/11-3/14	209	Midget rotary	-	2.2	460	14	Chessness et al., 1976

Table 4. Summary of current sprinkling data. (Cont.)

Species	Location	Dates of sprink-ling	Total hours operated	Sprinkler type	Nozzle size	Applica-tion rate	total water applied	Days delay	Reference
					(mm)		(mm)		
8. Peach	Kentucky	1/22-4/18	-	"Rainbird" MP-10	2.4	-	-	15	Bauer, et al 1976
9. Apple	New York	1975 4/14-5/13	-	"Rainbird" 30 and 30W	-	-	330	4-6	Swartz, et al 1977
		1976 4/1-4/28					246	5-7	
10. Peach	Texas	Early 1/1-3/1	-	Low angle lawn sprinkler	-	-	436	15	Lipe et al, 1977
						-			
		Late 3/1-4/1			-	-	381	15	
		Full season 1/1-4/1			-	-	813	15	
11. Peach	Florida	1/1-3/9	-	"Rainbird" 2400	-	-	-	10-14	Buchanan, et al., 1977

Table 5. Sweet cherry bloom dates (cv. Schmidt) and dates of last spring freeze in Van Buren County, MI.

	Full bloom	Petal fall	Last freeze at or below $-1.1^{o}C$	Predicted effect on frost damage with 10 day bloom delay
1967	4/30	5/9	5/3	prevent
1968	4/20	4/30	5/7	no effect
1969	4/28	5/5	4/30	prevent
1970	5/4	5/10	5/6	prevent
1971	5/7	5/16	5/13	prevent
1972	5/15	5/23	5/10	no effect
1973	4/26	5/8	5/17	no effect
1974	4/30	5/5	5/10	some effect
1975			4/23	
1976	4/16	4/21	5/19	no effect
1977	4/19	4/24	4/29	some effect

Table 6. Summary of three years' research on 6 to 15 day bloom delay of pears by evaporative cooling[z].

Response	Per cent of cases in which the response was significantly	
	Increased	Decreased
Fruit set	25	19
Yield	6	41
Fruit size at harvest	24	76
Seed content of fruit	71	0
Maturity based on pressure test[y]	0	18

[z]From Lombard, 1977.

[y]Increased - maturity hastened; Decreased - maturity delayed.

CHAPTER I

EVALUATION OF TWO CHILL UNIT MODELS IN MICHIGAN

Evaluation of Two Chill Unit Models in Michigan

Abstract. Two mathematical models (Utah Pheno Climatography and Robertson-Stang Ohio models) relating environmental temperatures to rest completion of sweet cherries (_Prunus avium_ L.) were evaluated under Michigan conditions. Accumulation of chill units began September 1 and ended no later than February 13 for the years 1975 and 1976. The model developed by Robertson and Stang proved to be more accurate in predicting the end of rest in Michigan.

Dormant buds of deciduous fruit trees will grow slowly, if at all, during late fall and early winter, even if temperature and soil conditions are favorable. This physiological condition, termed "rest" is broken by sufficient exposure to chilling temperatures.

Several methods have been developed for determining rest completion. The standard method of taking cuttings from the orchard and noting growth of 50% of the buds after 2 to 3 weeks is time-consuming (Calculation of the number of hours below a critical temperature, generally 7.2^{O}C, leads to great variability between years, for the chilling effect varies with temperature, with little or no effect below 0^{O} (Bennett, 1950).

In 1974, Richardson et al. proposed a weighted chill unit model which assigned varying chill unit coefficients to different temperatures. Coefficients ranged from -1 to +1 depending upon the effectivensss of the temperature in satisfying rest.

Robertson and Stang (1977) made a few alterations in the "Utah model" to allow for differences in environment and differences among species in response to chilling temperatures.

I computed rest requirement for sweet cherry using both of these latter models to determine which model best applies under Michigan conditions.

Materials and Methods

Daily maximum - minimum temperatures during fall and winter of 1975-1977 were obtained from the National Weather Service station at Bloomingdale, MI, the location of the test plot.

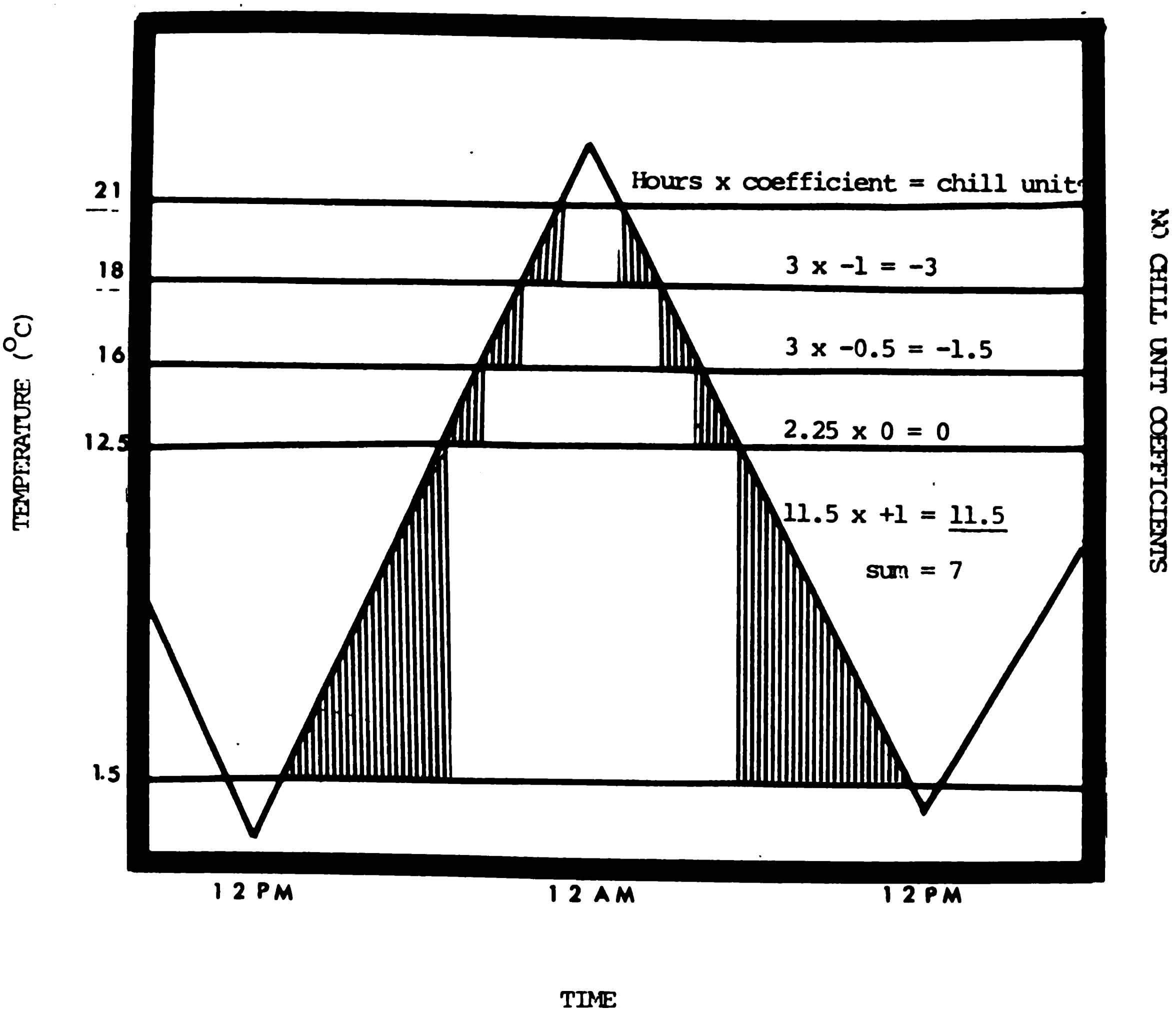
Assuming chill unit accumulation began on September 1 for each year, a daily temperature curve was approximated by plotting maximum and minimum temperatures for each day. Maximum temperatures were assumed to occur at noon, whereas minimum temperatures were plotted at midnight. These points were connected with a straight line, which was divided into 12 equal segments with the end point of each segment representing an hourly temperature. Each hourly temperature was then assigned the proper coefficient from either the Utah or the Ohio chill unit model (Fig. 1).

On February 13, 1977, cuttings were taken from the test plot in Bloomingdale, MI, to see if rest were completed. The test plot consisted of 20 sweet cherry trees approximately 12 years of age. The trees were planted on a 7.3 x 8.5 meter grid, and were approximately 4.6 meters high. Four cultivars, Hedelfingen, Emperor Francis, Viva, and Sam, were located within the plot, but only 'Hedelfingen' and 'Emperor Francis' were tested for completion of rest.

Two cuttings were taken from two trees of each cultivar and placed in a mist bed at a temperature of $20 \pm 3^{o}C$. The number

Fig. 1.

Method of calculating chill units from maximum and minimum temperatures, using method of Robertson and Stang (1977). Data for Bloomingdale, MI, September 29, 1977.



of buds which had reached Stage 3 (Ballard et al. 1971) was recorded on February 21, 1977.

Results

Using the Utah model, only 538.5 hours were accumulated during 1975-76 and only 479.5 hours during the 1976-77 chilling period (Table 1). On the other hand, the Ohio model indicated a chill unit accumulation of 879.5 hours during 1975-76 and 800.75 hours during 1976-77, both of which closely approximate the chill unit requirement (880 hr) reported for sweet cherry by Richardson et al (1975).

At least 50% of the buds on sweet cherry twigs sampled February 13 had reached Stage 3 on February 21 and, therefore, rest was broken following the accumulation of 800.75 chilling hours or less.

Table 1. Monthly and total chilling hours accumulated at Bloomingdale, MI in 1975-76 and 1976-77 as determined using two models.

Month	Utah Model	Ohio Model (Apple)
	1975 - 76	
September	75.8	199.5
October	168.5	313.0
November	196.2	243.0
December	98.0	124.0
January	0	0
February[z]	0	0
Total	538.5	879.5
	1976 - 77	
September	- 117.0	37.2
October	291.0	392.0
November	218.0	268.5
December	51.0	61
January	0	0
February	36.5	42
Total	479.5	800.7

[z]No chilling temperatures occurred until February 10, 1976, when rest was presumed to have been completed.

[y]Rest completed on or before February 13, 1977 as determined by forcing cuttings.

Discussion and Conclusions

From evaluations of both chill unit models using approximated hourly ambient temperatures, Robertson and Stang's (1976) model for apple was found to be the more precise at predicting end of rest of sweet cherries under Michigan conditions.

The reasons for this appear to be due to differences in environment from which the models were developed. The Utah model was designed to function under a sunny-arid environment, whereas the Ohio model more closely simulated the cloudy-humid growing conditions of Michigan.

I conclude that the Ohio model is the more logical choice for determining the end of rest of sweet cherries in Michigan. Through its use, a more precise and rapid method of determining end of rest is possible. With more precise records of end of rest, the time at which to start sprinkling for bloom delay through evaporative cooling may be determined more accurately.

Literature Cited

Ballard, J. K., E. L. Proebsting, Jr., and R. B. Tukey. 1971. Critical temperatures for blossom buds. Cherries. Wash. State Univ. Ext. Cir. 371.

Bennett, J. P. 1950. Temperature and bud rest period. Effect of temperature and exposure on the rest period of deciduous plant leaf buds investigated. Calif. Agr. 4: 11-16.

Richardson, E. A., S. D. Seeley, and D. R. Walker. 1974. A model for estimating the completion of rest for 'Redhaven' and 'Elberta' peach trees. HortScience 9: 331-332.

__________, __________, __________, J. L. Anderson, and G. L. Ashcroft. 1975. Pheno-climatography of spring peach bud development. HortScience 10: 236-237.

Robertson, J. L., and E. J. Stang. 1977. Personal communication.

CHAPTER II

DELAYING BLOOM OF SWEET CHERRIES

BY EVAPORATIVE COOLING

Delaying Bloom of Sweet Cherries by Evaporative Cooling.

Abstract. Sweet cherries (*Prunus avium* L., cultivars "Hedelfingen" and "Emperor Francis") were sprinkled intermittently using an overhead system. Sprinkling began March 8, 1977, approximately one month after the completion of rest. Water was applied using a 2 minute on - 1 minute off cycle, whenever the day temperature was greater than 7.2°C (45°F) until the control trees reached full bloom (April 19). Treated trees reached full bloom 2 days after the controls, with slightly more delay in the tops of the trees.

The loss of fruit from spring frost has been a perennial problem. After rest has been completed, the rate of bud development depends upon the temperature of the surrounding environment. If the early spring temperatures are below normal, blossoming is delayed; however, when temperatures are considerably above normal, bud development accelerates, increasing the potential for serious damage from a late spring freeze.

Sprinkler irrigation has been successfully employed to modify the micro-environment of many crops. Recently Alfaro et al. (1974) have used overhead sprinkling in Utah to evaporatively cool fruit buds and thereby delay bud development 10 to 15 days. Considerable delay has been noted in other locations throughout the United States and Canada.

The maximum effect might be expected in an arid environment, such as Utah, where relative humidity is low and evaporation is rapid. The higher relative humidity under Michigan conditions slows the rate of evaporation and hence reduces the cooling effect. Sunlight increases bud temperature above air temperature. Under the more overcast conditions in Michigan, bud temperature might be expected to remain lower than air temperature and evaporation rates would be slower; therefore, one would expect less cooling and less bloom delay. Delays of up to 9 days have been reported for apple in Ohio (Stang, 1976) and 5 to 7 days for the same species in New York (Swartz et al).

My purpose was to determine if evaporative cooling would delay bloom of sweet cherries under Michigan conditions, and what effects it might have on yield and fruit quality.

Materials and Methods

The experimental plot consisted of twenty sweet cherry trees approximately 12 years of age located near Bloomingdale, Van Buren County, Michigan. The trees were planted on a 7.3 x 8.5 meter grid and had attained the height of approximately 4.6 meters. Four cultivars, Hedelfingen, Emperor Francis, Viva, and Sam, were included within the sprinkled plot, but only Hedelfingen and Emperor Francis trees were used for measuring the effects of the treatment.

A sprinkler was placed in each of twenty trees. A 4.6 m galvanized iron riser, 12.7 mm in diameter, was fitted with a "Rainbird Full Circle Sprinkler - Model 14-V-TNT", with a 1.6 mm nozzle. Specifications for proper operation required at least 2.1 kg cm^2. Actual nozzle pressures varied from 2.6 to 2.7 kg cm^2 with a projected application rate of 0.044 liters/sec per sprinkler head. The diameter of coverage was 11.6 m, allowing for more than sufficient overlap.

Water was obtained from a deep well approximately 99.1 m from the first row of sprinkled trees. A PVC main (25.4 mm diam.) supplied water to each of four laterals of the same diameter. Each of the laterals in turn delivered water to five sprinkler heads.

A 24 hour day-night timer turned the current on at

8:00 a.m. and off at 8:00 p.m. Water flow was controlled with a thermostat which activated a variable 30 minute timer at temperatures above 7.2°C. The timer in turn controlled the 'on-off' cycle of the well pump. A lapse time accumulator recorded total operating hours. A second solenoid was controlled thermostatically to open at temperatures at or below 0°C to drain the line and thereby prevent ice from rupturing the system.

Maximum/minimum thermometers and rain gauges were installed in both sprinkled and non-sprinkled plots. Sprinkling began March 8, 1977. A 3 min on - 3 min off cycle was tried initially, but due to rapid evaporation the cycle was changed to 2 min on - 1 min off on March 15. Sprinkling ended April 19, 1977 after 35 days of operation.

Weekly precipitation and daily maximum and minimum temperatures were recorded in both the sprinkled and non-sprinkled plots. Differences in bud temperatures were measured on April 14 using a hand held potentiometer and copper constantan thermocouples (3 mil). Weather conditions were cloudy with a slight breeze, and ambient temperature was 14.4°C.

At approximately weekly intervals from (March 8 to April 8) one and two year old branches were collected from two trees of each cultivar in both the treated and control plots. Ten flower buds from each of 2 branches on each sampled tree were weighted (10 buds/ weighing).

Bud samples were also taken on April 8, 1977 to evaluate frost injury during the previous night (minimum temperature of $-5.5^{o}C$). Three to four 1-year-old shoots were selected from two trees of each cultivar in both the sprinkled and non-sprinkled plots. Buds were cut tranversely and the total numbers of injured and non-injured flowers recorded. Approximately 100 flower buds were counted May 6 on two limbs of each cultivar within each plot, and the numbers of dead and living flowers and developing fruits were subsequently recorded.

Fruit samples were harvested from both plots on June 16. Eight samples (2 samples per tree, 25 fruits per sample) of 'Hedelfingen' and six samples of 'Emperor Francis' were taken within each plot. Color, weight, suture diameter, firmness, and soluble solids were recorded. Diameters were measured with calipers. Fruits were separated into 4 color categories from 1 (light red) to 4 (deep red) and numbers of fruits in each category were recorded. Each sample was then weighed and 10 fruits from each sample were arbitrarily selected for determination of firmness and soluble solids. A durometer was used to measure flesh firmness following removal of a portion of the epidermis, then the soluble solids content of each fruit was determined with a hand refractometer. Data were analyzed by analysis of variance, and Duncan's (55) multiple range test was used for mean separation.

Results

Sprinkler operation. Total sprinkling time during 35 days of operation was 127 hours, with a total of 236 mm of water being applied at an average rate of 1.9 mm/hr. The total rainfall during the same period was 88.6 mm, for a total of 324.6 mm in the sprinkled plot.

Temperature variation. Maximum air temperatures were consistently lower within the sprinkled block with differences of from 0.6 to 4.4^{o}C between the two plots; however, minima were similar for both blocks. On April 14, sprinkled buds were 2.2 to 3.9^{o} cooler than non-sprinkled buds.

Bud development. Bud weights were not affected by sprinkling until the fourth week of sampling. Differences were apparent on April 2 (Table 1); however, variability was high and the differences were non-significant at the 5% level. Average values for sprinkled buds were consistently lower on all sampling dates with one exception ('Hedelfingen', March 8).

Frost injury. Sprinkling reduced frost injury to buds of both cultivars in samples collected April 8 (Table 2), although differences were non-significant at the 5% level. A difference of only 6% was noted in 'Emperor Francis' while the difference in

Table 1. Effect of overtree sprinkling on bud weight (mg/bud) for sweet cherry cultivars 'Emperor Francis' and 'Hedelfingen', 1977.

Treatment	Replicate	Sampling date 3/8	3/17	3/27	4/2	4/8
			'Emperor Francis'			
Control	1	41	45	52	83	78
	2	44	38	50	76	83
	3	38	55	70	-	81
	4	34	47	64	-	84
	Mean	39	46	59	80	82
Sprinkled	1	42	40	47	58	72
	2	32	47	67	61	82
	3	40	41	56	-	61
	4	36	42	56	-	70
	Mean	38	41	56	60	71
			'Hedelfingen'			
Control	1	39	45	57	69	81
	2	38	42	54	55	84
	3	35	46	55	76	-
	4	32	38	51	72	-
	Mean	36	43	54	68	83
Sprinkled	1	39	35	50	66	52
	2	37	37	50	54	54
	3	49	33	48	-	56
	4	35	44	46	-	58
	Mean	40	37	48	60	55

Table 2. Effect of evaporative cooling on frost injury and fruit set in sweet cherry, 1977.

Observation	Cultivar			
	Emperor Francis[z]		Hedelfingen[y]	
	Non-sprinkled	Sprinkled	Non-sprinkled	Sprinkled
Flowers killed (%) April 8 (Min. temp -5.5°C)	52	46	41	29
Number of living flowers per 100 flower buds, May 6	40	87	113[a]	158[a]
Number of fruits per 100 buds June 7	38	28	68[b]	25[a]
Number of fruits on June 7 per 100 living flowers	95	32	60[b]	16[a]

[z]Data for 'Emperor Francis' not analyzed because of limited replication.

[y]Mean separation within rows by Duncan's Multiple Range Test, 5% level.

'Hedelfingen' was 12%. Flowers of 'Hedelfingen' appeared to be more frost hardy than those of 'Emperor Francis'.

Bloom delay. The control trees reached full bloom (an estimated 50% of blooms open) on April 19, the sprinkled trees approximately 2 days later, with variation within a single sprinkled tree of up to 2 days. Flowers at the top of the sprinkled trees, which were closer to the sprinklers, showed slightly more delay than those on lower limbs. Less variability was noted on trees within the interior of the sprinkled plot. Both cultivars were equally retarded in development.

Fruit set. Data for fruit set (Table 2) were analyzed only for the cultivar 'Hedelfingen' due to limited replication. Sprinkling significantly reduced the number of fruits developing per 100 buds as well as the number of fruits per 100 living flowers. Data for 'Emperor Francis' paralleled those for 'Hedelfingen'.

Fruit maturity. Diameters and weights of fruits from non-sprinkled 'Emperor Francis' trees were smaller than those from sprinkled trees (Table 3), while the reverse was observed in 'Hedelfingen'. None of these differences was significant. Neither soluble solids nor fruit firmness was affected by sprinkling in either cultivar. Comparisons of sprinkled and non-sprinkled fruits revealed no obvious delay in color development.

Table 3. Effects of evaporative cooling on size and maturity of sweet cherry, 1977

	Cultivar			
	Emperor Francis		Hedelfingen	
Observation	Non-sprinkled	Sprinkled	Non-sprinkled	Sprinkled
Fruit diameter (mm)[z]	21	22	21	19
Fruit weight (g)[z]	4.68	5.56	6.36	5.64
Soluble solids (%)[y]	14.7	17.0	14.6	14.6
Flesh firmness (g)[y]	73	73	74	76
Color rating (% in each class)[zx]				
I	38	3	11	15
II	53	42	18	31
III	8	29	46	42
IV	0	24	23	11

[z] 25 fruit/sample x 4 replicates (trees)

[y] 10 fruits/sample x 4 replicates (trees)

[x] I-(light red), to IV - (deep red)

Discussion

The effects of evaporative cooling on bud temperature are influenced by solar radiation, ambient temperature, relative humidity and wind velocity. Under Michigan conditions, solar radiation is reduced due to cloudy skies, and relative humidity is higher in comparison with conditions in Utah. Therefore, one should not expect as much bloom delay in Michigan as in Utah. However, with adequate wetting of the buds, and initiation of sprinkling as soon as possible in the spring, a delay of one week should be possible. In this work, buds were not thoroughly wetted; apparently a finer spray of water will be necessary for this to occur. Cycle changes could be made to increase the time spent sprinkling, but without adequate coverage of the flower buds, the additional water would be wasted. Unevenness of bloom on the lower limbs of sprinkled trees indicated inadequate wetting. Branches near the sprinklers in the tops of trees, on the other hand, were fairly uniform in delay. In order to attain an even delay of bloom, a mist or combination mist and sprinkler system is needed which would not be overly affected by wind.

Frost injury to buds was decreased slightly as a result of retarded development. Further tests of hardiness at different stages of bud development are needed due to conflicting reports on the effects of evaporative cooling. Bauer et al. (1976) found buds of peach which had been retarded by sprinkling to be less hardy than the controls, while Swartz et al. (1977) noted greater hardiness of sprinkled apple buds.

Fruit set of 'Hedelfingen' was significantly decreased. This could be the result of reduced pollen production or viability due to water present on the flower buds, or of desiccation of tissues when sprinkling was discontinued.

Literature Cited

Alfaro, J. F., R. E. Griffin, J. Keller, G. R.Hanson, R. L. Anderson, G. L. Ashcroft, E. A. Richardson. 1974. Preventative freeze protection by preseason sprinkling to delay bud development. ASAE Paper No. 73-231, Amer. Soc. Agr. Engr., St. Joseph, MI.

Bauer, M., C. E. Chaplin, G. W. Schneider, B. J. Barfield, and G. M. White. 1976. Effects of evaporative cooling during dormancy on 'Redhaven' peach wood and fruit bud hardiness. J. Amer. Soc. Hort. Sci. 101: 451-454.

Duncan, D. B. 1955. Multiple range and multiple F tests. Biometrics 11: 1-42.

Stang, E. J. 1976. Personal communication.

Swartz, H. J., L. J. Edgerton, and L. E. Powell, Jr. 1977. The potential of evaporative cooling to delay bud break and dehardening of deciduous fruit trees in New York. The New York State Hort. Soc. Proc. 122: 172-174.

SUMMARY

With modifications allowing for better coverage, I feel there is a potential for delaying bloom and thereby increasing cold hardiness of sweet cherry with evaporative cooling. An accurate model (e.g. Ohio Model) for predicting rest completion is essential in order to achieve maximum delay. The earlier sprinkling begins, the more bud development can be delayed. Early blooming cultivars and species are more likely to benefit from evaporative cooling than are late blooming cultivars and species because of the greater frost hazard to the former.

An adequate water supply is of primary importance in determining feasibility of evaporative cooling. Minimum requirements for freeze protection are 3.8 - 5.1 mm/hr. With evaporative cooling, effective delays have been achieved with 1.8 mm/hr. Likewise, the cycling used in evaporative cooling allows recharging of the water source as well as simultaneous coverage of 2 or more blocks of trees. In contrast, with sprinkling for freeze protection, water must be applied continuously as long as the temperature remains below freezing. Often damage occurs to tree structure, and the excessive amounts of water applied may interfere with orchard practices. Evaporative cooling systems are less expensive than other forms of frost protection and might be adapted for pesticide or fertilizer application.

BIBLIOGRAPHY

Bibliography

Alfaro, J. F., R. E. Griffin, J. Keller, G. R. Hanson, J. L. Anderson, G. L. Ashcroft, E. A. Richardson. 1974. Preventative freeze protection by preseason sprinkling to delay bud development. ASAE Paper No. 73-231, Amer. Soc. Agr. Engr., St. Joseph, MI

Anderson, J. L. 1977. Personal communication.

Bauer, M., C. E. Chaplin, G. W. Schneider, B. J. Barfield, and G. M. White. 1976. Effects of evaporative cooling during dormancy on 'Redhaven' peach wood and fruit bud hardiness. J. Amer. Soc. Hort. Sci. 101: 451-454.

Bennett, J. P. 1950. Temperature and bud rest period. Effect of temperature and exposure on the rest period of deciduous plant leaf buds investigated. Calif. Agr. 4: 11-16.

Bidabe, B. 1965. L´action des temperatures sur l´evolution des bourgeons de l´entree en dormance a la floraison. 96th Congres de la Societe Pomologique de France, Paris; 55-66.

Buchanan, D. W., J. F. Bartholic, and R.H. Biggs. 1977. Manipulation of bloom and ripening dates of three Florida grown peach and nectarine cultivars through sprinkling and shade. J. Amer. Soc. Hort. Sci. 102: 466-470.

Chandler, W. H., M. H. Kimball, G. L. Philip, W. P. Tufts, and G. P. Weldon. 1937. Chilling requirements for opening of buds on deciduous orchard trees. Calif. Agr. Expt. Sta. Bul. 611.

Chessness, J. L., and H. J. Braud. 1969. Sprinkling to reduce heat stressing of strawberry plants. ASAE Paper No. 69-299, Amer. Soc. Agr. Engr., St. Joseph, MI.

__________, C. H. Hendershott, and G. A. Couvillon. 1976. Evaporative cooling of peach trees to break rest and delay bloom. ASAE Paper No. 76-2039. Amer. Soc. Agr. Engr., St. Joseph, MI.

Coville, F. V. 1920. The influence of cold in stimulating the growth of plants. J. Agr. Res. 20: 151-160.

Crossa-Raynaud, P. 1955. Effets des hivers doux, sur le comportement des abres fruitiers a feuilles eadugues. Ann. Serv. Bot. Agron. (Tunes) 29: 1-22.

Dennis, F. G., Jr. 1976. Trials of ethephon and other growth regulators for delaying bloom in tree fruits. J. Amer. Soc. Hort. Sci. 101: 241-245.

Duncan, P. B. 1955. Multiple range and multiple F tests. Biometrics 11: 1-42.

Erez, A., and S. Lavee. 1971. The effect of climatic conditions on dormancy development of peach buds. Proc. Amer. Soc. Hort. Sci. 96: 711-714.

Gilbert, D. E., J. L. Meyer, and J. J. Kissler. 1970. Evaporation cooling of vineyards. Sprinkler Irrigation Assoc. Proc.

Gray, A. S. 1970. Environmental control using a sprinkler system. National Irrig. Symposium, Lincoln, Nebr.

Hutchins, L. M. 1932. Unpublished paper presented at the 1932 Meeting of Amer. Soc. Hort. Sci.

Larsen, D. C., and W. J. Kochan. 1974. Using sprinklers to delay bloom for frost protection in apple trees. ASAE Paper No. PNW 74-44, Amer. Soc. Agr. Engr., St. Joseph, MI.

Lipe, W. N., O. Wilke, and O. Newton. 1977. Freeze protection of peaches by evaporative cooling in the post-rest, pre-bloom period. J. Amer. Soc. Hort. Sci. 102: 370-372.

Lombard, P. B. 1976. Improving stability of pear production by reducing frost damage. Southern Oregon Expt. Sta. Ann. Report 1976. p. 16.

__________, 1977. Personal communication.

Looney, N. E., and A. D. McMechan. 1975. Experiments in delaying apple bloom. British Columbia Orchardist, June, 1975. p. 6-7.

Miller, M. P., F. M. Turrell, and S. W. Austin. 1963. Cooling avocado trees by sprinkling. Calif. Agric. 17: 4-5.

Richardson, E. A., S. D. Seely, and D. R. Walker. 1974. A model for estimating the completion of rest for 'Redhaven' and 'Elberta' peach trees. HortScience 9: 331-332.

Richardson, E. A., S. D. Seeley, D. R. Walker, J. L. Anderson, and G. L. Ashcroft. 1975. Pheno-climatography of spring peach bud development. HortScience 10: 236-237.

Robertson,J. L., and E. J. Stang. 1977. Personal communication.

Stang, E. J. 1976. Personal communication.

Swartz, H. J., L. J. Edgerton, and L. E. Powell, Jr. 1977. The potential of evaporative cooling to delay bud break and dehardening of deciduous fruit trees in New York. New York State Hort. Soc. Proc. 122: 172-174.

Unrath, C. R. 1972. The evaporative cooling effects of overtree sprinkler irrigation on 'Red Delicious' apples. J. Amer. Soc. Hort. Sci. 97: 55-58.

Van den Brink, C., and R. L. Carolus. 1965. Removal of atmospheric stresses from plants by overhead sprinkler irrigation. Mich. Quart. Bul. 47: 348-363.

Weinberger, J. H. 1950. Chilling requirements of peach varieties. Proc. Amer. Soc. Hort. Sci. 56: 123-138.

Weldon, G. P. 1934. Fifteen years study of delayed defoliation of deciduous fruit trees in southern California. Calif. Dept. Agr. Bul. 23: 160-181.

Wheaton, R. Z., and E. H. Kidder. 1966. To control heat stress in plants. Agric. Engr. 47: 325.

Wolfe, J. W., P. B. Lombard, and M. Tabor. 1976. The effectiveness of a mist versus a low pressure sprinkler system for bloom delay. ASAE Paper No. 75-2007, Amer. Soc. Agr. Engr., St. Joseph, MI.