VALIDATION OF CHILL UNIT AND FLOWER BUD PHENOLOGY MODELS FOR 'MONTMORENCY' SOUR CHERRY

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Abstract

The chill unit and ASYMCUR GDH models were used to predict first bloom and full bloom dates for 'Montmorency' sour cherry for 3 years in Utah and 2 years in Michigan cherry orchards. The predicted full bloom dates were within 4 days of field observations.

1. Introduction

In the early 1970s, a research team at Utah State University began developing a series of models that would predict chill unit accumulation coinciding with the completion of rest and equate growing-degree-hour (GDH) accumulation to spring flower bud phenology. The models subsequently developed for field prediction utilize the most commonly available temperature data, maximum and minimum temperatures, as monitored in a standard U.S. Weather Service instrument shelter.

Chill unit requirements and GDH accumulations to full bloom for representative cultivars of major deciduous fruit species have been determined. Chill units for rest completion and GDH values for flower bud phenology stages of 'Montmorency' cherry are listed in table 1.

The chill unit model (Richardson, et al., 1974) contains three curves (figure 1). The outer curve represents the actual bud temperature. This is the temperature that the tree senses and to which it responds. The inner curve is the air temperature as measured in the instrument shelter. The middle curve designated the 'Effective Bud Temperature' is an index relating shelter temperature to bud temperature. It is the curve used in chill unit and GDH calculations. (Only the Effective Bud Temperature curve was shown in the 1974 publication.)

One chill unit is defined as one hour at the optimum temperature for meeting the chilling requirements of fruit trees. For the cultivars we have studied, 6° C is about the optimum chilling temperature. Temperatures above or below 6°C contribute less to the chill unit accumulation. Temperatures below 0°C as measured in the shelter do not contribute to chill unit accumulation and temperatures above 14.5°C reduce chill unit accumulation according to this model. This version of our chill unit model is adjusted from earlier versions (Richardson, et al., 1974; Anderson and Richardson, 1982) so that temperatures below an effective bud temperature of 0° or an actual bud temperature of -2°C provide no GDH accumulation.

Our original phenological model for flower bud development of fruit trees (Richardson, et al., 1975) was a linear model with a base temperature of 4.5 °C and an upper limit of 25 °C. Values were accumulated as *growing degree hours*. *One growing degree hour* was defined as 1 hour at a temperature 1 C above the base temperature. All temperatures above 25 °C were assumed equal to 25 °C; thus the greatest accumulation for any 1 hour was 20.5 GDH's.

As hourly temperatures are not readily available in most orchards, a method was devised to estimate hourly temperatures from daily maximum and minimum temperatures. The difference between the maximum and minimum temperature was divided by 11; hourly temperatures were assumed to increase or decrease by this amount, thus forming a modified sawtooth curve. This model divided the day into two 12-hour periods that were mirror images of each other. In a subsequent refinement of this linear model, the post-maximum period was not assumed to be a mirror image of the pre-maximum period. Instead temperatures ranged from the maximum to the minimum temperature of the following morning.

By 1982 we had developed an asymetric curvilinear model (Richardson, et al., 1982) that more closely represents the normal plant response to the environment than our previous models. This model, given the acronym ASYMCUR, is less site specific than the original linear phenological model. ASYMCUR also utilizes hourly temperatures, whether estimated or measured. Its modified cosine curve for fruit trees is defined by three cardinal temperatures: a base temperature of 4 °C, an optimum temperature of 25 °C, and a critical temperature (the temperature above which no appreciable growth will occur) of 36 °C.

The ASYMCUR model is a generalized model that can be used to describe the growth and/or development of a number of plant species and organisms associated with them (Richardson and Leonard, 1981). A graphic representation of the ASYMCUR curve for 'Montmorency' sour cherry as plotted by a computer is shown in figure 2.

GDH values for flower bud phenology of the various cultivars for which the models have been developed were determined from our own field observations and from phenology data supplied by cooperators at various research stations in the western (and in the case of peaches, southeastern) United States. Since sour cherries are not grown in many areas in the arid West, we decided to validate the models for 'Montmorency' sour cherry with field data from Utah and Michigan, the latter being the main production area of sour cherries in the United States.

2. Material and methods

Field observations were made in bearing 'Montmorency' sour cherry orchards at Utah State University's Farmington Field Station and Michigan State University's Northwest Michigan Horticultural Experiment Station during the spring of 1983, 1984 and 1985. Average dates of standard flower bud developmental stages (Dennis and Howell, 1974) were recorded at each station.

Daily maximum and minimum temperature data were recorded in U.S. Weather Bureau instrument shelters for 3 years in Utah and 2 years in Michigan. (We define a fruit tree year as beginning 1 September and lasting until 30 November of the following calendar year.)

Temperature data was entered into our computer system. Chill unit accumulation was determined by our chill unit model. When 954 chill units were accumulated, rest was considered to be completed and GDH accumulation was begun as defined by our ASYMCUR fruit-tree model. The ASYMCUR model consists of two cosine equations. Equation 1 (below) determines GDH accumulation at temperatures between the base and optimum temperatures.

$$GDH = FA/2\ (1 + \cos(\pi + \pi(TH-TB)/(TU-TB))) \qquad (1)$$

Where:

GDH = the accumulation of growing degree hours during an hour

when

TH = the hourly temperature

TB = the base temperature (4°C for fruit trees)

TU = the optimum temperature (25°C for fruit trees)

TC = the critical temperature (36°C for fruit trees)

A = TU - TB (the amplitude of the growth curve) and

F = a stress factor which can be used to represent various forms of plant stress (low humidity, soil moisture deficit, disease, competition, insect damage, nutrient deficiency, or a combination of these). Assumed to be 1.0 unless tree is under stress.

A review of the responses of several plant species to their environmental temperatures indicated that, rather than following a true cosine curve, response rates to increasing temperatures often varied, depending on whether the temperature was above or below the optimum temperature for the species. Leavitt (1980) also hypothesized a similar response in his growth curves. A second equation (2, below) was therefore developed to describe effective GDH accumulation at temperatures above the optimum.

$$GDH = FA\ (1 + \cos(\pi/2 + \pi/2\ (TH-TU)/(TC-TU))) \qquad (2)$$

If the values of TH are less than TU, equation (1) is used in the accumulation of GDH; if the values of TH are greater than TU, equation (2) is used.

Field observations of sour cherry flower bud phenology at the test sites were compared with predicted dates as determined with the chill unit and ASYMCUR models.

3. Results and discussion

Dates on which 'Montmorency' cherry orchards reached the standard flower bud developmental stages were determined subjectively by the authors at their respective experiment stations during the spring seasons of 1983, 1984 and 1985. Dates the trees would reach these stages were also determined using the chill unit and ASYMCUR models. Complete temperature data for the winter of 1982-1983 were not available from the Michigan station, so predicted developmental dates are not available from Michigan for 1983.

Differences between predicted and observed dates of bud phenology were usually within 5 days and generally within 2 days (table 2). It was difficult to determine the exact date trees reached a specified stage of development, especially at the Utah location. Under some environmental conditions, all flower buds on a 'Montmorency' cherry tree apparently are not in synchronous development. Flower buds on a tree's terminal shoots tend to develop earlier than its spur buds. For example, on 30 April 1985 the flowers on terminal shoots at Farmington, Utah, were in early petal fall while the spur buds had only reached 90% full bloom.

Observed dates of full bloom varied by 15 days in Michigan and 21 days in Utah. In Utah the springs of 1983 and 1984 were cool and rainly while 1985 was dry and warm. Considering the differences in site location between Utah and Michigan, the variation in environmental conditions among test years and the differences in bloom dates, the closeness of fit between predicted and observed dates indicates that the chill unit and ASYMCUR GDH models predict 'Montmorency' spring bud phenology in sour cherry production areas of the United States with sufficient accuracy to program cultural practices.

'Montmorency' sour cherry has been observed to be a relatively unstable cultivar (Bird, 1982). There are frequent problems of non-uniform production. There are both productive and unproductive mutants of 'Montmorency' that vary in precocity and range in fruit set from 10 to 30%. Fruit maturity has a certain amount of nonuniformity, perhaps correlated with the asynchronous blossom development. These problems make precise estimation of phenology dates in the field difficult for this cultivar. Further refinements in model accuracy for sour cherry are limited by the accuracy of field observations.

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Table 1 - Phenoclimatography values for 'Montmorency' sour cherry

Stage	Chill units	GDH (°C)
Begin chill unit accumulation	0	
End chill unit accumulation	954	
1. First swelling		1,010
2. Side green		1,580
3. Green tip		2,410
4. Tight cluster		3,230
5. Open cluster		3,470
6. First white		3,940
7. First bloom		5,380
8. Full bloom		6,130
9. Petal fall		7,560

Table 2 - Observed and predicted[a] dates of 'Montmorency' sour cherry flower bud developmental stages.

Site	Year	Developmental Stage	Observed Date	Predicted Date	Difference (days)
Utah	1983	open cluster	22 Apr	22 Apr	0
		first white	27 Apr	24 Apr	-3
		first bloom	5 May	7 May	+2
		full bloom	18 May	14 May	-4
Utah	1984	open cluster	1 May	8 May	+7
		first white	4 May	10 May	+6
		first bloom	9 May	14 May	+5
		full bloom	13 May	16 May	+3
Utah	1985	first white	16 Apr	13 Apr	-3
		first bloom	18 Apr	19 Apr	+1
		full bloom	27 Apr	25 Apr	-2
Michigan	1983	first white	15 May		
		first bloom	18 May		
		full bloom	21 May		
Michigan	1984	first bloom	19 May	20 May	+1
		full bloom	22 May	22 May	0
Michigan	1985	first bloom	3 May	5 May	+2
		full bloom	7 May	9 May	+2

[a]Date predicted by chill unit and ASYMCUR GDH models.

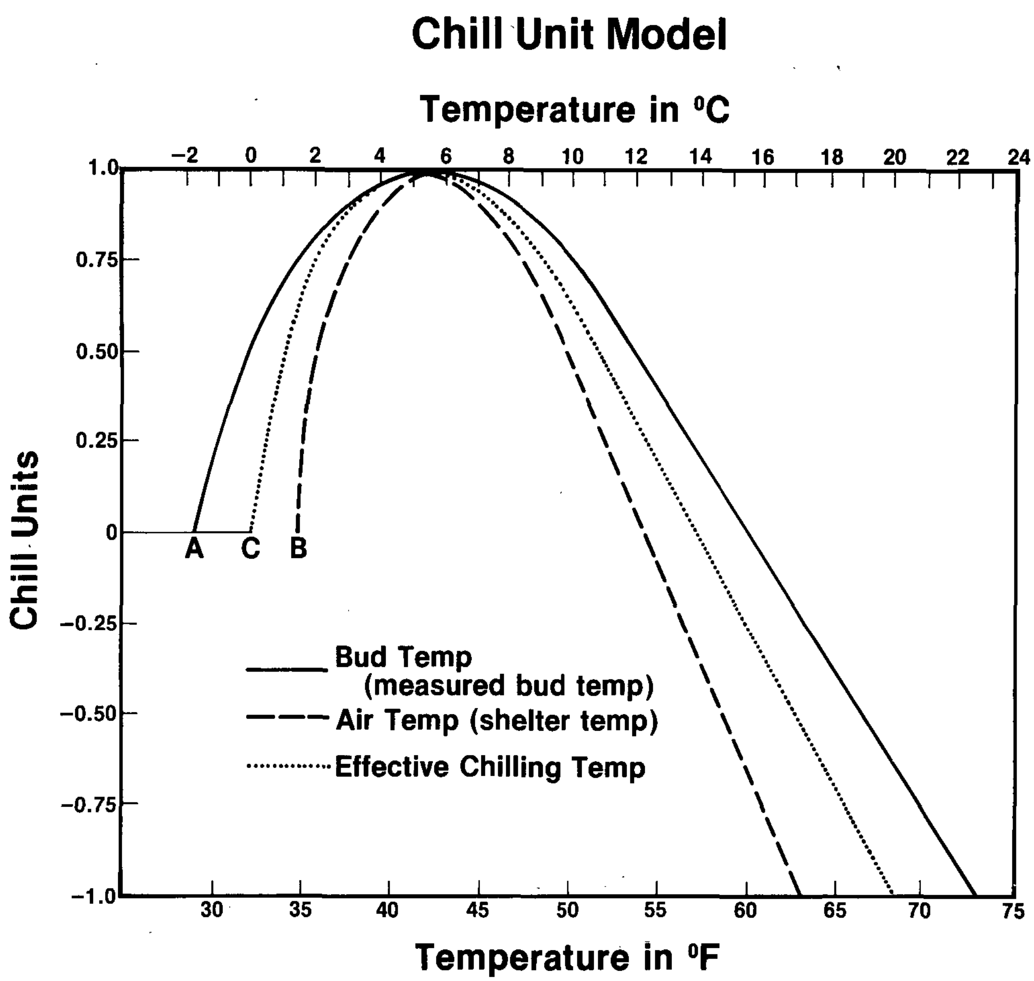

Figure 1. Curves used in estimating chill units.

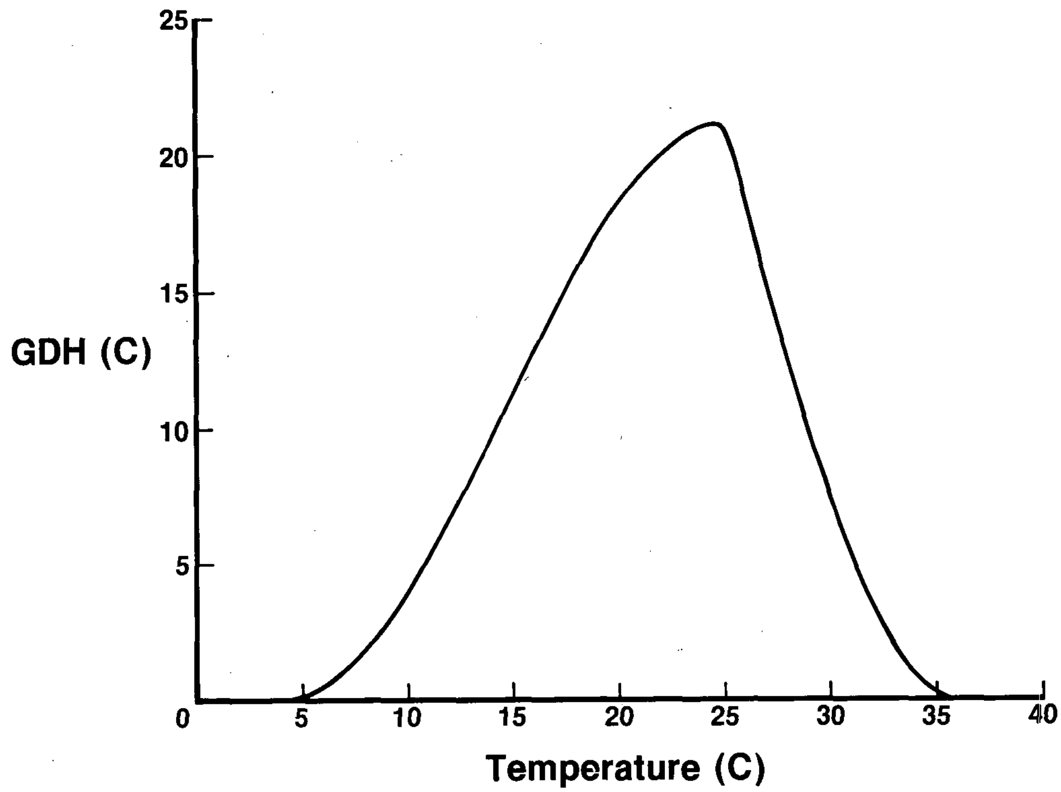

Figure 2. Computerized graphic plot of ASYMCUR curve for 'Montmorency' cherry.