P1.2 A NEW MODEL FOR ESTIMATING CHILL ACCUMULATION REQUIREMENTS FOR CROP AND NATURAL TREE SPECIES.

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1. INTRODUCTION

Bud break for deciduous fruit trees and the onset of foliage for forest species mainly depend on air temperature and its variation during the winter season. The exposure to a particular duration of cold temperature is needed to release dormancy (i.e., meet chilling requirements) followed by a spring growth. Several chill accumulation models presented in literature predict the data of bud break or leaf out in the current season from the previous harvest or leaf drop date. However, the effectiveness of time-temperature combinations on meeting chilling requirements varies between species. Tree crops and natural tree species have specific chill requirements that are related to the accumulated hours below a chill threshold, and several models have been developed to calculate chill units including: Weinberger (1950), Richardson et al. (1974), Shaultout and Unrath (1983), Erez et al. (1979), Linvill (1990), Cannell and Smith (1983), Hänninen (1990), and Linkosalo (2000). In this paper a new model for predicting bud break or leaf out is presented.

2. MATERIALS AND METHODS

Chill days (C_D), which are defined as the cumulative number of hours below a threshold temperature divided by 24 hours, are used to quantify chill unit accumulation. Anti-Chill days (C_A), which are defined as the cumulative number of hours above the same pre-selected threshold temperature divided by 24 hours, are also used to predict chill accumulation. The C_D values are given a negative sign and the C_A values are given a positive sign. In the model, the C_D values are accumulated until they reach a pre-selected value that is identified as the chill requirement (C_R). The C_D values are negative, so C_R is also negative. The chill requirement is met on the day when the $\Sigma C_D \leq C_R$. On the following day, the model begins to add anti-chill days to C_R. Bud break occurs when $C_R + \Sigma C_A \geq 0$ (Fig. 1).

Chill days and anti-chill days are calculated using the daily maximum (T_X) and minimum (T_N) temperature data and the single triangle method (Zalom et al., 1983) for calculating heat units. When $T_X \leq T_C$, there are no hours above T_C so the heat units are $H_1 = 0$. When $T_C < T_N$, the heat units above T_C are

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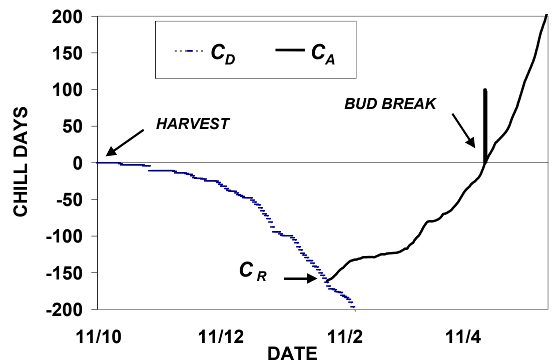

Figure 1. Chill (C_D) and anti-chill (C_A) accumulation from harvest to bud break. C_R represents the date when chill requirement is met.

given by: $H_2 = T_M - T_C$, where T_M is the mean temperature: $[T_M = (T_X - T_N)/2]$. If $T_N < T_C < T_X$, then the heat units above T_C are calculated as:

$$H_3 = \left(\frac{T_X - T_C}{T_X - T_N}\right)\left(\frac{T_X - T_C}{2}\right)$$

When $T_C = T_N$, the number heat units (H_4) above T_C is given by $H_4 = T_M - T_N$. This is the number of heat units within the triangle approximation. The number of hours per day below the threshold T_C divided by 24 hours provides a measure of the chill days (C_D). When $T_x \leq T_C$, then $C_D = -H_4$. If $T_C \leq T_N$, then $C_D = 0$. When $T_N < T_C < T_X$, then the chill days are calculated as the heat units within the triangle minus the heat units above T_C [e.g., $C_D = -(H_4 - H_3)$]. Note that the C_D values are always negative.

The anti-chill days (C_A) are calculated using heat units and the same chill threshold as used for the C_D calculations. When $T_x \leq T_C$, there are no heat units above T_C and $C_A = 0$. If $T_C \leq T_N$, then $C_A = H_2$. When $T_N < T_C < T_X$, then $C_A = H_3$.

The optimal value for T_C and for C_R are determined using trial and error until the root mean square error between predicted and observed days between harvest or leaf drop and bud break or leaf out is minimized. The root mean square error for days between harvest or leaf drop until bud break is calculated as:

$$RMSE = \sqrt{\frac{(d_p - d_o)^2}{N}}$$

where d_P is the predicted number of days, d_O is the observed number of days, and N is the number of years of record. Since the goal is to identify the threshold temperature and chill requirement that give the best prediction of days from harvest or leaf drop to bud break, minimizing the *RMSE* provides the best possible prediction.

3. RESULTS AND DISCUSSION

The model was applied to several data sets phenological observations made on of fruit tree (cherry, kiwi, pear, and olive) and forest species in two sites located in Sardinia, Italy. Resulting chill threshold (T_C), chill requirement (C_R), *RMSE* values for days from leaf drop to bud break, and years of record (*N*) are shown in Tables 1 and 2. The model generally predicted the days from harvest to bud break for fruit trees to within 12 days or better. The chill thresholds and chill requirements were consistent within species and seemed reasonable. There was more variability in the *RMSE* results for natural species, but the chill thresholds and requirements again seemed reasonable for predicting bud break

Table 1. Threshold temperature (T_C), chill requirements (C_R), and *RMSE* statistics for several fruit tree species.

SPECIES	*RMSE*	T_C	C_R.	*N*
Tempio (40° 55' N, 9° 7' E 429 asl)				
Cherry cv Burlat	8.9	7.5	-95	10
Cherry cv Moreau	8.9	7.5	-92	10
Cherry cv D.Osini	11.9	7.6	-96	8
Cherry cv Comune	9.3	7.5	-86	9
Cherry cv Forlì	11.7	7.7	-94	10
Cherry cv Ferrovia	10.7	7.7	-94	10
Cherry cv Marracocca	9.1	8.0	-95	8
Kiwifruit cv Hayward	7.0	7.9	-168	7
Pear cv Butirra	1.7	6.0	-103	4
Pear cv Coscia	7.0	6.0	-94	4
Pear cv Precoce	6.5	6.3	-105	4
Pear cv S. Maria	4.1	5.8	-106	4
Oristano (39° 53' N, 8° 37' E 11 asl)				
Olea europea	13.3	10.0	-145	6
Pear cv Butirra	1.7	6.0	-103	4
Pear cv Coscia	3.9	6.0	-103	4
Pear cv Precoce	2.5	6.1	-105	4
Pear cv S. Maria	3.5	6.0	-103	4

Table 2. Threshold temperature (T_C), chill requirements (C_R), and *RMSE* statistics for days from leaf drop to bud break for several natural tree species.

SPECIES	*RMSE*	T_C	C_R.	*N*
Oristano (39° 53' N, 8° 37' E 11 asl)				
Celtis australis	8.8	9.0	-165	8
Cercis siliquastrum	10.0	10.0	-145	10
Populus tremula	17.8	10.0	-158	11
Robinia pseudacacia	4.2	10.0	-147	6
Salix chrysocoma	21.6	10.2	-112	11
Tilia cordata	8.4	9.9	-169	11
Myrtus communis	0.9	10.0	-161	6
Quercus ilex	7.5	10.0	-245	6
Spartium junceum	5.7	7.8	-197	6

4. CONCLUSIONS

A model for predicting bud break or leaf out based on accumulation of negative chill units until reaching a chill requirement and then accumulating positive anti-chill units until reaching zero was described. The chill thresholds and requirements are determined by trial and error and tested to obtain the smallest least squares regression in days. This model performed well for a variety of species as illustrated for pears in Figure 2.

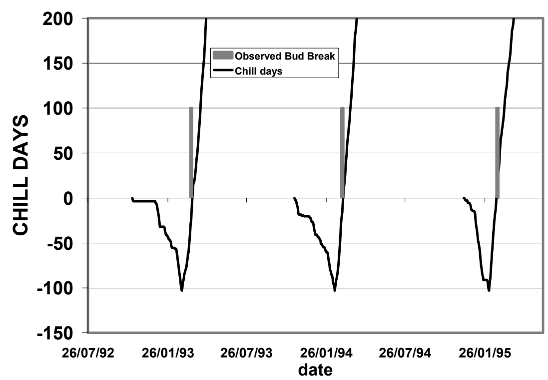

Figure 2. Prediction of bud break for pear trees

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