P 1.4 IMPROVEMENT OF CHILLING AND FORCING MODEL TO PREDICT BUD-BURST

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1. INTRODUCTION

Prediction of onset of the growing season is crucial for estimating the length of the growing season, which can affect the seasonal energy balance and net CO_2 exchange and hence yield potential and water usage. Timing of initial growth in the spring affects the risk of frost damage to crops, which is more likely when crops have early bud-burst, and it can influence grower cultural practices. Global warming could lead to inadequate chilling in certain areas, which could affect the suitability for certain species to survive or produce in that location.

Timing of bud-burst for deciduous fruit trees and forest species mainly depends on air temperature variation during the winter season. Exposure to a particular duration of cold temperature is needed to meet chill requirements and overcome quiescence. However, the effectiveness of time-temperature combinations on meeting chilling requirements varies among or across species.

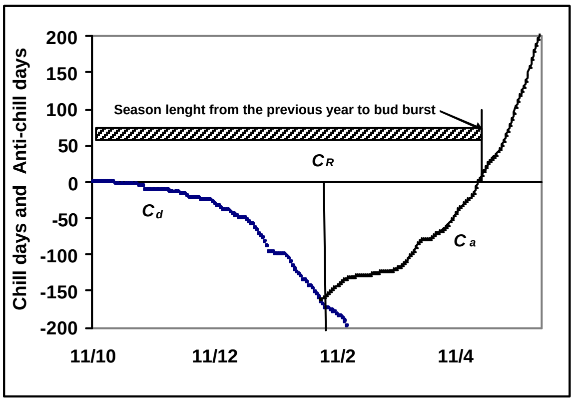
In this paper, a recently developed chilling accumulation model (Chill days model, Cesaraccio *et al.*, 2004) to estimate the timing of bud-burst was modified for improving the ability in predicting dates.

The Chill days model is based on the idea that chilling accumulates to break rest and heating accumulates to overcome quiescence (i.e. similar to the sequential approach of Sarvas, 1974; Cannell and Smith, 1983; Hänninen, 1990; Linkosalo, 2000). The model uses degree day calculations to determine chill days (units for chilling) and anti-chill days (units for heating).

2. MATERIALS AND METHODS

The Chill days (C_D) model is a sequential model (Fig. 1) for predicting the timing of bud burst based on the accumulation of chill days (C_d) during rest and anti-chill days (C_a) during quiescence (Cesaraccio *et al.*, 2004). Negative C_d values are accumulated until they reach a pre-selected value that is identified as the chilling requirement (C_R), which corresponds to breaking rest. On the following day, the model begins to add C_a on each day until the predicted bud-burst. The C_d and C_a both depend on the selection of a temperature threshold, T_C, and C_R. Both T_C, used for calculating the chill and anti-chill days, and C_R, needed to determine when rest is broken, were found by trial and error to minimize the root mean square error of predicted and observed bud-burst dates. Chill days and anti-chill days were calculated using the single triangle method to estimate degree days relative to a threshold temperature (Zalom *et al.*, 1983; Snyder *et al.*, 1999) (Tab. 1)

Fig. 1. Chill (C_d) and anti-chill (C_a) accumulation from harvest to bud burst. C_R represents the date when chill requirement is met.



Tab. 1. Equations for the five cases of Chill day Model

Cases	Chill days	Anti-chill days
$0 \le T_C \le T_n \le T_x$	$C_d = 0$	$C_a = T_M - T_C$
$0 \le T_n \le T_C < T_x$	$C_d = -\left[(T_M - T_n) - \frac{(T_x - T_C)^2}{2(T_x - T_n)}\right]$	$C_a = \frac{(T_x - T_C)^2}{2(T_x - T_n)}$
$0 \le T_n \le T_x \le T_C$	$C_d = -(T_M - T_n)$	$C_a = 0$
$T_n < 0 \le T_x \le T_C$	$C_d = -\left[\frac{T_x^2}{2(T_x - T_n)}\right]$	$C_a = 0$
$T_n < 0 < T_C < T_x$	$C_d = -\frac{T_x^2}{2(T_x - T_n)} - \frac{(T_x - T_C)^2}{2(T_x - T_n)}$	$C_a = \frac{(T_x - T_C)^2}{2(T_x - T_n)}$

Since the parameters of the Chill days model are determined by optimizing the prediction of bud-burst for a particular locations, they are site specific. The model was modified to include the effect on chill day accumulation of the temperature thresholds. Two approaches were followed in the calculation:

1. *New Chill Day Model (NEW)* - Anti-chill day (C_a) were calculated exactly the same as in the original model. The Chill day values (C_d) were calculated using a modified single triangle where the top of the triangle is the minimum temperature and the bottom of the triangle is the maximum temperature. For the C_d calculations, the area of the triangle is related to the distance between the minimum temperature and the

threshold temperature. The equations used to estimate the C_d values are reported in Table 2.

Tab. 2. Equations for the five cases of *NEW* Model.

Cases	Chill days	Anti-chill days
$0 \le T_C \le T_n \le T_x$	$C_d = 0$	$C_a = T_M - T_C$
$0 \le T_n \le T_C < T_x$	$C_d = \frac{(T_n - T_C)^2}{2(T_n - T_x)}$	$C_a = \frac{(T_x - T_C)^2}{2(T_x - T_n)}$
$0 \le T_n \le T_x \le T_C$	$C_d = T_M - T_C$	$C_a = 0$
$T_n < 0 \le T_x \le T_C$	$C_d = (T_M - T_C) - \left[\frac{T_n^2}{2(T_n - T_x)}\right]$	$C_a = 0$
$T_n < 0 < T_C < T_x$	$C_d = -\frac{(T_n - T_C)^2}{2(T_n - T_x)} - \frac{T_n^{\,2}}{2(T_n - T_x)}$	$C_a = \frac{(T_x - T_C)^2}{2(T_x - T_n)}$

2. *Fraction-Time Model* (*FT*). This model is based on the fraction of the 24-hour period during which daily temperature values are between the threshold temperature and the minimum temperature or 0 °C (if the T_n is lower than 0 °C). This approach considers the period of time when the air temperatures are effective or contribute to chill accumulation. The equations used to estimate the C_d values are reported in Table 3.

Tab. 3. Equations for the five cases of *FT* Model.

Cases	Chill days	Anti-chill days
$0 \le T_C \le T_n \le T_x$	$C_d = 0$	$C_a = 1$
$0 \le T_n \le T_C < T_x$	$C_d = -\frac{(T_C - T_n)}{(T_x - T_n)}$	$C_a = \frac{(T_x - T_C)}{(T_x - T_n)}$
$0 \le T_n \le T_x \le T_C$	$C_d = -1$	$C_a = 0$
$T_n < 0 \le T_x \le T_C$	$C_d = \frac{T_x}{T_x - T_n}$	$C_a = 0$
$T_n < 0 < T_C < T_x$	$C_d = -\frac{T_C}{T_x - T_n}$	$C_a = \frac{(T_x - T_C)}{(T_x - T_n)}$

The accuracy of the models was evaluated with the root mean square error (RMSE) between predicted and observed dates:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(d_{pi} - d_{oi}\right)^2}{N}}$$

where d_{Pi} is the predicted number of days for the year i, d_{oi} is the observed number of days for the year i, and N is the number of years of observation.

The model results were also compared with the biased standard deviation of the observed dates about the mean observed bud-burst date ($\overline{d_o}$) to have a measure of the bud-burst date variability.

$$s_b = \sqrt{\frac{\sum_{i=1}^{N}\left(d_{oi} - \overline{d_o}\right)^2}{N}}$$

The models were applied to phenological observations (Tables 4 and 5) made on tree crops and forest tree species in Tempio (40°55′N, 9°7′E, 429 m asl) and Oristano (39°53′N, 8°37′E, 11 m asl) on the island of Sardinia (Italy). Tables 4 and 5 show also the number of seasons with observations.

Table 4. Mean phenological stage dates and number of recorded seasons (*N*) for crop tree species.

SPECIES	***Harvest***	***Bud burst***	***N***
Tempio			
Cherry cv Burlat	03-Jun	18-Mar	9
Cherry cv Moreau	02- Jun	13-Mar	9
Cherry cv D.Osini	06-Jun	15-Mar	7
Cherry cv Comune	03- Jun	06-Mar	8
Cherry cv Forlì	08- Jun	15-Mar	9
Cherry cv Ferrovia	21- Jun	19-Mar	9
Cherry cv Marracocca	10- Jun	14-Mar	7
Kiwifruit cv Hayward	04-Nov	03-Apr	7
Pear cv Butirra	08-Aug	29-Feb	3
Pear cv Coscia	02-Aug	29-Feb	3
Pear cv Precoce	21-Jul	04-Mar	2
Pear cv S. Maria	08-Aug	10-Mar	3
Oristano			
Olea europea	06-Oct	04-Apr	5
Pear cv Butirra	23-Jul	07-Mar	3
Pear cv Coscia	27-Jul	07-Mar	3
Pear cv Precoce	12-Jul	10-Mar	3
Pear cv S. Maria	05-Aug	08-Mar	3

Table 5. Mean phenological dates and number of recorded seasons (*N*) for forest species in Oristano.

SPECIES	***Leaf fall***	***Bud burst***	***N***
Celtis australis	9-Nov	9-Apr	8
Cercis siliquastrum	6-Dec	29-Mar	9
Populus tremula	2-Dec	10-Apr	10
Robinia pseudoacacia	16-Nov	7-Apr	5
Salix chrysocoma	1-Nov	16-Mar	10
Tilia cordata	2-Dec	11-Apr	10
Myrtus communis	19-Oct	8-Apr	5
Quercus ilex	19-Oct	11-May	5
Spartium junceum	20-Jul	6-Apr	5

3. RESULTS AND DISCUSSION

The RMSE values for the C_D, *NEW*, and *FT* models performed in general better than using the mean calendar date (s_b) for predicting the timing of bud-burst of forest species (Table 6). When used for predicting harvest to bud-burst of tree crops, the models gave good results for pear varieties, olive trees and kiwifruit (Table 7). For cherry varieties, the results were not as good as using the mean calendar date except for the *FT* model, which gave the best results. Some improvements for cherry tree varieties were also obtained using the *NEW* model when compared with the C_D model results. Only for Precoce and S.Maria pear varieties, the RMSE values for the *FT* model were lower than for the C_D model. For forest species, a clear improvement in the bud-burst prediction was observed for *Quercus ilex* species using the *FT* model when compared with the original model and the mean calendar date. The C_D model performed better than the NEW and *FT* models and the mean calendar date for *Myrtus* and *Spartium*.

Table 6. *RMSE* values for predicted versus observed days for forest species in Oristano.

SPECIES	*CD*	*NEW*	*FT*	s_b
Oristano				
Celtis	9.0	13.5	8.3	7.7
Cercis	9.8	9.1	10.9	14.2
Populus	18.6	19.6	19.3	15.9
Robinia	3.0	4.5	3.9	9.2
Salix	21.3	22.6	20.4	22.1
Tilia	8.8	9.6	9.3	6.0
Myrtus	2.8	8.3	10.1	7.9
Quercus	8.9	9.0	4.4	5.2
Spartium	6.1	7.9	7.7	10.5

Table 7. *RMSE* values for predicted versus observed days for fruit tree crops.

SPECIES	C_D	*NEW*	*FT*	s_b
Tempio				
Burlat	9.5	8.8	5.3	7.3
Moreau	11.1	8.9	5.2	6.8
D.Osini	10.4	7.2	5.1	7.7
Comune	12.1	7.6	6.2	7.5
Forlì	13.1	10.2	5.8	6.9
Ferrovia	10.3	9.5	4.1	6.9
Marracocca	8.3	7.9	5.2	6.9
Hayward	7.4	7.8	7.0	9.3
Oristano and Tempio				
Butirra	4.7	9.9	5.4	9.1
Coscia	4.8	10.3	6.4	8.3
Precoce	7.7	8.3	6.0	9.0
S. Maria	7.4	9.9	6.6	8.2
Oristano				
Olea	8.8	9.1	8.1	12.6

4. CONCLUSIONS

The C_D model was compared with two modified versions (*NEW* and *FT* models) of the model for improving the ability in predicting dates when compared with observed dates. The analysis was conducted on phenological data from seven cherry varieties, four pear varieties in two locations, kiwifruit, olive tree, and nine forest species. Better performances by the modified models were obtained only for some tree crops and forest species. However, the *FT* model gave better results than the null model (i.e., using the mean calendar date) except for four of the forest species. In general, the *FT* model performed better than the C_D model for the tree crops and showed some promise.

5. REFERENCES

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