15A.4 PREDICTING CHILL ACCUMULATION REQUIREMENTS USING DIFFERENT MODELS

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1. INTRODUCTION

Timing of bud break for deciduous fruit trees and leaf out for forest species mainly depends on air temperature variation during the winter season. Exposure to a particular duration of cold temperature is needed to meet the chill requirement and break dormancy. 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. Chill models to predict breaking dormancy include: 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, several models were used to predict bud break or leaf out for cultivated and natural species. The accuracy of the estimates was evaluated comparing observed and predicting dates.

2. MATERIALS AND METHODS

Five chilling models were compared.

1. *Chill Day* (***CD***) *Model* (Cesaraccio et al., 2002). Chill days (C_D), which are defined as the cumulative number of hours below a threshold temperature (T_C) 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 T_C 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 $C_R + \Sigma C_A \geq 0$. 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.
2. ***Utah*** *Model* (Richardson et al., 1974). This is a weighted chilling unit (CU) model where one CU equals 1 hr of exposure at 6.1°C. CU accumulation becomes less than one as temperature deviates from optimum. A negative contribution occurs above 15°C and zero CU are accumulated below 1.4°C. Positive chilling units begin to accumulate immediately after the day when the largest negative accumulation is experienced.
3. *North Carolina* (***NC***) *Model* (Shaltout et al., 1983). This model is similar to the Utah model, but proposes a broader range of effective temperatures and incorporates a great negative effect when temperature exceed 21°C. The optimum chilling peak is at 7.2°C.
4. *Low Chilling* (***LCM***) *Model* (Gilreath and Buchanan, 1981). The model was developed from the relationship between temperature and days required to bud break, which correlates temperature with hourly chill unit values. This method has a broader range of effective temperatures and a higher optimum for rest completion than the Utah model.
5. *Positive Chill Units* (***PCU***) *Model* (Linsley-Noakes et al., 1995). Hourly temperatures are derived using a sine wave function from sunrise to sunset and a logarithmic equation during nighttime. Hourly temperature values are then converted in positive chill units using modifying intervals from the Utah model. If negative, the sum of the 24 hour period is set to zero.

Because 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 root mean square error (*RMSE*) provides the best possible prediction. The *RMSE* for days between harvest and bud break or leaf drop and leaf out is calculated as:

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

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.

The models were applied to phenological observations (Tables 1 and 2) made on fruit trees and natural 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).

3. RESULTS AND DISCUSSION

The CD model was better than the other models for predicting harvest to bud break for fruit trees (Table 3). For natural species, the CD model performed considerably better than the others (Table 4). Rather than using chill units that are empirically weighted for fixed temperatures as in the Utah, NC, LWC and PCU models, the CD model uses trial and

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error to find the best T_C and C_R for predicting bud break. In addition, the CD model starts at harvest or leaf drop rather than when the chill model reaches its most negative value. These factors help explain the better CD model performance.

Table1. Mean phenological stage date and number of recorded years (*N*) for several fruit tree species.

SPECIES	*HARVEST*	*BUD BREAK*	*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 2. Mean phenological dates and years (*N*) for several natural species in Oristano.

SPECIES	*LEAF DROP*	*LEAF OUT*	*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

Table 3. *RMSE* values for predicted versus observed days for fruit tree crops.

SPECIES	*CD*	*UTAH*	*NC*	*LWC*	*PCU*
Tempio					
Burlat	8.9	19.0	13.9	12.7	12.6
Moreau	8.9	17.6	11.8	11.9	11.6
D.Osini	11.9	13.6	11.1	13.1	10.7
Comune	9.3	17.1	10.8	11.3	8.3
Forlì	11.7	15.7	12.7	14.8	11.1
Ferrovia	10.7	13.8	10.9	11.2	14.2
Marracocca	9.1	14.6	9.4	9.3	10.4
Hayward	7.0	14.4	14.2	12.9	9.7
Butirra	1.7	17.7	11.6	10.3	15.5
Coscia	7.0	19.3	12.4	10.9	16.5
Precoce	6.5	16.2	8.1	7.2	13.0
S. Maria	4.1	23.7	8.0	7.2	12.6
Oristano					
Olea	13.3	36.8	24.3	22.2	25.6
Butirra	1.7	20.3	17.3	12.3	23.8
Coscia	3.9	19.0	16.3	11.5	22.0
Precoce	2.5	24.5	21.7	17.7	19.4
S. Maria	3.5	21.4	18.4	14.6	24.1

Table 4. *RMSE* values for predicted versus observed days for natural species in Oristano.

SPECIES	*CD*	*UTAH*	*NC*	*LWC*	*PCU*
Celtis	8.8	45.3	61.8	56.6	36.7
Cercis	10.0	33.7	19.4	20.6	33.3
Populus	17.8	49.7	18.5	17.6	37.9
Robinia	4.2	59.5	36.4	34.7	42.1
Salix	21.6	57.3	25.5	24.0	28.2
Tilia	8.4	47.1	19.6	17.7	36.4
Myrtus	0.9	33.4	21.1	27.3	19.1
Quercus	7.5	58.0	39.3	32.3	43.0
Spartium	5.7	32.4	18.4	15.8	19.9

4. CONCLUSIONS

The CD 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 performed better than all other commonly used models for a variety of species.

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