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An Apple Rest Model for Mild Winter Conditions

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AN APPLE REST MODEL FOR MILD WINTER CONDITIONS

by

José Ignacio del Real Laborde

A dissertation submitted in partial fulfillment
of the requirements for the degree
of

DOCTOR OF PHILOSOPHY
in
Plant Science

Approved:

Major Professor	Committee Member
Committee Member	Committee Member
Committee Member	Dean of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

1989

DEDICATION

To María del Rosario,
Clara Luisa, Rebeca and Andrea,
the women of my life,
with all my love.

To my parents
José Ignacio and María Luisa del Real,
my brother and sisters and their families
Sergio, María Eugenia, Mariana
and María Fernanda Rodríguez,
Fernando, Judith, Cecilia
and José Fernando del Real,
Roberto, María Josefa, Juan Pablo, Alejandra,
Mónica and José Ignacio Curiel,
Bernardo, Beatríz María and Ana Paola Rivas,
and María Luisa del Real.

To all of you belongs a piece of my life
and a part of my work, thanks for being there
and God bless you always.

ACKNOWLEDGMENTS

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I thank Dr. Schuyler Seeley for his willingness to help with my work and for his advice and patience.

I thank E. Arlo Richardson and Drs. Anthony H. Hatch, Donald V. Sisson and Gail E. Bingham for serving on my committee.

My thanks go to Raymundo Rojas Martínez, my friend and fellow student, for his dedicated help and insight.

My thanks to Ignacio A. González-Cepeda for his support during all these years. Thank you for leading me along this path.

I thank James William Frisby for his help and friendship during my time in Logan.

Finally, I thank the people of my country, México, for supporting my education. I hope I can serve you as well as you deserve.

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ABSTRACT

An Apple Rest Model For Mild Winter Conditions

by

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Utah State University, 1989

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Department: Plant Science

Two areas of research are reported: an experiment on the effects of warm temperature prestratification treatments on seed dormancy and a new chill unit model.

Crabapple seeds (Malus sargentii Rehd.) were allowed to imbibe water and were given warm pretreatments at temperatures of 16, 20, 24 and 28C for periods of 3, 10, 20 or 30 days before cold stratification at 4C for 20, 40, 60, 80 or 100 days. Pretreatments resulted in increased chilling requirements for seedling emergence. A short chilling period (20 days) also altered the leaf area, shoot length, internodal length and root/shoot ratio of the resulting seedlings.

The new chill unit model was developed from data from seed experiments and tested with records of 11 years. A three-dimensional model for the transition through apple tree dormancy is proposed. The new model evaluates the effectiveness of different temperatures for the transition between dormancy induction and dormancy release according to physiological time. The standard of measurement for this model is the chill unit (CU), which is defined as the equivalent of one-hour exposure to the optimal temperature during the optimal physiological time for dormancy development. The general pattern of temperature activity for dormancy development is sigmoidal; and temperature effectiveness through the process varies according to length of exposure, temperature cycling and time. The new model permits a more accurate prediction of dormancy development under subtropical conditions than previous models and will predict the amount of leafing that will occur in spring. The prediction efficiency of leafing under subtropical conditions was improved from an r^2 of 0.66 for the Utah Chill Unit Model to an r^2 of 0.74 for the new model when compared under Mexican conditions.

(77 pages)

CHAPTER I

INTRODUCTION

Deciduous fruit production under subtropical conditions is practiced in México, Israel, South Africa, Australia, New Zealand, Venezuela, Brazil and other countries. The profits from these crops are very important for the economy of these areas. Under local climatic conditions, growth and development of plants are affected by temperature, especially by warm winter temperatures that interact with rest (dormancy that requires a period of chilling to complete) release. If rest requirements are not properly satisfied, plant development is modified and longevity, in comparison to trees growing under temperate zone conditions, is reduced. As a result of environmental stress caused by the unsuitable temperatures, low yields and short plant life are common.

To help trees overcome these problems, rest-breaking sprays are applied at the end of the dormant season to enhance bud break and reduce the length of the blooming period in spring. These sprays have to be scheduled carefully to obtain the best results possible. Scheduling requires the use of predictive models or systems that can warn, in advance, the type of response to expect from the plants as well as the length of the bloom period as calculated from the fall and winter weather conditions. With this information the grower can better schedule spray application(s) and know the concentration that will be required each year.

Current models developed under temperate zone conditions have not been accurate under subtropical situations. Previous studies have shown that dormancy development is not linear with temperature changes during rest. This knowledge suggests that a modified chill unit model could reflect dormancy development more accurately.

The aim of this study was to provide a chill evaluation model better adapted to the temperature changes that occur during rest of apple trees growing under subtropical conditions.

Literature Review

Annual cycle. Deciduous fruit trees pass through two main stages during the yearly cycle relative to their vegetative activity.

Vegetative cycle. The active cycle of the plant begins at bud swelling in spring and continues until leaf fall in autumn. During the first part of this cycle tissue development is rapid. Development slows as the season advances, eventually reaching a point at which no new growth can be observed in the above-ground portions of the tree.

Rest cycle. Dormancy is now defined (ASHS Dormancy Working Group, unpublished) as: A suspension of growth of a plant organ(s) containing a meristem(s). The control can be external and/or internal. The term rest also refers to this condition and is used here as a synonym for dormancy. Rest begins before the vegetative cycle is completed. It is divided into three general stages called prerest; rest, divided into early, deep and late rest; and postrest (Weinberger, 1956). Prerest is controlled by environmental factors and can be broken by forcing plants to grow after cessation of growth if an adequate temperature stimulus is applied. According to Vegis (1964), the range of temperatures that can cause growth becomes narrower as the season advances. When external conditions cannot force the tree to grow, the trees are considered to be in rest. Rest is thought to be controlled by an internal balance of plant growth substances (Lavee, 1973). The chemical processes to overcome this stage develop gradually between cool temperature thresholds, the optimum temperature being around 6°C. When this condition is overcome the plant reaches the postrest stage, during which it is again subject to environmental and or structural control (e.g., bud scales, seed coat). The range of temperatures that can induce growth during late rest widens as the season advances. This description is a summary of the work by

Bidabe (1967), Chandler (1957), Chandler and Brown (1951), Chandler et al. (1937), Ketchie and Beeman (1973), Lavee (1973), Samish (1954, 1960), Samish and Lavee (1962), Samish et al. (1967) and Vegis (1964).

Temperature during rest. Temperature appears to be the main environmental factor controlling rest development. It has a direct effect on the inception of dormancy and control of the early, deep and late rest periods. During rest, temperature determines the rate of physiological processes that lead to rest completion. In 1956, the concept of a threshold temperature for chill accumulation was developed (Weinberger, 1956). Temperatures below the threshold were considered to help the tree progress through rest, while temperatures above it induced delayed foliation (Weinberger, 1967b). Temperature in fruit buds can be as much as 15°C higher during the day and lower at night than those measured in standard U.S. Weather Bureau instrument shelters. Therefore, the actual temperature within the bud often differs from that predicted using air temperatures (Brown, 1958, 1960). However, since the temperature measurement of individual fruit buds is impractical on a commercial basis, bud phenology is generally correlated with the more widely available temperatures recorded in instrument shelters.

Chill accumulation systems. Diverse methodologies have been developed to evaluate the development and predict the end of rest.

Chilling concept. Although winter temperature has always been considered an important factor for fruit production, it was not until 1893 that Jost, as reported by Samish (1945), initiated the technical study of cold temperature responses. Several studies and reviews have been devoted to the understanding of rest (Lavee, 1973; Samish, 1954, 1960). In 1932, Hutchins proposed 7°C as the threshold temperature for chilling (Weinberger, 1950a). In 1934, Weldon observed that when the average temperatures for December and January were above 9.4°C, fruit trees suffered from delayed foliation. Based on these and other observations, Weinberger (1950a, 1950b) correlated the performance of peach cultivars to the accumulated hours at temperatures below 7°C, which he designated as chill hours (CH). Later (Weinberger, 1954), the effect of warmer temperatures began to be considered not just as unfavorable for the development of rest but as negating the effect of previously accumulated cold temperatures (Chandler, 1960).

Chill hours systems. Weinberger proposed a set of values of CH based on the average temperatures of the winter months in California and concluded that the summed mean temperature values of December and January could be correlated with tree responses (Weinberger, 1956, 1967a, 1967b). Meanwhile, in Brazil, Da Mota (1957) developed an equation to calculate CH under the conditions of Rio Grande do Sul in an attempt to evaluate chilling under mild winters. Chilling requirements for different species have been calculated using these and other methods (Bidabe, 1967; Tabuenca, 1970).

It was common to calculate the CH from thermograph records by summing the hours below a threshold temperature. In 1969, Muñóz Santa María reviewed some CH systems and concluded that the values obtained by Da Mota's equation were the most suitable of the existing systems for Central México. In 1972, González-Cepeda introduced a concept of adjusted chill hours in which the final value for the day was calculated by the equation: CU = [hours below 7°C - 2(hours above 18°C)]. This calculation was considered accurate under Northern México conditions when used from November 1st to February 28th.

<u>Chill unit models.</u> In 1974 Richardson et al. formulated a new idea to evaluate the effect of winter temperature action on rest development of peach trees and published what has become to be known as the Utah Chill Unit Model. In this model the temperatures were evaluated as relatively less effective as they diverge from 6°C, which was considered to be the optimum temperature for chill accumulation. The model

coincided with the results from Erez and Lavee (1971). One hour of exposure to 6°C would give the plant one chill unit (CU). This model incorporated negative values for temperatures above 16°C and considered as without value those that were below 1.4°C. The algebraic summation of the hourly values gave the daily total. The development of flower bud phenology was predicted by the calculation of growing degree hours (GDH) after the end of the CU accumulation (Ashcroft et al., 1977; Richardson et al., 1975a, 1975b). Some additional models have evolved from this initial proposition for different species (Anderson and Richardson, 1987; Anderson et al., 1986; Lombard and Richardson, 1979; Saure, 1985). The original Utah model has been modified as to the temperature limits in order to adjust it better to the real bud temperature (Anderson et al., 1986; Richardson et al., 1986).

Chilling under mild winter conditions. Growing conditions for deciduous trees normally require a cold winter to overcome rest. Deciduous fruit trees are also grown in tropical and subtropical climates where these conditions are not fulfilled. To grow fruit trees under mild winter conditions requires special cultural practices similar to those reported by Giesberger (1972 and 1975) and Janick (1974). The trees must be forced out of rest using dinitrophenol + oil sprays (Chandler et al., 1937; de Villiers, 1946; Erez, 1971 and 1979; Erez and Lavee, 1971 and 1974; González-Cepeda, 1972; Samish, 1945; Strydom and Erasmus, 1966; Strydom and Skinner, 1965; and Weinberger, 1940). Treatment must be timed properly for effective results.

Bennett (1950) noticed delayed foliation in 'Beurre Hardy' pears grown under high temperatures. In 1954 Weinberger associated the high temperatures with bloom delay and lateral bud inhibition (Weinberger, 1954).

De Villiers, in 1946, reported that South African winter temperatures above 12.2°C (54°F) caused delayed foliation problems.

In 1962, Samish and Lavee suggested that the solution for mild winter climates would be dependent on an accurate measurement of chilling that allows for appropriate timing of the rest-breaking practices. In 1967, Weinberger (1967b) showed that rest could be correlated with the maximum average temperatures during November and December in the San Joaquin Valley.

In 1967, Samish et al. demonstrated that the optimum accumulation of chilling occurred at 6°C and that temperatures above 22°C caused inhibition of bud opening in peaches.

In 1971, Erez and Lavee found that the response to chilling at 6°C was twice as effective as at 10 or 3°C in breaking rest on peach buds. Alternating periods between

6 and 21°C nullified the chilling effect. Temperatures of 18°C had no effect on bud opening.

Chilling methods under mild winter conditions. Del Real-Laborde (1982) and del Real-Laborde and González-Cepeda (1982) evaluated fourteen different methods to measure the effect of chilling on apple using nine years of data from Northern México conditions. They found that the behavior of apple trees was not accurately predicted by any of the then published systems. The best correlation of phenological responses to temperature was obtained with their modification of the Utah model. They found that the leaf bud opening pattern of their trees fell into three groups and that their responses to temperature were not predicted by the available models. In years having the least delayed foliation, bud opening averaged greater than 75% ten days after full bloom. In the average years it ranged from 50 to 75%. In the years more affected by delayed foliation the average bud opening was lower than 50% and has been as low as 25% (1982). Their work showed that one of the weak points of the Utah CU model when used under Mexican climatic conditions was that the hourly temperature calculation based on maximum and minimum temperatures did not reproduce the daily fluctuation pattern properly and caused an estimation error, which had been noted previously by Aron (1975). To solve this problem, an improved daily temperature curve using a sine exponential approach to calculate the temperature was developed. Using this curve, suggested from the work of Parton and Logan (1981), Rojas-Martinez et al. (1990) were able to reproduce the fluctuations of temperature as experienced under Mexican conditions. The use of this tool greatly improved the estimation of the hourly temperatures (del Real-Laborde, 1987a). Nonetheless, the chill evaluation models were still not able to accurately predict the completion of rest under mild winters. The closest correlation value of was an r^2 of 0.64. These studies were reviewed by del Real-Laborde (1987c) and analyzed for a better forecasting method. He proposed a variable chill unit (VCU) model under which one VCU will be equivalent to one hour exposure to the optimal temperature during the optimal chilling time.

Fishman et al. (1987a, 1987b) published a model based on the work of Couvillon and Erez (1985), Erez et al. (1979a, 1979b) and Erez and Couvillon (1982). This model presents a two-step accumulation approach. It fits that data from which it was developed but has not been tested under field conditions.

Warm temperature effects on apple seed germination. Apple seeds have been used as research models for dormancy study as they are easy to handle in large numbers and have a chilling requirement similar to the buds of their parent trees (Thevenot, 1982.)

A number of experiments conducted by del Real-Laborde (1987a) and del Real-Laborde et al. (1986, 1987) with apple seeds have shown that chilling is not a linear process, results that agree with those of Seeley and Damavandy (1985). They also showed that the effectiveness of different temperatures during rest depends on the physiological time of their application. The duration and timing of the exposure were many times more important than the temperature applied. Short-term interruptions during stratification (10% of the optimal stratification time) showed the presence of a critical period at approximately 60 to 80 % of the optimal stratification time. When interruptions were applied during that time, the plant responses were more pronounced than those predicted for a linear process. At that time interval, the processes were either occurring at a faster rate or were changing from one phase to another. Interruptions for longer periods of time (25% of the optimal stratification time) caused larger disruption of the responses with the same critical time that was present with the shorter interruptions. These results were reviewed in a model for seed stratification by Seeley and del Real-Laborde (1987).

Another group of experiments by del Real-Laborde (1987b) and del Real-Laborde et al.(1987) showed that interruptions (for 25% of the optimal stratification time) with a temperature regime consistent in fluctuations from 4-24°C in 24-hour cycles have the same pattern of responses as those with constant temperatures.

Except for the reports of Nichols et al. (1974) on the induction of dormancy in apple and peach seedlings and those reported by Dreyer and Mauget (1986) on _Juglans regia_, there is no information available on the prechilling effect of high temperatures and the relationship between late summer and fall conditions to the onset and depth of dormancy.

Objectives

The purpose of this study was:

1. to study the effect of warm temperature pretreatments and interruptions on chilling requirements of _Malus_ sp. seeds as representation of subtropical field conditions and
2. to develop a chill unit model better adapted to subtropical apple production.

CHAPTER II

WARM TEMPERATURE PRESTRATIFICATION EFFECTS ON CRABAPPLE *Malus sargentii* SEED DORMANCY

Abstract. Crabapple seeds (*Malus sargentii* Rehd.) were allowed to imbibe water and were given warm pretreatments at temperatures of 16, 20, 24 and 28C for periods of 3, 10, 20 or 30 days before cold stratification at 4C for 20, 40, 60, 80 or 100 days. Pretreatments resulted in increased chilling requirements for seedling emergence. A short chilling period (20 days) also altered leaf area, shoot length, internodal length and root/shoot ratio of the resulting seedlings.

Introduction

Dormancy release in deciduous fruit buds and seed occurs at cool temperatures with an optimum near 6C (Erez et al., 1979a,b; Richardson et al., 1974; Seeley and Damavandy, 1985). Warm temperatures above 16C negate the cool temperature effect and retard dormancy release (Erez and Lavee, 1971). Deciduous fruit trees are not cultivated in many subtropical areas because of the effects of warm periods during the cool season on dormancy release. This phenomenon has not been evaluated adequately by available dormancy models (del Real-Laborde, 1987b). Peach tree dormancy studies point to a need to incorporate a time factor into models to account for the effect of warm temperatures (Erez et al., 1979a,b). Apple (Malus domestica Borkh.) seeds exposed to warm temperature periods during stratification have been shown to respond differently, depending on the timing and length of the exposure (del Real-Laborde, 1987a). Warm periods during prechilling have also been shown to result in decreased bud break in peaches and decreased shoot growth in peaches and apples (Nichols et al., 1974). These effects are greater under inadequate chilling conditions. Dormancy models, such as the Utah Chill Unit Model (Richardson et al., 1974), that use temperature data to predict the end of dormancy may be improved by the inclusion of a component to evaluate the effects of warm temperature exposure during prechilling dormancy development on later dormancy release. (Richardson et al., 1975).

This study was conducted to determine the effects of pretreatment temperatures above 16C on the subsequent chilling requirements of Malus sargentii Rehd. apple seeds.

Materials and Methods

Malus sargentii seeds were obtained from F. W. Schumacher Co. of Sandwich, Mass., and were treated as follows: Seeds were placed on blotter paper in 60-mm Petri dishes and flooded with 3 ml of an aqueous solution of captan (3a,4,7,7a-tetrahydro-2-[(trichloromethyl)thiol]-1*H*-isoindole-1,3(2*H*)-dione; 3000 ppm a.i. w/v). The Petri dishes were sealed with Parafilm to prevent seed desiccation and covered with aluminum foil to avoid exposure of the seeds to light.

For temperature treatments, controlled-temperature boxes made of high-density extruded Styrofoam (60x60x120 and 120x120x120 cm) were used. The boxes were kept in a 0C cold room. Constant temperatures (±0.2C) were maintained with Model 70-A (RFL 90310) controllers and sensors (#27687-3, Dowty Electronics of Brandon, VT). Heat was supplied by a 200-W light bulb.

Pretreatments of 16, 20, 24 or 28C were applied for 30, 20, 10, 3 and 0 days. Stratification treatments were given subsequently for periods of 100, 80, 60, 40, 20 or 0 days at 4C. Optimal isothermal stratification time for *M. sargentii* was found to be 40 days at 4C (Rader et al., 1986). The seeds were then planted in plastic liners on greenhouse trays with a root volume of 10 cm^3 per plant filled with 1 perlite : 1 peatmoss (by volume). The trays were placed in the greenhouse and seedlings were grown at a temperature of 20 ± 5C in a 16/8 hr light/dark environment of 800 mol s^{-1} m^{-2} provided by 400-W high-pressure sodium lamps. Plants were irrigated every 48 hr and were harvested after 120 days. The following parameters were measured: emergence at 10, 15, 20 and 25 days after planting; leaf area; shoot length; number of leaves; leaves + shoot dry mass and root dry mass at harvest. Results are expressed as percent emergence, leaf area, shoot length, internodal length and root/shoot ratio. The experimental design was a four-way split plot factorial with three replications of 24 seedlings each.

Due to the size of the experiment and the facilities available the treatments were replicated inside the same temperature box, thus making them pseudoreplications or subsamples of the treatment.

The statistical analysis performed showed P values for the main effects in a range so low that makes them clearly significant under this design (Appendix A).

Results

Emergence. Emergence increased with increased cold stratification time (Fig. 1a). Pretreatments generally reduced germination and subsequent emergence. No emergence was obtained from the 0 days of cold treatment seeds. For seeds chilled for a 20-day period, 3 days of warm pretreatment increased emergence significantly over that of the control and longer pretreatments. A similar interaction between pretreatment duration and chilling duration resulted in increased seedling emergence at 10 days of pretreatment plus 40 days of cold treatment, 20 days of pretreatment plus 60 days of cold treatment and

30 days of pretreatment plus 100 days of cold treatment, suggesting a compensational pattern between the warm and cold treatments.

The general emergence of pretreated seedlings was significantly lower than the control (no pretreatment) throughout the experiment (Fig. 1b). This delay indicated a negative effect of the warm pretreatment, which increased the chilling requirement for seedling emergence.

Analysis of variance for emergence data showed a highly significant (.01) response to chilling duration and pretreatment durations but not to pretreatment temperature. Interactions between chilling duration and pretreatment duration and between chilling duration and pretreatment temperatures were significant (.01 and .05, respectively).

<u>Leaf area</u>. Differences in seedling leaf area were observed only on plants from the 20-day chilling treatment. Leaf area at 20 days of chilling was significantly increased by the 16C pretreatment but significantly decreased by higher pretreatment temperatures (Fig. 2).

<u>Mean shoot length</u>. Mean shoot length was significantly (.05) affected by chilling duration and pretreatment temperatures (Fig. 3a). Warm pretreatment conditions markedly reduced the mean shoot length of the seedlings

from seeds that received only 20 days of chilling (Fig. 3a,b). The interactions between pretreatment duration and cold treatment duration and between pretreatment durations and pretreatment temperatures were also significant (.05).

Mean internode length. Internodal length was reduced (.05 level) in the plants from seeds that received 20 days of chilling as a result of both pretreatment duration and pretreatment temperature except for the 3-day pretreatment. The reduction was directly proportional to both of these factors (Fig. 4a,b).

Root-to-shoot ratio. The plants treated with the 20-day chilling regime showed marked responses in root/shoot ratio during growth. Root/shoot ratio of those plants pretreated for 3 days was not different than those receiving longer chilling times. The seeds pretreated for 10 days and chilled for 20 days produced plants that had the largest root-to-shoot ratio of any treatment. Plants from seeds pretreated for 20 or 30 days had a much smaller top and were significantly smaller than those from all the other treatments (Fig. 5).

Discussion

Warm temperature pretreatments given to stratifying seeds reduced emergence, subsequent leaf area and shoot and internode lengths of the resulting seedlings. These plant growth effects were highly significant on seeds that received insufficient chilling time. Longer periods of chilling were necessary to compensate for the effect of the warm pretreatment. Emergence from pretreated seeds did not recover to the level obtained for non-pretreated seeds after 40 days at 4C until after 80 days of chilling (Fig. 1b).

The pattern of emergence shown in Fig. 1a indicates interactions between the warm pretreatment and the cold treatment that at different intervals result in enhanced emergence. Short pretreatment duration (3 days) enhanced the emergence and growth of seedlings from seeds that received only 20 days of chilling; but longer pretreatments reduced emergence, root/shoot ratio and size of the plants from seeds that were chilled for 20 days. Longer pretreatments reduced emergence, root/shoot ratio and size of seedlings from seeds that were chilled inadequately (20 days). However, when chilling was adequate, effects of pretreatment time and temperatures on leaf area, shoot length, internode length and root/shoot ratio were not significantly different from the control (40 days at 4C).

These observations are important when evaluating dormancy development and dormancy release under subtropical climates where chilling is likely to be insufficient. The results of these experiments indicate that warm conditions prior to chilling increase the subsequent chilling requirement. Warm periods during chilling may have the same effect. Evaluation of the effect of prechilling warm periods in years with low chilling accumulation must consider the length of the warm exposure. The warm periods may not always be negative, depending on their physiological timing. More precise dormancy models for warm climates will need to incorporate duration and timing of high-temperature prechilling exposures.

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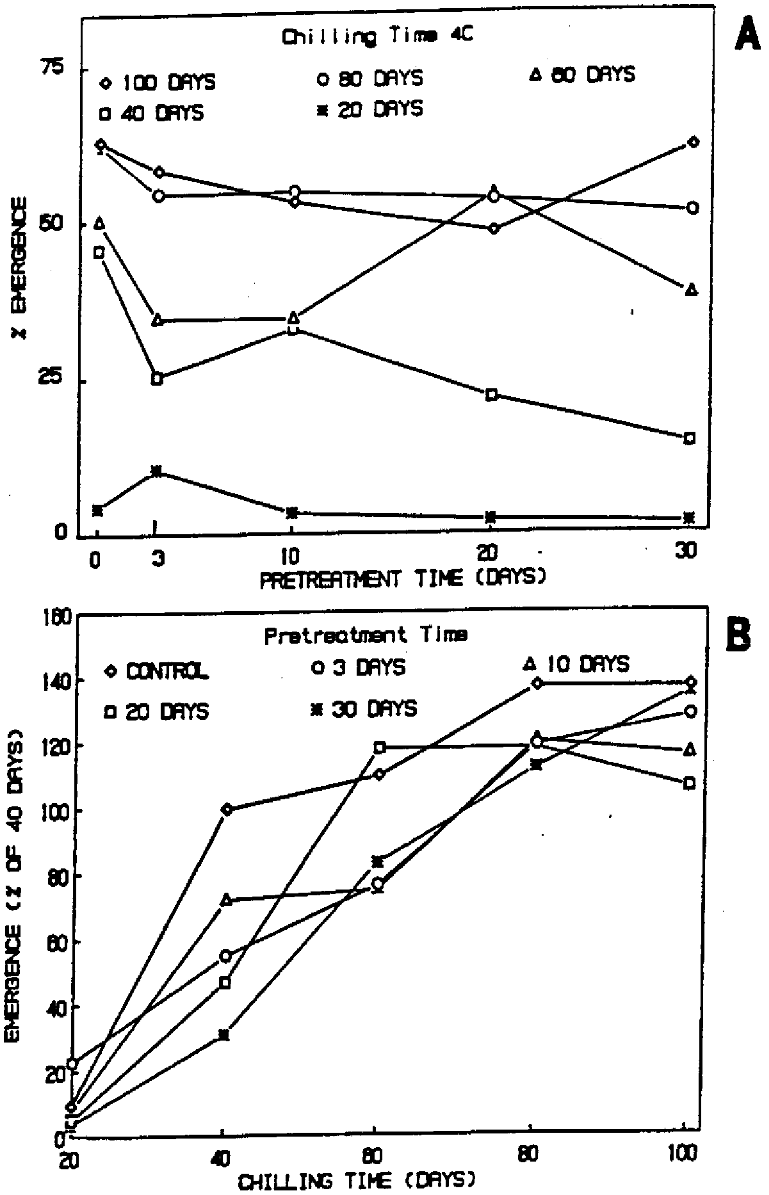

Fig. 1.a). Percent emergence of <u>Malus</u> <u>sargentii</u> seedlings 25 days after chilling treatments of 20 to 100 days as affected by warm pretreatments of 16, 20, 24 or 28C for 0 to 30 days. b). Emergence of <u>M.</u> <u>sargentii</u> seedlings 25 days after 20 to 100 days of chilling at 4C given subsequent to warm pretreatments of 16, 20, 24 or 28C for 0 to 30 days. The results are expressed as percentage of the emergence of the control treatment (40 days, 4C).

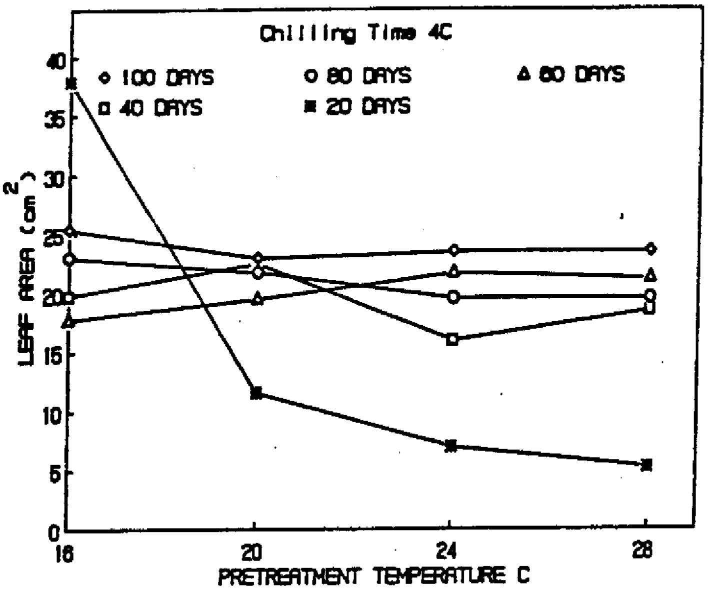

Fig. 2. Leaf area of Malus sargentii seedlings from seeds chilled for 20 to 100 days as a result of warm pretreatment temperatures of 16 to 28C.

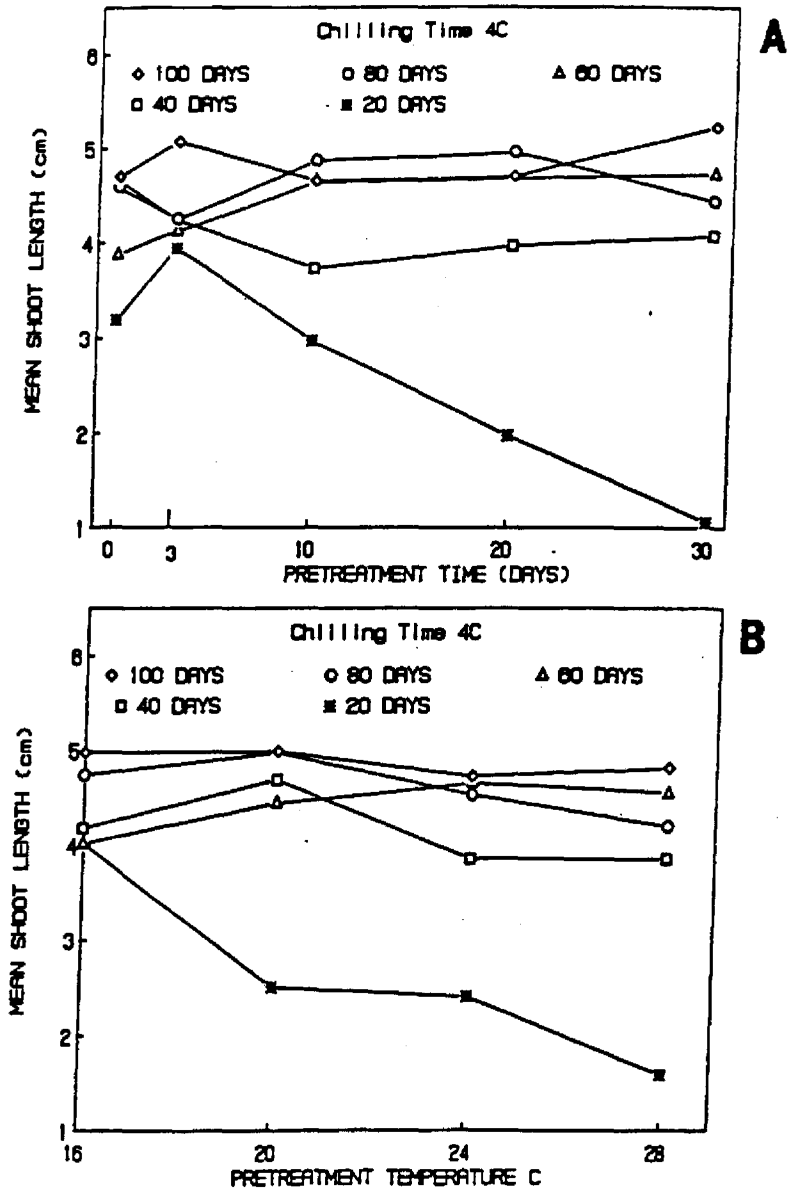

Fig. 3. a). Mean shoot length of Malus sargentii seedlings chilled for 20 to 100 days as a result of warm pretreatments of 16, 20, 24 or 28C for 0 to 30 days. b). Mean shoot length of M. sargentii seedlings chilled for 20 to 100 days as a result of warm pretreatment temperatures of 16 to 28C.

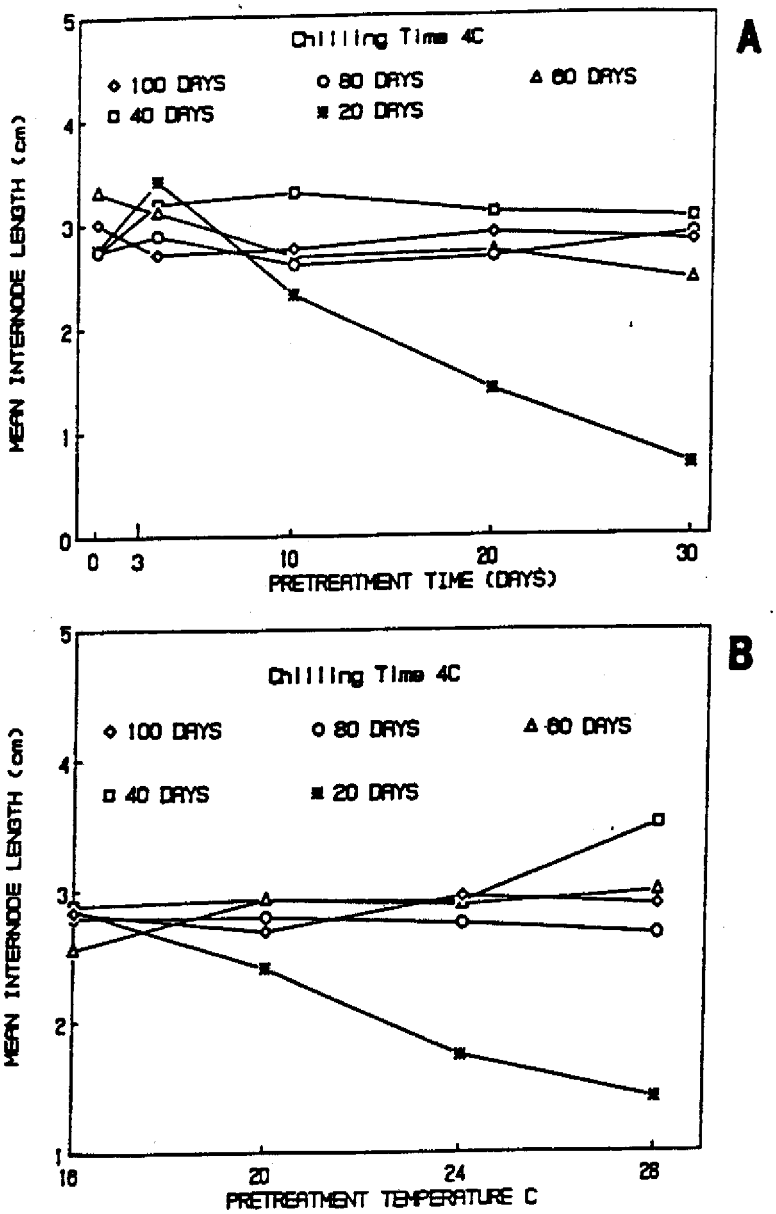

Fig. 4.a). Mean internode length of <u>Malus sargentii</u> seedlings chilled for 20 to 100 days as a result of warm pretreatments of 16, 20, 24 and 28C for 0 to 30 days. b). Mean internode length of <u>M. sargentii</u> seedlings chilled for 20 to 100 days as a result of warm temperature pretreatments of 16 to 28C.

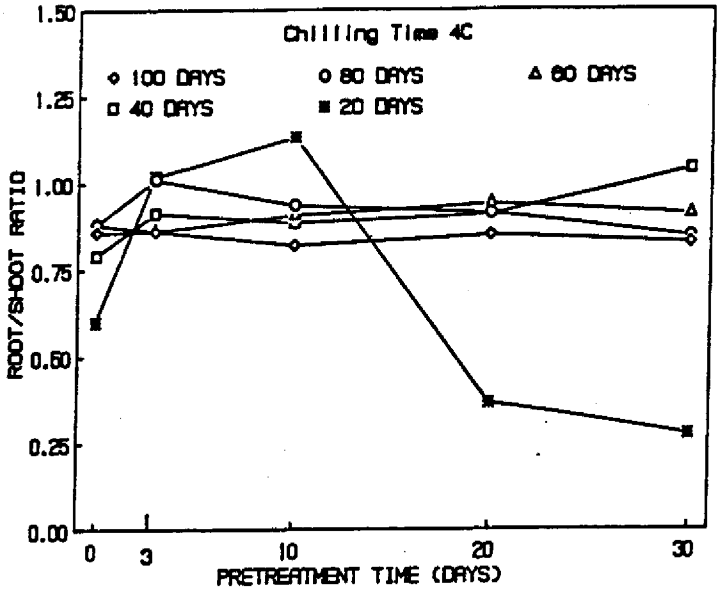

Fig. 5. Root/shoot ratios of Malus sargentii seedlings chilled for 20 to 100 days after warm pretreatments of 16, 20, 24 or 28C for 0 to 30 days.

CHAPTER III

AN APPLE TREE DORMANCY MODEL FOR SUBTROPICAL CONDITIONS

Abstract. A three-dimensional model for the transition through apple tree dormancy is proposed. The model evaluates the effectiveness of different temperatures for the transition between dormancy induction and dormancy release according to physiological time. The standard of measurement for this model is the chill unit (CU), which is defined as the equivalent of one-hour exposure to the optimal temperature during the optimal physiological time for dormancy development. The general pattern of temperature activity for dormancy development is sigmoidal, and temperature effectiveness through the process varies according to length of exposure, temperature cycling and time. The model permits a more accurate prediction of dormancy development under subtropical conditions than previous models. The model will also predict the amount of leafing that will occur in spring. The prediction efficiency of leafing under subtropical conditions has been improved from an r^2 of 0.66 for the Utah Chill Unit Model to an r^2 of 0.74 for the CU model, when tested under Mexican conditions.

Introduction

Dormancy development in the subtropics is affected by daily and seasonal temperature fluctuations. Dormancy development is inhibited by lack of chilling, and under such conditions trees tend to experience delayed foliation. Rest-breaking practices can be applied, but these require precise scheduling in order to be successful. Models that predict bloom time and leafing are needed. The most useful models currently available were developed to predict time of blossoming in peach trees (Richardson et al., 1974, 1975). When these models were tested under subtropical conditions they were proven unreliable to predict apple blooming date (Anderson and Richardson, 1987; del Real-Laborde and Gonzalez-Cepeda, 1982; del Real-Laborde, 1987b). Fishman et al. recently proposed another model, but it has not been developed far enough to be used as a predictive tool. Its system of calculation has not been tested with data independent from those used to derive the model (Fishman et al., 1987a, 1987b). Results from many experiments on dormancy development and dormancy release of Malus species seeds treated under different temperature conditions have shown that chilling accumulation is not a linear process and that the contribution of temperature towards dormancy development changes through time (Seeley and Damavandy, 1985; del Real-Laborde, 1987a; del Real-Laborde et al., 1988a and 1988b). The model presented here has been derived from these results.

Materials and Methods

Creation of the chill unit model. From the results of studies by Seeley and Damavandy (1985) and del Real-Laborde (1987a) germination surfaces for Malus domestica were obtained for various periods of isothermal stratification conditions. Seeley and Damavandy treated the seeds at temperatures from -2 to 16C and for periods up to 90 days, while the del Real-Laborde experiments were conducted at temperatures from 0 to 24C at 2C intervals and for periods up to 70 days. The emergence response surfaces obtained from these experimental data were transformed to evaluate the contribution to dormancy development of each temperature at different times during stratification. From these studies it was concluded that the general pattern of chill accumulation was not linear but sigmoid. It was also concluded that during the grand phase of the sigmoid curve the optimal temperature range is wider than at any other time.

In their studies the authors were not able to obtain seedling emergence from seeds stratified at temperatures below -2C or above 14C. The effect of temperatures above 12C was derived from the results of experiments by del Real-Laborde (1987a) and del Real Laborde et al. (1986, 1987 and 1988a). These experiments studied the effect of interruptions during stratification.

Interruptions with temperatures ranging from 0 to 24C were applied to Malus domestica and Malus sargentii seeds at different intervals during stratification at 4C. The length of the interruptions ranged from 1/10 to 1/4 of the optimal isothermal stratification duration for the species. From these results the contribution of temperatures in the range 12 to 24C was calculated. The contribution of these temperatures towards dormancy development was considered negative and was calculated from the reduction in seedling emergence caused by the temperature interruption relative to that obtained by the isothermal 4C control treatment. In some instances the effect of the interruption treatment caused a higher emergence rate than that from the control (del Real-Laborde et al., 1988a). However when evaluated with the set of results from all the interruption experiments, this was not found to be constant and was not used to generate the model array.

The interruption experiments showed a period from approximately 60 to 75% of the stratification time in which the negation caused by the higher temperatures was greater than that at any other time (del Real-Laborde, 1987a; del Real-Laborde et al., 1986, 1987). These results were incorporated into the model array as an area of larger negative contribution during dormancy development.

The characteristics of the temperature contribution to dormancy development that were used to formulate this model are:

1. Chilling is not a linear process.
2. A sigmoid time response curve better describes chill accumulation.
3. Temperature effects change according to physiological time of application and length of exposure.
4. Temperature changes during the grand phase of the sigmoid accumulation curve have larger positive and negative effects on dormancy development that those that occur at other times.

Chill unit model. The chill unit model is described as a three dimensional surface. The axes of this surface are temperature, physiological time and chill units.

A chill unit (CU) is defined as equivalent to one hour at the optimal chilling temperature during the optimal chilling time.

Physiological time is divided into chill unit accumulation fractions (CUAF) that cover the duration of dormancy development. Once a fraction has been completed it becomes fixed and cannot be reversed. Temperature activity changes within and between CUAF. The chill unit matrix is presented in Table 1.

From the matrix a three-dimensional surface was derived. The surface is shown in Fig. 1 in topographical view and in Fig.2 in a three-dimensional representation.

The surface is employed in the model to calculate the CU values that will be used for chill unit accumulation, the primary measure of dormancy development. As accumulation occurs and dormancy progresses the precise potential chill unit values for any particular time are given by interpolations on the temperature and time surface.

Given the relatively small range of the model (-1.5 to 1.0 CU), arithmetic interpolation is used.

The model estimates the CU accumulation from the summation of the hourly values. After every 24-hr period the total accumulation is calculated. The position of the surface coordinates is also calculated to obtain the CU values to be used for the next 24-hr period calculations.

The computer programs to use the model were written in Turbo Pascal 5.5 for IBM personal computers.

Temperature records. Fifteen years (from Nov 1971 to Nov 1986) of daily maximum and minimum temperature records collected at Rancho Guadalupe, Arteaga, Coahuila, México, located at 25° 15' N and 100° 41' W, were used to test the model. Calculation of the hourly temperatures was accomplished using Rojas-Martinez et al. (1990) sine-exponential model.

Phenology records. Eleven years (from 1972 to 1982) of phenological observations from the same location were used to analyze the model for correlation between CU accumulation and bloom date and foliar development. Bloom dates were evaluated by observations of 1000 mixed buds, and full bloom was considered as the date at which 80% of the mixed buds had reached the full-bloom stage. Leafing percentage values were obtained ten days after full bloom from counts of 1000 vegetative buds on one-year wood.

Results

The model was tested against temperature and phenology records from a Mexican location for a total of 11 data-years of temperature and leaf bud opening and compared against the original Utah model. The results of these trials showed that the Utah model had an r^2 of 0.66 for the Mexican data, the new model had an r^2 of 0.74 (figures 3 and 4).

Examples of the chill accumulation obtained during a good chill unit accumulation year (1976-77, 85% leaf opening) and a bad chill unit accumulation year (1981-82, 25% leaf opening) are shown in Fig. 5.

Discussion

The new model is a promising tool for prediction of dormancy development under subtropical conditions. It will be further tested in the field and the results evaluated. We are continuing to make adjustments in the model, particularly in the magnitude of the CUAF used to formulate the surface. The program to run the model is available through the Plant Science Department, Utah State University, Logan, UT 84322-4820.

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Table 1 - Matrix of chill unit (CU) values used to calculate the model surface.

	Chill Unit Accumulation Fractions									
Temp°C	1	2	3	4	5	6	7	8	9	10
-2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0	0.0	0.0	0.3	0.5	0.7	0.7	0.7	0.5	0.0	0.0
2	0.0	0.3	0.5	0.7	1.0	1.0	1.0	0.7	0.5	0.0
4	0.5	0.5	0.7	1.0	1.0	1.0	1.0	1.0	1.0	0.5
6	0.7	0.7	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.7
8	0.5	0.5	0.7	1.0	1.0	1.0	1.0	1.0	0.7	0.5
10	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.3	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	-0.3	-0.3	-0.3	-0.3	-0.5	-0.5	-0.5	-0.3	-0.3	0.3
16	-0.3	-0.5	-0.5	-0.5	-0.7	-0.7	-0.7	-0.5	-0.5	0.3
18	-0.5	-0.5	-0.5	-0.7	-1.0	-1.0	-1.0	-0.7	-0.7	0.5
20	-0.5	-1.0	-1.0	-1.0	-1.0	-1.5	-1.5	-1.0	-0.7	0.5
22	-1.0	-1.0	-1.0	-1.0	-1.0	-1.5	-1.5	-1.0	-1.0	1.0
24	-1.0	-1.0	-1.0	-1.0	-1.0	-1.5	-1.5	-1.0	-1.0	1.0

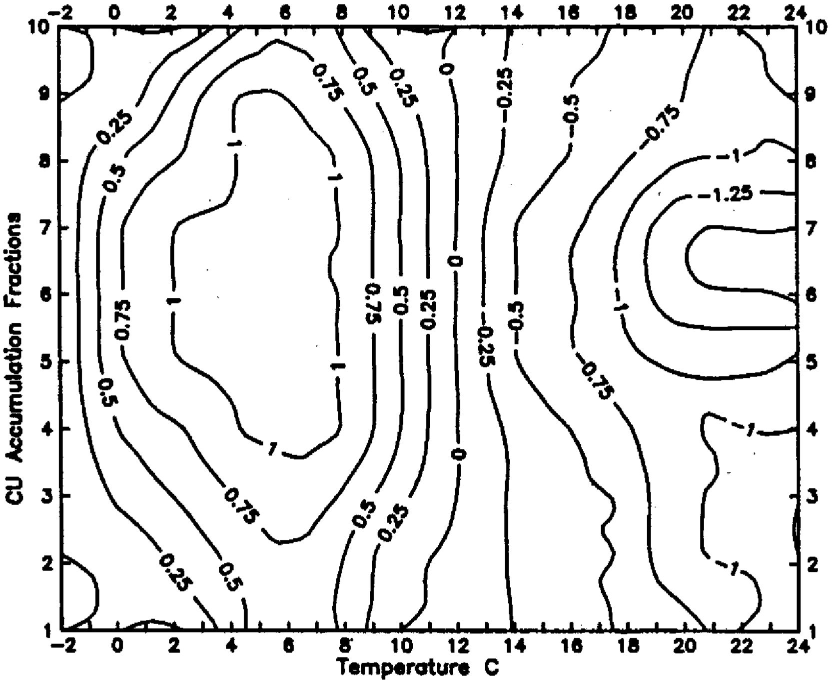

Fig.1. Topographic map of the chill unit (CU) model response surface. The level distances are drawn every 0.25 CU.

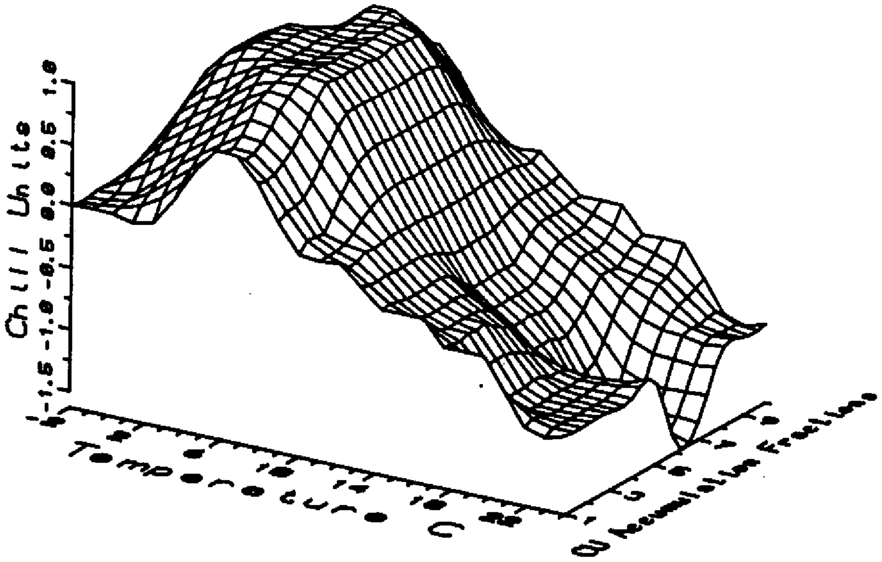

Fig.2. Three-dimensional response surface of the CU model.

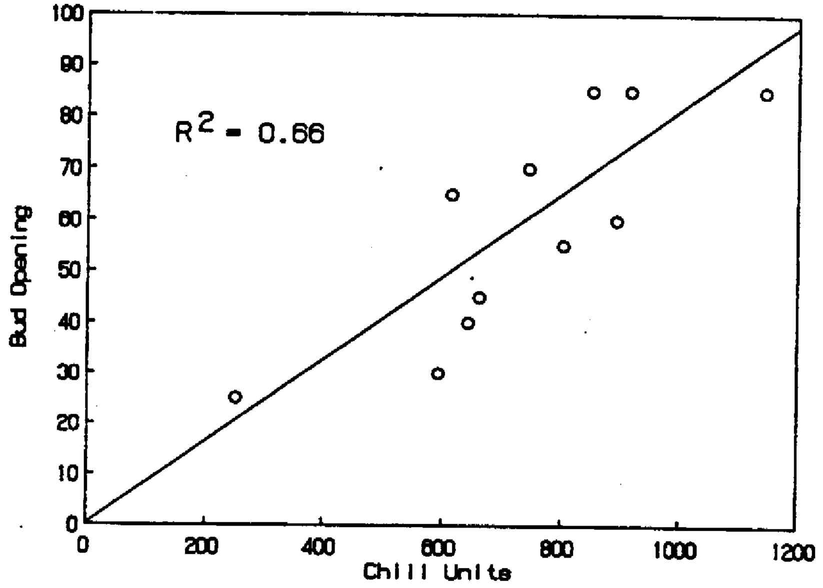

Fig.3. Regression between the accumulation of chill units under the Utah Chill Unit Model and leaf bud opening percentages calculated 10 days after full bloom in Rancho Guadalupe, Arteaga, Coahuila, México, from 1972 to 1984.

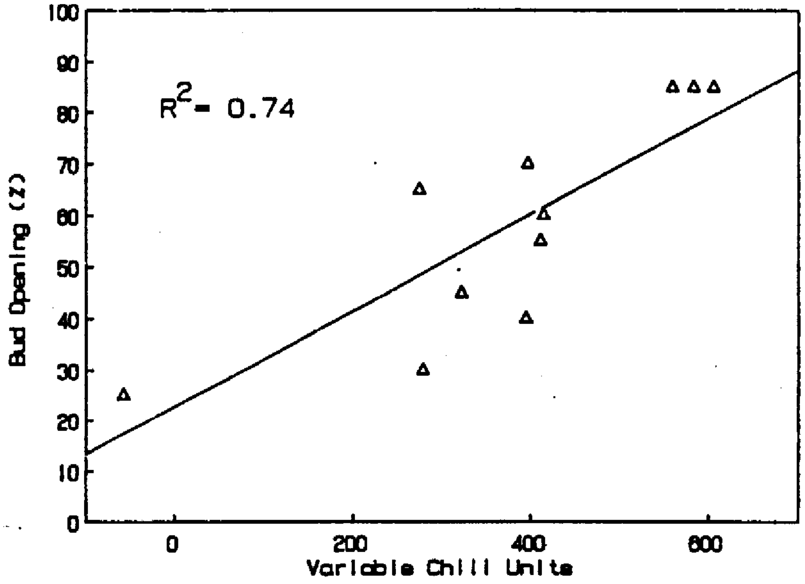

Fig.4. Regression between the accumulation of chill units and leaf bud opening percentages calculated 10 days after full bloom in Rancho Guadalupe, Arteaga, Coahuila, México, from 1972 to 1984.

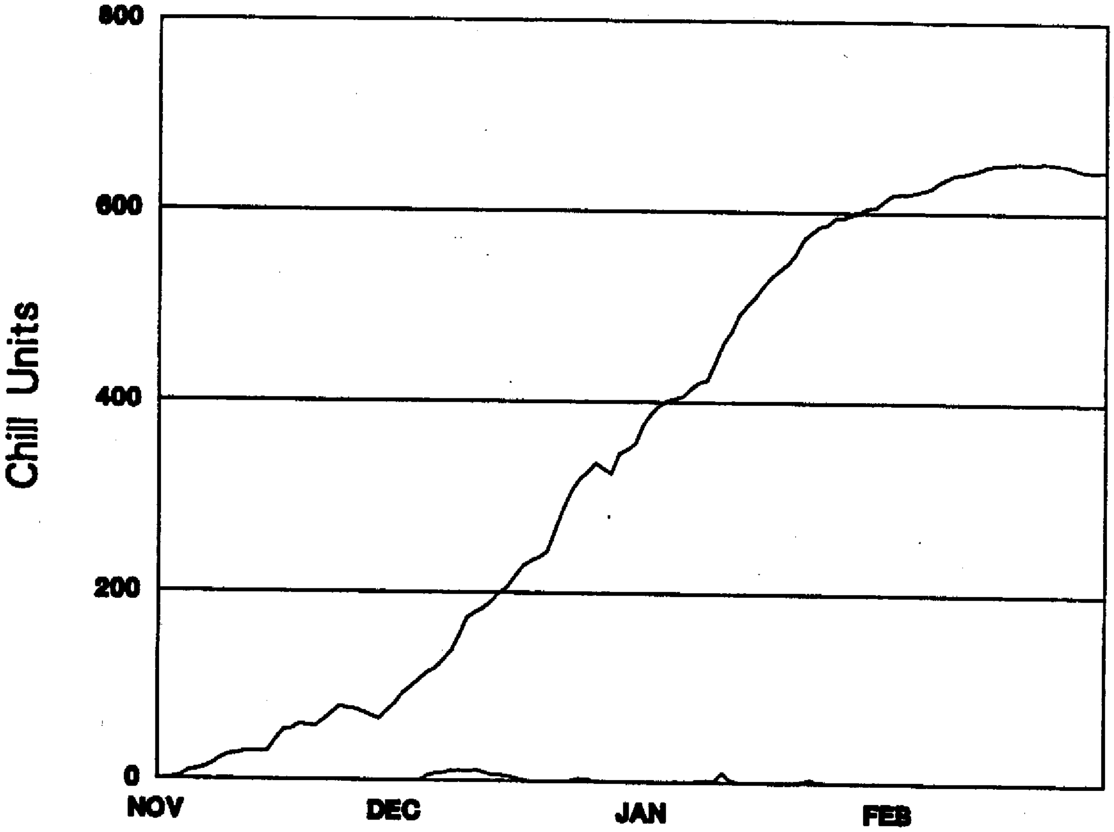

Fig.5. Accumulation patterns for a) A year with good chilling accumulation (1976-77) and b) A year with bad chilling accumulation (1981-82).

CHAPTER IV

CONCLUSIONS AND DISCUSSION

The bases for a variable chill unit system have been discussed by del Real-Laborde (1987c) and by del Real-Laborde et al.(1988b) and are described as follows:

1. Chilling is a sigmoidal process; therefore, a model that describes its development cannot be linear.

2. Plant response to temperature effects changes according to physiological time of application and length of exposure.

3. Temperature changes during the grand phase of the sigmoid accumulation have greater effects on dormancy release than those that occur at other times.

4. Exposure of seeds to non-optimal temperatures for 10% of the stratification time can reduce germination as much as 50-70% from that of the optimal isothermal treatment when applied during a critical period from 60-90% of the chilling accumulation.

5. Preconditioning during organ evolution affects chilling requirement.

The chill unit concept that is proposed is described in the following manner: one chill unit (CU) is equivalent to one hour at the optimal temperature during the optimal accumulation time. This model considers time-temperature interactions during dormancy release.

Two areas of research were performed. First some basic information on the behavior of resting organs was needed to substantiate the CU model. Based on the data collected previously (del Real-Laborde, 1987b), the presence of a critical period during chilling was postulated. This information needed to be confirmed using other species and different types of interruptions.

The second area of research was the elaboration of the model using the data collected at Arteaga, Coahuila, México, for testing and verification.

The chill unit model presented in this dissertation is more efficient in dormancy development evaluation under mild winter conditions in the subtropics than the chill unit model presented by Richardson et al. in 1974. This was tested with Mexican temperature and phenology data records.

The determination coefficient for regression between chill unit accumulation and leafing percentage was 0.74. This value, though higher than previous models, needs to be improved. Various factors that could improve this value include:

1. The model was derived from seed dormancy studies and needs to be adjusted with bud dormancy data.

2. The model was derived from studies that involved isothermal temperature treatments and isothermal interruption treatments. The effect of daily temperature

fluctuations was not evaluated in the model. Diurnal temperature cycles need to be studied and the results incorporated into the model.

3. Dormancy inception can account for different chilling requirements in different years. The model does not consider dormancy inception.

4. A variable that could evaluate depth of dormancy would make this model more efficient in the evaluation of dormancy development.

5. The duration of the chill unit accumulation fractions and the chill unit contribution at each fraction can be adjusted to accrue higher precision. This should be done after testing the model in field situations for leafing percentage prediction and scheduling of rest-breaking practices.

There is no correspondence between the values for chill completion under the old and the new chill unit models, the accumulations have to be calculated in the field for different species. Appendix B shows the daily and seasonal accumulation under both models for the winter of 1971-1972.

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APPENDIXES

Appendix A

Analyses of Variance of *Malus sargentii* Seed Pretreatment Experiment.

Emergence.

SOURCE	DF	SS	MS	F	P
CD	4	26199.87	6549.97	204.96	.0000
PD	4	1134.43	283.61	8.87	.0000
PT	3	64.15	21.38	.67	.6700
CD X PD	16	2112.48	132.03	4.13	.0000
CD X PT	2	686.59	57.22	1.79	.0518
PD X PT	12	494.56	41.21	1.29	.2266
CD X PD X PT	48	1503.93	31.33	.98	.5167
ERROR	200	6391.50	31.96		
DAYS	3	12547.41	4182.47	504.94	.0000
ERROR	6	49.70	8.28		
CD X D	12	2245.80	187.15	56.01	.0000
PD X D	12	96.90	8.08	2.42	.0045
PT X D	9	25.83	2.87	.86	.5610
CD X PD X D	48	727.46	15.16	4.54	.0000
CD X PT X D	36	334.28	9.29	2.78	.0000
PD X PT X D	36	170.24	4.73	1.42	.0558
CD X PD X PT X D	144	499.34	3.47	1.04	.3721
ERROR	594	1984.80	3.34		
TOTAL	1199	57269.26	47.76		

Leaf area.

SOURCE	DF	SS	MS	F	P
CD	4	2226.19	556.55	1.56	.1864
PD	4	2520.88	630.22	1.76	.1384
PT	3	2575.31	858.44	2.40	.0690
CD X PD	16	6385.66	399.10	1.12	.3384
CD X PT	12	8493.82	707.82	1.98	.0277
PD X PT	12	3148.16	262.35	0.73	.7211
CD X PD X PT	48	16488.10	343.50	0.96	.5524
ERROR	200	71510.48	357.55		
TOTAL	299	113348.62	379.09		

Mean shoot length.

SOURCE	DF	SS	MS	F	P
CD	4	187.82	46.95	35.57	.0000
PD	4	6.01	1.50	1.14	.0339
PT	3	16.51	5.50	4.17	.0068
CD X PD	16	75.38	4.71	3.57	.0000
CD X PT	12	46.23	3.85	2.92	.0009
PD X PT	12	27.29	2.27	1.72	.0647
CD X PD X PT	48	53.17	1.11	0.84	.7596
ERROR	200	264.47	1.32		
TOTAL	299	676.90	2.26		

Mean internode length.

SOURCE	DF	SS	MS	F	P
CD	4	31.41	0.78	1.16	.3297
PD	4	17.85	0.45	0.67	.6135
PT	3	0.87	0.29	0.43	.7317
CD X PD	16	48.17	3.01	4.49	.0000
CD X PT	12	24.98	2.08	3.10	.0004
PD X PT	12	10.21	0.85	1.27	.0239
CD X PD X PT	48	43.03	0.90	1.34	.0855
ERROR	200	133.81	0.67		
TOTAL	299	310.34	1.04		

Root/shoot ratio.

SOURCE	DF	SS	MS	F	P
CD	4	2.39	0.60	2.68	.0329
PD	4	1.47	0.37	1.64	.1656
PT	3	2.16	0.72	3.23	.0234
CD X PD	16	6.21	0.39	1.74	.0419
CD X PT	12	2.79	0.23	1.04	.4137
PD X PT	12	1.88	0.16	0.70	.7505
CD X PD X PT	48	7.94	0.16	0.74	.8914
ERROR	200	44.66	0.22		
TOTAL	299	69.50	0.23		

Appendix B

Comparison of the Chill Unit Model of Richardson et al. and the New Chill Unit Model.

Season 1971-1972.

	Richardson chill units		New Model chill units	
Date	Daily total	Season total	Daily total	Season total
01/11/71	-2.50	0.00	-7.54	0.00
02/11/71	-2.50	0.00	-7.33	0.00
03/11/71	0.00	0.00	-3.90	0.00
04/11/71	-4.00	0.00	-7.47	0.00
05/11/71	1.00	1.00	-2.85	0.00
06/11/71	2.50	3.50	-2.03	0.00
07/11/71	-1.50	2.00	-5.73	0.00
08/11/71	1.50	3.50	-0.88	0.00
09/11/71	3.50	7.00	-2.95	0.00
10/11/71	5.50	12.50	1.38	1.38
11/11/71	1.00	13.50	-1.61	0.00
12/11/71	4.00	17.50	-0.20	0.00
13/11/71	4.00	21.50	-2.31	0.00
14/11/71	5.00	26.50	-1.91	0.00
15/11/71	5.50	32.00	0.85	0.85
16/11/71	5.50	37.50	0.81	1.66
17/11/71	0.50	38.00	-4.34	0.00
18/11/71	4.00	42.00	-1.31	0.00
19/11/71	4.50	46.50	-0.05	0.00
20/11/71	4.50	51.00	-0.78	0.00
21/11/71	3.50	54.50	-1.36	0.00
22/11/71	5.50	60.00	0.16	0.16
23/11/71	5.50	65.50	0.84	1.00
24/11/71	4.50	70.00	-1.71	0.00
25/11/71	3.50	73.50	0.14	0.14
26/11/71	5.50	79.00	0.79	0.94
27/11/71	8.00	87.00	1.60	2.53
28/11/71	1.50	88.50	-1.37	1.16
29/11/71	1.50	90.00	-2.63	0.00
30/11/71	4.00	94.00	-0.92	0.00
01/12/71	1.50	95.50	-1.55	0.00
02/12/71	6.00	101.50	0.12	0.12
03/12/71	5.00	106.50	0.20	0.32
04/12/71	0.50	107.00	-1.81	0.00
05/12/71	7.50	114.50	2.31	2.31
06/12/71	4.00	118.50	0.23	2.54
07/12/71	7.00	125.50	0.93	3.47

08/12/71	9.00	134.50	1.59	5.06
09/12/71	10.00	144.50	2.13	7.19
10/12/71	11.50	156.00	2.38	9.57
11/12/71	6.00	162.00	1.40	10.97
12/12/71	9.00	171.00	2.89	13.86
13/12/71	5.50	176.50	-0.75	13.11
14/12/71	7.00	183.50	0.74	13.84
15/12/71	6.00	189.50	0.61	14.46
16/12/71	6.50	196.00	-0.01	14.45
17/12/71	15.50	211.50	6.35	20.80
18/12/71	12.00	223.50	4.27	25.07
19/12/71	12.50	236.00	3.07	28.15
20/12/71	2.50	238.50	-1.13	27.02
21/12/71	2.50	241.00	-0.51	26.51
22/12/71	2.00	243.00	-1.98	24.54
23/12/71	0.50	243.50	-3.43	21.11
24/12/71	2.00	245.50	-1.77	19.34
25/12/71	9.00	254.50	1.15	20.48
26/12/71	7.00	261.50	0.78	21.27
27/12/71	5.50	267.00	-0.63	20.64
28/12/71	8.00	275.00	2.25	22.88
29/12/71	5.50	280.50	-0.88	22.00
30/12/71	6.50	287.00	0.13	22.13
31/12/71	12.50	299.50	4.52	26.66
01/01/72	8.50	308.00	1.12	27.77
02/01/72	13.00	321.00	3.38	31.16
03/01/72	1.50	322.50	-4.50	26.66
04/01/72	15.00	337.50	6.10	32.75
05/01/72	7.00	344.50	1.48	34.23
06/01/72	4.00	348.50	0.04	34.27
07/01/72	20.50	369.00	9.61	43.88
08/01/72	9.00	378.00	1.81	45.69
09/01/72	4.00	382.00	-0.55	45.14
10/01/72	5.50	387.50	0.95	46.09
11/01/72	4.00	391.50	0.01	46.10
12/01/72	7.00	398.50	1.33	47.43
13/01/72	3.00	401.50	-1.77	45.66
14/01/72	4.00	405.50	0.04	45.70
15/01/72	14.00	419.50	5.46	51.16
16/01/72	23.50	443.00	12.27	63.43
17/01/72	20.00	463.00	9.93	73.36
18/01/72	18.00	481.00	10.48	83.84
19/01/72	15.50	496.50	7.34	91.18
20/01/72	8.50	505.00	4.85	96.03
21/01/72	9.00	514.00	5.78	101.82
22/01/72	3.50	517.50	3.93	105.75
23/01/72	9.00	526.50	4.35	110.10
24/01/72	5.50	532.00	2.52	112.62
25/01/72	2.00	534.00	-1.37	111.25
26/01/72	5.00	539.00	1.55	112.79
27/01/72	8.50	547.50	4.55	117.34
28/01/72	4.50	552.00	3.06	120.41

29/01/72	9.50	561.50	5.53	125.94
30/01/72	6.00	567.50	0.19	126.12
31/01/72	12.50	580.00	6.72	132.85
01/02/72	12.50	592.50	8.58	141.42
02/02/72	4.50	597.00	4.79	146.21
03/02/72	16.00	613.00	17.10	163.31
04/02/72	22.00	635.00	21.28	184.59
05/02/72	7.50	642.50	8.62	193.22
06/02/72	5.00	647.50	6.30	199.52
07/02/72	2.50	650.00	3.69	203.20
08/02/72	6.00	656.00	3.79	207.00
09/02/72	6.50	662.50	7.23	214.23
10/02/72	13.00	675.50	9.61	223.84
11/02/72	1.00	676.50	3.48	227.31
12/02/72	12.50	689.00	9.71	237.02
13/02/72	14.50	703.50	10.70	247.72
14/02/72	12.00	715.50	10.70	258.43
15/02/72	12.00	727.50	15.77	274.20
16/02/72	7.50	735.00	6.69	280.89
17/02/72	6.50	741.50	6.30	287.19
18/02/72	3.00	744.50	4.47	291.66
19/02/72	3.50	748.00	2.56	294.21
20/02/72	3.00	751.00	4.19	298.41
21/02/72	-0.50	750.50	0.05	298.45
22/02/72	0.50	751.00	0.46	298.92
23/02/72	3.50	754.50	-1.43	297.48
24/02/72	3.00	757.50	-3.62	293.87
25/02/72	2.00	759.50	-4.10	289.77
26/02/72	2.50	762.00	-2.69	287.07
27/02/72	1.50	763.50	1.54	288.61
28/02/72	7.50	771.00	2.96	291.57
29/02/72	4.00	775.00	1.69	293.26
01/03/72	3.00	778.00	2.65	295.91
02/03/72	0.50	778.50	1.68	297.59
03/03/72	4.50	783.00	1.68	299.27
04/03/72	3.00	786.00	-2.61	296.66
05/03/72	3.00	789.00	-2.97	293.69
06/03/72	3.50	792.50	-1.12	292.57
07/03/72	0.50	793.00	-4.98	287.59
08/03/72	4.00	797.00	-1.19	286.40
09/03/72	2.50	799.50	-2.54	283.86
10/03/72	9.50	809.00	5.34	289.20
11/03/72	8.50	817.50	4.45	293.64
12/03/72	7.50	825.00	3.71	297.35
13/03/72	11.50	836.50	6.91	304.26
14/03/72	2.00	838.50	2.24	306.50
15/03/72	5.50	844.00	0.35	306.85
16/03/72	6.00	850.00	3.71	310.56
17/03/72	7.50	857.50	5.59	316.15
18/03/72	7.50	865.00	3.31	319.47
19/03/72	15.00	880.00	11.04	330.51
20/03/72	4.00	884.00	-0.67	329.84

21/03/72	3.00	887.00	-3.40	326.44
22/03/72	3.50	890.50	-1.76	324.68
23/03/72	4.00	894.50	-0.42	324.27
24/03/72	3.50	898.00	1.04	325.31
25/03/72	4.50	902.50	-0.47	324.84
26/03/72	3.50	906.00	-1.87	322.97
27/03/72	2.00	908.00	-2.10	320.87
28/03/72	3.50	911.50	-1.75	319.12
29/03/72	3.50	915.00	-2.00	317.12
30/03/72	3.00	918.00	-2.55	314.57
31/03/72	9.50	927.50	6.20	320.77

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Awards and Society Memberships and Positions

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  Plant Science Department Representative to the Graduate Student Association. 1987-1989.
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  Graduate Senator 1988-1989.
  Graduate School Honor Roll.
  National Dean's List. 1989.
International Society for Horticultural Science.
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  Mexican Representative to the International Council. 1982.
  Invited speaker at the Symposium "Producing Temperate Zone Fruit Trees at Low Latitudes". XXII International Congress, Davis, Cal. 1986.
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  Author of the paper "Basis for a variable chill unit system for dormancy evaluation". First Place in the Student Paper ASHS-Western Region. 1988.
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  Author of the paper "Basis for a variable chill unit system for dormancy evaluation", winner of the "Laurence M. Klauber" Division Wide Award for Excellence given by the Pacific Division of AAAS. 1988.
Sociedad Mexicana de Ciencias Hortícolas.
  Member since 1986.
Inter-American Society for Tropical Horticulture.
  Member since 1987.

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