The Influence of Chilling and Heat Accumulation on Nonpareil and Mission Bloom Timing and Length and Crop Yield

Project No.: **10-HORT17-Covert/Pedersen**

Project Leaders:
Melanie M. Covert
2600 Park Meadows Dr. #A207
Bakersfield CA 93308
(925) 788-9347
mcovert@calpoly.edu

Mary Pedersen
California State Polytechnic University
Building 11-211
One Grand Avenue
San Luis Obispo, CA 93401
(805) 756-2161
mpederse@calpoly.edu

Project Cooperators and Personnel:
Lauren Garner, Jeffrey Wong and Steven Rein, Cal Poly Professors:
Joseph Connell, Farm Advisor, UCCE - Butte County.

Objectives:

1. Evaluate correlations between temperature patterns prior to bloom and bloom timing.
2. Evaluate correlations between temperature patterns during bloom and bloom length.
3. Evaluate correlations between temperature patterns during bloom, bloom length and corresponding yields.

Interpretative Summary:

Melanie Covert was an Almond Board sponsored UC Pomology Farm Advisor intern during the 2010 season. This is a report of her masters thesis work at Cal Poly, San Luis Obispo, which was also supported by the ABC.

Year-to-year variations in crop production have been linked to weather conditions before and during almond bloom. Before blooming in the spring, trees must receive adequate chilling and heat accumulation to progress from dormant to growing stages. Research has shown that temperatures during pollen shed affect pollen tube growth and the effective pollination period. Therefore, a greater understanding of the

temperature factors influencing bloom timing, bloom length and crop yields would benefit growers.

Data for this study was taken from the 1996-2006 Regional Almond Variety Trials (RAVT) located in Butte, San Joaquin and Kern Counties. Information on site (Butte, San Joaquin or Kern Co.), variety (Nonpareil and Mission), year (1996-2006), date of 10% bloom, date of 90% bloom and yield (lbs/tree) were collected from these reports. These data were compared with temperature data taken from the California Irrigation Management Information System (CIMIS) website. Temperatures were calculated into Chilling Hours (CH), Utah Chilling Units (CU), Chilling Portions (CP) and Growing Degree Hours (GDH°).

Objective 1: Temperature Patterns Prior to Bloom and Bloom Timing

Five models were used to predict the date of 90% bloom from 1996-2006 in Nonpareil and Mission at each RAVT location.

- Calendar Model: The average date of 90% bloom for each year, site and variety was used to predict the actual date of 90% bloom.
- Chill Models: The dates that Nonpareil and Mission reached their chilling requirement using the CH, CU and CP models were determined for each year and site (**Table 1**). GDH° were then summed from this date until the date of 90% bloom for each year, variety and site. The average amount of GDH° between chill date and the date of 90% bloom (for each site and variety) was used as a threshold to predict the date of 90% bloom at a given site in a given year according to when that GDH° threshold amount was achieved.
- Heat Model: The average GDH° for each year were summed from January 1st until the date of 90% bloom for each variety and site. The average GDH° for each site and variety was then used as a threshold to predict the date of 90% bloom.

Key findings for bloom timing were that the Calendar Model was found to have the smallest average errors in predicting 90% bloom dates in Nonpareil and Mission. There was no significant difference in average error between the Calendar and the CP model for predicting 90% bloom in Nonpareil. There was no significant difference in average error between the Calendar and CU models when predicting 90% bloom in Mission. Of the temperature models, the CP model performed best for predicting 90% Nonpareil bloom while the CU model performed best for predicting 90% Mission bloom.

Objective 2: Bloom Length and GDH° during Bloom

The total accumulated GDH° during bloom (from 10% bloom date to 90% bloom date) for each year and site was calculated. GDH° during bloom was correlated with the length of bloom (number of days between 10% bloom date and 90% bloom date for each year and site).

Key findings were that bloom length was found to be positively correlated with accumulated heat during bloom in both varieties. Bloom length was longest at the Kern site for Nonpareil.

Objective 3: Yield, Bloom Length and GDH° During Bloom

Total GDH° during bloom was correlated with yield (averaged pounds per tree) for each year and site, while controlling for worm damage in Nonpareil. Worm damage was omitted in Mission due to missing values for some years. Length of bloom in days and yield were correlated. GDH° during the first four days of bloom and yield (averaged pounds per tree) were correlated as well.

Key findings were that GDH° during the first four days of bloom was significantly related to yield in Nonpareil, with each additional GDH° associated with a 0.4 pound per tree increase in yields. Bloom length was not significantly correlated with yield in either variety. No significant relationship was found between temperatures during bloom or bloom length and yield in Mission.

The larger errors found with the ability of the CH, CU and CP models to predict the actual date of 90% bloom may be attributed to the fact that growth and rest stages in almonds involve a variety of factors and not yet fully understood. Future studies on the accuracy of different chilling models are needed and will contribute to a greater understanding of the temperature patterns leading up to and influencing almond bloom timing. Additional research under controlled conditions is needed to further correlate temperature patterns during bloom and effective nut set.

Crop yields are another complicated matter involving growing conditions during the entire current season, the previous growing season and sometimes reaching as far back as the beginning of a tree's life. Although temperatures during bloom and bloom length may indicate a good start to the season, they are just a portion of the complete process from bud break to harvest.

Materials and Methods:

Data for this study were taken from the University of California Cooperative Extension Regional Almond Variety Trials (RAVT) (Lampinen et al., 2002). The RAVT were planted in Butte County at the CSU Chico farm, in San Joaquin County at the Delta College farm, and in Kern County at a Paramount Farming Co. orchard south of Shafter, CA. The trials included tree data from many almond cultivars, but only data from Nonpareil and Mission were used for this study due to their commercial popularity. The orchards were planted in 1993 and came into bearing in 1996, therefore data for this study include the years 1996 to project completion in 2006 (Lampinen, et al., 2002).

Nonpareil and Mission Data

Bloom data on Nonpareil and Mission were used from the three RAVT. Farm advisors in each county made observations on bloom progression at two to three day intervals and data were estimated as the percentage of open flowers on tree varieties across one row of trees (i.e. 10% is equal to 10% of the flowers on trees across the entire being open on that date). Data include dates that trees reached 10% and 90% bloom for all three sites. The date of 90% bloom was used to define bloom timing to ensure the greatest amount of consistency in observations across the three sites. The length of bloom progression for each cultivar in the trial was represented as the number of days between 10% bloom and 90% bloom. Yield data used were in pounds per tree (Lampinen et al., 2002).

Weather Data

Temperatures for all eleven years were gathered from the CIMIS (California Irrigation Management Information System) website (cimis.water.ca.gov/cimis/data.jsp) using weather stations nearest to each of the experimental orchards: Durham #12 (Butte), Manteca #70 (San Joaquin) and Shafter #5 (Kern). Temperatures were converted via R project software (r-project.org) into Chilling Units (CU), Chilling Hours (CH), Chilling Portions (CP) and Growing Degree Hours (GDH°).

Objective 1:Bloom Timing

- Calendar Model: the average date of 90% bloom for each year, site and variety was used to predict the actual date of 90% bloom. Nonpareil and Mission 90% bloom dates at the Butte, San Joaquin and Kern County sites were collected by year from the Regional Almond Variety Trial reports located online on the UC Davis Fruit and Nut Research and Information Center website. These dates were averaged by site and variety and used to predict the actual date of 90% bloom from 1996-2006. For each predicted date, the standard error in prediction (days off the actual date of 90% bloom) was determined.

- Chill Hour Model: Chill Hours (CH) were calculated as follows (Bradley and Maurer, 2002):

$$CH = \sum_{i-1}^{t} T_{45F,} with\ T_{45F} = \begin{cases} 32F < T < 45F & : 1 \\ else & : 0 \end{cases}$$

$$CU = \sum_{i-1}^{t} T_{CU}, \text{ with } T_{CU} = \begin{cases} T \leq \mathbf{34°F} & : 0.0 \\ 35°F < T \leq 36°F & : 0.5 \\ 37°F < T \leq 48°F & : 1.0 \\ 49°F < T \leq 54°F & : 0.5 \\ 55°F < T \leq 60°F & : 0.0 \\ 61°F < T \leq 65°F & : 0.5 \\ T > 65°F & : -1.0 \end{cases} \qquad \text{(Equation 1)}$$

- Utah Chill Unit Model: Utah Chill Units (CU) are the summation of weighted hourly temperatures between 34 and 65°F (Richardson, 1974), beginning on November 1st of each year. CU at time T (in hours) are calculated as follows:

  CU= $\sum_{i-1}^{t} T_{CU}$, with T_{CU}

$$= \begin{cases} T \leq \mathbf{34°F} & : 0.0 \\ 35°F < T \leq 36°F & : 0.5 \\ 37°F < T \leq 48°F & : 1.0 \\ 49°F < T \leq 54°F & : 0.5 \\ 55°F < T \leq 60°F & : 0.0 \\ 61°F < T \leq 65°F & : 0.5 \\ T > 65°F & : -1.0 \end{cases} \qquad \text{(Equation 2)}$$

- Dynamic Chill Portion Model: Chill Portions (CP) were calculated using the downloadable Microsoft® Excel file available through the UC Davis Fruit and Nut Center website. Hourly CIMIS weather data for from November 1st until January 31st were downloaded for the years 1996-2006 at following stations: Durham #12 (Butte), Manteca #70 (San Joaquin) and Shafter #5 (Kern). These data were imported into the Dynamic Model Microsoft® Excel file, which automatically calculated the CP when the CP formula was applied to new data.

The formula used for calculating CP is as follows:

$$x_i = \frac{e\ slp \bullet tetmlt\ \frac{t_K - tetmlt}{T_K}}{1 + e\ slp \bullet tetmlt^{\wedge}\ \frac{t_K - tetmlt}{T_K}}$$

$$x_S = (a_0 / a_1) \bullet e^{\frac{e1-e0}{T_k}}$$

$$ak_1 = a_1 \bullet e^{-\frac{e1-e0}{T_k}}$$

$$inter_E = x_S - (x_S - inter_S) \bullet e^{-ak_1}$$

$$inter_S = \begin{cases} t = t_0 & : 0 \\ t > t_0 \wedge inter_{E_{t-1}} \quad < 1 & : inter_{E_{t-1}} \\ t < t_0 \wedge inter_{E_{t-1}} \quad \geq 1 & : inter_{E_{t-1}} \cdot 1 - x_i \end{cases}$$

$$delt = \begin{cases} t = t_0 & : 0 \\ t > t_0 \wedge inter_E < 1 & : 0 \\ t < t_0 \wedge inter_E \geq 1 & : x_i \cdot inter_E \end{cases}$$

$$CP = \begin{cases} t - t_0 & : delt \\ t > t_0 \quad < 1 & : delt + CP_{t-1} \end{cases} \qquad \text{(Equation 3)}$$

e_0= 4.15E +03
e_1= 1.29E +04
a_0= 1.4E +05

a_1= 2.57E +18
slp = 1.6
tetmlt = 277
aa= a_0/a_1 = 5.43E -14
ee= e_1-e_0 = 8.74E +03
t = time

The equation constants used were originated from horticultural standards used in field experimentation (Luedeling et al., 2011; Fishman et al., 1987a; Glozer & Grant, 2005).

For each of the chilling models (CH, CU and CP), November 1st was the date corresponding to the start of chilling accumulation. CH, CU and CP were accumulated until the date the trees reached their CH, CU or CP requirement. The CH requirements used for Nonpareil and Mission were 400 and 500 CH, respectively (**Table 1**) (Bradley & Maurer, 2002). The CU requirements used for Nonpareil and Mission were 300 and 320 CU, respectively (**Table 1**) (Kester et al., 1973; Alonso, 2005). The CP requirements used for Nonpareil and Mission were 30 and 38, respectively (**Table 1**) (Luedeling et al. 2011).

The dates at which each variety reached its chilling requirement using the respective model were used as the end dates of chilling accumulation (designated chill date) and the dates at which to begin accumulating GDH°, for each site, year and variety. GDH° calculation is further explained in the next section. The average amount of GDH° between the chill date and the date of 90% bloom at each site was then used as a threshold to predict the date of 90% bloom at a given site in a given year according to when that GDH° threshold was achieved. For each predicted date, the standard error in prediction (days off the actual date of 90% bloom) was determined.

Table 1. Calculated chill requirements for Nonpareil and Mission in the form of Chill Hours (CH), Chill Units (CU) and Chill Portions (CP)

Variety	CH	CU	CP
Nonpareil	400	300	30
Mission	500	320	38

- Heat Model: Growing Degree Hours **(**GDH°) were calculated as one degree above a base threshold temperature (T_{BASE}) for one hour (Equation 2). When the base temperature is below the hourly minimum temperature (T_{HOUR}), the base temperature is subtracted from the minimum temperature to determine GDH° accumulation. When the base temperature is above the maximum hourly reading, no GDH° are accumulated (Snyder, 1985). Base temperature and upper threshold temperatures used were 41 and 50°F, respectively (Tombesi et al., 2010).

$$GDH° = (T_{HOUR} - T_{BASE}) \qquad \text{(Equation 4)}$$

Temperatures were sourced via CIMIS and GDH° calculated using R statistical software and summed over a 24 hour period from January 1st until the date of 90% bloom for each variety, site and year. The average amount of GDH° between January 1st and the date of 90% bloom at each site was then used as a threshold to predict the date of 90% bloom at a given site in a given year according to when that GDH° threshold was achieved. For each predicted date, the standard error in prediction (days off the actual date of 90% bloom) was determined.

Objective 2: Bloom Length and GDH° During Bloom

The total accumulated GDH° during bloom (from 10% bloom date to 90% bloom date) for each year and site was calculated. GDH° during bloom was correlated with the length of bloom (number of days beginning on the 10% bloom date and ending on the 90% bloom date for each year and site).

Objective 3: Yield, Bloom Length and GDH° During Bloom

Total GDH° during bloom was correlated with yield (averaged pounds per tree) for each year and site, while controlling for worm damage in Nonpareil. Worm damage was omitted in Mission due to missing values for some years. Length of bloom and yield were correlated. GDH° during the first four days of bloom and yield (averaged pounds per tree) were correlated as well. Statistical analysis was made using the Student's paired t-test.

Results and Discussion:

Objective 1: Temperature Patterns Prior to Bloom and Bloom Timing

Average dates of 90% bloom were fairly similar across sites with Butte being the earliest and Kern the latest to reach 90% bloom for both Mission and Nonpareil (**Tables 2&3; Figures 1&2**). The northern portion of the Sacramento Valley, including Butte County, is above the Tule fog area. The lack of fog reduces air insulation and exposes orchards to greater amounts of cold temperatures, thus allowing them to complete their chill requirement earlier and bloom earlier (Doll, 2010).

Kern County 90% bloom dates were later in the spring for both varieties with an average of February 28th for Nonpareil and March 9th for Mission. Average Butte and San Joaquin 90% bloom dates occurred earlier than Kern for both varieties. Mean 90% bloom dates were very close for Butte and San Joaquin County for both varieties, occurring within a three day span for Nonpareil and within a seven day span for Mission (**Tables 2&3; Figures 1&2**). Actual bloom start date (10% bloom) averaged 5 to 15 days before corresponding 90% bloom dates for both varieties.

Table 2. Mean dates of 90% bloom for Nonpareil by location, (+/- s.d.)

Site	Mean	(± s.d.)
Butte	25-Feb	±5.8
San Joaquin	23-Feb	±5.5
Kern	28-Feb	±5.1

Table 3. Mean dates of 90% bloom for Mission by location, (+/- s.d.)

Site	Mean	(± s.d.)
Butte	2-Mar	±5.4
San Joaquin	4-Mar	±6.1
Kern	9-Mar	±5.3

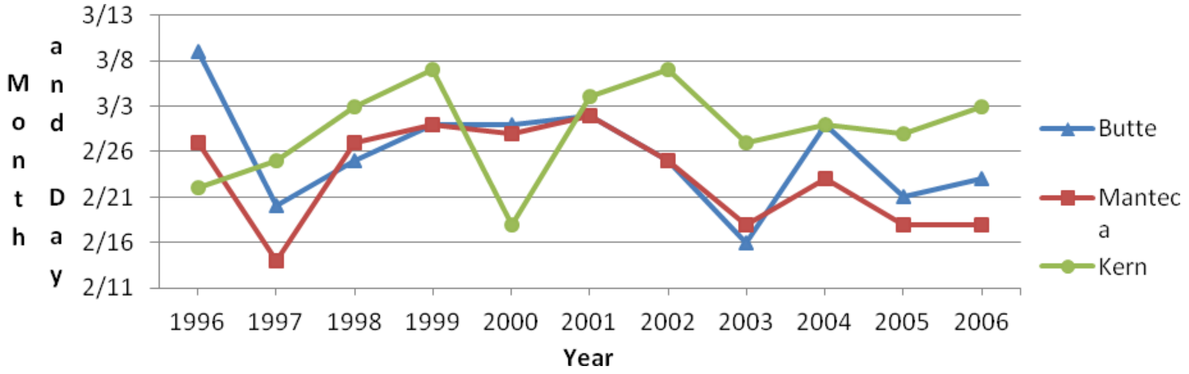

Figure 1. Observed yearly dates of 90% bloom in Nonpareil for Butte, Manteca (San Joaquin) and Kern County locations.

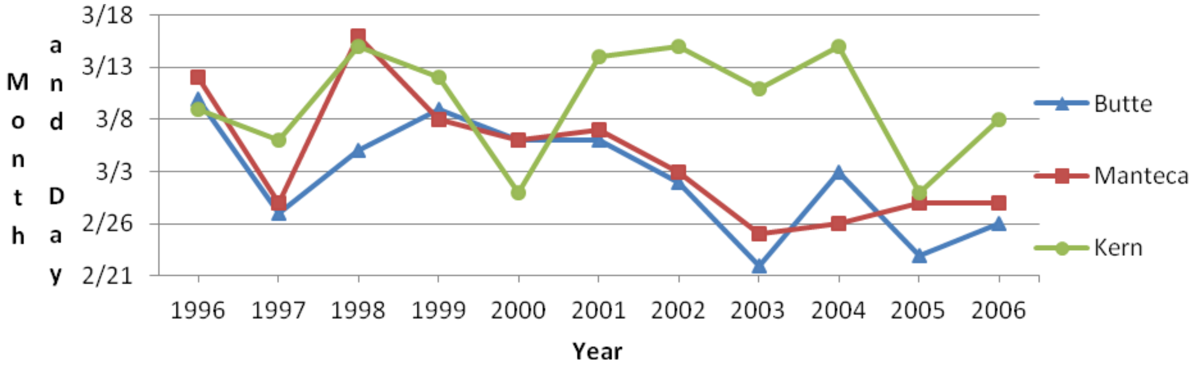

Figure 2. Observed yearly dates of 90% bloom in Mission for Butte, Manteca (San Joaquin) and Kern Counties.

Table 4. Mean standard errors from comparing the capacity of the Calendar model vs. CH, CU, CP and Heat Models to accurately predict the date of 90% bloom in **Nonpareil** for the years 1996-2006 in Butte, San Joaquin and Kern Counties.

Model	t-statistic	p-value
Calendar vs. CH	2.891	0.003
Calendar vs. CU	2.675	0.006
Calendar vs. CP	1.278	0.105
Calendar vs. Heat	4.332	<0.001

Table 5. Mean standard errors from comparing the capacity of the CH vs. CP and the CU vs CP models to accurately predict the date of 90% bloom in **Nonpareil** for the years 1996-2006 in Butte, San Joaquin and Kern Counties.

Model	t-statistic	p-value
CH vs. CP	1.838	0.038
CU vs. CP	0.630	0.267

When comparing the Calendar model to each CH, CU and CP and to the Heat model, the Calendar model had the smallest average errors in predicting the actual date of 90% bloom in Nonpareil and Mission (**Table 4&6**). Average error in prediction was not significantly different between the Calendar and CP models in Nonpareil, and not significantly different between the Calendar and CU models in Mission. There was no significant difference in average errors between CU and CP for either variety (**Tables 5&7**). The Heat model consistently had the largest errors in prediction compared to the Calendar model **(Tables 4&6**).

Table 6. Mean standard errors from comparing the capacity of the Calendar Model vs. CH, CU, CP and Heat Models, and CP vs. CH, CP Models to accurately predict the date of 90% bloom in **Mission** for the years 1996-2006 in Butte, San Joaquin and Kern Counties.

Model	t-statistic	p-value
Calendar vs. CH	2.589	0.007
Calendar vs. CU	1.231	0.095
Calendar vs. CP	1.712	0.048
Calendar vs. Heat	3.648	<0.001

Table 7. Mean standard errors from comparing the capacity of the CH vs. CP and the CU vs. CP Models to accurately predict the date of 90% bloom in **Mission** for the years 1996-2006 in Butte, San Joaquin and Kern Counties.

Model	t-statistic	p-value
CH vs. CP	1.161	0.254
CU vs. CP	-.0724	0.474

The fact that the CU and CP models were more accurate than CH in predicting 90% bloom may be attributed to issues that frequently arise with the CH model when temperatures below 45°F alternate with temperatures above 45°F, resulting in a cancelling effect that is unaccounted for in the chilling hour model (Glozer & Grant, 2005). This cancelling effect commonly occurs in warm climates, such as California. The CU and CP models both include calculated controls for this cancelling effect (Luedeling et al., 2009). Graphs are included below to better illustrate the range of each model's predicted 90% bloom dates by site and variety (**Figures 3-8**).

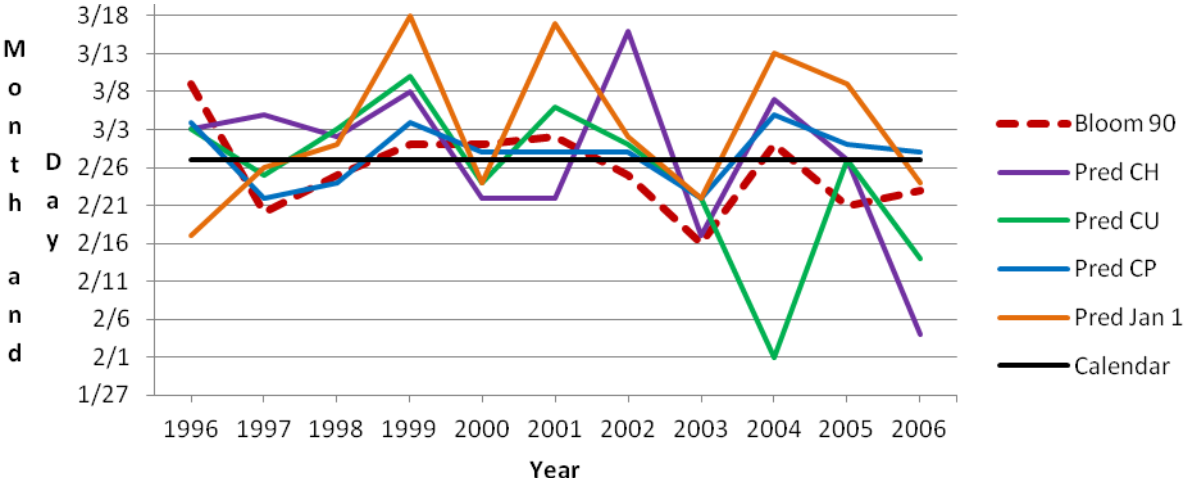

Figure 3. Butte County predicted dates of 90% Nonpareil bloom (Bloom 90) using the CH, CU, CP, Calendar and Heat models compared with the actual dates of 90% bloom

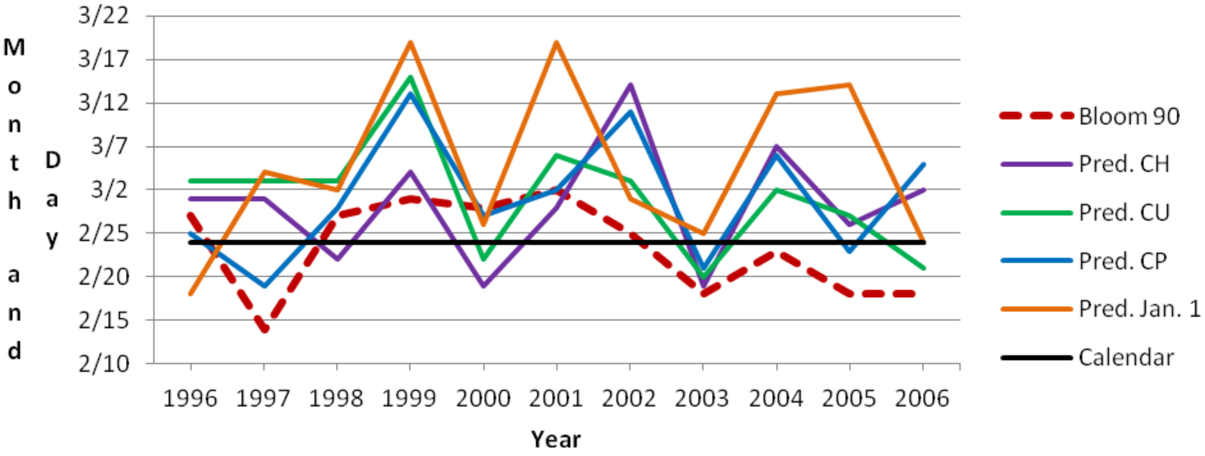

Figure 4. San Joaquin County predicted dates of 90% Nonpareil bloom (Bloom 90) using the CH, CU, CP, Calendar and Heat models compared with the actual dates of 90% bloom

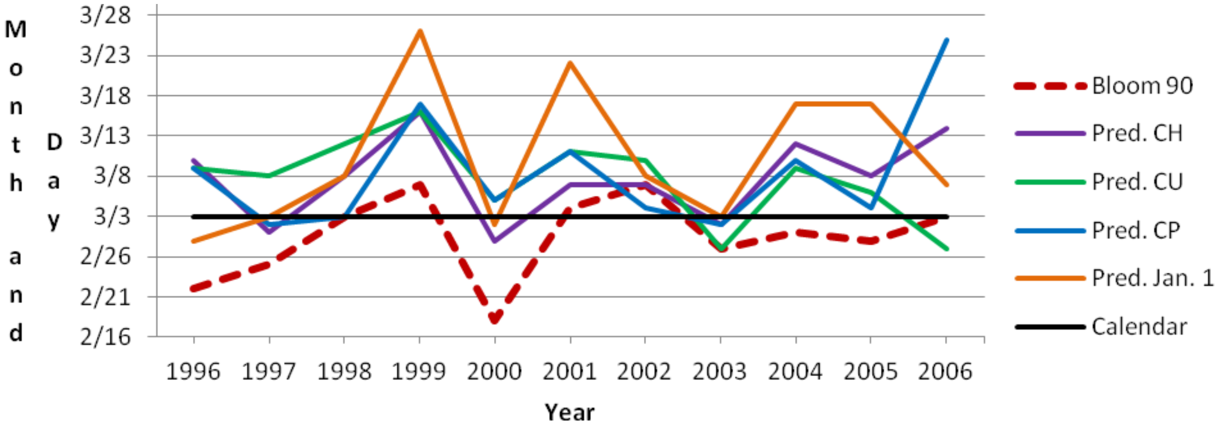

Figure 5. Kern County predicted and actual dates of 90% Nonpareil bloom (Bloom 90) using the CP, CH and CU Models.

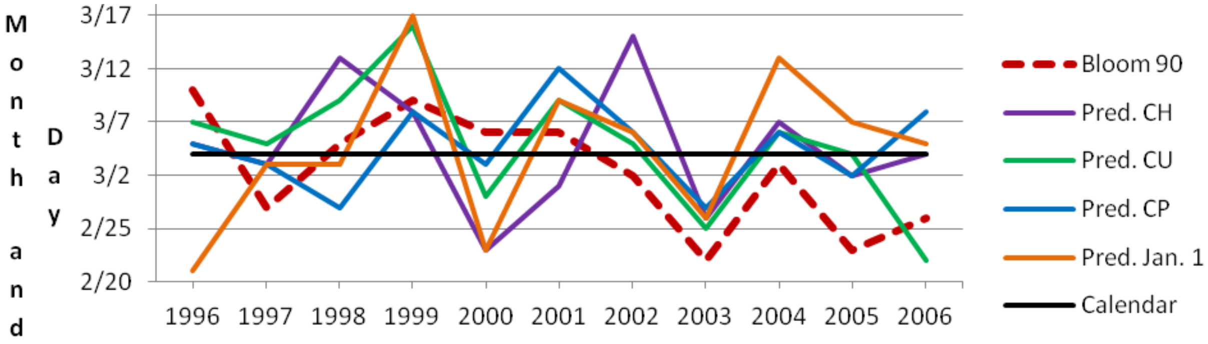

Figure 6. Butte County predicted dates of 90% Mission bloom (Bloom 90) using the CH, CU, CP, Calendar and Heat models compared with the actual dates of 90% bloom

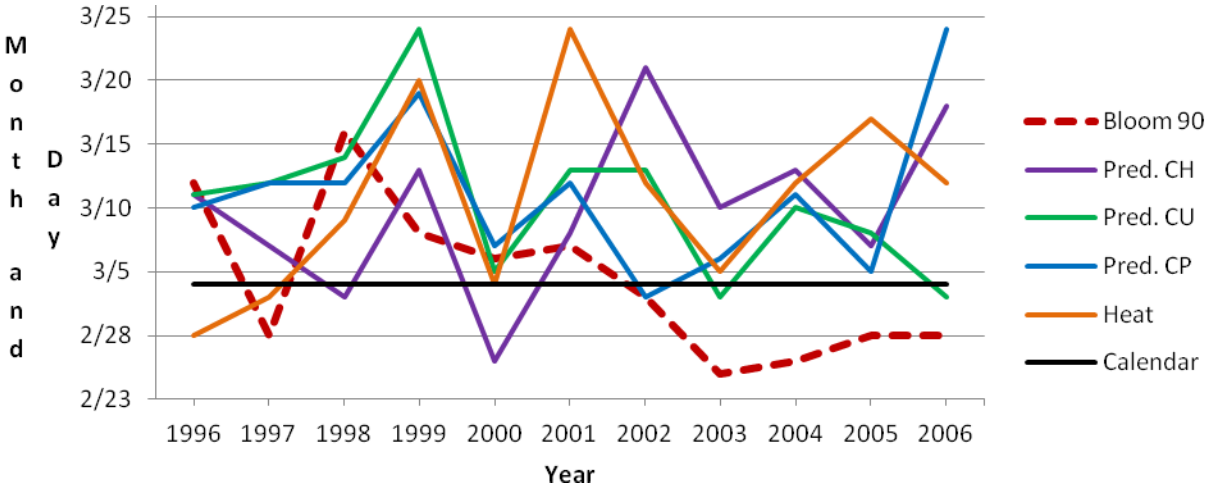

Figure 7. San Joaquin County predicted dates of 90% Mission bloom (Bloom 90) using the CH, CU, CP, Calendar and Heat models compared with the actual dates of 90% bloom.

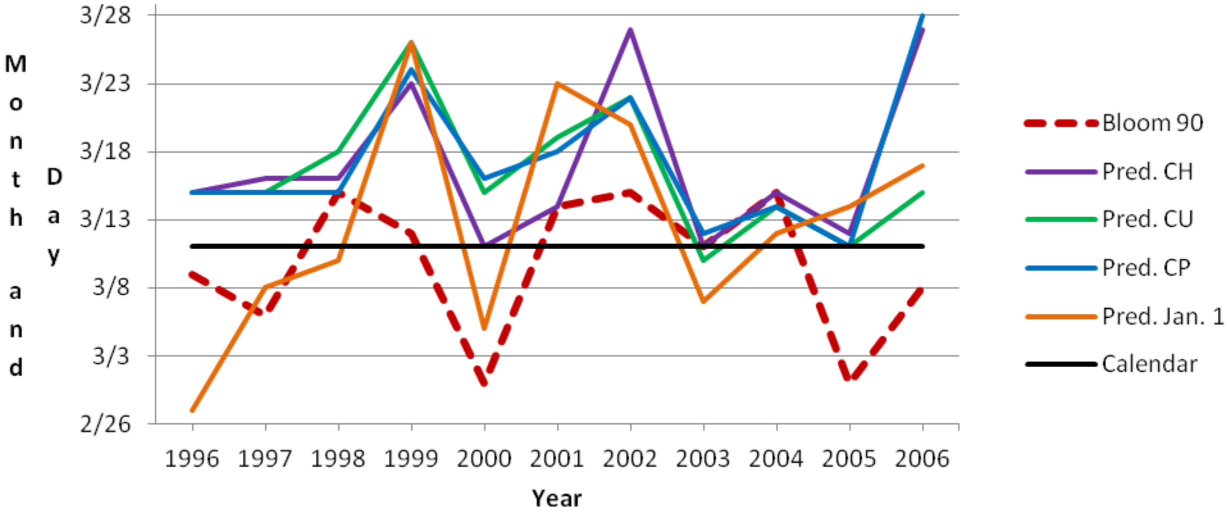

Figure 8. Kern County predicted dates of 90% Mission bloom (Bloom 90) using the CH, CU, CP, Calendar and Heat models compared with the actual dates of 90% bloom

Objective 2: Bloom Length and GDH° During Bloom

There was a positive correlation between total accumulated GDH during bloom and bloom length in days for both Nonpareil and Mission (**Figures 9 & 10**) However, when looking at the average GDH° per day (total GDH° during bloom divided by the number of days of bloom), there was no determinable relationship between bloom length and GDH during bloom for either variety. When looking at Nonpareil bloom length by site, the Kern site had a longer bloom length on average than either the Butte or San Joaquin County sites (**Tables 8 & 9**).

Table 8. Mean Nonpareil bloom length in days by County, (+/- s.d.)

Site	Mean	(± s.d.)
Butte	9	±4.3
San Joaquin	7	±2.2
Kern	15	±5.1

Table 9. Mean Mission bloom length in days by County, (+/- s.d.)

Site	Mean	(± s.d.)
Butte	6	±1.9
San Joaquin	9	±3.8
Kern	17	±3.2

Further information is needed on whether the bloom was compact and normal or irregular. Viti and Monteleone (1991) suggested that extreme variations in winter temperatures during bud development could be the cause of flower bud anomalies in apricot (Viti & Monteleone, 1991).

Most temperate and subtropical perennial plant species require exposure to cold temperatures for their normal development during the dormancy period. Growers must understand the relationship between a variety, its necessary chilling requirement and the orchard's climate for successful production. If winter temperatures do not satisfy a variety's chilling requirement, trees will show signs of delayed bloom and foliation, reduced fruit set and buttoning (flowers which have visually set but never develop into fruit) and decreased fruit quality (Byrne & Bacon, 1992).

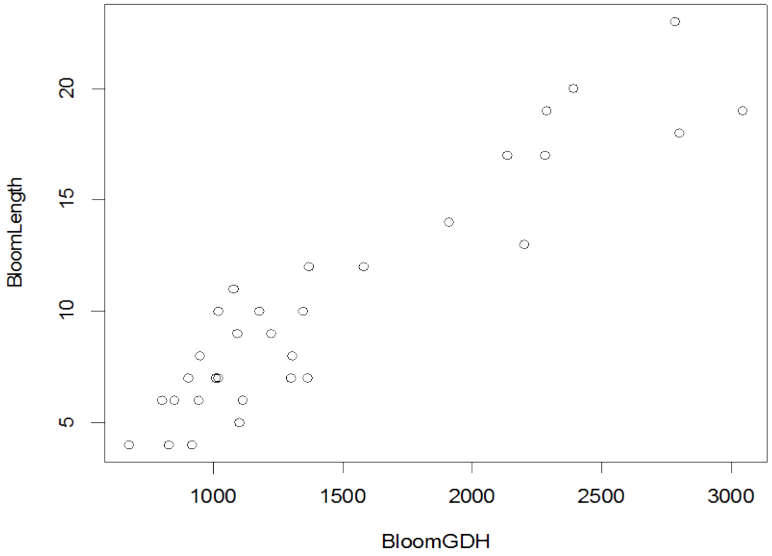

Figure 9. Scatterplot of bloom length (in days) versus GDH during bloom for Nonpareil.

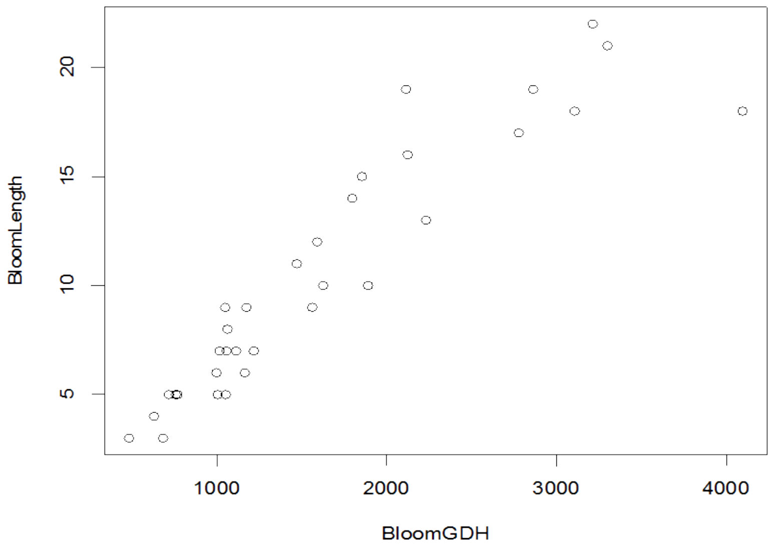

Figure 10. Scatterplot of bloom length (in days) versus GDH during bloom for Mission.

Objective 3: Yield, Bloom Length and GDH° During Bloom

Kern and Butte Co. had the highest mean yields across eleven years for both Nonpareil and Mission (**Tables 10&11**).

Table 10. Mean Nonpareil yield (lbs./tree) by County., (+/- s.d.)

Site	Mean	(± s.d.)
Butte	28.9	±10.6
San Joaquin	20.8	±9.5
Kern	29.7	±9.4

Table 11. Mean Mission yield (lbs./tree) by County., (+/- s.d.)

Site	Mean	(± s.d.)
Butte	22.9	±10.4
San Joaquin	20.8	±7.7
Kern	26.1	±7.8

There was no determinable relationship between bloom length and yield in Nonpareil or Mission when controlling for site (**Table 12**). The pest damage factor was omitted for Mission due to missing values for some years.

Table 12. Multiple Regression Analysis of yield versus bloom length. Site and worm damage factors were controlled in Nonpareil, while only site was controlled for in Mission (P>0.05).

Variety	Standard Error	t-statistic	p-value
Nonpareil	0.68	0.59	0.56
Mission	0.92	-0.49	0.63

Nonpareil yield showed a significantly positive relationship with GDH° during the first four days of bloom when controlling for worm damage, bloom length and site (**Table 13**). Each additional GDH° during the first four days of bloom was correlated with a yield increase of 0.04 pounds per tree. Accumulated GDH° during the first four days of Nonpareil bloom was significantly correlated to yield when not controlling for worm damage as well.

No significant relationship was found between GDH° during the first four days of bloom and Mission yield while controlling for site and bloom length. The pest damage factor was omitted due to missing values for some years (**Table 13**).

Table 13. Multiple Regression Analysis of yield versus GDH° during the first four days of bloom. Bloom length, site and worm damage factors were controlled in Nonpareil, while only bloom length and site were controlled for in Mission (P>0.05).

Variety	Standard Error	t-value	p-value
Nonpareil	0.02	2.67	0.013
Mission	0.02	1.5	0.14

The fact that heat accumulation during the first four days of bloom in Nonpareil was positively related to yield, especially when controlling for a growing season factor such as worm damage, is significant. In a study on chilling in Granada peach, high temperatures negatively affected pre-blooming and blooming reproductive periods by delaying the female gametophytes and causing malformation in the male gametophytes, resulting in low pollen viability and poor fertilization rates (Nava et al., 2009)

The lack of relationship between Mission bloom characteristics and crop yield may be attributed to the lack of controlling factors such as worm damage. Another reason that Mission produced differing results than Nonpareil may be explained by varietal differences. The variety (genetic factor) most greatly determines the degree of tree sensitivity to high temperature stresses during the pre-blooming, blooming and fructification stages (Citadin et al., 2009).

Conclusion:

The larger errors found with the ability of the CH, CU and CP models to predict the actual date of 90% bloom may be attributed to the fact that growth and rest stages in almonds involve a variety of factors and not yet fully understood. For example, alternating low and high temperatures are more favorable for plant growth than consistent temperatures. However, temperature optimums, including lower and upper thresholds, differ across species and varieties, even individual plants, their specific organs and the age or developmental state of those organs (Opik & Rolfe, 2005).

Original studies on physiological dormancy and bloom initiation (bud break) in annual and perennial species have proposed a hormone regulated mechanism (involving several combinations between ABA, auxin, cytokinin, GA and ethylene) that drives progression from one stage to the next (Nooden, 1978; Suttle & Hulstrand, 1994). More recent research shows a more complex relationship involving temperature thresholds, drought induced stress and PGRs, which combine to stimulate vegetative and reproductive bud primordia dormancy or growth (Anderson et al., 1986; Rinne et al., 1993). In order to better understand the ability of each chilling model to predict bloom timing, a study that controlled for non-temperature related interactions would be advised. Additionally, the study would need to internally examine floral buds for morphological and hormonal characteristics on a regular basis during dormancy to accurately determine chilling completion.

Additionally, it is very difficult to directly compare one site’s chilling or heat accumulation threshold to another location, because small differences in microclimate and growing conditions can alter results. If possible, chilling requirements should be determined for a specific site rather than used as an industry standard (Luedling et al. 2009).

Crop yields are another complicated matter involving growing conditions during the entire current season, the previous growing season and sometimes reaching as far back as the beginning of a tree’s life. Bloom length and temperatures during bloom are critical determinants for successful bee activity, pollination, fertilization and nut set, but a multitude of additional factors are involved during the remainder of the season, including but not limited to: conditions following bloom, nut set, pest pressure, drought stress, variety, and conditions during hull split and harvest. Although temperatures during bloom and bloom length may indicate a good start to the season, they are just a portion of the complete process from bud break to harvest.

Research Effort Recent Publications:

Anticipated future submission to California Agriculture or American Society of Horticultural Science

References Cited:

Alonso J., Anson J., Espiau M., Socias i Company R. 2005. Determination of endodormancy break in almond flower buds by a correlation model using the average temperature of different day intervals and its application to the estimation of chill and heat requirements and blooming date. J. Am. Soc. Hort. Sci. 130.

Anderson J.L., Kesner C.D., Richardson E.A. 1986. Validation of chill unit and flower bud phenology models for “Montmorency” sour cherry. Acta Horticulturae. 184:71.

Bradley, L., & Maurer, M. (2002). Deciduous fruit and nuts for the low desert. In U. o. Arizona (Ed.), (Vol. March, pp. 1-9): University of Arizona.

Byrne D.H., Bacon T. 1992. Chilling estimation: its importance and estimation. The Texas Horticulturist. 18:5.

Citadin I., Raseira M.C.B., Herter F.G., Silva J.B. 2001. Heat requirement for blooming leafing in peach. HortScience. 36:305.

Doll D.A. 2010. Orchard tasks to help prevent frost damage, in: D. A. Doll (Ed.) The Almond Doctor. Merced, CA.

Glozer, K., & Grant, J. A. (2005). Use of the Dynamic Model and Chill Portions to time chemical rest-breaking treatments in 'Bing' sweet cherry. In C. C. A. Board (Ed.):University of California Cooperative Extension.

Fishman S., Erez A., Couvillon G.A. 1987b. The temperature dependence of dormancy breaking in plants: Computer simulation of processes studied under controlled temperatures. Journal of Theoretical Biology. 126.

Kester D.E., Raddi P., Asay R. 1973. Correlation among chilling requirements for germination, blooming and leafing in almond Genetics. 74:135.

Lampinen B., Gradziel T.M., Yeager J.T., Thorpe M.A., Micke W.C. 2002. Harvest maturity of almond cultivars in California's Sacramento Valley. Acta Horticulturae. 591:457.

Luedeling E., Zhang M., Luedeling V., Givetz E.H. 2009. Sensitivity of winter chill models for fruit and nut trees to climatic changes expected in California’s Central Valley. Agriculture, Ecosystems and Environment. 133:23.

Luedeling E., Brown P.H. 2011. A global analysis of the comparability of winter chill models for fruit and nut trees. International Journal of Biometeorology. 55:411.

Nava G.A., Dalmago G., Bergamachsi H., Paniz R., Pires dos Santos R., Marodin G. 2009. Effect of high temperatures in the pre-blooming and blooming periods on ovule formation, pollen grains and yield of ‘Granada’ peach. Scientia Horticulturae. 122:37.

Nooden, L. D., & Weber, J. A. (1978). Environmental and hormonal control of dormancy in terminal buds of plants. In M. E. Cutter (Ed.), *Dormancy and Developmental Arrest*. New York: Academic Press.

Opik H., Rolfe S. 2005. The Physiology of Flowering Plants. 4th ed. University Press. Cambridge. pp. 221-239, 270-315.

Richardson E.A., Seeley S.D., Walker D.R. 1974. A model for estimating the completion of rest for Redhaven and Elberta peach trees. HortScience. 82:302.

Rinne P., Tuominen H., Junttila O. 1993. Seasonal changes in bud dormancy in relation to bud morphology, water and starch content, and abscisic acid concentration in adult trees of Betula pubescens. Tree Physiology. 14:549.

Snyder, R. L. (1985). Hand calculating degree days. Agriculture and Forest Meteorology, 35, 353-358.

Suttle, J. C., & Hulstrand, J. F. (1994). Role of endogenous abscisic acid in potato microtuber dormancy. Plant Physiology, 105, 891-896.

Tombesi S., Scalia R., J.Connell, Lampinen B., DeJong T.M. 2010. Fruit development in almond is influenced by early spring temperatures in California. Journal of Horticultural Science and Biotechnology. 85:317.

Viti R., Monteleone P. 1991. Observations on flower bud growth in some low yield varieties of apricot. Acta Horticulturae. 293:319.