# Using physiological concepts to understand early spring temperature effects on fruit growth and anticipating fruit size problems at harvest

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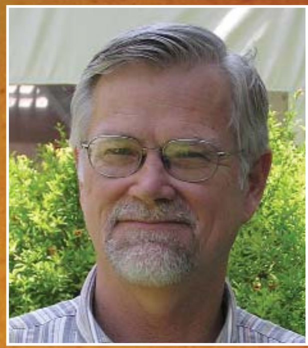
**In Spring, 2004, California experienced record temperatures during bloom time of peach trees. Subsequently fruit growers experienced problems with attaining the fruit sizes desired by the market and fruit harvests for specific cultivars were advanced by as much as two weeks compared to "normal" years. This situation provided an excellent test and application of the physiological and developmental concepts governing peach fruit and development that had been previously developed in our laboratory. Specifically these concepts are: *for any given time interval, realized fruit growth rate is governed by relative growth rate determined fruit growth potential and the availability of growth resources; and fruit development rates are primarily governed by exposure to heat in the first 30 days after bloom.* This paper will demonstrate how these concepts can be combined to explain the fruit growth behavior experienced in California in 2004 and make general recommendations for dealing with fruit thinning especially in years with warm springs and heavy fruit set.**



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Over the past two decades research in my laboratory has been focused on modeling peach fruit and tree carbon budgets in order to identify key factors that limit peach tree growth and productivity. This process has identified a series of physiological and developmental principles that can be applied in developing management techniques to minimize those limitations. An overarching principle is the concept that, for the purposes of understanding tree growth and carbon allocation, a tree can be viewed as an organism made up of semi-autonomous parts and the genetic code of a tree primarily governs the potential behavior of those semi-autonomous parts. The actual behavior of each organ is a function of the plant's genetic code, the environment and the interactions between organs (primarily competition for resources) within the context of the whole plant. This general principle is clearly illustrated in the concept that fruit growth potential follows a relative growth rate (compound interest rate) pattern (Figure 1). It also has clear implications for understanding fruit size responses to fruit thinning as well as optimizing timing and extent of fruit thinning operations.

A second and related phenomenon is that fruit development rate is clearly linked to exposure to heat in the first 30 days after bloom. Research has shown that the length of the fruit development period (days from bloom to harvest) for a given cultivar in a specific year is a linear function of the number of growing degree hours experienced by the trees from full bloom to 30 days after bloom (Figure 2). Several years of work using this relationship in California to predict harvest dates of specific peach cultivars over the past several years since the original report has provided further evidence of its validity.

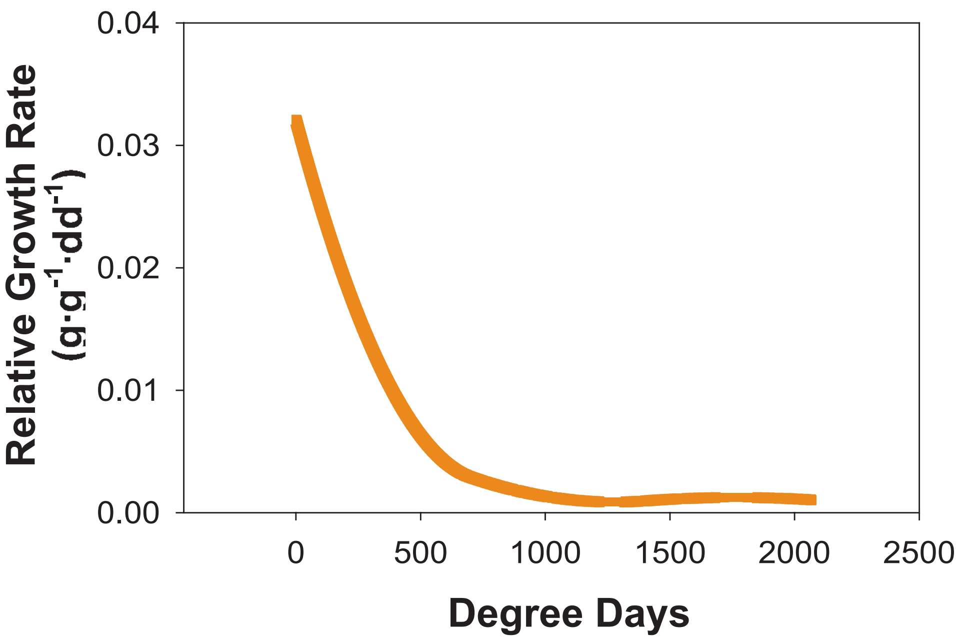


**Figure 1.** The general relative growth rate pattern for a late maturing peach cultivar. Time is expressed in day degrees to account for the influence of temperature on developmental rate.

## The concepts of relative growth rates and fruit growth potential.

Peach fruit growth has been described as a double sigmoid growth curve for nearly a century and researchers have been trying to understand the cause of the three traditional stages of peach growth ever since. Several years ago our research showed that the double sigmoid growth of peach fruit could be explained by simple relative growth rate analysis and that the concept of relative growth rate and its linkage to fruit respiration rates could be used to calculate daily fruit carbohydrate costs. Subsequently, while developing the integrated PEACH model of tree growth and crop productivity, we developed the concept fruit growth potentials and later documented that the concept of fruit relative growth rate (Figure 1) can be used to express that potential for specific time intervals throughout the fruit development period. The discovery that relative growth rate analysis of peach fruit growth performed on lightly cropped trees in one year can be used to approximate the fruit growth potential in other years was a major step toward developing a demand driven means for modeling carbon

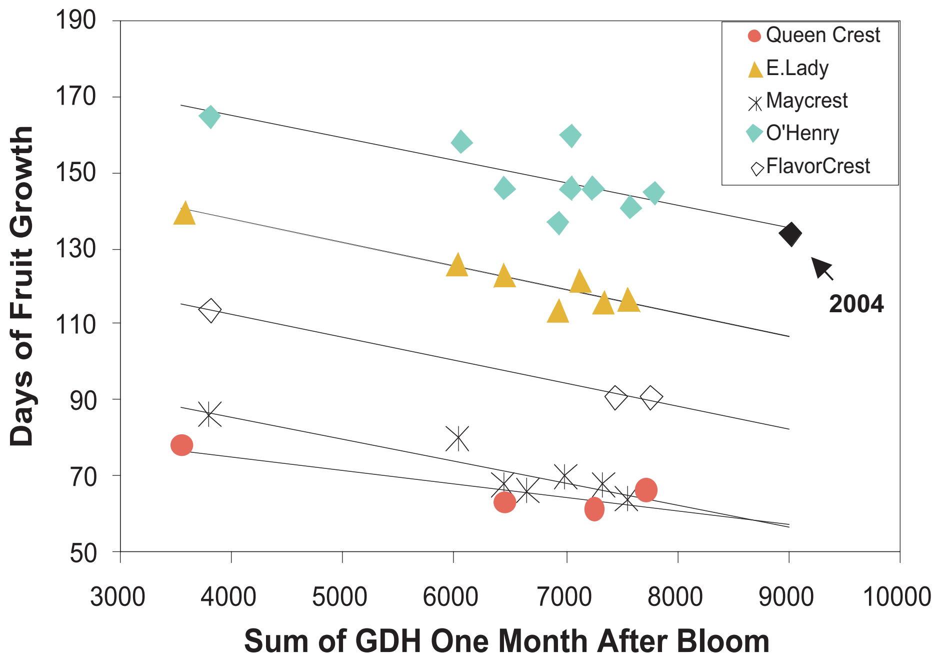


**Figure 2.** The relationships between days of fruit growth (bloom to harvest) and the accumulation of heat GDH (growing degree hours) over the first 30 days after bloom for five different peach cultivars. The 2004-point on the O'Henry line indicates how well the previous model fit the 2004 data.

partitioning in peach trees.

However, this discovery also has major implications for the practical understanding and development of optimizing fruit thinning practices that have been overlooked by most practitioners. Since fruit growth potential for any time interval subsequent to bloom follows a relative growth rate pattern (growth expressed as mass added during a given growth interval per unit of original mass at the beginning of the growth interval) the potential growth of a fruit can be predicted for any growth period along the course of fruit development. However, if the tree cannot supply the resources to support the growth potential, the realized growth may be less than the growth potential for that interval. If this occurs, the growth potential during the subsequent period is still governed by the same pattern of relative growth rates but it will be less than the original potential because the mass of the fruit at the beginning of the interval is less than it would have been if all of the growth potential was fulfilled in the previous intervals. Thus the relative growth rate function operates like a compound interest rate in banking. Since growth during any time interval is dependent on both the starting mass (principle) and the relative growth rate (compound interest rate) a biomass increase below the potential of either factor will result in a less than maximal increase in the accumulation of mass (funds) for that interval and subsequent intervals. However, if one knows the mass (principle) and the relative growth rate (interest rate) at the beginning of any interval, one can estimate the potential growth for the subsequent interval.

This knowledge can be used to explain, understand and optimize fruit thinning practices. Shortly after bloom the genetically programmed fruit relative growth rates are high but because fruit mass is small, the actual resources required to meet fruit growth potentials are relatively low. However, this situation changes rather quickly as fruit mass accumulates and fruit growth can become resource limited after a few weeks of growth. If the grower thins early enough to avoid this first period of potential resource limitation, the potential growth of the fruit will remain close to the genetically determined maximum potential until stage three of fruit growth when growth may again be resource limited. If thinning is done early enough, final fruit size will be directly proportional to fruit number on the tree during the third stage of fruit growth and the grower will be better able to manage crop loads to attain a desired fruit size. However if the grower thins late and the potential growth of the fruit is compromised because of the compounding effect of the relative growth rate function, the grower will have compromised the ability to attain desirable fruit sizes already by the time of thinning even if large numbers of fruit are removed in the late thinning.

## The effect of early spring temperatures on fruit development rates and time of harvest

Because of an interest in fruit production modeling we also became interested in the factors than determine the length of the fruit development period and discovered the key role of spring temperatures in this process. For the majority of peach cultivars grown in California it appears clear that the length of the fruit development period (bloom to harvest) is linearly related to heat accumulation (growing degree hours or GDH) between bloom and 30 days after bloom (Figure 2). The exact biologically relevant length of the critical period may vary with cultivar and even year but it is clear that for most years accumulation of heat units during 30 days after bloom is sufficient to predict harvest date. Our interpretation of this phenomenon is that, since temperatures in spring generally tend to be quite cool and thus limiting organ development, developmental rates during this period are highly correlated with temperature changes and thus the rate at which fruit development proceeds down the relative growth rate trajectory (Figure 1) is probably also highly correlated with spring heat accumulation.

## Applying these concepts to the California experience in 2004

The 2004 peach and nectarine harvest season in California was very difficult for many growers because of problems with small fruit and early harvests. Many cultivars ripened as much as two weeks earlier than “normal” and produced fruit with size distributions that peaked at sizes that were at least one or two size categories less than in previous years. At the end of the season we were asked if we could explain what had happened based on physiological concepts. An analysis of the temperatures during bloom and the period for 30 days after bloom provided rather direct answers.

According to local weather station data collected in numerous fruit growing regions, the amount of heat accumulation (growing degree hours between 7 and 35° C) from bloom time to 30 days after bloom ranged between 20 and 100 % greater than in the previous five years, depending on the year of comparison (Figure 3). When these data were used to estimate the effect of this early heat on harvest date for the cultivars that we had data for (Figure 2, for example) the models for most of the cultivars predicted harvest dates that were 10 to 14 days earlier than average. For some cultivars such as O'Henry peach for which we were able to get current year bloom and harvest date records as well as have a pre-calculated model, the 2004 data point fit right on the previous modeled line (Figure 2).

Therefore, it is clear that the early harvest in California in 2004 was primarily related to the high temperatures experienced in the 30 days after bloom. The remaining question is; why did that also alter fruit size? Unfortunately we did not have any ongoing experiments in which the seasonal patterns of fruit growth were being measured in sufficient detail to provide experimental proof, however from previous work an interpretation of the season is fairly apparent. The previous developmental data indicate that early fruit developmental rates are clearly related to heat accumulation (Figure 2). This means that the fruit would have traveled down the developmental relative growth rate trajectory (Figure 1) very rapidly and therefore the demand for resources of individual fruit on a daily basis would have been substantially higher than with more normal temperatures. On top of that, many varieties had heavy initial fruit sets so there were high numbers of fruit requiring higher than normal amounts of resources to meet potential fruit growth demands.

On the resource supply side of the picture, carbon supply during this period is dependent on mobilization of reserves (largely from the roots) and current photosynthesis from newly formed leaves. Since photosynthesis is dependent on light and daytime temperature does not influence the amount of light on a daily basis it is highly unlikely that there was any corresponding increase in current photosynthesis to match the increased demand of the fruit. In fact the high temperatures probably increased respiration rates and decreased carbon available for growth. Similarly, since soil temperatures lag behind air temperatures in the spring it is unlikely that root mobilization of reserve carbohydrates increased to meet the increased carbohydrate demand of the fruit. Thus fruit growth potential was likely lost early in the season and, since fruit growth potential is governed by a relative growth rate function, it could not be recovered by heavy fruit thinning later in the season. To compound the problem, many growers did not realize the effect that the early heat

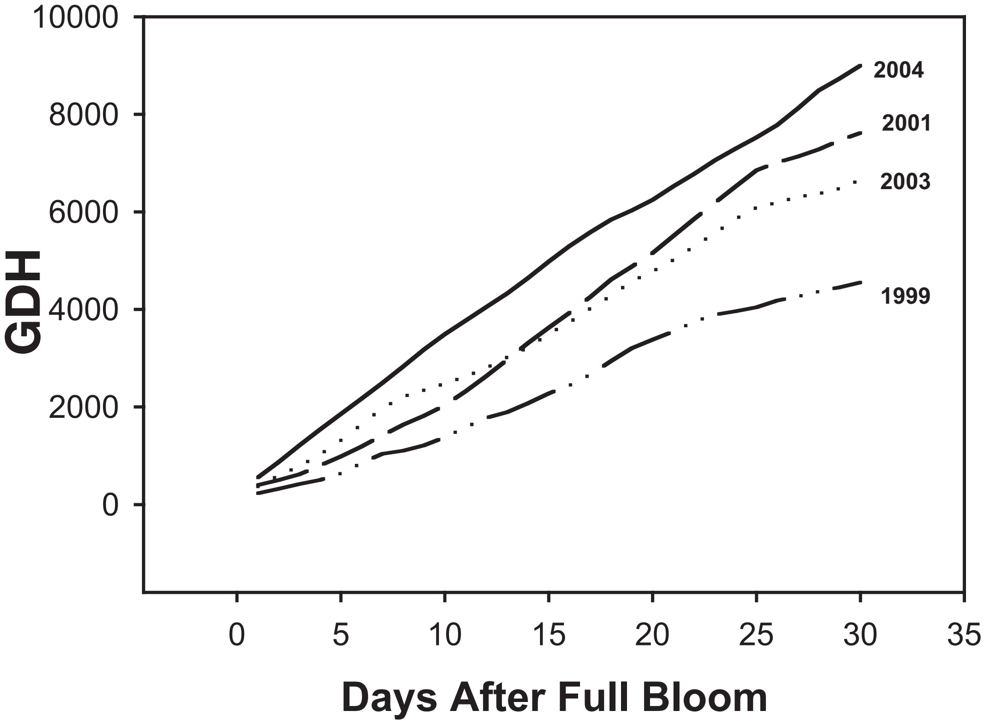


**Figure 3.** A comparison of heat accumulation (growing degree hours or GDH) during the first thirty days after bloom for 2004 compared to three previous years.

**Table 1.** Fruit yield data from four clingstone peach cultivars in commercial orchards near Kingsburg California that were thinned on two different dates in 1992. Data indicate means +- se for six, four-tree replications per cultivar and thinning date. Adapted from DeJong et al. 1992.

| Cultivar/Thinning Date | Fruit size (gFW/fruit) | Crop Load (fruit/tree) | Yield (tons/Ha) |
|---|---|---|---|
| Loadel | | | |
| 20 March | 113.3 ± 1.4 | 1681 ± 64 | 56.7 ± 2.0 |
| 18 May | 91.9 ± 2.4 | 1649 ± 40 | 45.3 ± 1.6 |
| Carson | | | |
| 20 March | 127.8 ± 4.7 | 1576 ± 74 | 59.4 ± 2.0 |
| 18 May | 108.2 ± 2.5 | 1427 ± 53 | 46.0 ± 2.0 |
| Andross | | | |
| 21 March | 123.6 ± 2.1 | 1888 ± 96 | 69.3 ± 2.7 |
| 18 May | 115.0 ± 1.7 | 1766 ± 58 | 60.8 ± 2.7 |
| Ross | | | |
| 27 March | 163.9 ± 7.0 | 1862 ± 99 | 80.7 ± 2.5 |
| 19 May | 163.9 ± 3.2 | 1638 ± 69 | 72.2 ± 3.1 |

was having on the fruit development rates and thus failed to adjust their thinning practices to mitigate the circumstances.

## Recommendations for compensating for similar problems in future years.

Based on this understanding we recommend that growers keep track of bloom dates and use local weather information to determine heat accumulation for the period of 30 days after bloom. Then they can compare the current year to previous years to predict fruit harvest dates relative to previous years (in California this can be done by visiting the weather services page at fruitsandnuts.ucdavis.edu). If growers want more specific predictions for individual cultivars they can develop models for those cultivars by using their own historical bloom to harvest data and the weather data from the weather station nearest to their location.

In years with warm springs it is recommended that growers thin fruit as early as is economically feasible and plan to thin the most heavily set and earliest harvested cultivars first. Previous experiments have shown that thinning early and mid-season cultivars within 50 days of bloom can increase both fruit size and crop yields while having more fruit per tree than thinning at 80 days after bloom. Thus fruit thinning before fruit growth is resource limited even in years with "normal" temperatures can significantly improve production results but it becomes even more critical in years of heavy fruit set and high spring temperatures.

The California experience in the Spring of 2004 as well as the experimental data collected previously clearly indicates the value of understanding the physiological and developmental concepts governing fruit growth because they allow the grower to understand and anticipate what is going to happen and plan accordingly. Hopefully future research will lead to greater concept-based understanding in pomology so that growers can better anticipate problems and manage their crops accordingly.

## References

Anderson J.L., E.A. Richardson and C.D. Kesner, 1986. Validation of chill unit and flower bud phenology models for "Montmorency" sour cherry. Acta Horticulturae 184: 71-78

Ben Mimoun, M. and T.M. DeJong. 1999. Using the relation between growing degree hours and harvest date to estimate run-times for *PEACH*: a tree growth and yield simulation model. Acta Horticulturae 499:107-114.

Chalmers, D.J. and B. van den Ende. 1977. The relation between seed and fruit development in the peach (*Prunus persica* L.). Annals of Botany 41:707-714.

Conners, C.H. 1919. Growth of fruits of peach. New Jersey Agricultural Experiment Station Annual Report 40:82-88.

DeJong, T.M. 1999. Developmental and environmental control of dry-matter partitioning in peach. HortScience 34(6):1037-1040.

DeJong T.M., H. Andris, R. Beede, K. Day, R.S. Johnson, W. Olson, D. Ramos, J. Yeager and F. Yoshikawa. 1992. Feasibility of increasing cling peach yields by early thinning. Cling Peach Research Report, California Cling Peach Board, Sacramento CA. 9 pp.

DeJong, T.M. and J. Goudriaan. 1989. Modeling peach fruit growth and carbohydrate requirements: reevaluation of the double sigmoid growth pattern. Journal of the American Society for Horticultural Science 114(5):800804.

DeJong, T.M. and Y.L. Grossman. 1994. A supply and demand approach to modeling annual reproductive and vegetative growth of deciduous fruit trees. HortScience 29(12):1435-1442.

DeJong, T.M. and Y.L. Grossman. 1995. Quantifying sink and source limitations on dry matter partitioning to fruit growth in peach trees. Physiologia Plantarum 95:437-443.

Grossman, Y.L. and T.M. DeJong. 1994. PEACH: A simulation model of reproductive and vegetative growth in peach trees. Tree Physiology 14: 329-345.

Grossman, Y.L. and T.M. DeJong. 1995a. Maximum fruit growth potential and seasonal patterns of resource dynamics during peach growth. Annals of Botany 75:553-560.

Grossman, Y.L. and T.M. DeJong. 1995b. Maximum fruit growth potential following resource limitation during peach growth. Annals of Botany 75:561-567.

Pavel, E.W. and T.M. DeJong. 1993a. Relative growth rate and its relationship to compositional changes of nonstructural carbohydrates in the mesocarp of developing peach fruits. Journal of the American Society for Horticultural Science 118(4):503-508.

Pavel, E.W. and T.M. DeJong. 1993b. Source- and Sink-limited growth periods of developing peach fruits indicated by relative growth rate analysis. Journal of the American Society for Horticultural Science 118(6):820-824.