# Why Do Early High Spring Temperatures Reduce Peach Fruit Size and Yield at Harvest?

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## Abstract

**High temperature stress is often considered to involve situations when temperatures are above the typical optima for plant assimilatory functions but higher than normal temperatures at specific times can also negatively influence source-sink relations to the detriment of fruit growth and yields. Previous research has documented that years with above-normal early spring temperatures (within 30 days after bloom) correspond to years with early fruit harvest and below-average fruit sizes. This has been a particular problem for California peach growers because the market is increasingly intolerant of small fruit. Our research indicates that fruit development and growth potential of a given cultivar is governed by a relative growth rate function which is driven by both time and temperature. However it is clear that fruit development and growth potential do not always equate to actual fruit growth. Furthermore, fruit growth potential that is not realized within a given time interval is lost and cannot be made up. In this paper we will show how higher than normal temperatures within 30 days of full bloom can result in increased fruit growth potential per day but decreased actual fruit growth over the fruit development period. This represents a form of heat stress that would not be typically considered as heat stress because the temperatures involved are not above temperature optima for assimilatory processes but can have important practical consequences for fruit size and yield.**

## INTRODUCTION

Recent concerns about global climate change have stimulated much interest in the potential effects of high temperatures and increasing atmospheric $CO_2$ concentrations on plant performance. Much of this research has been focused on plant metabolic processes such as photosynthesis, respiration and photorespiration, or altered carbon/nitrogen ratios because of potential increased efficiency of carboxylation reactions due to higher ambient $CO_2$ concentrations (Ziska, 2007). However less attention has been paid to the potential affects of high temperatures on plant phenological development and non-assimilatory processes that are major determinants of yield in tree crops. While tree crop yields are dependent on assimilation of $CO_2$ and other nutrients to supply requirements for plant growth, ultimately the marketable yield of fruit crops is highly dependent upon successful passage of developmental processes through a series of bottlenecks such as: flower bud initiation, flower bud differentiation, anthesis, pollination, fertilization and early fruit development. Many of these processes are known to be temperature sensitive and high temperature stress on many of these processes can have potentially greater effects on marketable tree fruit yields than high temperature stress on $CO_2$ or nutrient assimilatory processes.

For example, the influence of high temperatures coupled with water stress are known to influence fruit bud development in cherries, peaches and nectarines resulting in fruit doubling and fruit with deep sutures (Beppu and Kataoka, 1999; Micke et al., 1983; Johnson et al., 1992). High winter temperatures can result in a lack of chilling, irregular resumption of growth after dormancy, prolonged and erratic bloom and in severe cases, bud drop (DeJong and Johnson, 1989). Unusually high temperatures during bloom in prunes have caused crop failures in California presumably due to sensitivity of pollen tube growth and lack of fertilization of ovules (DeCeault and Polito, 2008).

Temperatures during the first 30 days after bloom have been shown to be a major determinant of the length of the fruit developmental period from bloom to harvest maturity in peaches, nectarines, plums and prunes (Ben Mimoun and DeJong, 1999; Day et al., 2008). Furthermore unusually high temperatures during the first 30 days after bloom of peaches have resulted in small fruit sizes and decreased yields (Lopez and DeJong, 2007; Lopez et al., 2007). Thus, it appears that, contrary to popular belief, higher than normal temperatures (but as low as 25-30°C) during the early fruit development period lead to reductions in fruit size and marketable yield of peaches. The objective of this paper will be to present an explanation for how this occurs or of this observation?

**Physiological Background**

The growth potential of peach fruit is a function of a genetically determined fruit development pattern that is driven by time and temperature. The relationship between potential fruit growth and temperature can be efficiently modeled as functions of relative growth rates per degree-day (DeJong and Goudriaan, 1989; Pavel and DeJong, 1993; Grossman and DeJong, 1995a). Fruit growth potentials generated by the relative growth rate-described developmental patterns of a specific peach cultivar are time dependent (Grossman and DeJong, 1995b). That is, if actual growth does not accompany growth potential over a given time interval, the growth potential is lost and can not be made up and will influence all subsequent growth because all future growth is a function of fruit size at the beginning of a growth interval. This is similar to compounding interest in an investment account. Any reduction in the accumulation of principle results in a decreased rate of growth of the account over all subsequent compounding intervals (Grossman and DeJong, 1995).

The length of the fruit development period for a given cultivar in a specific year is a function of the general genetically determined pattern of growth for the cultivar and the temperatures experienced in the field during the first 30 days after bloom (Ben Mimoun and DeJong, 1999; Marra et al., 2002). Temperature dependence of the length of the fruit development period has been successfully quantified by calculating the cumulative Growing Degree Hours during the first 30 days after full bloom (GDH30) for several Californian peach cultivars over numerous growing seasons (Ben Mimoun and DeJong, 1999; Day et al., 2009). Subsequent research has shown that most of the temperature dependent differences in the time between full bloom and the date of fruit maturity among years for a specific cultivar can be accounted for by differences in the time between full bloom and reference date (pit hardening + 10 days) (Lopez and DeJong, 2007). The same and subsequent research (Lopez et al., 2007; Lopez and DeJong, 2008) documented that in years when early spring temperatures were high (GDH30 >6000) there was a strong tendency for fruit sizes to be small while fruit sizes tended to be large in years when GDH30 <6000. The explanation for trends in fruit size responses was linked to decreased or increased fruit development periods but there was no clear quantification of how fruit size at harvest was linked to the length of the fruit development period. The goal of this research was to provide quantitative explanations for how early spring temperatures are linked to fruit size at harvest.

## MATERIALS AND METHODS

This research was based on assembling data from previous research to estimate the influence of early spring temperatures on potential absolute fruit growth rates which can be used to calculate the daily crop demand for carbohydrates. To do this we started with the fruit relative growth rate per degree-day (dday) functions for ‘Spring Lady’ and ‘Cal Red’ peach cultivars from Grossman and DeJong (1995a). These functions were developed by thinning crop loads down to very low numbers per tree right after bloom and then measuring fruit growth over time with the assumption that the fruit were growing at or near their maximum potential fruit growth rate (Grossman and DeJong, 1995a). Using the RGR/dday functions (Fig. 1) we then calculated the predicted seasonal pattern of fruit dry weight accumulation for the same two peach cultivars growing in 3 different sample years (1990, 2004 and 2006). The sample years were chosen for the number of growing degree hours that accumulated between bloom and 30 days after full bloom (GDH30) in each year. GDH30 values were calculated based on the temperatures reported on the California Irrigation Management System website for Parlier, CA. The 1990 season was a representative normal year with a GDH30 of 5400. The 2004 season was the warmest spring on record with a GDH30 of 8500 and 2006 was one of the coolest springs on record with a GDH30 of 3000. The length of the fruit development period for the two cultivars was adjusted for each year according to the fruit development period/GDH30 relationships reported by Ben Mimoun and DeJong (1999) and the RGR/dday functions and the weather data were used to estimate the pattern of cumulative potential fruit dry weight over the season (Fig. 2). To accentuate the influence of early spring temperatures on the potential fruit growth rate/day during the early part of the season the data in Figure 2 were used to calculate potential absolute growth rates of fruits during the first 50 days after bloom of both the early-maturing ('Spring Lady'), and the late-maturing ('Cal Red') peach cultivars during three contrasting growing seasons (Fig. 3). The potential absolute fruit growth rate functions were then used to approximate differences in potential cumulative crop growth dry weight demands between the three simulated years for each cultivar (Fig. 4). These calculations were based on modest fruit set values (1000 and 2000 fruit per tree for 'Spring Lady' and 'Cal Red', respectively).

## RESULTS AND DISCUSSION

Using the relative growth rate functions (Fig. 1) coupled with the total fruit development period/GDH30 relationships (Ben Mimoun and DeJong, 1999) to calculate the projected seasonal pattern of fruit dry weight accumulation for the 'Spring Lady' and 'Cal Red' cultivars in 1990, 2004 and 2006 (Fig. 2) indicated that spring temperatures could potentially influence fruit size in two ways. The first was by influencing the length of the total fruit development period. The RGR functions that described the pattern of growth for a given cultivar were based on heat sums (degree-days); the length of the fruit development period was measured in days; and the exposure to temperatures within 30 day after full bloom determined the length of the fruit development period (in days). Therefore, in the years with warmer spring temperatures the total fruit development period was decreased and the total heat sums that fruit were exposed to were less than in years with cool springs. This resulted in both shorter fruit development periods and decreased calculated potential fruit size (Fig. 2). Since the original fruit RGR functions were calculated based on data collected in 1990 (Grossman and DeJong, 1995a) it was possible that a slightly different RGR/dday function was in operation in years with substantially warmer or cooler springs. More research needs to be done to verify that the same RGR/dday function was valid for all years. However this analysis provides a mechanism for how potential fruit growth could vary from year to year even when the genetic factors that control fruit are constant.

A second, and potentially more important, factor leading to small fruit sizes in years with high spring temperatures demonstrated by this analysis involved the effect of temperatures on carbohydrate demands for fruit growth during the early fruit development period. When the potential fruit dry weight data (Fig. 2) were used to calculate and compare the potential absolute growth rates among years and cultivars, large differences became apparent. Within 20 to 30 days after bloom the calculated carbohydrate demands of the fruit growing in the year with the warmest spring were 5 to 10 times higher on a given day after full bloom than in the coolest spring (Fig. 3). When this was multiplied by a conservative estimate of the fruit load on a whole tree basis the potential significance of the differences between years became even more apparent (Fig. 4).

It could be argued that warm weather should mean clear skies and the potential for high leaf photosynthetic rates but high temperatures also lead to higher respiration rates

(Grossman and DeJong, 1996). Furthermore canopy $CO_2$ assimilation during the first 30 to 50 days after bloom in peach is probably more limited by lack of leaf development and daylength (Grossman and DeJong, 1994) than temperature or incident radiation intensity. In addition fruit growth during this period is highly dependent on mobilization of carbohydrates stored in the trunk and roots (Loescher et al., 1990) but relatively little is known about the influence of spring air temperatures on this process. It seems unlikely that short-term changes in air temperature would alter root temperatures quickly enough to increase the rate of mobilization out of the roots. Thus it is unlikely that warm spring temperatures within thirty days after bloom would have enough positive effects on carbohydrate supply processes (canopy photosynthesis, mobilization of stored carbohydrates) to meet the increased daily demands for carbohydrates of the fruits (not even considering the potential increased demands of other growing organs).

Realization of these principles has caused us to develop a website (http://fruitsandnuts.ucdavis.edu/Weather_Services/) where growers can easily access GDH30 data from weather stations in the vicinity of their orchards to estimate crop harvest dates and if acceptable fruit sizes are likely to be difficult to attain due to high spring temperatures. The more GDH30 values exceed 6000, the greater the likelihood of significant problems (Lopez and DeJong, 2008).

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**Figures**

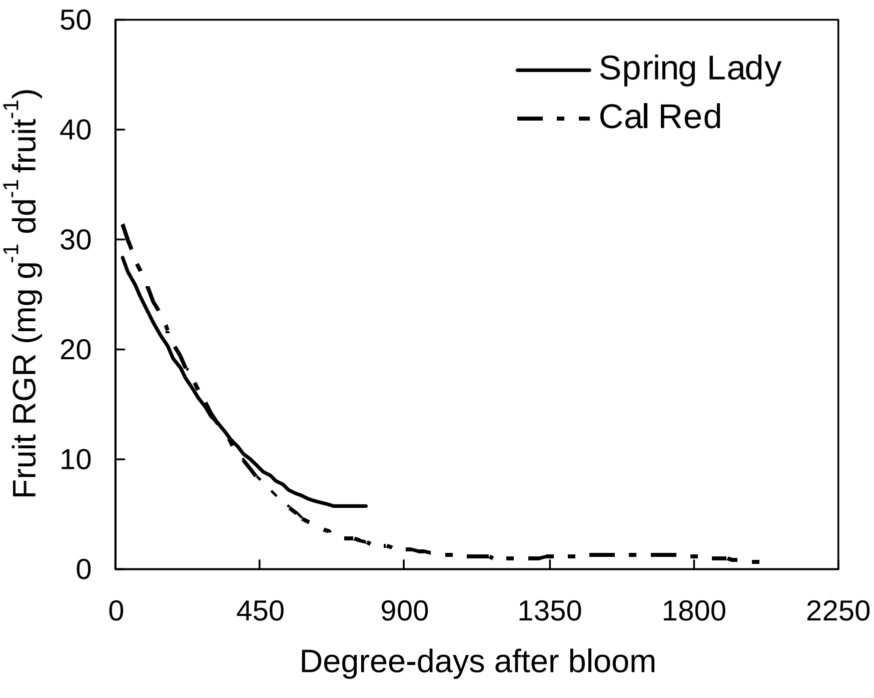


Fig. 1. Seasonal patterns of potential relative growth rates (RGR) for fruits of early-maturing ('Spring Lady'), and late-maturing ('Cal Red') peaches during the 1990 growing season (adapted from Grossman and DeJong, 1995a).

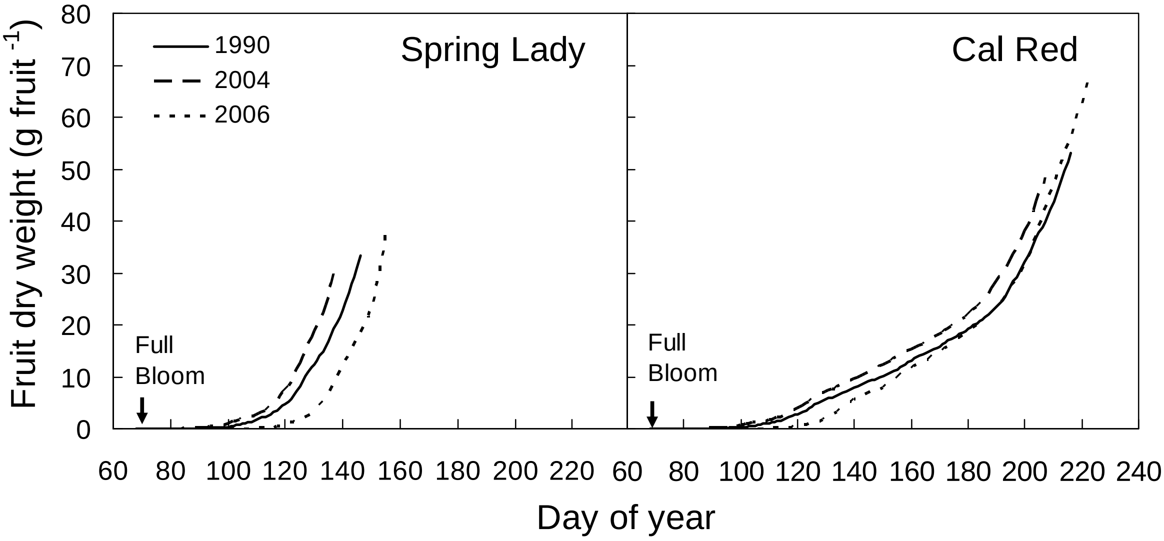


Fig. 2. Simulated seasonal patterns of potential individual fruit dry weight of early-maturing (‘Spring Lady’), and late-maturing (‘Cal Red’) peaches during three growing seasons with contrasting early spring temperatures.

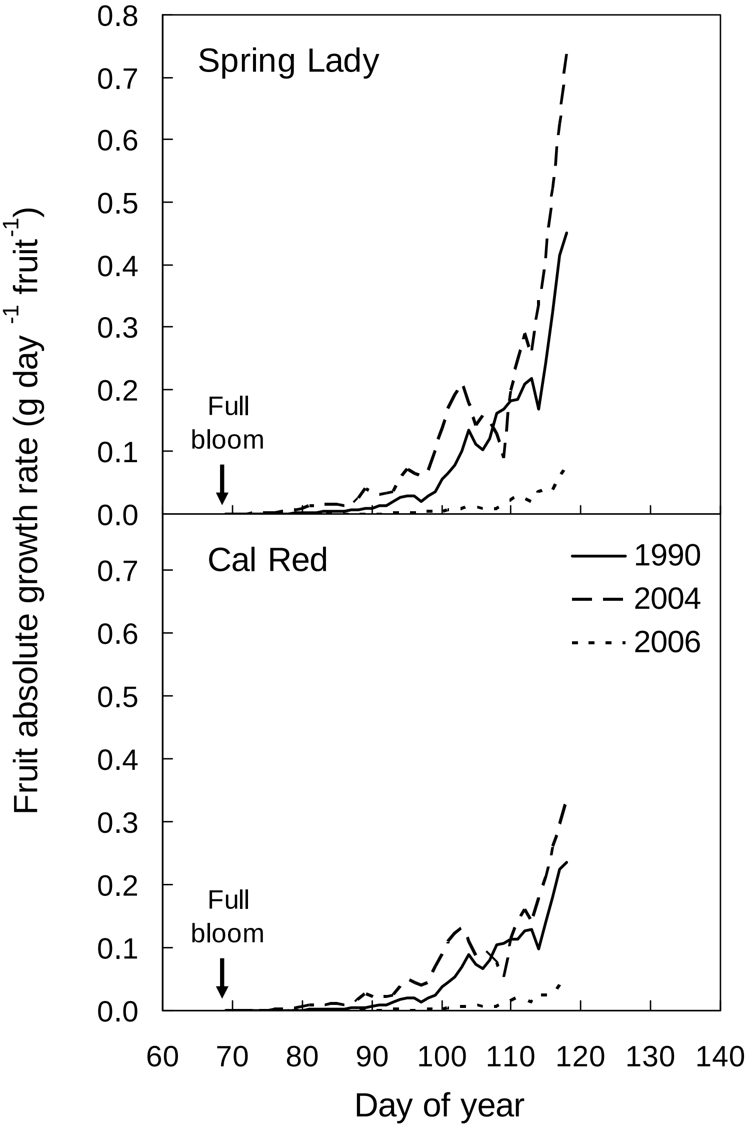


Fig. 3. Simulated patterns of potential absolute growth rates for fruits during the first 50 days after bloom of early-maturing ('Spring Lady'), and late-maturing ('Cal Red') peaches during three growing seasons with contrasting early spring temperatures.

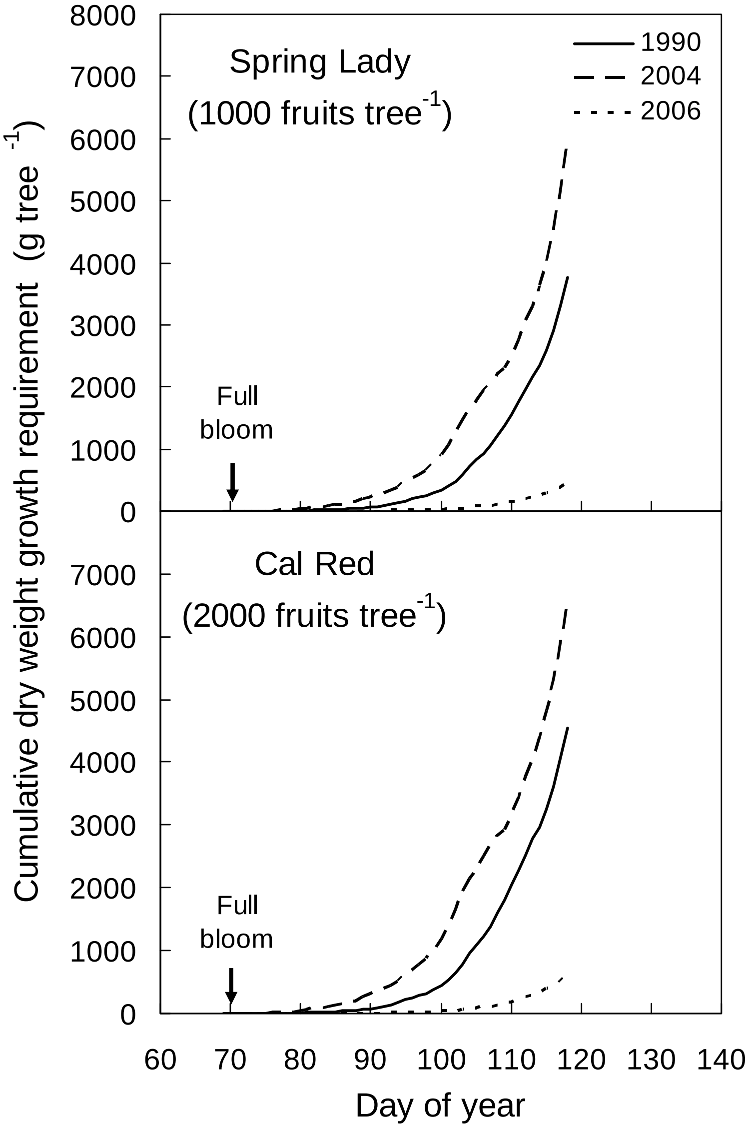


Fig. 4. Simulated potential cumulative dry weight growth requirements per tree of early-maturing ('Spring Lady'), and late-maturing ('Cal Red') peaches during three growing seasons with contrasting early spring temperatures.