Fruit Growth and Development as it Relates to Crop load, Thinning and Climate Change

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Abstract

Peach fruit growth and development is classically described as following a double sigmoid pattern of increasing fruit mass. But just describing the pattern of fruit mass increase does not provide a functional approach to analyzing factors that limit fruit growth. The key to understanding these limitations is to be able to compare fruit growth that occurs under specified limiting conditions with the potential growth that would have occurred without the limitation. Two decades ago my colleagues and I demonstrated that fruit relative growth rate analysis could be used to provide an approximate description of the genetic fruit growth potential of a given cultivar when that cultivar was grown under near optimal conditions with very low fruit loads. Subsequently we have demonstrated how relative fruit growth rate analysis can be used to develop mathematical models that simulate fruit growth for any given time interval during a growing season. These analyses and models have provided a means to understand the basis of the classical double-sigmoid growth curve, calculate carbohydrate requirements of fruits during growth; evaluate the effects of nitrogen deficiency on fruit growth and yield; analyze time of thinning; amount of thinning and fruit distribution effects on fruit size and crop yield; and study spring temperature effects on fruit size and crop yield. The goal of this paper is to summarize this research and show how the understanding resulting from these analyses and models has been used to provide growers with decision support information that helps them refine their practical crop management operations in the field.

INTRODUCTION

Many aspects of peach fruit growth and development have been studied over the past century since Conners (1919) first described the double-sigmoid pattern of peach fruit growth. Many of these studies have attempted to interpret or determine the factors that cause or regulate the rate of growth during the various stages of fruit growth (Zucconi 1986). For example, Chalmers and van den Ende (1975) suggested that the growth should be divided into six parts to account for the differences in behaviour between fresh weight and dry weight accumulation and went to lengths to try to correlate the various stages to seed and stone development as well as hormone activity during various periods of development. However most of this work concentrated on long season cultivars and largely ignored extra-early maturing cultivars which don’t characteristically exhibit a double-sigmoid growth curve and have overlapping periods of seed, endocarp and mesocarp development (Pavel and DeJong, 1993a). In 1989 DeJong and Goudriaan modeled peach fruit growth as a relative growth rate (RGR) function and demonstrated that using this type of analysis resulted in similar shapes of curves for both early and late maturing cultivars. They also demonstrated how two characteristics of the RGR curves (the initial slope and the asymtote) determine if the curve of fresh or dry mass accumulation exhibits a single or double sigmoid pattern. Subsequently Pavel and DeJong (1995) demonstrated how the RGR of apple fruits result in a single-sigmoid mass accumulation pattern. However the utility of fruit RGR analysis became more apparent as we attempted to use it to understand limitations to peach fruit growth and develop models of peach crop production. Early on we demonstrated that RGR's were linearly related to fruit growth respiration rates and that they could be used to estimate the total carbohydrate cost of a growing fruit over specific intervals of time during development (DeJong and Goudriaan, 1989). Later this became very useful for development of crop production models for peach trees (DeJong et al., 1990; Grossman and DeJong, 1994; Allen et al., 2005; Lopez et al., 2008).

LIMITATIONS TO FRUIT GROWTH

Logically peach fruit growth is limited both by the potential of the fruit to grow (sink) or the availability of resources (source) during specific intervals of growth. However it is not possible to ascertain which is most limiting by comparing fruit mass accumulation curves or fruit absolute growth rates. However comparison of fruit relative growth rate data from trees with little crop and with large crops has been used to indicate that primary periods of fruit growth limitation due to source limitation occur in the early and late stages of growth and growth during the middle period is largely sink limited (Pavel and DeJong, 1993b; Grossman and DeJong, 1995a). The primary effect of crop load on individual fruit size is a function of the amount of time fruit growth is source-limited compared to sink-limited. Furthermore, source-limitations to individual fruit growth can be a function of either lack total resources available in the tree to support fruit growth or transport/competition limitations imposed by transport resistances or competiton from other sinks. DeJong and Grossman (1995) used RGR analysis to show that transport/competition limitations are prominent during early phases of fruit growth but overall resource supply is more important later. Subsequently, using similar techniques, Marsal et al. (2003) documented that patterns of fruit thinning within a tree had substantial influence on transport/competition limitations to fruit growth. An attempt to use fruit RGR analysis to determine if peach fruit size reductions due to nitrogen deficiency were caused by increased source or sink limitations yielded the rather surprising result that fruit RGR's of N deficient trees were similar to N sufficient trees during the course of the fruit growth and the most important factor causing decreased fruit size in N deficient trees appeared to be a shortening of the fruit development period (Saenz et al., 1997).

THINNING EFFECTS ON FRUIT GROWTH, SIZE AND YIELD

Probably the most practical application of fruit relative growth rate analysis is in using it to understand fruit growth and crop yield responses to fruit thinning. Fruit RGR's can be used to quantify the growth potential of fruit of a given cultivar for any interval throughout the fruit development period because mass accumulation is expressed per existing mass at the beginning of the interval and the elapsed time during the interval. Thus the potential RGR for an interval is equivalent to the potential "interest rate" compounded on the mass at the beginning of an interval. Growth is compounded based on the potential RGR, the mass at the beginning of the interval and the abililty of the tree to supply the resources to achieve the potential RGR. If the potential RGR is not achieved, the actual growth is less than the potential and both the potential and actual growth for every subsequent interval is less than it would have been because the growth for each subsequent interval is based on the mass at the beginning of that interval. This means that any potential fruit growth that is not achieved early in the season cannot be made up later. Thus final fruit size is not only a function of crop load near harvest but also on crop load throughout the season.

This behavior of dry mass fruit growth has been verified with whole-tree, fruit thinning experiments of early and late maturing peaches in California (Grossman and DeJong, 1995b), crop modeling studies (DeJong et al., 2000; Grossman and DeJong, 2005; Lopez et al., 2008) and commercial orchard thinning trials (Tables 1-3). Fruit thinning trials in commercial California peach orchards over two years and several sites showed that thinning earlier than was previously recommended for commercial clingstone peach orchards in California could result in either larger fruit sizes at similar crop loads or similar fruit sizes at higher crop loads, or both larger fruit sizes at higher crop loads (Tables 1-3) without any significant increases in fruit defects such as split-pits.

SPRING TEMPERATURE EFFECTS ON FRUIT SIZE

If global climate change brings an increase in temperatures one of the most pronounced effects of these increased temperatures will likely to be on shortening the fruit development period and a tendency for reduced fruit size of individual peach cultivars. Reductions in fruit size resulting form warm springs can also be explained by relative growth rate analyses (Lopez et al., 2009). 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., 2008). 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 the 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 these trends in fruit size responses among years have been explained by running fruit RGR models for springs with high and low spring temperatures (Lopez et al., 2009). These analyses indicate that in springs with high early temperatures not only is the total fruit development period of a given cultivar shortened but the daily carbohydrate requirements for fruit growth are much higher, earlier in the season. As previous fruit RGR analysis has shown, carbon deficits early in the season that result in reductions in fruit size relative to the potential, cannot be made up later in the season and final fruit sizes tend to be small. Furthermore it is likely that the carbon deficits that limit fruit growth early in the season may be due to transport limitations rather than general supply limitations (DeJong and Grossman, 1995) since much of the carbon supplying fruit growth early in the season is from storage rather than current photosynthesis. If this is the case there is little a grower can do to mitigate against smaller fruit sizes linked to high early spring temperatures. For the same reasons growers of peaches in warm subtropical regions often experience small fruit sizes that cannot be substantially improved with early fruit thinning.

In California, knowledge of the dependence of the length of the fruit development period and fruit size on early spring temperatures has been put to use to provide growers with a web-based decision support tool. If growers keep track of the date of full bloom for an orchard they can go to the weather page of the UC Davis Fruit and Nut Research and Information Center website (http://fruitsandnuts.ucdavis.edu) thirty days after bloom and obtain data regarding the accumulated growing degree hours from a weather station nearest to their orchard. From this they can determine if the fruit development period is going to be shorter or longer than normal and adjust management practices accordingly.

CONCLUSIONS

Understanding that peach fruit growth potential at any given period of the growing season is governed by a genetically determined relative growth rate pattern that is based on time and temperature experience has provided a useful means to understand and analyze environmental, genetic and physiological factors that determine actual fruit growth in the field. This concept has been useful for identifying, improving and understanding the horticultural practices that can be used to optimize fruit sizes under specific management conditions. Further research needs to be conducted to determine how much genetic variation exists regarding the general pattern of the fruit RGR curves of different peach genotypes to determine if it would be possible to select for genotypes that have specific fruit RGR patterns that would be advantageous for specific environments or management strategies.

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Tables

Table 1. Fruit yield data from two clingstone peach cultivars in commercial open-vase trained orchards near Kingsburg, California that were thinned on three different dates. Data indicate means±SE for eight, two-tree replications per cultivar and thinning date. Adapted from DeJong et al. (1991).

Cultivar/thinning date	Fruit size (gFW/fruit)	Crop load (fruit/tree)	Yield (tons/ha)
Loadel			
10 April	149.8±3.2	1201±80	53.4±2.9
30 April	137.6±2.7	1248±55	51.1±1.8
23 May	134.6±2.5	969±40	38.8±1.6
Carson			
10 April	140.9±8.4	1559±148	63.0±3.6
30 April	132.4±3.1	1518±44	59.9±1.6
23 May	133.4±3.4	1128±43	44.6±1.1

Table 2. Fruit yield data from four clingstone peach cultivars in commercial, open-vase trained orchards near Kingsburg, California that were thinned on two different dates. 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

Table 3. Fruit yield data from two clingstone peach cultivars in commercial, open-vase trained orchards near Yuba City, California that were thinned on two different dates. The 19,4-40 cultivar was grown on two different soil types. Data indicate means of 5 two-tree replications and letters indicate significant differences with the Duncan's Multiple Range test at 5%. Adapted from DeJong et al. (1992).

Cultivar (soil type)/ thinning date	Fruit size (gFW/fruit)	Crop load (fruit/tree)	Yield (tons/ha)
19,4-40 (heavy)			
23 April	117 a	1160 a	37.5 a
12 May	109 b	1088 a	33.2 a
19,4-40 (light)			
24 April	122 a	1271 a	51.1 a
14 May	119 a	908 b	35.9 b
Loadel			
29 April	103 a	1544 a	52.7 a
22 May	107 a	1268 b	45.3 b