COMPUTER SIMULATION OF THE CARBOHYDRATE ECONOMY OF PEACH CROP GROWTH

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Abstract

A peach crop production computer simulation model is described and field validation data are presented. The simulation model contains two submodels, one for estimating daily peach fruit growth potential and photosynthate demand and the other for estimating daily photosynthate availability for fruit growth. Field validation of the model consisted of adjusting the fruit growth submodel for early, mid-season and late clingstone peach cultivars (cvs. Carson, Andross and Starn, respectively) using field data from early-thinned trees with minimal crop load. We then tested the ability of the model to predict fruit growth and yield of grower managed trees. The model predicted the seasonal pattern of fruit growth and final yield of the early cultivar (Carson) very well, not quite as well for the mid-season cultivar (Andross) and poorly for the late cultivar (Starn). The data indicates that the overall concept of the model appears to be functional, however more specific information is needed concerning the fruit growth characteristics of late season cultivars and canopy photosynthesis.

1. Introduction

The development of computer simulation models for the fruit crops has been much slower than in agronomic crops because of tree size, structure and longevity. Also there has been a greater research emphasis on tree growth regulation than on tree crop production physiology. In spite of the almost universally recognized importance of fruits as "sinks" that influence carbohydrate partitioning there have been relatively few quantitative studies on the carbon budgets of fruit crops. Using a detailed study of the seasonal patterns of reproductive and vegetative sink activity in two peach cultivars (DeJong et al. 1987) as a data base, DeJong and Goudriaan (1989a) re-evaluated the double-sigmoid pattern of peach fruit growth and developed a fruit relative growth rate model for estimating the daily carbohydrate requirements of fruit growth and respiration through the fruit growth period. Additionally, DeJong and Goudriaan (1989b) developed a computer simulation model that links the fruit relative growth rate model with leaf and canopy photosynthesis. This model provides a framework for the quantitative integration of environmental effects on canopy photosynthesis and crop growth rate on a daily basis. Given inputs such as tree spacing, date of bloom, initial fruit loads, thinning level, standing biomass, leaf area index, daily temperature and solar radiation; the model can be used to predict mean daily fruit growth, mean daily fruit size and final yield at harvest.

The purpose of the present research was to test and validate this approach to modeling fruit growth on peach cultivars other than those on which the original model was developed. A corollary to this primary objective was to test the relative growth rate concept of determining fruit growth potential and carbon partitioning to fruit growth in peach trees.

2. The Model

The peach crop growth simulation model is functionally comprised of two submodels; one for estimating potential fruit growth rate and photosynthate demand and the other for estimating the daily photosynthate available for crop growth. As a starting point for this model it is assumed that fruit growth potential is genetically determined and defines the potential pattern and rate of fruit growth and development for a given set of environmental conditions. The actual field environmental conditions are integrated with the genetic fruit growth potential to determine the actual fruit growth potential. The actual fruit growth potential and the fruit number determine the daily crop demand for photosynthates which is then coupled with the daily available photosynthate (canopy photosynthesis part of the model) to determine actual fruit and crop growth rate.

Fruit growth rate potential was modeled as a relative growth rate function. Previous research has shown that this approach can be used to simulate the double-sigmoid pattern of peach fruit growth and to estimate respiration requirements of developing peach fruits (DeJong and Goudriaan, 1989b). Temperature effects on fruit growth were incorporated into the model by developing fruit relative growth rate equations on a degree-day basis and then deriving fruit growth potential with degree-day inputs.

Fruit number was treated as an input variable. That is, until a detailed mechanistic model can be developed that accounts for the factors that determine fruit set, fruit set is determined empirically and simply stated as an input in terms of number per tree.

In the canopy photosynthesis submodel leaf area development was treated as an input variable that changed over time. The seasonal pattern of leaf area development was estimated from previous research (DeJong et al., 1987). Eventually it is hoped that subroutines for shoot growth and leaf area development will become interactive parts of the simulation model.

3. Field Validation

In February, 1988, orchard study sites were selected approximately 3 miles north of Yuba City, CA. These study sites included selected trees in blocks of Carson, Andross and Starn. In early April, 6 trees of each cultivar were thinned to a fruit load that we estimated to be substantially less than the grower might thin to. Thinned fruit were collected from 3 of the 6 thinned trees and the total number of fruit thinned was estimated by counting and weighing subsamples of these fruit.

Following fruit thinning weekly fruit samples (50 fruit per treatment) were taken from the early-thinned trees as well as samples from 6 additional trees that were thinned later according to standard grower practices. Weekly measurements of fruit fresh weight, dry weight and diameter were made on these fruits. Final fruit yields from each of the study trees were recorded individually and mean fruit size and crop load were calculated. A summary of the field data regarding initial crop load, number of fruit thinned, final crop loads, size of fruit at thinning and individual tree yields is given in Table 1. Data on the weekly increase in dry weight of the fruit was also used to estimate the potential fruit relative growth rate of each cultivar throughout the season.

Temperature data were collected at hourly intervals in the Andross orchard throughout the season with a Campbell Scientific Data Logger. Sensors were placed at three levels in the tree canopy to determine if there was a significant difference in the degree-day accumulation between the top and base of the tree over an entire season. Degree-days were calculated from each of the sensor positions in the canopy and compared with degree-day accumulations calculated from the nearest UC IPM Computer System Weather Station (Yuba City Station, #T1). Although there were some differences in degree day calculations between the field and the nearest weather station (with the weather station reading slightly higher) the weather station data reflected what was going on in the field and appeared to be more than adequate for our modeling purposes. There were no substantial differences in degree-day accumulation between the top and the base of an individual tree.

Fruit relative growth rates calculated on a degree-day basis for the early-thinned trees, field crop load and thinning data and local environmental data were then used to adjust the peach fruit growth simulation model to each of the three cling peach cultivars growing in these orchards near Yuba City. Simulation runs of the model to predict the seasonal pattern of fruit growth compared to actual fruit growth curves for Carson, Andross and Starn are shown in Figures 1, 2, and 3, respectively. With each cultivar, actual fruit growth rates of the early thinned trees were substantially greater, early in the season prior to grower thinning, than in the grower thinned trees. This is particularly pronounced in the Carson and Andross trees where initial fruit sets were heavy. These differences in fruit growth rate due to crop load were simulated quite well by the peach fruit growth models in Carson and Andross. The seasonal pattern of Starn fruit growth was much more variable than the other two cultivars and consequently the model of Starn fruit growth was relatively poor. It is difficult to determine at this point if the rather variable growth characteristics of Starn are inherent in the cultivar or were because of management practices that were not accounted for in the model.

The ability of the model to accurately predict fruit growth increments decreased as the season progressed. With Carson the differences between observed and predicted fruit sizes were relatively small at the end of the season for comparable fruit loads but these differences were larger in Andross and Starn. Since the predicted fruit growth with a minimum fruit load of 200 fruit per tree is substantially greater than the actual fruit growth pattern, it appears that the model underestimated the amount of photosynthate available for fruit growth late in the season rather than underestimating the fruit growth potential. Therefore the differences between actual and predicted fruit growth appear to be due to the photosynthesis section of the model and not the fruit growth section. We are currently attempting to determine the basis of the underestimations of photosynthates available for fruit growth.

4. Conclusions

In spite of the difficulties in getting the model to accurately predict fruit growth patterns throughout the season in all three cultivars, the results of both the model predictions and the field data are consistent with the hypothesis that there are two primary periods when carbohydrate availability is likely to limit fruit growth in the field. These are from approximately one month after bloom to the time of fruit thinning and during the final stage of rapid fruit growth. The severity of the carbohydrate deficit and depression of fruit growth during the first period is dependent on initial fruit set and climatic conditions during this period. The severity of the carbohydrate deficit during the second period is dependent on crop load and fruit size after thinning and environmental conditions affecting fruit growth and photosynthate production. It is also apparent that losses that occur in fruit growth potential suffered during the first period cannot be recovered by over-thinning later in the growing season.

Although this model is still in its preliminary stages of development and validation, this research has pointed out several areas where we have gaps in our understanding and has provided mechanisms for focusing future research in this area. We intend to continue to refine this simulation model so that we can more accurately predict and understand peach fruit growth and yield phenomena.

References

DeJong, T.M., Doyle, J.F. and Day, K.A. 1987. Seasonal patterns of reproductive and vegetative sink activity in early and late maturing peach (Prunus persica) cultivars. Physiol. Plant. 71:83-88.

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Table 1. Summary of field cropping data for the three cling peach cultivars. Data represent means ± s.e.

	Cultivar		
	Carson	Andross	Starn
Early thinning date	4-6-88	4-8-88	4-11-88
no. fruit thinned/tree	6081±198	6175±93	2396±256
$\bar{x}$ fruit FW at thinning (g)	2.4±0.4	2.3±0.2	5.3±0.2
$\bar{x}$ fruit DW at thinning (g)	0.36±0.05	0.38±0.02	0.75±0.02
Grower thinning date	5-2-88	5-23-88	5-30-88
no. fruit thinned/tree*	5698	5967	2352
$\bar{x}$ fruit FW at thinning (g)*	21.4	22.3	25.2
$\bar{x}$ fruit DW at thinning (g)*	2.5	4.0	5.6
Harvest date	7-8-88	7-26-88	8-29-88
fruit no./tree			
early thinned	516±107	1200±145	877±87
grower thinned	1024±51	1548±78	1086±76
crop/tree (FW) at harvest (kg)			
early thinned	109.6±17.9	230.6±22.7	169.6±17.6
grower thinned	143.8+6.0	258.0+14.3	194.0+13.6

*data on grower thinned fruit are calculated from weekly fruit sampling data and initial fruit set data combined with final harvest data rather than actual counts and weight of thinned fruits.

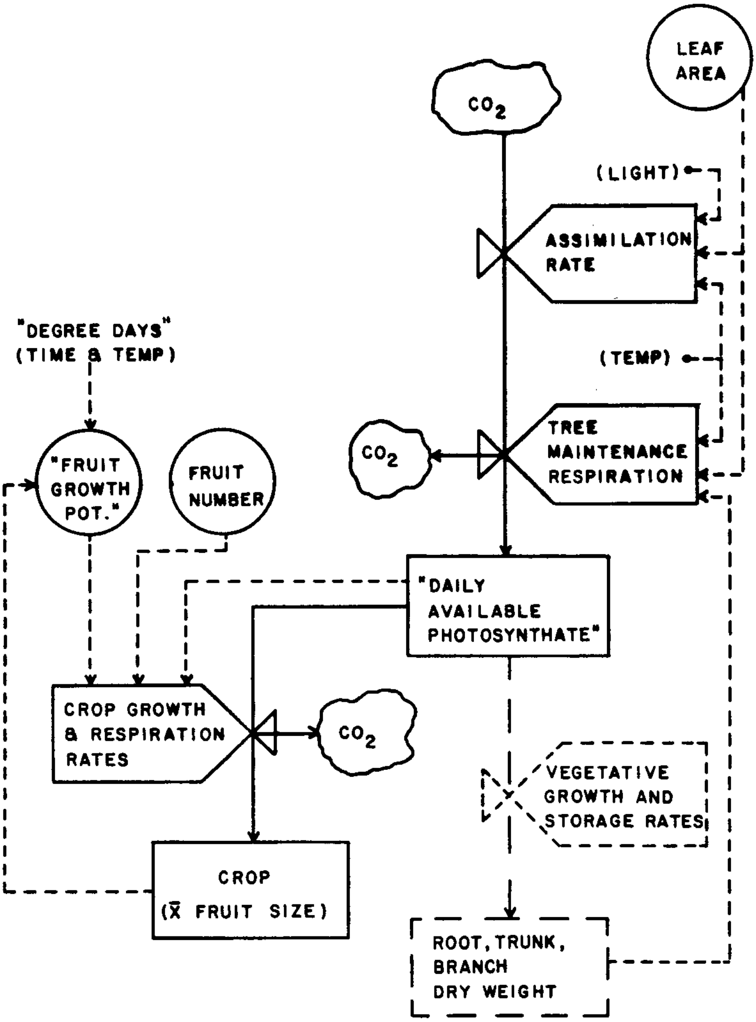

Figure 1. A relational diagram illustrating the manner in which crop growth ($\bar{x}$ fruit size) is calculated in the peach model. Boxes are state variables and valves are rate variables. Circles represent auxiliary input variables. Solid lines indicate the flow of carbon and short dashed lines, the flow of information. The lower right-hand vegetative growth section (dashed boxes) is not a functional part of the model at this time.

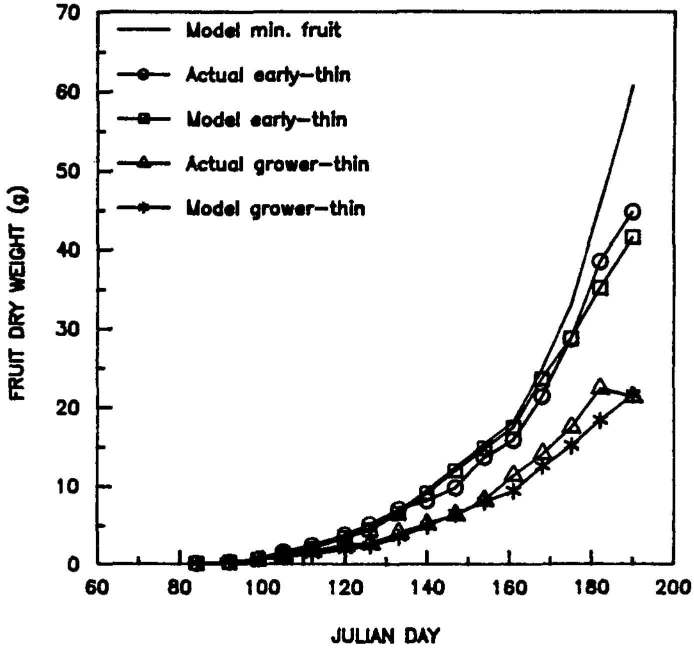

Figure 2. A comparison of actual and predicted seasonal patterns of fruit growth for Carson peach. The "Model min. fruit" line indicates the model prediction for fruit growth with only 200 fruit per tree. As such it represents the "maximum fruit growth potential". The "Actual early-thin" line represents the actual pattern of fruit growth measured in the field on the trees that we thinned early with the pre and post-thinning crop loads given in Table 1 (i.e. 6081 fruits prior to thinning and 516 fruits after thinning for Carson). The "Model-early thin" line indicates the model prediction for fruit growth with the crop loads of the early-thinned trees. The "Actual grower-thin" line indicates the actual pattern of fruit growth in the grower thinned trees and the "Model grower-thin" line indicates the model prediction of fruit growth with thinning time and crop loads in the grower thinned trees (from Table 1).

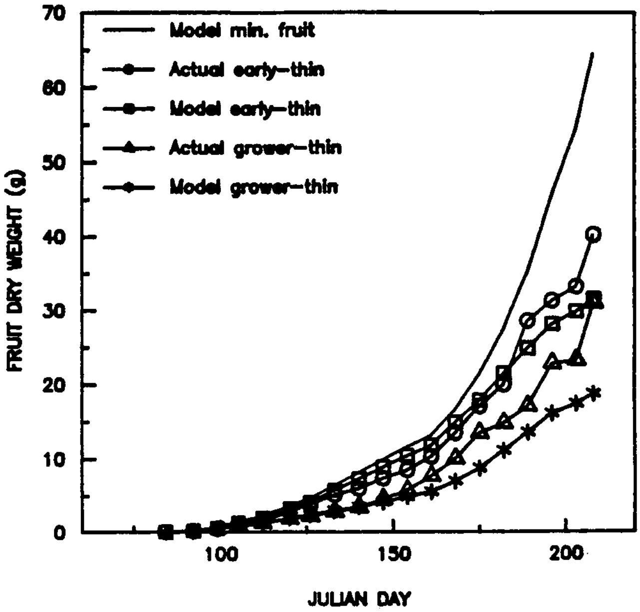

Figure 3. A comparison of actual and predicted seasonal patterns of fruit growth for Andross peach. (See Fig. 2 for details).

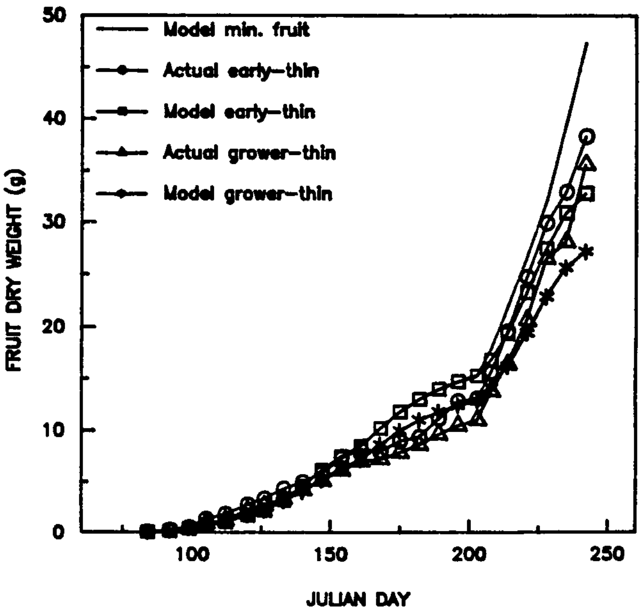

Figure 4. A comparison of the actual and predicted seasonal patterns of fruit growth for Starn peach. (See Fig. 2 for details).