MODELING THE CARBOHYDRATE ECONOMY OF PEACH FRUIT GROWTH AND CROP PRODUCTION

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Abstract

This paper outlines a generalized model of the carbohydrate economics of peach fruit growth and crop production and describes some of the implications of the model regarding photosynthetic limitations on fruit yield. The model provides a framework for integrating environmental and physiological factors controlling carbohydrate supply and demand for fruit growth at the orchard level. The primary processes of canopy photosynthesis and peach fruit growth potential are described by submodels. These submodels are then combined in an interactive way so that daily peach fruit growth and crop development are dependent on the calculated daily availability of current photosynthates. The model predicts that there are two potential periods when fruit growth is likely to be limited by availability of current photosynthates. The duration and severity of photosynthate limitations are dependent on environmental conditions as well as initial fruit set, thinning level and timing and canopy light interception characteristics. Although the model is still in the preliminary stages of development it is already useful for indicating gaps in our knowledge of tree function and indicating potential avenues for future research.

1. Introduction

During the past two decades there has been increasing interest in the development of mathematical and physiological models to describe and predict growth and yield phenomenon in agricultural crops. Highly sophisticated models for annual and biennial agronomic crops such as corn, wheat, sugar beets, etc. have been developed. These have served to increase the understanding of integrated crop physiology and yield limiting parameters as well as help in programs for integrated pest management and development of integrated cropping systems (Loomis et al. 1979, Gutierrez et. al. 1984, Wit 1986). Modeling of tree crop production has been much slower than in agronomic crops because of tree size, structure and longevity, and traditionally a greater research emphasis on tree growth regulation than on tree crop production physiology.

Landsberg (1986) presented a generalized model of the production cycle of fruit trees. This model emphasized the physiological rather than the empirical approach to modeling fruit tree production. Landsberg outlined the processes that determine fruit production in the orchard. Key among these processes were fruit growth and carbohydrate production. As an initial attempt to develop a computer simulation model for peach fruit production this paper describes a simulation model of the daily carbohydrate economics of peach fruit growth and crop production.

2. Approach

In this study the carbohydrate economy of peach fruit growth and crop production was divided into the factors that determine the carbohydrate demand of the fruit crop and the carbohydrate supply available to the fruit on any given day. The factors are outlined in the diagram below.

Carbohydrate Economy of Fruit Growth

Demand Side

1. fruit set
2. genetic fruit growth potential (dependent on genotype)
3. environmental factors influencing fruit growth rate (temp., water stress, nutrients, etc.)

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net photosynthate demand for fruit growth

Supply Side

1. leaf area development
2. genetic photosynthetic potential (dependent on genotype)
3. environmental factors influencing photosynthetic rate. (light, temp., water stress, nutrients, etc.)
4. competition for photosynthate from other sinks.

↓

net photosynthate available for fruit growth

→ ↓ ←

ACTUAL FRUIT AND CROP GROWTH RATE

On the demand side fruit set was treated as a state variable. That is, until a detailed mechanistic model can be developed that accounts for the factors that determine fruit set, it is just stated to be a certain number per tree.

The fruit growth potential was considered to be the genetically determined potential pattern of fruit growth and development. The genetic potential interacts with the prevailing environment to determine the actual fruit growth potential. This actual fruit growth potential determines the daily fruit demand for photosynthates and with the supply side of the picture it determines the actual fruit and crop growth rate. Fruit growth potential was modeled as a relative growth rate function. This approach provides a method for both simulating the double sigmoid growth pattern of peach fruit and for estimating the respiration requirements of developing peach fruit (DeJong and Goudriaan, 1988). Temperature effects on fruit growth were accounted for by calculating fruit relative growth rate on a degree-day basis. Other environmental factors such as water stress or nutrients were assumed to be non-limiting although in the future we hope to also include these factors.

On the supply side, leaf area development was treated as a changing state variable. The seasonal pattern of leaf area development was estimated from previous research (DeJong and Doyle, 1984, DeJong et.al., 1987) and treated empirically. Eventually it is hoped that subroutines for shoot growth and leaf area development can become interactive parts of the simulation model.

Daily canopy photosynthates was estimated by modifying an updated version of the canopy photosynthesis subroutine (Kropff et.al., 1987) of SUCROS (Simple and Universal CROp growth Simulator) (Keulen et.al.,1982) to account for gaps between rows in a peach orchard. This modification involved using actual determinations of the daily pattern of light interception within peach orchards to adjust the effective leaf area index as the sun moves across the tree row. This submodel for canopy photosynthesis allowed for the integration of numerous environmental and plant determined factors to calculate a daily tree photosynthate availability.

Gross estimates of tree maintenance respiration requirements were also achieved as outlined by the SUCROS crop growth model. Tree biomass was estimated based on previous measurements by Chalmers and Van Den Ende (1975b), DeJong and Doyle (1984) and DeJong (unpublished data).

It was assumed that tree maintenance respiration would have the highest priority for daily tree photosynthates. Although it is probably unrealistic, for the purposes of running this initial model, fruit growth was assumed to have the highest priority over the remaining daily available photosynthates after tree maintenance requirements were met. Thus net photosynthate demand for fruit growth was linked with the net photosynthate available for fruit growth to calculate the actual fruit and crop growth rate on a daily basis. Any photosynthate available after fruit growth requirements were met was assumed to be used in other parts of the tree. If the net photosynthate available for fruit growth was less than the demand for fruit growth, the actual fruit growth increment of all of the fruit was recalculated accordingly. Any time daily fruit growth was hindered by lack of daily available photosynthates this had feedback effects on future fruit growth potential because fruit growth potential was a function of fruit size at any point during the season.

3. Model Predictions

An example of a simulation run for O'Henry peach fruit growth from 25 days after bloom to harvest is given in Figure 1. Initial fruit set was set at 6000 fruit per tree and 247 trees/hectare, which is reasonable for standard peach orchards in California. The thinning level was set at 1200 fruit per tree with thinning occurring on April 15 (48 days after full bloom). Environmental and bloom data were from the 1986 growing season.

This simulation run indicated that there are two periods when fruit growth is likely to be limited by the availability of current photosynthates: just prior to fruit thinning and again just prior to fruit harvest. The extent of photosynthate limitation on fruit growth during the prethinning period is related to environmental factors affecting canopy photosynthesis, initial fruit set and time of thinning. If initial fruit set is low or the trees are thinned earlier the model predicts that the initial period of photosynthate limitation can be eliminated.

The second period of potential photosynthate limitation occurs later in the season when temperatures in central California are often above 35°C. These high temperatures have a substantial affect on daily photosynthate availability because the respiration requirements increase with a Q_{10} of 2 and 35°C is substantially above the optimum temperature for photosynthesis in peach leaves. The fruit demand for photosynthates during this final period is dependent on fruit load per tree and the size of the fruit. Therefore if fruit size is substantially hindered by heavy initial set or late thinning during the early period of photosynthate limitation, the significance of this second period of photosynthate limitation is decreased. Thus the model predicts that there is a significant potential for interaction between the first and second potential periods of photosynthate limitation on final fruit size and yield.

The results of this predicted interaction can be demonstrated by doing a series of model simulation runs where thinning level and initial fruit set are varied (Figure 2). The differences in predicted yield and mean fruit size between trees with initial sets of 3000 and 6000 fruits are entirely due to photosynthate limitations prior to thinning. The degree of curvature in relationships between thinning level with yield and fruit size is due to photosynthate limitations during the later stages of fruit growth.

4. Conclusions

Although this model is still in its preliminary development stages with many of its inputs needing to be more precisely quantified and its predictions validated, it provides a conceptual and functional framework for studying interactions between photosynthesis and cropping in peach trees. We recognize that some of the assumptions used in the model are probably too simplistic or incorrect. But it is only after a conceptual and functional framework for studying the carbohydrate economy of fruits is developed that these assumptions can be tested.

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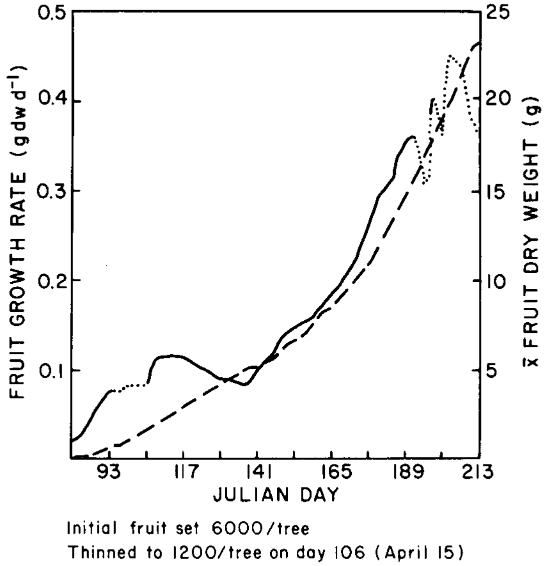

Fig. 1. A sample simulation run of the model for 'O'Henry' peach fruit from 25 days after bloom to harvest. The solid line indicates predicted fruit growth rate. Dotted portions of this line indicate periods when fruit does not grow to its potential because of carbohydrate shortages. The dashed line indicates predicted x̄ fruit dry weight.

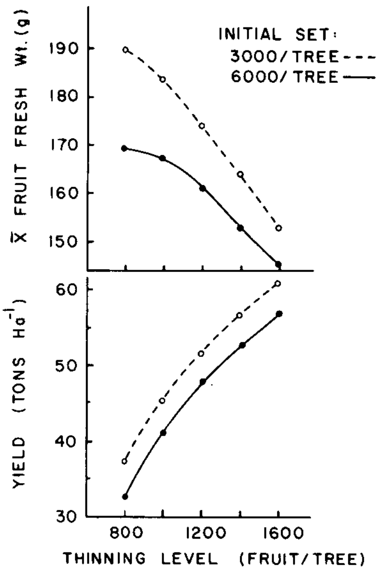

Fig. 2. Results of a series of model simulations with two initial set levels and five thinning levels. Simulated thinning occurred on Julian Day 106 (April 15).