Modeling Productivity of Zacatecan Peaches

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Abstract

Most of the commercial peach production in the central-north Mexican highlands (about 20,000 ha) is located in the state of Zacatecas and is based on "*Criollo*" seedling peach trees. Peach yields in this region are, in general, low and variable and peach productivity potential is unknown. The objective of this research was to simulate productivity of Zacatecan peaches and compare it with that obtained in California. Our approach was to adjust the existing *PEACH* model developed at the University of California, Davis for Californian cultivars. *PEACH* is a carbon balance model that allows integration of genotype, environment and orchard management aspects, all being important for predicting productivity. Zacatecan cultivars differ architecturally and physiologically from Californian cultivars due to both genetic and orchard management induced causes. In this study, model simulations were run for both the Californian mid season maturing cv. 'Cal Red' and the Zacatecan mid season cv. 'Criollo' growing in Fresno CA, USA and Jerez, Zac. Mexico. Model modifications focused on the environmental parameters and the fruit growth potential equations. The model simulates carbon assimilation as function of solar radiation, minimum and maximum temperatures, degree days, tree light interception, leaf area index and photosynthetic rates. Simulation of respiration, growth and carbon partitioning integrate the organ carbon demand. Results show that the Zacatecan environment may restrict productivity of cv. 'Cal Red' up to 22.0 %. Crop growth limitations were predicted mostly during the final two thirds of the growing season. Yield reductions of 'Criollo' peaches was predicted to be low with a productivity for this cultivar representing just 39.9% that of 'Cal Red'. New avenues of applied research to increase productivity of Zacatecan peaches were identified.

INTRODUCTION

The main peach growing area of Mexico is the central-north region (Zacatecas and Aguascalientes states) with 25,000 hectares established with peach seedlings. Regional peach yields are usually low (seldom exceeding 15 ton ha^{-1}) and variable as compared to other peach growing areas such as California (60 ton ha^{-1}) (DeJong et al., 1994). The peach productivity potential in the region is unknown due to genotype variation, microclimate diversity, and differential orchard management.

Delimitation of peach productivity in Zacatecas have been reported based on environmental variables (Rumayor et al., 1998). The approach was, however, empirical and did not consider genotype variation and orchard management aspects. An integration of tree physiology, productivity, environment, and orchard management using a mechanistic approach is needed to define productivity potential for local peach selections. Carbon budget models represent one of the best options for doing this. Physiological models have been used to relate plant growth to environmental conditions for several years (Thornley, 1990). Unfortunately, very few of these models have been developed for fruit tree crops, particularly for considering whole trees (DeJong and Grossman, 1992, 1994). The *PEACH* model was developed to fill this research need (Grossman and DeJong, 1994). *PEACH* simulates the annual carbon supply and demand for reproductive and vegetative growth of peach trees on a daily basis. It is a state variable simulation model in which fruit, leaf, stem, branch, trunk and root weight are the state variables, and minimum and maximum air and soil temperatures, degree days, solar radiation and canopy light interception are the driving variables.

The central concept behind *PEACH* is the hypothesis that trees are collections of semi-autonomous but interacting organs whose carbon partitioning is driven by competition based on their growth potential, their source proximity and carbohydrate availability (DeJong and Grossman, 1992; Grossman and DeJong, 1994). The way the model simulates carbon supply and demand as well as carbon partitioning can be reviewed in detail in previous publications (Grossman, 1993; Grossman and DeJong, 1994; DeJong et al., 1996). The assimilated carbon represents the “supply” part of the model; this carbon pool is available for growth and respiration, which represent the “demand” part. Carbon assimilation is simulated as a function of the seasonal patterns of canopy light interception, photosynthesis, and daily maximum and minimum air temperatures. Organ growth simulation is based on experimentally determined maximum achievable growth in trees growing with no limitation of water or nitrogen in which the fruit load has been manipulated to minimize competition for carbohydrates (potential growth rates).

Partitioning of carbon is simulated first by satisfying the maintenance respiration needs; then, carbon is allocated to organ growth based on sink strength (potential growth rates), source-proximity (fruits, leaves, stems and branches first, then trunk, and roots last), and carbon availability (for details see Grossman, 1993 and Grossman and DeJong, 1994). During the first 200 degree-days, fruits, leaves, stems and branches are left to grow at their potential growth rates, and their cost is subtracted from the trunk and root reserves. The code of the model is written in Visual Basic™ (DeJong et al., 1996).

Field validation has shown that *PEACH* simulates the vegetative and reproductive growth of peach trees growing under different fruit loads and environmental conditions reasonably well (Grossman and DeJong, 1994; DeJong et al., 1996). Recent research has demonstrated the feasibility of adapting *PEACH* to other fruit tree species (Esparza et al, 1999). Thus, *PEACH* should be easily adapted to simulate productivity of local Zacatecan peach selections. This paper reports *PEACH* simulations comparing productivities of ‘Cal Red’ and a local ‘Criollo’ peach selection when grown at Jerez, Zac., Mexico and Fresno, CA. USA.

MATERIALS AND METHODS

Simulations presented in this paper were based on parameters and growth potential equations for the mid-season maturing cv. Cal Red as reported in Grossman (1994). The main modifications to the model parameters for simulations of ‘Criollo’ peaches are shown in Table 1 and were based on data from commercial peach trees growing in 1999 in an experimental orchard in Los Haro, Jerez, Zac, Mexico. Degree days rather than calendar days were used to fit the fruit growth potential equation. This equation was obtained by fitting cubic splines with knots at 700 and 1400 degree days to log-transformed dry weight data vs. degree days after bloom for fruit growing on 10 heavily thinned 7-year-old ‘Criollo’ peach trees. The fitting was done by using the method of least squares regression (SAS, Cary. NC. USA) as in Grossman (1995). Since this was a preliminary study to adjust *PEACH* to simulate productivity of Zacatecan peach cultivars, no other modifications to the supply and demand modules were made.

The environmental input variables used in the first set of simulations (maximum and minimum soil and air temperatures and solar radiation) corresponded to the weather station located at Parlier, Fresno, CA. for 1993 as originally used in *PEACH* (Grossman, 1994). In the case of Mexico, temperature data were obtained from a weather station located at El Durazno in Jerez, Zac., Mex. for 1999 and solar radiation data that were taken from a weather station located at Guadalupe, Zac, Mexico. The weather data were facilitated by CONAGUA-Zacatecas and the calculation of degree-days was done by the single sine, horizontal cutoff method, with critical temperatures of 7 and 35 ^{o}C (Zalom et al, 1983; DeJong and Goudriaan 1989).

RESULTS AND DISCUSSION

Environmental Variables

Figure 1 shows the environmental variables used as basic inputs in the model simulations. In general, Fresno, CA exhibited a Mediterranean-type weather pattern with a well defined warm, dry period as the season progressed. Jerez, on the other hand, had an environmental pattern that was fairly constant during the season. This ‘stability’ of the environment of Jerez compared to Fresno is the result of the different altitude and latitude of both locations (2,028 meters above sea level and 22^{o} 24’ lat. N vs. 110 meters above sea level and 36^{o} 36’ lat. N, respectively).

The beginning of the growth cycle was warmer in Jerez than in Fresno, but as the season progressed this situation reversed, with a consequent effect on degree day accumulation, physiology of the tree (photosynthesis, respiration, growth) and fruit productivity. Solar radiation also differed between locations (Fig. 1) with more and subsequently less radiation in Jerez than in Fresno at the beginning and end of the season, respectively. The rainfall season in Fresno occured during the winter, with open skies during the summer; on the other hand, Jerez had rain and therefore much more cloud cover than Fresno during the summer. The summer cloudiness of Jerez together with the short day length due to latitude caused less radiation than during mid-season at Fresno. The greater radiation at Fresno during the cycle growth, particularly when the foliage was fully developed, led to greater potential for CO_2 fixation and therefore carbohydrate availability for growth and productivity.

Model Simulations

The environmental differences between the two locations strongly influenced simulated carbohydrate assimilation of Cal Red peaches (Fig. 2). The simulated assimilation pattern was the result of the seasonal availability of photosynthetically active radiation intercepted by the tree canopy together with the total radiation received during the whole growth cycle as well as differences in temperature (Fig. 1). Consequently, simulated assimilation was slightly higher in Jerez at the beginning of the growth season during canopy development, but was lower later during the final two thirds of the growth cycle when the canopy was fully developed. Therefore simulated assimilation was greater in Fresno than in Jerez.

The greater assimilation in Fresno, particularly during the final two thirds of the growth cycle led to differences in simulated productivity of the peach trees in the two locations (Fig. 2). As the season advanced, the difference in simulated fresh fruit yield between both locations became more evident. Simulated yield differences were 12.4 kg tree^{-1} or 12.1 ton ha^{-1} for the same cultivar growing in both locations with a reduction of 41.5 g in predicted size of individual fruits in Jerez compared to Fresno (Table 2). Thus, the lower amount of available carbohydrates during fruit growth apparently limited the simulated fruit growth rates, fruit size, and tree productivity in Jerez compared to Fresno.

The second set of simulations considered the fruit growth potential equation for ‘Criollo’ peaches as well as the other specified changes (Table 1). The growth response of cv ‘Criollo’ represented just 26.2% that of ‘Cal Red’; that is, the individual fruit growth potential of ‘Cal Red’ is 3.8 times that of the ‘Criollo’ (Fig. 3).

The simulated fruit yield of “Criollo’ peaches when grown at Jerez, Mex., indicate that the genotype had a large influence on simulated final yield (Fig.4) in addition to environment (Fig. 2). The adjusted model predicted 22.4 ton fresh fruit ha^{-1} less with ‘Criollo’ than with ‘CalRed’ peaches growing at Jerez, Mexico. This represents a potential yield reduction of 60.1% with respect to ‘Cal Red’ peaches growing in California (Table 2).

Whereas California growers can attain yields of 60 ton ha^{-1} with little problem (DeJong et al, 1994), Zacatecan growers rarely attain more than 15-20 ton ha^{-1}.

Experience of some peach growers of Aguascalientes, the neighboring state to Zacatacas with a similar environment, indicate that yields of 30-35 ton ha^{-1} have been possible with some selected local cultivars in exceptional years.

Although preliminary and theoretical, the simulations presented here indicate possible explanations for the low yields of Zacatecan peaches even under the best local management practices as compared with those obtained in California. Both environmental conditions and cultivar characteristics, particularly fruit growth potentials, seem to contribute to the large disparity in yields.

Current research is being conducted to adjust the supply and demand modules of *PEACH* with equations and parameters for local Zacatecan cultivars, so the simulations presented here can be re-evaluated and validated. Our intent in this paper was to show how the *PEACH* model can be used as a tool for integrating genetic, physiological and environmental factors determining carbohydrate supply and demand for growth and productivity of peach trees at an orchard level.

ACKNOWLEDGMENTS

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Tables

Table 1. Parameters and calibration equations used in the model simulations. Dates given as day of year.

Parameter	Cultivar/Weather		
	CalRed/Fresno'93	Criollo/Jerez'2000	
		Simulation 1	Simulation 2
Latitude (ºN)	36	22	22
Training system	KAC-V	KAC-V	KAC-V
Vegetative budbreak date	80	80	66
Bloom date	75	75	61
Beginning fruit number	600	600	600
Final fruit number	300	300	400
Thinning date	121	121	91
Beginning fruit weight (g)	$6.15x10^{-4}$	$2.27x10^{-7}$	$2.27x10^{-7}$
Individual fruit weight eq'n	exp [-7.39 +0.032dd $-3.81x10^{-5}dd^2$ $+1.65x10^{-8}dd^3$ $-(dd>700)(1.44x10^{-8})(dd-700)^3$ $-(dd>1400)(2.73x10^{-9})(dd-400)^3$]	Exp [-15.29 +0.07dd $-9.69x10^{-5}dd^2$ $+4.59x10^{-8}dd^3$ $-(dd>700)(4.55x10^{-8})(dd-700)^3$ $-(dd>1400)(7.03x10^{-10})*(dd-1400)^3$]	

Table 2. Simulation results for individual fruit harvest weight and yield of 'Cal Red' and 'Criollo' peaches growing at Jerez, Mex. and Fresno CA.

Cultivar	Location	Fruit weight (g)		Fruit yield (kg tree^{-1})		Fruit yield (ton ha^{-1})		Difference with respect to the highest yield (%)
		Dry	Fresh	Dry	Fresh	Dry	Fresh	
Cal Red	Fresno, CA. USA	35.0	200	10.5	59.9	9.6	55.1	-
Cal Red	Jerez, Zac. Mex	27.8	158.5	8.3	47.5	7.6	43.0	22.0
Criollo	Jerez, Zac, Mex	10.3	58.9	4.13	23.5	3.8	21.6	60.1

Figures

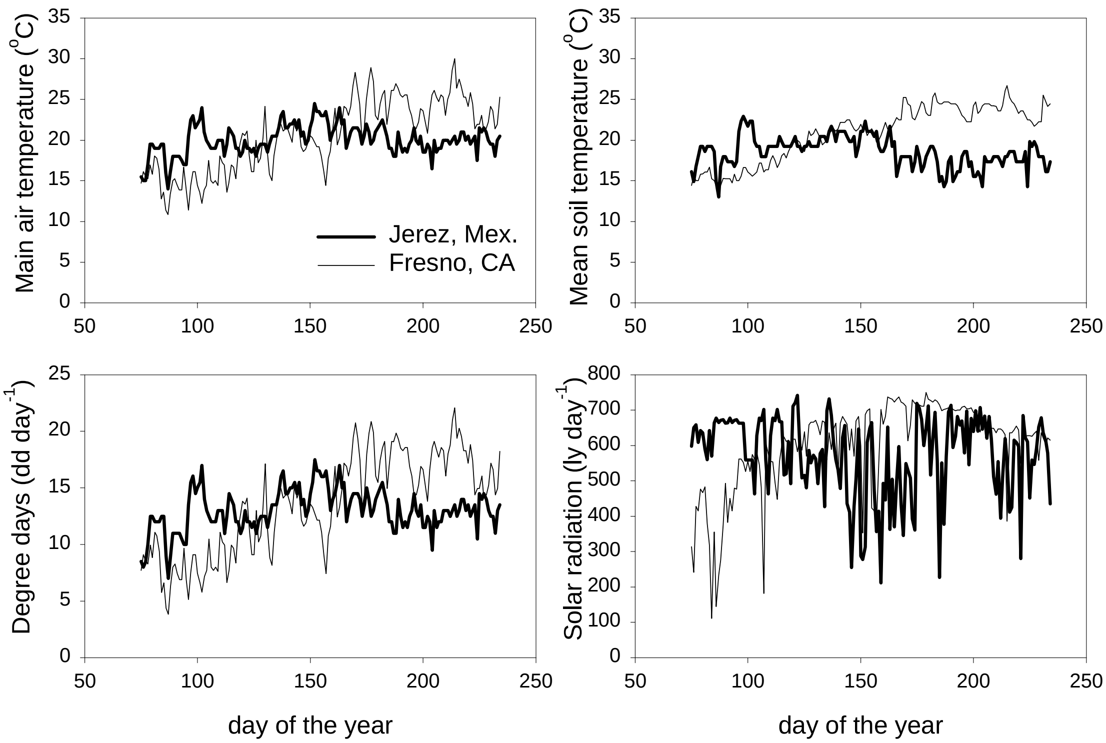

Fig. 1. Seasonal patterns of the environmental input variables used in the model simulations for two locations: Jerez, Zac. Mexico and Fresno, CA. USA.

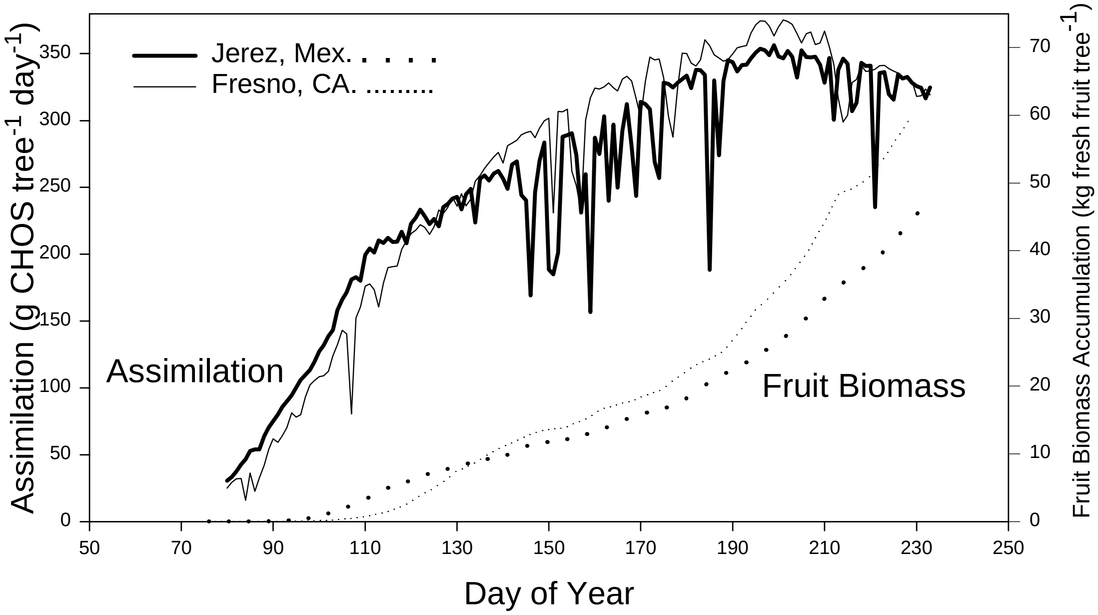

Fig. 2. Simulated carbohydrate assimilation and total fruit biomass accumulation of 'Cal Red' peach trees growing at Jerez, Zac. Mexico and Fresno, CA. USA

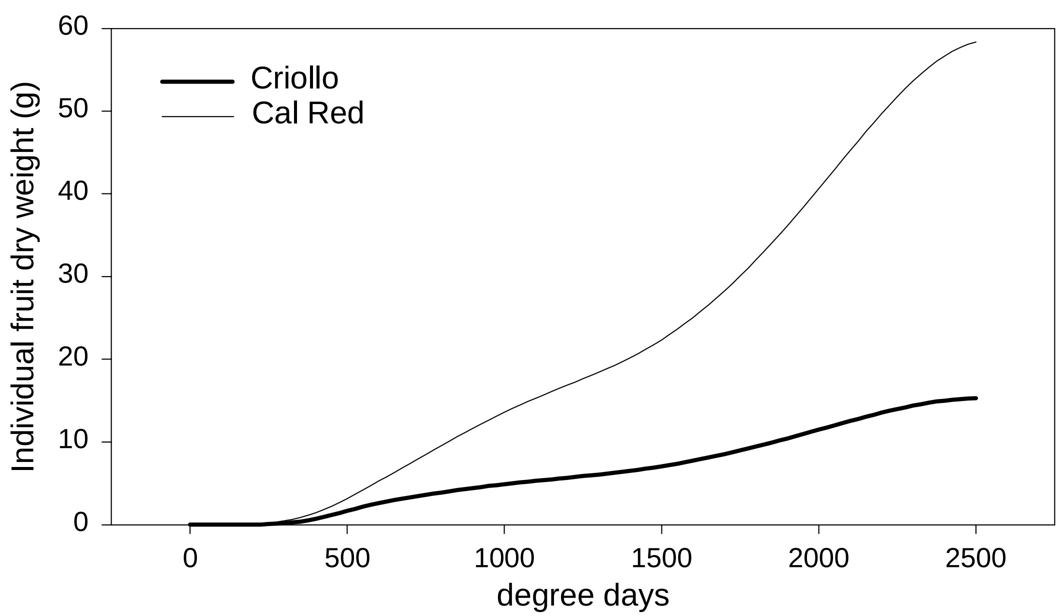

Fig. 3. Modeled individual fruit growth curves for 'Cal Red' and a local 'Criollo' peach selection of Zacatecas, Mexico.

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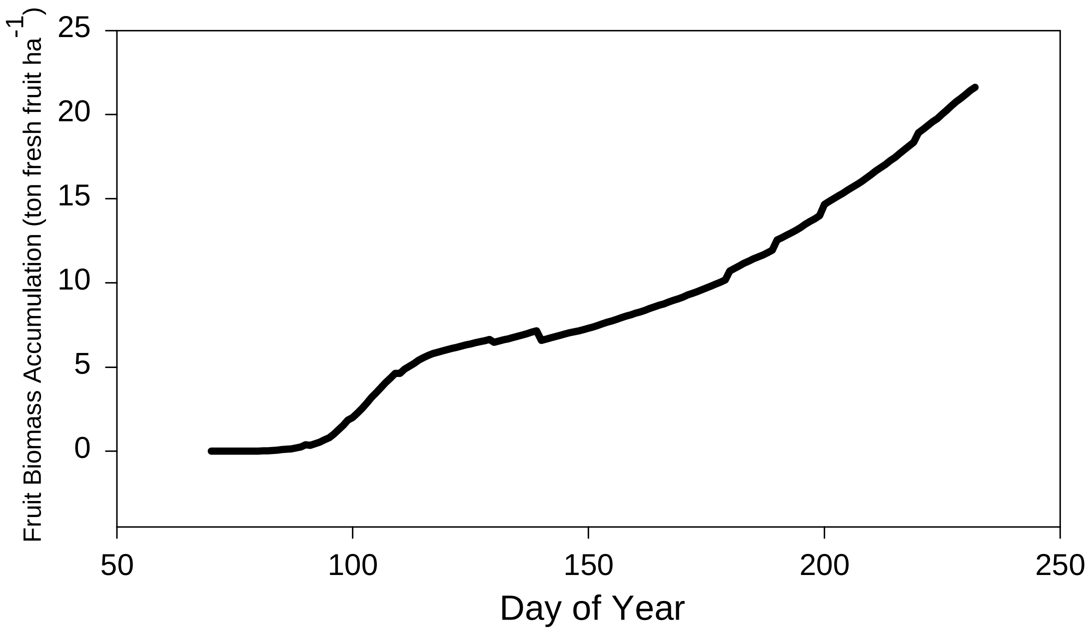

Fig. 4. Simulated fruit biomass accumulation for 'Criollo' peach trees growing at Jerez, Zac. Mexico