Using a 3-D Computer Simulation Model of Peach Tree Architectural Growth and Dry Matter Partitioning to Evaluate the Production Potential of Peach Trees on Size-Controlling Rootstocks

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Abstract

In this project, we developed a peach tree model that adapts all of the features of the L-PEACH model to simulating peach tree growth and crop productivity on size-controlling vs. standard rootstocks. This project can be thought of as an attempt to build a working peach tree *in silico* by assembling all the pertinent physiological and developmental concepts, information and data required to make a peach tree functional into a unified, integrated model. During the past year, we continued to improve the general model by developing a more detailed version of the model that simulates water uptake and transport so that the water potential of every part of a simulated tree is calculated hourly and fluctuates based on time of day, light, temperature, and leaf transpiration. Subsequently, we began improving the methods used to calculate carbohydrate transport within the model so that carbohydrate transport would be linked with water transport processes. At the same time more realistic sub-models of leaf and stem growth were developed and incorporated in the model so that vegetative growth can be updated hourly and is linked to the daily patterns of temperature and water potential. In 2010 we also completed anatomical and physiological studies of the xylem characteristics of size-controlling rootstocks compared to the standard Nemaguard rootstock. The theoretical xylem hydraulic conductance of the specific rootstocks that we have been studying in the rootstock project have been used as inputs to the L-PEACH model to simulate the dwarfing effect of specific rootstocks of tree growth and development.

Introduction

Crop growth and yield is dependent on a complex set of interactions involving the tree scion and rootstock genotype, the physiological and developmental processes that occur within the tree, the interaction of these processes with the environment that the plant grows in, and responses to horticultural manipulation of the tree by the crop manager. Understanding crop growth and yield responses of trees are more complex than most crops because the effects of all these factors are carried out over multiple years. Most experimental research concerning factors that influence these complex processes and the interactions between them has been limited to dealing with one, two, or at most three, environmental and/or management factors at a time and then monitoring a limited set of plant responses at the tissue, organ, or whole plant level. While these experimental approaches have yielded substantial information about tree crop responses to specific factors, many times experiments have led to conflicting results and it has been very difficult to develop an integrated understanding of crop growth and yield responses over multiple years in complex environments. Because of this lack of integrated understanding, research tends to be repeated in various forms over the years and true progress in some areas tends to stagnate until new experimental approaches are developed. Furthermore, research tends to get concentrated on specific topics that are measurable with newly available equipment (like photosynthesis, stomatal conductance, water potential, etc.), while information on other important topics (like canopy development processes, canopy architecture, bud fates, carbohydrate storage, etc.) tends to be neglected.

At the same time, molecular level plant biologists and geneticists are eager to apply their new-found tools of genomics, proteomics and metabolomics to solve crop production problems but they have even less understanding of the complex factors and processes controlling or influencing crop growth and yield than the field biologists/pomologists. If these modern techniques of plant biology are ever to be successfully applied to solving complex crop production problems, a more complete understanding of the factors influencing plant growth processes and the complex interactions between these processes and the environment, will be necessary. It will also be important to be able to predict outcomes of specific metabolic or developmental changes over several years.

Recent advances in computer technology have made it possible to develop functional-structural plant models that simultaneously simulate whole plant photosynthesis, tree architectural growth and carbon partitioning within the structure of the tree and simultaneously display tree structural development in three dimensions on a computer screen (Allen et al. 2005, 2007). The most advanced of these types of models is being developed to simulate peach tree growth and development and recent advances have successfully simulated responses to pruning and fruit thinning as well as environmental factors such as light and temperature (Lopez et al.2008).

Objective

The overall objective of this project is to develop a peach tree model that would adapt all of the features of the L-PEACH model to simulating peach tree growth and crop productivity on size-controlling vs. standard rootstocks. This project can be thought of as an attempt to build a working peach tree *in silico* by assembling all the pertinent physiological and developmental concepts, information and data required to make a peach tree functional into a unified, integrated model. It can be likened to trying to build a working car by studying a car and how it functions and then trying to build a working car by having a third of its parts, no manual and creating the missing parts by understanding the general behavior of how the car is supposed to work; and then assembling the car. This exercise forces one to pay attention to all parts (not just the ones that appear most important or interesting at first glance, or those that are easy to measure) and develop integrated understanding of tree function. This process points out the most important things that we don't understand about trees but also provides a means for the evaluation of new information or data within the context of whole plant functioning as it becomes available. Previous work on this model led us to the discovery that peach fruit grow according to a relative growth rate function and the importance of early spring temperatures on predicting harvest date and fruit sizing potential. This information is now at the center of recommendations for fruit thinning. This modeling work has also led to greatly increased understanding of tree and fruit growth responses to pruning. This type of understanding is what will be necessary to develop new approaches to manage tree growth, with or without size-controlling rootstocks, and develop more labor efficient orchard management practices.

During the past year we continued to improve the general model by developing a more detailed version of the model that simulates water uptake and transport so that the water potential of every part of a simulated tree is calculated hourly and fluctuates based on time of day, light, temperature, and leaf transpiration (Da Silva et al. 2011). Subsequently, we began improving the methods used to calculate carbohydrate transport within the model so that carbohydrate transport would be linked with water transport processes. This has been a very complex problem but we have successfully changed the model so that the modeled carbohydrate transport processes are more realistic. At the same time, more realistic sub-models of leaf and stem growth and development were developed and incorporated in the model so that vegetative growth can be updated hourly and is linked to the daily patterns of temperature and water potential. During 2010, we continued to refine and validate numerous aspects of the model. We also initiated detailed field studies of leaf and stem growth and development in order to develop accurate mathematical functions that describe leaf and stem growth.

In 2010 we also completed anatomical and physiological studies of the xylem characteristics of size-controlling rootstocks compared to the standard Nemaguard rootstock. These analyses showed that there are clear differences in the xylem anatomy of the size-controlling rootstocks. The differences in xylem anatomy directly relate to reduced theoretical hydraulic conductance among the various rootstocks (Tombesi, et al 2010 a and b) and thus, coupled with previous physiological studies (Basile et al. 2003 a and b; Solari et al, 2006 a, b, and c), provide the anatomical and physiological basis for understanding the size-controlling behavior of specific genotypes. We have also shown that analysis of xylem anatomy may be an efficient way to screen for size-controlling capacity among new rootstock genotypes (Tombesi et al. 2011). The theoretical xylem hydraulic conductance of the specific rootstocks that we have been studying in the rootstock project have been used as inputs to the L-PEACH model to simulate the dwarfing effect of specific rootstocks of tree growth and development (Figure 1).

This has been a very ambitious and challenging project that built on nearly 20 years of modeling experience with peach trees. It tested our current concepts of how environmental factors such as light and temperature as well as management factors such as pruning, fruit thinning, scion cultivar, rootstock, and irrigation interact to influence tree growth and fruit yield. In doing so, it has provided information about how to optimize management of orchards to meet grower needs.

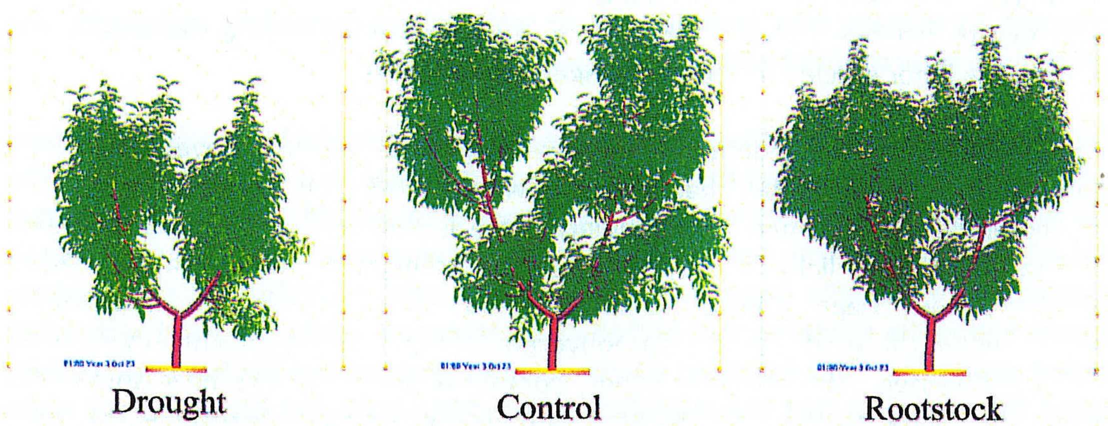

Figure 1. Graphical output of the L-PEACH virtual plant model after three different 4-yr simulation runs. The center (Control) tree shows simulated tree growth under well-watered conditions towards the end of the growing season after the 3rd leaf in an orchard situation. The tree on the left (drought) shows the simulated growth of the same tree when it was grown with modest drought caused by only irrigating at three week intervals and limiting root growth to a defined volume of soil so that the tree experienced mild water stress at the end of each irrigation cycle. The tree on the right (Rootstock) shows the growth of the same scion cultivar growing on a size-controlling rootstock with hydraulic conductance characteristics similar to HBOK 32. All trees were pruned on the computer during the "dormant" season to develop a perpendicular "V" structure.