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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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 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 so-called 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, the complex interactions between them, 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).

The overall objective of this proposal 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 the general model has been improved by developing a more detailed version of the model that uses an hourly rather than a daily time step for simulation so that the hourly course of environmental factors such as temperature and solar radiation can more accurately drive the carbon assimilation and tree growth. An entirely new sub-model for calculating the stem water potential throughout the tree has also been developed and this will permit dynamic simulations of interactions between organ water potential, carbon assimilation and tree and fruit growth. The work on incorporation of water potential calculations is not complete but enough progress has been made to determine that what we are trying to do is possible and we hope to have a working version of the model with this feature incorporated by the end of 2009.

In 2008 we began to calibrate the current L-PEACH model with data collected from trees growing on size-controlling rootstocks and also validate the parameters currently in the model for trees growing on a vigor-inducing (Nemaguard) rootstock. We collected and analyzed stem growth data from trees growing on Nemaguard as well as the new HBOK series of size-controlling rootstocks that are currently being evaluated in another project. Specifically, data was collected on architectural characteristics and bud fates on five categories of shoots growing on pruned trees growing on Nemaguard and HBOK 32 rootstock growing at the Kearney Agricultural Research and Extension Center. These data were statistically analyzed in collaboration with colleagues in France to develop Hidden Semi-Markov Chain (HSMC) models of bud fates on five different types of shoots (watersprouts (32-90 nodes with syleptic shoots), long shoots (19-35 nodes, no syleptic shoots), medium shoots (12-26 nodes), short shoots (8-18 nodes and spurs (5-11 nodes). Figure 1 provides a graphical example of the HSMC models developed for watersprouts of the same scion cultivar growing on two different rootstocks. These types of models will be used as input parameters in the L-PEACH model.

We have also begun collecting and analyzing data available from previous research to incorporate modeling of the nitrogen economy within the peach tree in conjunction with carbon assimilation and tree growth and development. When this aspect of the model is complete we hope to be able to have the nitrogen status of the tree be an additional factor that moderates simulations of tree growth and fruit yield and quality.

This is a very ambitious project that builds on nearly 20 years of modeling experience with peach trees. It will both test 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, irrigation and nitrogen fertilization interact to influence tree growth and fruit yield and quality. In doing so, it will provide information about how to optimize management of orchards to meet grower needs.

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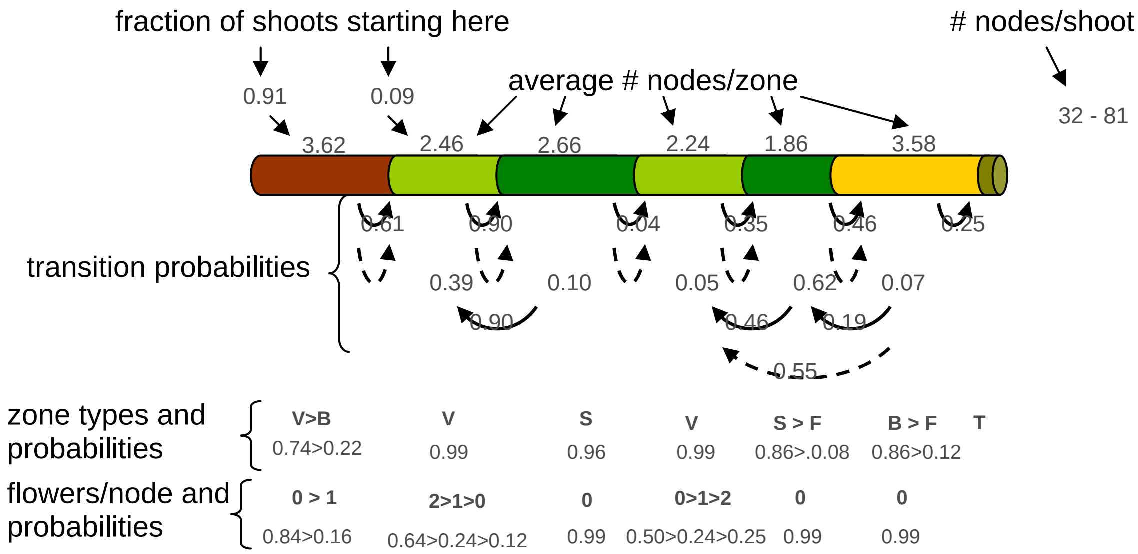
HBOK 32

Watersprout: 6 states + Terminal bud



Nemaguard

Watersprout: 6 states + terminal bud

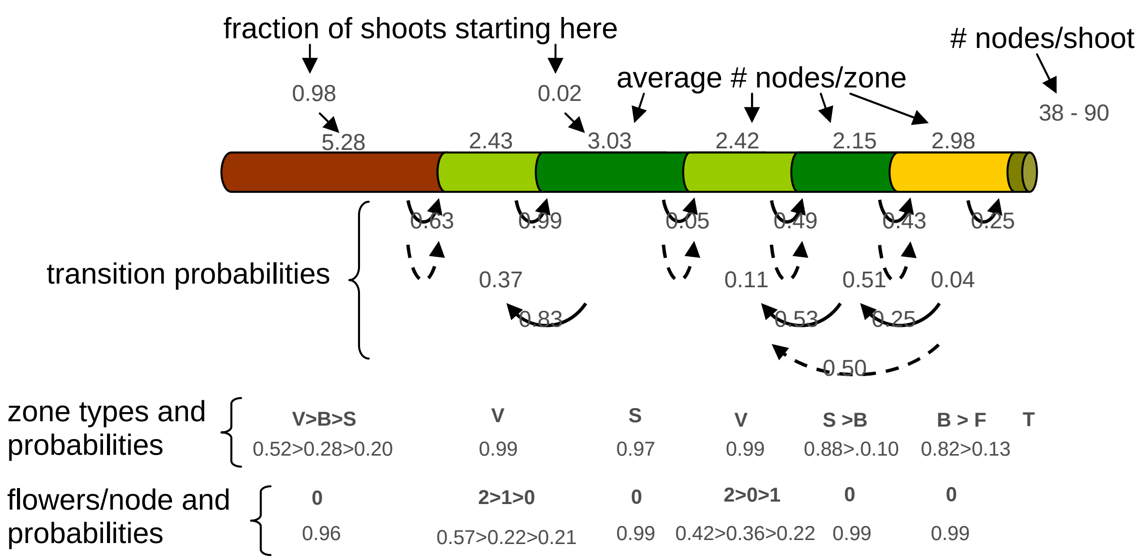


Figure 1. Examples of statistical HSMC shoot models for shoots of nectarine. Each shoot is statistically divided into zones according to bud fates in those zones. Bud types are vegetative (V), syleptic (or side shoot (S)), blind (B) or floral (F). Flowers can be produced either lateral to V buds (as in the 2nd zone) or as lateral buds on the main stem as in 6th zone. Transition probabilities indicate the likelihood of moving forward to the next zone or reverting to s previous zone.

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