Assessing the Carbon Budget of Almond Trees & Developing a 3-D Computer Simulation Model of Almond Tree Architectural Growth and Dry Matter Partitioning

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Objectives:

This project has two major objectives. The first is to review and develop research data on almond (and related species) tree growth; biomass production; dry matter partitioning; and carbon and nitrogen assimilation, utilization and distribution in order to estimate the amount of carbon that is sequestered in almond orchards.

The second and longer term objective is to develop a comprehensive, functional- structural tree model of almond tree architectural development, growth, and carbon partitioning/source-sink interactions within the tree. This model will simulate growth and physiological responses to light distribution within the canopy, seasonal and hourly temperature, pruning, crop load and water stress.

Pertinent data from both of these projects will be compiled and provided to Johan Six's laboratory for greenhouse gas modeling purposes.

Introduction:

In order to estimate the ability of almond orchards to sequester carbon it is important to be able to estimate the amount of carbon contained in the biomass of trees. To do this we need to establish relationships between the above and below ground biomass accumulation. This question was approached by first looking at the published literature on almond and peach and subsequently attempting to obtain standing biomass data from professional tree removal companies.

Almond tree growth and yield is dependent on a complex set of interactions involving the plant genotype, the physiological and developmental processes that occur within the tree, the interaction of these processes with the environment that the tree grows in, and responses to horticultural manipulation of the tree by the grower. Understanding carbon budget, growth and yield responses of perennial crops like almond are even more complex than most crops because the effects of all these factors are carried out over multiple 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 display tree structural development in three dimensions on a computer screen. The most advanced of these types of models is the L-Peach model that is being developed to simulate peach tree growth and development. The long-term objective of this project is to continue the development of the L-Peach model and convert it to an L-Almond model.

Developing a database on standing biomass in almond and related species:

The first objective of this proposal was to review the published literature on almond and a closely related species (peach) to gain insight into whole tree biomass accumulation rates as trees age. It was also important to know the relative proportions of that biomass that are found in roots compared to the tops of trees. Unfortunately relatively little published data are available on whole tree biomass accumulation in almond trees and the published data were insufficient to make reliable estimates of the amount of carbon contained in the standing biomass of mature almond orchards at this time. However in the past several years it has become standard practice to engage professional tree removal companies to remove almond orchards at the end of their productive life. Since these companies haul and weigh the chippings subsequent to the removal of an orchard, reasonable estimates of orchard standing biomass should be available from these operations.

We have contacted several of these companies and requested their cooperation in sharing data resulting from orchard removal. We have had some difficulties in obtaining detailed data because of information privacy issues but hope to solve those issues soon. The data we are attempting to compile includes location of removed orchard (so that we can get an arial view of it from Google earth images), age of the orchard, spacing of the trees and cultivars. In addition, Bruce Lampinen's laboratory has measured the total canopy light interception of some orchards just prior to removal to be able to calibrate the biomass estimates with ground cover estimates from Google images and make adjustments for missing trees. We believe that this approach will provide good estimates of standing biomass of mature almond orchards and will be useful for estimating beneficial environmental aspects of orchards.

Developing an L-Almond Model:

The first step was to develop statistical models to describe patterns of buds that occur along Nonpareil almond shoots of different lengths. Preliminary statistical models were developed last year based on data collected in 2008. During 2009 and 2010 three field studies were initiated to develop more detailed statistical shoot models to describe shoots of cultivars with contrasting growth habits (Nonpareil, Aldrich and Winters) and to study shoot architectural responses to water stress and pruning. The data collection phase of these studies will be completed in 2011.

The second step was to begin converting the L-Peach model into an L-Almond model by inserting leaf photosynthetic characteristics of almond trees and the statistical models of almond shoots into the L-Peach model. Preliminary work on this was done in 2008 and this exercise documented that it could be done. However we must now wait until the more robust statistical models are developed based on the field work described above.

In the meantime we have completed research to incorporate water transport within the tree structures generated by the L-Peach model so that hourly values for water potential can be calculated each hour for every node within the structure of the simulated trees. The hourly water potential values calculated by the model now interact with the physiological functioning of the trees so that tree growth and yield responses to irrigation scheduling can now also be simulated by the model (Figures 1 and 2). Development of this integrated dynamic simulation model of almond tree growth and productivity is a challenging project but will result in the most sophisticated environmental physiology-based model of a fruit or nut tree ever developed.

A corollary effort associated with this project has been to analyze data from the spur dynamics study carried out by Dr. Lampinen's laboratory from 2001 to 2007, in order to develop data on long-term spur behaviour that can be used in the L-Almond model. In the spur-dynamics study twenty-four hundred spurs were initially tagged in 2001. During the first three seasons (i.e. until 2004) spurs died at the rate of about 9% per year. After 2004 this mortality rate increased to approximately 24% per year (Figure 3). Previous year leaf area (PYLA) of spurs was directly related to whether spurs remained alive and the number of flowers they bore in the following year (Figures 4, 5 and 6). The probability of flowering was over 80% for spurs with PYLA values over 48.5 cm^2. The same level of probability of survival after not bearing occurred with PYLA values >8.96 cm^2. The probability of flowering in spurs that bore fruits in a previous year was very low, indicating a clear pattern of alternate bearing at the spur level. The probability of different numbers of flowers occurring on a spur was significantly related to the spur PYLA (Figure 6). For spurs with PYLA values less than 44.47 cm^2, the probability of having two or less flowers was significantly greater than having three or more flowers per spur. Spurs with PYLA values higher than 44.47 cm^2 had a higher probability of having three or more flowers per spur than having less than two flowers.

These data provide clear insights into the mortality and reproductive behaviour almond spurs. These data also will provide valuable information for the development of the L-Almond model but they also provide insights into factors that determine the yield in almond trees. The lower spur mortality rate in the early years of the study corresponded with years just prior to canopy "closure" while the trees were still "filling their allotted space". After 2005 most trees had filled the alleyway and the trees reached near maximum light interception for this orchard. During this period, approximately 25% of the spurs died in each year. This means that it would have been necessary to renew ~25% of its spur population each year in order to maintain a constant level of production. This study provides just an initial picture of the importance of maintaining spur health and spur renewal in mature bearing almond trees. We are continuing to further analyze the "spur dynamics" dataset to develop a clearer picture of the relationship between individual spur performance and orchard productivity.

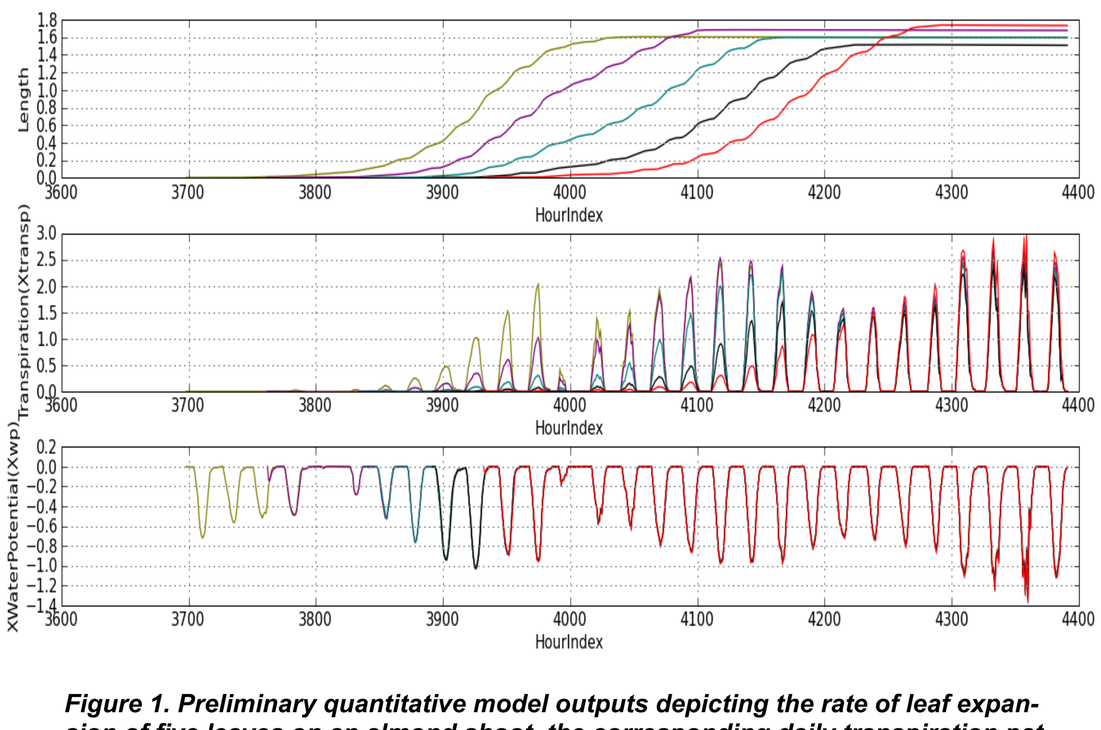

Figure 1. Preliminary quantitative model outputs depicting the rate of leaf expansion of five leaves on an almond shoot, the corresponding daily transpiration pattern of those leaves, and the daily pattern of xylem water potential of the stem bearing the leaves for a well-watered tree.

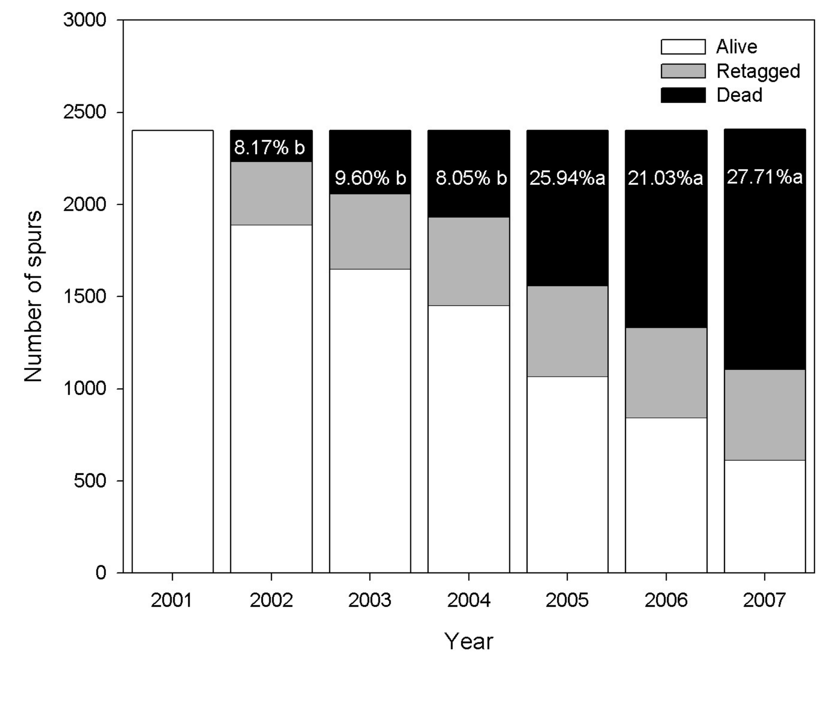

Figure 3. Number of living, dead and retagged almond spurs tagged in 2001 (total 2400). Percentages reflect the number of dead spurs in relation to the number of spurs alive in the previous year.

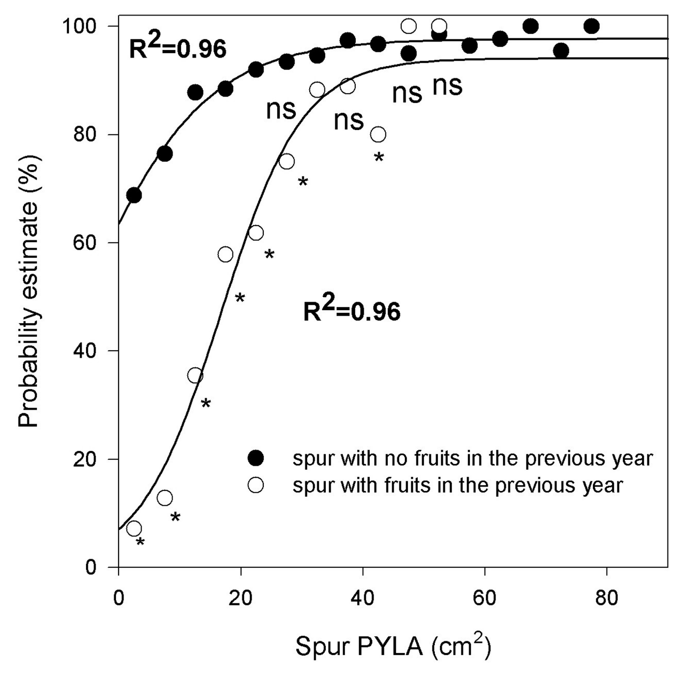

Figure 5. Probability estimation (%) of spur survival after bearing and not bearing fruit in the previous year in relation to frequency classes of spur previous year leaf area (PYLA, cm^2).

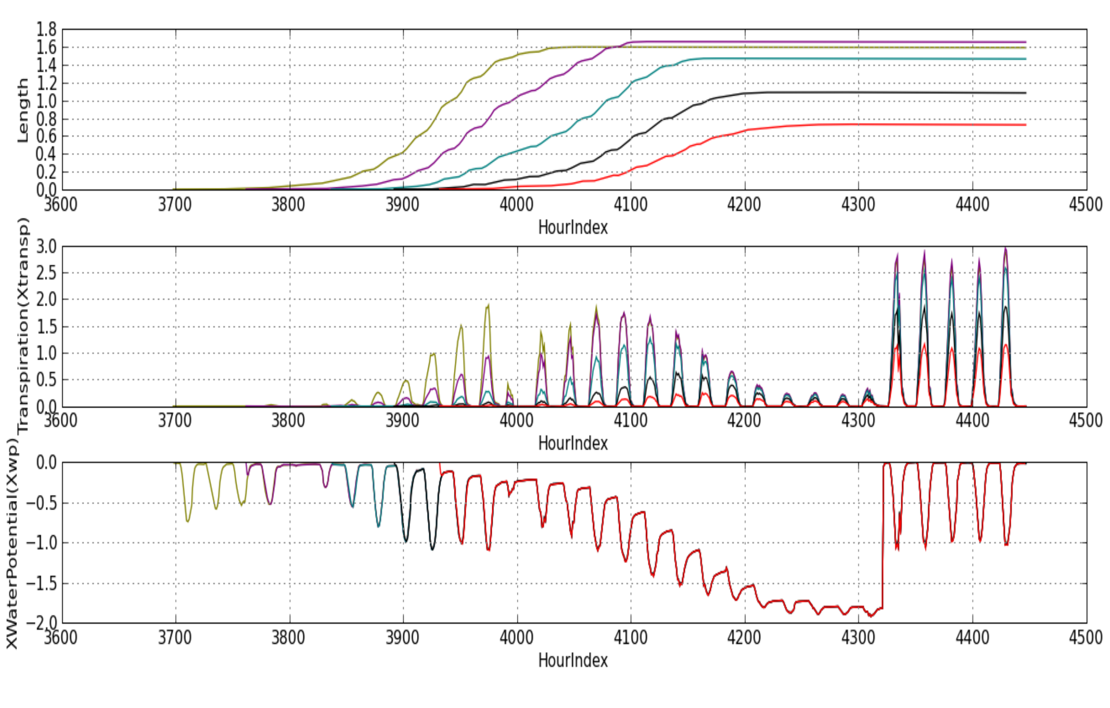

Figure 2. Preliminary quantitative model outputs depicting the rate of leaf expansion of five leaves on an almond shoot, the corresponding daily transpiration pattern of those leaves, and the daily pattern of xylem water potential of the stem bearing the leaves for a water stressed tree.

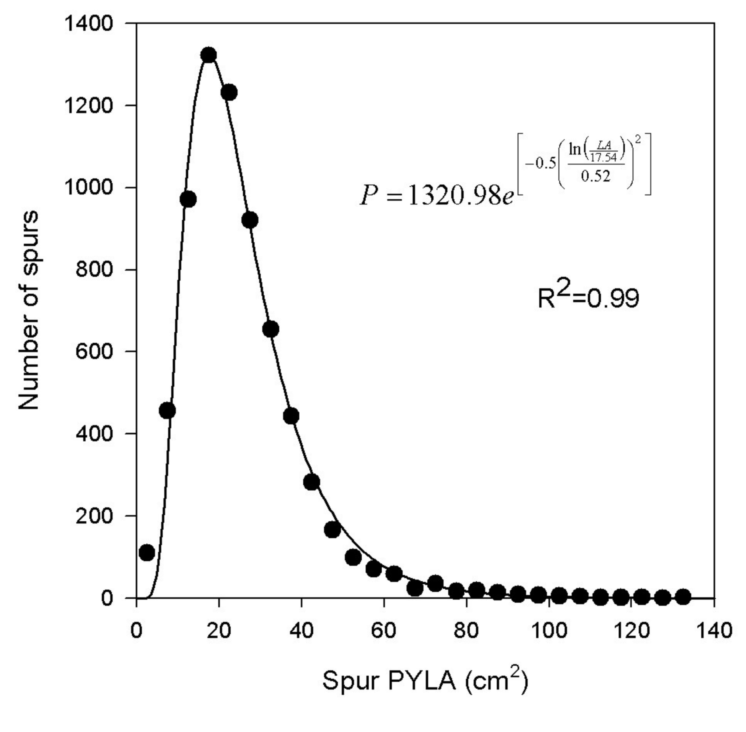

Figure 4. Spur distributions with respect to their previous year leaf area (PYLA, cm^2). (n=6,890)

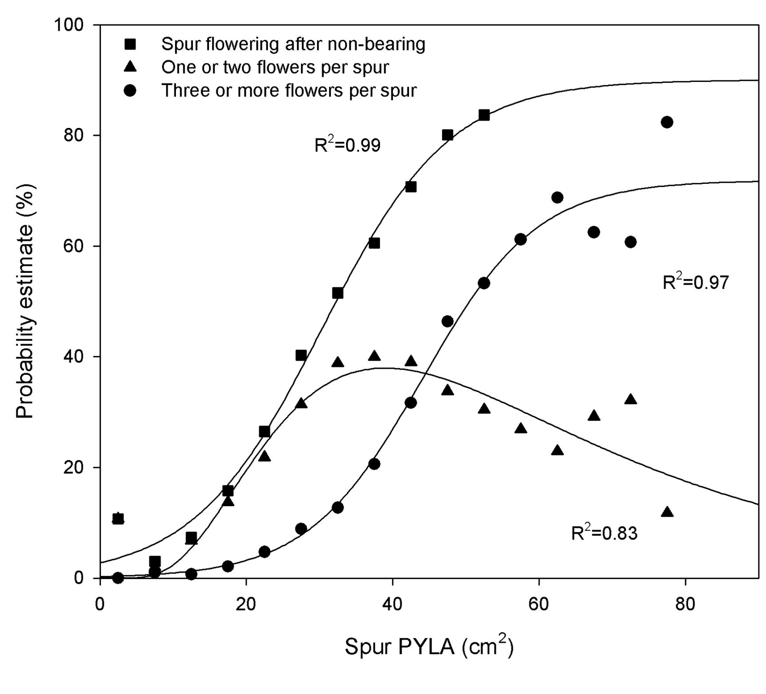

Figure 6. Probability estimation (%) of spur flowering and probability of spur bearing fewer than 2 flowers or 3 or more flowers after not bearing in the previous year in relation to frequency classes of spur previous year leaf area (PYLA, cm^2).

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