Precision canopy and water management of specialty crops through sensor based decision making

Annual Report (2010-11)

A. UC Davis:

Objective #1: Canopy architecture measurement:

(i) **Light bar unit:** The third generation mobile platform light bar was used extensively to map midday canopy PAR interception in approximately 20 almond orchards and 20 walnut orchards in 2011. This included trials looking at new rootstocks, varieties, pruning treatments as well as methyl bromide alternatives. In addition, seasonal midday canopy PAR interception was followed in one mature almond orchard as well as one 4 year old and one 10 year old walnut orchard. Finally, the mobile platform light bar was used to assess diurnal patterns of PAR interception in almond orchards planted in a north/south versus east/west row orientation. The unit was also tested in hazelnut orchards in Oregon. The mobile platform performed well in all the orchards surveyed.

(ii) **LIDAR:** The mobile platform was retrofitted with a LIDAR and some preliminary data was obtained in an walnut orchard on UC Davis campus. The data has been analyzed to recognize individual trees and determine the canopy height and volume. Plans to correlate LIDAR data with light bar data are currently underway.

Objective #2: Plant water status determination:

(i) **Sensor suite:** A mobile sensor suite was developed and evaluated by our research group to predict plant water status by measuring the leaf temperature of fruit and nut trees. It consists of an infrared thermometer to measure leaf temperature along with relevant ambient sensors (- wind speed, PAR normal to the leaf surface, RH, and atmospheric temperature). It was successfully evaluated for classifying stressed and unstressed almond and walnut trees with maximum error of 10% and 7%, respectively. Stepwise linear regression models developed for leaf temperature yielded coefficient of multiple determination ($R^2$) values of 0.82 and 0.90 for almonds and walnuts, respectively. The applicability of the system for grapevines was also studied. Field experiments were done on grapevines with controlled irrigation levels and stepwise regression analysis was used to develop a model for predicting leaf temperature. It was found that due to the complex shape of grape leaves and its large size, temperature distribution over the leaf had high variability (maximum range of about 3-5 deg C) making it difficult to measure one representative temperature value per leaf. Therefore, model developed from
sunlit leaf temperature values had a low $R^2$ value of 0.71. On the other hand, shaded leaves do not have significant problem of temperature variation over a single leaf. Stem water potential (SWP), air temperature and PAR were found to be significant parameters for the shaded leaf model and the model had a coefficient of multiple determination of 0.86. These results show the feasibility that the sensor suite can be used to determine plant water status for irrigation and quality management in grapevines.

(ii) **Psychrometer:** During the 2011 season, a total of 6 irrigation treatments were applied in a Dunnigan Hills vineyard to obtain a wide range of stress levels and stress timings. From July to mid-August, stem water potential (SWP) ranged from -0.6 MPa in the control vines to -1.4 MPa in the early deficit vines, and from mid-August through harvest (early October), SWP ranged from -0.4 MPa to -1.7 MPa. These values cover essentially all of the physiological range exhibited by grapevine under cultivation, and hence provided an adequate framework for the calibration of the remote and local sensor suites being used. A recently developed automated (psychrometric) method for frequent, in-situ measurement of SWP was also evaluated in grapevine and other crops, and in most cases for all crops, the psychrometric measurement of SWP agreed very closely (within 0.1 MPA) with SWP as measured by the pressure chamber. In some cases for grapes, however, agreement was not good (+0.5 MPa higher in the psychrometric method than the pressure chamber), and the reasons for this are being investigated. A reliable, automated device for the measurement of SWP will be invaluable for research as well as for practical irrigation management.

**Objective #3: Universal Navigation Computer:**

Engineering development of the Universal Navigation Computer has resulted in the implementation of a new high sensitivity GPS algorithm using a Kalman Filter. This new high sensitivity GPS algorithm is capable of tracking GPS under the heavy canopy found in orchards. Extensive testing of the algorithm has been done in California, primarily in walnut orchards, and in Arizona in a variety of different orchards. Typical GPS positioning yield has been over 99%, even under very heavy canopy. Work has started integrating the measurements from a newly developed inertial measurement unit (IMU) (3-axis gyro and 3-axis accelerometer) into the Kalman Filter to aid the positioning accuracy.

Testing of the logging capability of the data logging GPS receiver (aka Universal Navigation Computer) has started. Initial results show a data synchronization issue that must be resolved.

**Objective #5: Variable Rate Irrigation Management:**
We developed a valve control system that is integrated with the eKo Pro wireless crop monitoring system (MEMSIC, Andover, Massachusetts). The system consists of battery-powered and solar-recharged nodes (radios) that transmit data to a base radio and computer using a mesh-network topology. Valve actuator hardware and embedded software were designed to operate a latching solenoid valve. A web-based user interface was created to allow users to send and monitor actuation commands. The actuator design was stress-tested by actuating four valves over 11,000 times each. Three valves were short-circuited and actuated over 6,000 times. Two soil moisture sensors were evaluated for use with this network. The VH400 (Vegetronix, Sandy, Utah) is a relatively new sensor with similar capabilities, but half the cost of the popular EC-5 (Decagon Devices, Pullman, Washington). Sensor voltage was calibrated against actual volumetric water content for both sensors. The VH400 was found to be more temperature sensitive than the EC-5, but may be a viable alternative to the EC-5 if buried beneath sufficient soil to limit temperature swings.

For summer 2012 we are planning a comparison of two different irrigation strategies in nut crops (walnuts and almonds) and vineyards that will be carried out using the wireless network. The first irrigation strategy will be based on a measurement of plant stress levels, given by “Objective 2” of the project as a prescription schedule. The second strategy will be based on ET as a standardized model of conventional irrigation. The ET-based irrigation strategy will use the climate data from the CIMIS available on their web, and freely available for every grower. To get and parse the climate data from the web, we are developing software that reads and processes the data to get water needs based on ET. This software application will be connected to the actuation interface so it can send commands to the wireless nodes that control the valves. The field test will be organized in pairs where a group of 5 trees will receive the plant stress level measurement treatment, independent for each block. The other group of 5 trees will receive the ET-based strategy uniformly for all the blocks in the orchard. In addition, the grower strategy will be compared, based on whatever criteria the grower uses for the irrigation of the commercial orchard. The independent variables to consider in the analysis of the study should be based on water use and crop yield that will be translated into economic units for a better understanding by the growers.

B. University of Arizona:

Arizona

The PI’s from the University of Arizona have met to discuss issues with site selection, instrumentation, and field deployment of platform. Two sites from our
grower cooperator (FICO) were selected: a) Fields 7-8 in San Simon AZ are two blocks in a young orchard that was chosen to carry out the irrigation control component of the project due to the existing irrigation infrastructure; and b) Field 24 in Sahuarita AZ and Field 24 in Continental AZ were chosen to study the light penetration and ambient monitoring characteristics of mature orchards under intensive pruning management.

Objective #2: Detect soil and plant water status.

a) Soil. On 11/11/2010 we performed an apparent electrical conductivity survey of Fields 7-8-San Simon to characterize field zones with different physical/chemical characteristics. Based on these data, we selected two trees to install watermark sensors to monitor the dynamics of soil moisture content along the year. On 3-24-2011 we installed sensors at two depths (20 and 40 inches) in all four directions (N, E, W, and S) 5 feet away from the tree trunk. The data-loggers were set to record moisture data every hour. In a different front, we worked on the design and field testing of a probe for mc measurements. In this task we worked with Retrokool Inc. who provided a resonant circuit that we connected to the tip of a stainless steel cone penetrometer and to the rod of the probe. This set-up was meant to be a prototype for concept testing. Simultaneously Veris Technologies worked on the development of an optical system for soil mc measurements. Recent performance tests show good results of the resonant frequency sensor but mechanical stability of the probe remains an issue that needs to be solved.

b) Plant/ambient. During the Summer months we spent significant time in the construction of a platform for sensor deployment. Specifically we worked on front-mounted boom and hardware fabrication, sensor mounting/connection, and data-acquisition software. The sensors mounted in the moving platform include a 25ft wide bar of light (PAR) sensors, anemometer, 3 infra-red thermometers (in nadir position), pyranometer, and temperature/relative humidity sensors. Geo-positioning data were generated with a GPS receiver (Trimble AgGPS-442) with an antenna mounted in the center of the front mounted boom. All these instruments were connected to a Campbell Scientific (CR-3000) data logger. In addition to the sensor system in the moving platform, we worked on the integration of sensors for a portable weather station. This station included: anemometer - wind direction, ambient temperature – RH, and a pyranometer. These sensors were serially connected to a lap-top for data acquisition. We successfully deployed the full system on 9/28/2011 in Field 24-Sahuarita and Field 24-Continental.

Objective #7: Evaluate social implications
During the annual AZ pecan growers meeting on 9/16/2011, I requested the assistance of growers to answer a questionnaire prepared by Peter Noak for the purposes of this objective. Eight questionnaires were returned out of 17 that were hand delivered on that day.

New Mexico

1) Conducted search for NMSU graduate student. Hired graduate student (Ph.D.) Marisa Thompson-Potter to work for the New Mexico portion of the project.

2) Found mature commercial pecan orchard in New Mexico suitable for study. Made arrangements with grower to work at that site.

Due to the timing of pecan harvest in Year 1 (2011) relative to the finalization of the equipment at the University of AZ, the first measurements will be made in the New Mexico orchard in Year 2 (2012). Arrangements were made to conduct the New Mexico pecan survey at the Western Pecan Growers Association Conference (March 4-6, 2012, Las Cruces, NM). There were two in-person meetings in AZ (one at FICO in San Simon, one at the APGA conference in Tucson. There was one meeting on UA main campus in Tucson that I attended remotely via telephone.

C. Washington State University:

(i) Objective #1: Measure Canopy Architecture and PAR Absorption

A computer data acquisition system suitable for high-density cherry/apple orchard measurement with real-time data visualization capability has been developed. This system was implemented under LABVIEW environment, and the developed software could be easily shared with all project partners. A series of cherry orchard PAR measurement tests were conducted in WSU Roza Research Orchard located near Prosser, WA. PAR data were collected from two rows of high density cherry trees in “UFO” canopy architecture. The PAR measurement tests were also conducted in apple trees in “Y” trellis at commercial apple orchards near Prosser. All the data acquisition tests were conducted from Dawn (5:00 AM) to Dusk (9:00 PM), with a 2-hr interval in between the measurements. The system was re-calibrated to the light condition of the data recording time about 5 min prior to each measurement, and the scan rate of the data acquisition system was set at 10 Hz. From the results obtained from these experiments, it was found that the light interception for ‘Y’ trellis was higher than that for UFO over the whole day, and the largest difference was detected around noon, and the differences in early morning and later afternoon between these two architectures were negligible. This study also found that if the measurement were conducted
between 9 and 11 am, the obtained results would be very close to their daily average for both canopy structures.

(ii) **Objective #2: Detect Soil and Plant Water Status**

The sensors for the sensor suite have been purchased and wired up. We have a PhD student that is working on this sensor suite and another student (supported on other funds) will arrive in January to assist him. This sensor suite will be available to collect data during the 2012 season. In addition, we have investigated the possibility of using a sensor suite integrated by an infrared thermography, a handheld light bar, and a multi-spectral camera to monitor water stress of grape vines. This integrated sensor suite used the infrared thermography to detect temperature distribution patterns of sunlit and shaded canopies; used the handheld light bar and the multi-spectral camera to measure the percentage of PAR interception of grape canopy under different water stress level. Some useful data have been obtained so far. A follow-up experiment has been planned for the next year for obtaining sufficient data to draw conclusions.

(iii) **Objective #4: Develop a Visualization and Decision Support System**

We have been extending the data visualization module with the following capabilities: (1) customizable data importing routine for importing data from multiple source and multiple format, and users may define their own meta data models; (2) improved 2D and 3D visualization capability, including multiple-layer 3-D visualization for multiple data sets and customizable color map that supports multi-dimensional data visualization; (3) integration with USDA/NRCS geographic database (near completion); (4) a new user interface for farmers (under development); and (5) a prototype of Mobile (iPad) app (under development) that enables the on-the-go access to the visualization/decision support system. We have also conducted research on the following topics, and obtained some preliminary results: (1) automated rating of pruning degree using image processing technique and neural networks; and (2) automated identification of tree positions using PAR data.

(iv) **Objective #5: Develop Variable Rate Water Application System**

We are waiting on the availability of valve actuator control boards that interface with the eKo wireless network sensors. These will allow us to simultaneously collect data from up to three sensors and control up to four latching solenoid valves. This will allow us to create the precision irrigation control system in a test orchard that we have set up. We plan to set this system up this winter so that it will hopefully be available by spring. We are confident that we will be on track to meet the project's requirements.
D. Objective #6: Economic Analysis (Oregon State University, UC Davis, and University of Arizona)

The economic team met in Las Vegas in May to discuss software tools for growers to assess their ability to adopt technology and provide a framework to determine the rate at which they can invest in new technology.

Two software programs were reviewed and modifications suggested before their final stages of development - Budget Planner and AgFinance™. The Budget Planner program will be used to generate enterprise budgets for nut, apple and grape crops. These budgets will be developed from input cost and return data from field trials. The AgFinance™ program is a whole farm and ranch analysis program that generates financial ratios and performance measures - liquidity, solvency, profitability, repayment capacity, and efficiency. This program will determine the financial feasibility of adopting sensory technologies by farm size based on assets, liabilities and net worth.

The team also developed a data collection form. This form serves as a guide for researchers as they gather data from their field trials. This form is a template to record the location of the trial and to insert production information, land preparation and cultivation operations, chemicals used, fertilizer and water applications. This information will be inserted into Budget Planner to generate enterprise budgets to compare the return and costs of each field treatment.

E. Objective #7: Social Implications

A comprehensive survey that focuses on the sensors and technologies being developed in this project has been developed and posted at http://questionpro.com/t/AGtjsZLAR1. We are in the process of contacting growers to take this survey.