PennState
College of Agricultural Sciences

PROPOSAL TRANSMITTAL

Date: 12/17/2018 **PSU Ref. No: 206014**

Title: A Sensor-Based Irrigation Test System for Apple Orchards

Submitted to: Patti Keller

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Proposed Project **3/1/2019 - 2/29/2020** **Total Project Request: $13,244**

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Research Grant Proposal for 2019
State Horticultural Association of Pennsylvania

Title: A Sensor-Based Irrigation Test System for Apple Orchards

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Duration of Project: Continuing project; year 2/2

This project is a continuing project from 2018, which addresses the 2018/2019 SHAP Research Priority: "Use of new technology to improve data collection for decision making." The primary goal and research objectives are proposed in our original proposal, the research activities in the year 2019 will be emphasized here. In 2018, we have tested a few sensors, and conducted four different irrigation scheduling strategies using sensor data and weather data. The research activities for 2019 include: 1) crop/soil water status monitoring; 2) automated irrigation system with center controller and wireless communication; and 3) evaluation of the crop production with the different irrigation treatments.

Sensor monitoring and irrigation planning strategy

In our original proposal, we planned only using infrared thermal sensors to monitor the crop water stress of apple trees, thus to establish the irrigation scheduling plan based on the crop water stress index (CWSI). While, due to the high relative humidity, too much cloudy and rainy days, the calculation of CWSI was in a big variation. We added the soil moisture sensors to monitor the soil water content and potential since early June 2018, and investigated the irrigation scheduling strategies based on these sensors. Based on the sensors tried in 2018, soil moisture sensors, including soil water content and soil water potentials sensors presented more stable and robust indication for the irrigation (Details will be in the project report). Figure I shows the soil moisture sensor system used in our test orchard. There are three soil moisture sensors and two soil potential sensors, which were installed at different depth of ground in tree root zone. In 2019, we will mainly use the soil moisture sensors to provide the decision making for the irrigation events. While the thermal sensors will be still used to monitor the crop as a reference information. With the integration of using soil moisture sensors and infrared thermal sensors, it will provide the opportunity to tune the soil moisture based irrigation scheduling strategy.

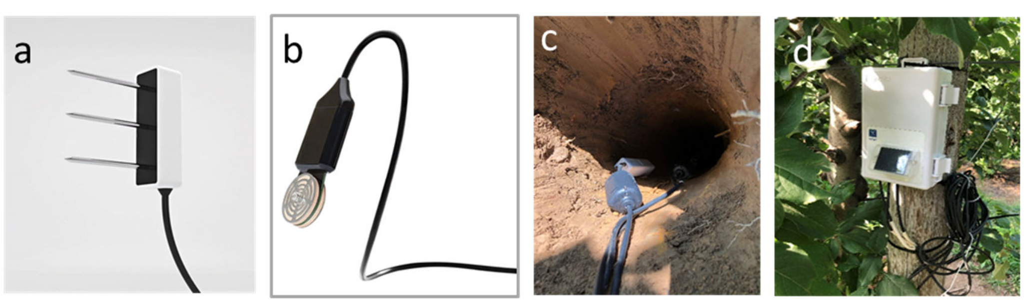

Figure I. Soil moisture sensor systems. a) soil water content sensor; b) soil potential sensor; c) installation of sensors; and d) sensor data acquisition

Automated irrigation with center controller and wireless communication

A wireless communication system will be developed to record the data from sensors/climate station and conduct the decision making for the on/off of the irrigation system. These sensor data will be accessible from remote end-user units, such as laptops and cell phones, which will provide the real-time crop monitoring information for growers. A center control system including solenoid valves and controller will be developed for automated irrigation operation. Additionally, we will evaluate the use of a small UAV (Unmanned Aerial Vehicle) with a thermal camera to monitor the crop canopy water stress. (We will use our previously purchased Drone and camera for this data acquisition.) This will give us the overall canopy water stress information for the test block.

Evaluation of crop production with different irrigation treatments

We will still use the same orchard block for the test in 2019 as in 2018 (0.9 acre Fuji block with tall spindle tree architecture). In the test block, six rows will be used for our experiment, including two rows with soil moisture based irrigation, two rows with ET based irrigation, and two rows with conventional irrigation. The final fruit quality and yield will be evaluated for these different irrigation treatments.

Original proposal we submitted in 2018:

Justification: Irrigation is the application of controlled amounts of water to plants at needed intervals. Irrigation helps grow agricultural crops, maintain landscapes, and revegetate disturbed soils in dry areas and during periods of inadequate rainfall. Precipitation in Pennsylvania averages about 37 inches each year. About 13 inches of this precipitation runs off land into streams, while 24 inches infiltrates into the soil, where it can be used by crops. While uneven precipitation can cause plant stress during critical growth periods, which will affect both crop productivity and produce quality, most horticultural crops require supplemental irrigation to minimize plant stress. Proper timing of water applications during appropriate periods can increase the yield and quality of most horticultural crops in Pennsylvania in most years. The critical periods for the irrigation of apples include during flower formation, early fruit set, and during final fruit swell (Penn State Extension, 2017: Irrigation for fruit and vegetable production).

For high density apple orchards, water relations are even more important. Irrigation is essential for ensuring optimum growth of newly planted and young apple orchards and also to obtain desired fruit size. For high density orchards, the economic success really depends on obtaining significant yields in the third, fourth, and fifth years to repay the establishment costs. To obtain the expected high yields requires excellent tree growth during the first three years after planting. However, one of the biggest problems we see with new high-density orchards is inadequate tree growth during the first three years. It is estimated that when poor tree growth in the early years delays cropping of a new orchard, peak investment is increased by 20% and the total profits are reduced by 66% over the 20-year life of the orchard (Robinson et al., 2013: Precision irrigation management in apples). Much of the problem of poor tree growth can be traced to inadequate water supply during the first three years. Therefore, it is very important to have a precision irrigation system for high density apple orchards.

In terms of irrigation methods, drip irrigation (also trickle or micro irrigation) involves emitting water directly to the soil where the roots of plants are growing at a very slow rate. Drip is the most efficient way to irrigate. It is usually about 90% efficient compared to about 70% for sprinkler and often 50% for surface irrigation. Surface irrigation is difficult to use effectively in sandy soil due to high infiltration rates, sprinkler irrigation is difficult to use effectively in heavy clay soils due to low infiltration. However, drip is suitable to all soil types because of its extremely slow application rate and high degree of control over timing and amounts (Peters, 2015: Drip irrigation for agricultural producers). Typically, tree fruit growers use two types of irrigation systems: solid set sprinklers and drip. Drip irrigation is primarily used in humid climates, and therefore, in this project, we will use a drip irrigation system for the test apple orchard. Figure 1 shows an example of drip irrigation in an apple orchard.

To precisely irrigate crops, the water status should be carefully monitored and recorded. Previous studies have shown that canopy (leaf) temperature can be used as a good indication of crop stress (Washington State University Extension, 2017: Irrigation automation using tree fruit canopy temperatures). A plant pulls water up out of the soil and moves it out through the leaves where the water is transpired out of microscopic openings in the plant leaves called stomata. This cools the leaves of the plant. If the plant is water stressed, then it will close the stomata and restrict water loss and therefore the plant leaves will be relatively warmer than a non-stressed plant. The leaf temperature can be sensed remotely using infrared temperature sensors. These temperature signals have been used in row-crop plants to completely automate the irrigation system. Researchers have found that this method is more responsive to plant stress than soil moisture deficits based on measurement with a neutron probe soil moisture meter.

Results of this project will provide research-based information on how the irrigation system should be controlled and operated based on sensing information related to crop water stress and climate data. This information will be used to make recommendations to Pennsylvania apple growers to help them grow annual crops of high yield and fruit quality. Meanwhile, the outcome from this project will provide effective evidences for seeking future federal grants on developing an intelligent orchard management system for fruit crops.

Goal and Objectives:

The ***primary goal*** of this project is to investigate using infrared temperature sensors to assess fruit tree canopy water stress, and thus to provide a potential precision management irrigation system for PA apple growers. The detailed objectives are:

1) To develop a test orchard for evaluating precision irrigation for apple trees;
2) To assess crop water stress and determine an irrigation plan by collecting information on canopy/leaf temperature as well as weather station data;
3) To evaluate the sensor-based precision irrigation system by comparing to controls with no irrigation, with respect to the canopy temperature, fruit quality and yield.

Procedure(s):

<u>Develop a test orchard for evaluating precision irrigation for apple trees (accomplished)</u>: As earlier mentioned, a drip irrigation system will be used to evaluate the sensor based decision making for irrigation. We will use the one current drip irrigation setup in an apple block at Penn State FREC with some modification. For this practice, we will either use current generator for water supply (need to manually turn on and off) or we will use a small electric water pump to get water from a well or other ground water sources. It can be set for automation by using a hose-end-timer. A hose bib kit (including a backflow device, a filter, a pressure regulator and a swivel adapter) will be attached between timer and drip line. An emitter will be place at each individual tree trunk to distribute water to the tree roots. Make sure to flush out any debris before closing the line with a hose end. In the system, tubing stakes will be used to secure the emitters being above the ground. Six rows of apple trees will be randomly selected for installing irrigation system.

<u>Assess crop water stress and determine an irrigation plan:</u> As we mentioned earlier, infrared temperature sensors are a good way to assess crop water stress. In this project, sensors will be set up in the six tree row replicates with irrigation (Figure 2), and also the six tree row replicates without irrigation. Crop water stress index (CWSI) will be used to schedule irrigation. The index is based on the difference between canopy temperature and air temperature normalized for the vapor pressure deficit of the air. The index can be used to determine when to irrigate based on the stress level of the plant. Meanwhile, the climate data will also be taken into consideration.

We will collect the climate data from the nearest weather station. Normally, the irrigation plan will be changed if there is a big rainfall ahead, and also after a big rainfall, while we still use the sensors to monitor the crop canopy temperature to make the comprehensive decision. An IoT (Internet of things) communication system will be developed to record the data from sensors/climate station and conduct the decision making for the on/off of the irrigation system. Additionally, we will evaluate the use of a small UAV (Unmanned Aerial Vehicle) with a thermal camera to monitor the crop canopy water stress. (We will use our previously purchased Drone and camera for this data acquisition.) This will give us the overall canopy temperature information for the test block.

Evaluate the sensor-based precision irrigation system by comparing to controls with no irrigation: In the test block, we will have six irrigated rows and six control rows (without irrigation) arranged in a randomized block design to reduce variability due to soil physical properties. The experiment will be conducted at the periods of early fruit set and during final fruit swell, which are two stages of fruit growth during which water supply is critical. Temperature data will be recorded during 10:00 am to 2:00 pm. Canopy temperature will be compared at the same time in the same day before and after irrigation in the irrigated rows and control rows. At the end of the season, fruit production and fruit quality will also be evaluated for both irrigated rows and control rows. In the first year of the project, we will focus on the crop water stress measurement, irrigation system development, and corresponding irrigation plan; for the second year, we will work on the automated irrigation system using the decision making with the sensors.

Figure 1. An example of drip irrigation in an apple orchard

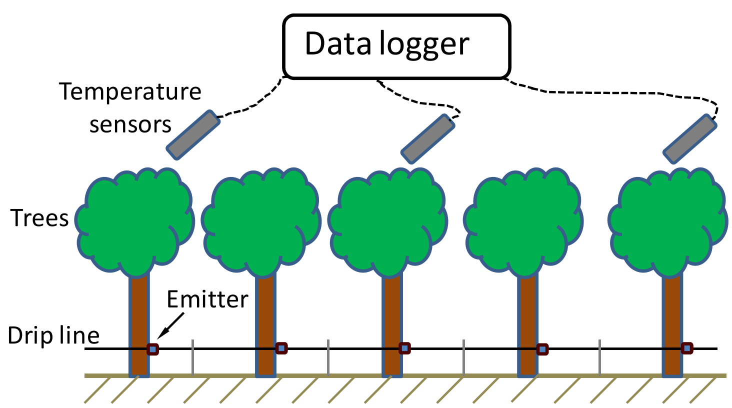

Figure 2. Illustration of sensor-based drip irrigation system

Budget and Budget Justification (For 2019)

Project Title: A Sensor-Based Irrigation Test System for Apple Orchard
Project Dates: March 1, 2018 – February 28, 2020 (2 years)
Principal Investigator: Long He
Co-Investigators: Daeun Choi; James Schupp
Co-operator: Tara Baugher

Budget:

	Year 2
Wages	$6,720
Fringe	$524
Materials and Supplies	$5,000
Travel (in state)	$1,000
Total	$13,244

Budget Justification:

Wages $6,720

- Wages ($5,120=$16/hr*20 hr/week*16 weeks) for a student wage payroll position (TBD) are requested. A student will work on field setup/experiment as well as data collection/analysis.
- Wages ($1,600=$16/hr*20 hr/week*5 weeks) is required for hiring a student working on the crop growth and final fruit production evaluation.

Fringe Benefits $524

Fringe benefits are computed using the fixed rates of 38.97% applicable to Category I Salaries, 14.74% applicable to Category II Graduate Assistants, 7.81% applicable to Category III Salaries and Wages, 0.18% applicable to Category IV Student Wages, and 25.34% for Category V, Postdoctoral Scholars and Fellows, for fiscal year 2019 (July 1, 2018, through June 30, 2019). If this proposal is funded, the rates quoted above shall, at the time of funding, be subject to adjustment for any period subsequent to June 30, 2019, if superseding Government approved rates have been established. Fringe benefit rates are negotiated and approved by the Office of Naval Research, Penn State's cognizant federal agency.

Materials and Supplies - $5,000

- $3,000 is required for purchasing solenoid valves, and soil moisture sensors and an updated data logger.
- $2,000 is required for building the wireless communication system for the irrigation system

Travel - $1,000

All travel will be in accordance with University travel regulations and mileage will be charged at the current rate on the data of travel. Travel costs are estimated as follows:
Travel expense ($1,000) for PIs and cooperators are requested for commercial field visit and field experiments, as well as project meetings.

Total Requested from Sponsor: $13,244