Research Grant Proposal for 2022

State Horticultural Association of Pennsylvania

Title: Orchard Canopy Stress Monitoring with In-Field and Remote Sensing Technologies

Personnel: *Long He* (PI), Department of Agricultural and Biological Engineering, Penn State Fruit Research and Extension Center, P. O. Box 330, Biglerville, PA 17307. Phone: 717-677-6116, Email: luh378@psu.edu.

Paul Heinemann (Co-PI), Department of Agricultural & Biological Engineering, Penn State, University Park, 16802

Meetpal Kukal (Co-PI), Department of Agricultural and Biological Engineering, Penn State, University Park, 16802

Suat Irmak (Co-PI), Department of Agricultural and Biological Engineering, Penn State, University Park, 16802

James Schupp (Collaborator), Department of Plant Sciences, Penn State, Biglerville, PA 17307

Duration of Project: New project; 1 Year

Project Budget: $14,719

Justification: This project addresses the 2022 SHAP Research Priority: “Use of new technology to improve data collection for decision making”.

Irrigation is an important component of field management for tree fruit crops. Nutrient uptake is closely associated with the water status in the soil and plant. Water makes it easier for plants to take up nutrients, so a structured irrigation strategy will assist with sufficient nutrient uptake. Under-irrigating causes inadequate water uptake due to a lack of availability, which also affects the nutrient uptake to the plant. More commonly, over-irrigation leaches nutrients from the soil thus affecting plant nutrition (Fernandez, 2018).

Irrigation practice based solely on irrigator’s experience (soil feel and visual interpretation) can cause under- or over-irrigation. Also, irrigation managed using only predetermined soil moisture thresholds does not always represent the real crop water status at a specific location and growing stage. Furthermore, the relationship among the available nutrient, irrigated water, and plant nutrient need is unknown. Nutrient requirements can be different for irrigation during different tree crop growth stages. Therefore, it is important to identify the crop stress status by evaluating the irrigation plan and associated nutrient supplies throughout the season.

Defining water stress using canopy temperature for irrigation applications has been extensively employed in grain crop production. However, specialty crop production such as tree fruit orchards has had limited exposure to this approach (Osroosh et al. 2015; Osroosh et al. 2016; Berni et al. 2009). There is substantial scope for orchard systems to benefit from a decision framework based on effective sensing of water stress and its use for irrigation and nutrient management, accounting for both water deficits in the soil as well as atmosphere (Zhang et al. 2021). Crop water stress index (CWSI) and further improved methods such as CWSI with a time threshold (CWSI-TT) have been used to identify crop canopy water stress status (Jackson et al., 1988, O'Shaughnessy et al., 2012). In these methods, sensing technologies are used to detect conditions of water transpiration, internal plant temperatures, and surrounding weather parameters.

Recently, unmanned aerial vehicles (UAVs) have become an advanced field phenotyping platform to provide data with high spatio-temporal resolution. UAVs have been equipped with various sensing systems for different tasks, and monitor crop stress status is among them. The availability of UAVs has enabled us to assess the crop stress in a faster way and large scale.

Primary Goal and Objectives

The **primary goal** of this study is to monitor orchard canopy stress status with both in-field and UAV based sensing technologies, thus to provide an optimal decision-making system for nutrient and water management.

Objective 1: Apply in-field sensing to detect and quantify canopy stress due to nutrient and water limitations.

Objective 2: Apply remote sensing (autonomous vehicle imagery) for canopy growth and health monitoring.

Objective 3: Develop a decision-support system for nutrient and water applications in tree fruit orchards.

Procedures

Experimental Field Layout: An experimental field will be selected for this study at Penn State Fruit Research and Extension Center (FREC). Three rows (or six rows if possible) of apple trees (Fuji tall spindle trees) will be used, and each row will be divided into five sections (at least five trees in each section). Different irrigation strategies will be applied to each row (or two rows if in total of six rows will be used), including 100% irrigation, 50% irrigation, and 150% irrigation (100% means the irrigation will be applied at the exact amount of water deficit calculated by the evapotranspiration). Soil moisture sensors will also be installed in each row for measuring soil moisture as references.

Task 1: Assess canopy-level water stress and nutrient uptake induced by varying irrigation water applications

To establish an effective framework for orchard health, it is critical that signals of water and nutrient stressors are captured appropriately. These signals can be detected in the spectral properties of plants in the electromagnetic spectrum. Critical indicators of orchard water and nutrient status will be measured, including canopy temperature and greenness, respectively via manually operated and in-field mounted sensors. Orchard microclimatic variables such as ambient temperatures, relative humidity, wind speed, solar radiation, and vapor pressure deficit will be monitored. Robust relationships among traditionally obtained orchard health assessments and tree-scale sensing information will be developed, to be scaled up using remote sensing technologies for entire orchards in task 2.

We will deploy stationary infrared radiometers to monitor canopy temperatures (T_c) for individual canopies experiencing different water stress regimes. Additionally, critical microclimate measurements such as air temperatures and relative humidity will be measured to deduce vapor pressure deficit (VPD). These measurements will consequently aid in estimation of crop water stress index (CWSI), which allows to quantify and report crop water stress that can occur in the canopy. CWSI is calculated as:

$$CWSI = \frac{(\Delta T - dT_{LL})}{(dT_{UL} - dT_{LL})}$$

Prior to calculating CWSI, we will develop non-water-stressed and water-stressed baselines for orchards, i.e. dT_{LL} and dT_{UL}, respectively. dT_{LL} and dT_{UL} are the lower and upper limits of difference between measured canopy and air temperatures (T_c-T_a). There is a linear relationship between dT_{LL} and VPD for a given non-stressed crop:

$$dT_{LL} = T_c - T_a = m \times (VPD) + b$$

Where m and b are slope and intercept of the linear relationship, respectively.

Leaf chlorophyll will be measured at regular intervals using a SPAD meter during the study period. Differences in leaf chlorophyll will be related to CWSI values observed under various water stress treatments.

We will then assess the translation of water stress on tree nutrient uptake. Soil samples and leaf samples will be acquired during the growing season for nutrient analysis. At least 10 samples per treatment will analyzed for this purpose.

Task 2: Using UAV based thermal and multispectral imageries for canopy health monitoring in apple orchards

Thermal imaging is one of the most commonly used imaging techniques in agricultural systems, and it can be applied in the detection of stressful conditions due to the significant relationships between foliar surface temperature and leaf gas exchange or stomatal conductance. The crop water stress status will be calculated based on the thermal information acquired by these images. Normalized difference vegetation index (NDVI) is another indicator that has been widely used for evaluating the crop vigor and health conditions. Crop canopy NDVI can be computed as the difference between near-infrared (NIR) and red (RED) reflectance divided by their sum. NDVI is Normally, the NDVI falls in the range of 0-1 for agricultural crop surfaces, with larger value representing healthier canopy.

We will use two types of sensor systems integrated with a UAV (DJI Matrice 200) for canopy health monitoring. First, a five-channel multispectral camera will be mounted on the UAV to capture images from the top of the canopies. The channels are red, green, blue, near-infrared (NIR), and red-edge. Second, we will measure the canopy temperature using a thermal camera for the same tree canopies. A set of data will be acquired during the entire growing season from May to October. With the collected imaging data, the NDVI maps and thermal maps for the test block will be created right after each data collection.

Task 3: Decision-support system development for water and nutrient applications

The data collected from the sensors mounted on the aerial vehicle will be assessed for plant health indicators described in task 2. These indicators will be spatially depicted in an “orchard health map”. The maps will be available for manual review by growers or serve as input to a decision support system which uses artificial intelligence approaches to interpret the results and provide a management recommendation. Potential management actions to be taken based on these recommendations include manually initiating irrigation and/or adding appropriate nutrients. The data can also be used for automated control of irrigation scheduling and nutrient injection through fertigation. The procedures include: 1) Process image data collected in task 2 utilizing machine learning approaches to assess the state of stress in the trees. The output from the processing will be quantitative water and/or nutrient stress levels. 2) Capture expert’s decision-making processes in categorizing the levels from task 1 into actionable recommendations, utilizing logic models. The logic can come from pomologists or can be derived from tree fruit production guides. 3) Develop a framework for decision support system by implementing the processes captured in task 2 into a device-based software program (laptop, phone).

References

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Budget and Justification

Budget: ($14,719)

	Year 1
Salaries/Wages	$9,000
Fringe	$719
Materials/Supplies	$4,000
Travel	$1,000
Total	$14,719

Budget Justification:

Salaries/Wages – $9,000

Two wage students will be hired in the summer to conduct the field test. $3,000 (10 weeks, 30 hours per week @ $10 per hour) for student to work on Objective #1 under Co-PIs Kukal and Irmak, and $6,000 (15 weeks, 40 hour per week @ 10 per hour) for student to work on Objective #2 and #3 under PI He and Co-PI Heinemann.

Fringe Benefits - $719

7.98% applicable to Category III Salaries and Wages, which is $719 in total.

Materials and Supplies - $4,000

We request budget for 2 infrared radiometers ($1,300), sample analysis fee ($1,000), data logger ($650), drone pilot certificate fee ($200), software ($500), and other field test supplies ($350).

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:

Trips from State College to FREC, or other field trips. In total of six State College to FREC trips are planned, and $150 for each trip. $100 for local trips to some commercial orchards.