



PRECISION ORCHARD MANAGEMENT: IRRIGATION AND PESTS

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Bambach (UC Davis), Pat Biddy (Vanguard Ag),
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Water stress sensors and what they have taught us about almond irrigation.

12/9/21 / Ken Shackel



TABLE OF CONTENTS

- 01. THE PERFECT SENSOR**
- 02. DIRECT WATER STRESS SENSORS**
- 03. IN-DIRECT WATER STRESS SENSORS**
- 04. 19 'DAYS IN THE LIFE' OF AN ALMOND**
- 05. SUMMARY/CONCLUSIONS**





The quest for the 'Holy Grail' of plant water stress sensors...

Diagnosing plant physiological activities and drought stress effects



*In the TV series Star Trek, a tricorder is a handheld scanning and analysis diagnostic device

What would a plant "tricorder" measure?

- Plant water potential



- Stress-responses, hormones, transcripts, metabolites

- Growth rate

- Growth direction and orientation

Image credit: iStockphoto.com

What is the 'Perfect' sensor?

Predicts if profit (\$) will go up or down if you irrigate or not.
...We don't have that one yet.

Current sensors

Direct: Measures the level of water stress in the plant **now**.

Indirect: Measures something about what the plant is doing **now**.

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- | | | |
|------------------|---------------|--|
| 1) Pressure bomb | Not automated | } All measure the same thing: water potential
“SWP” |
| 2) FloraPulse | Automated | |
| 3) Saturas | | |
| 4) ICT | | |

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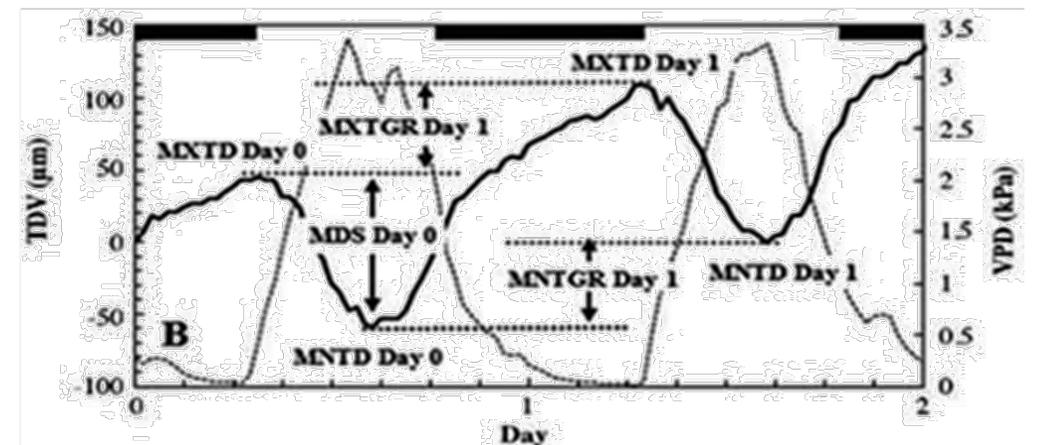
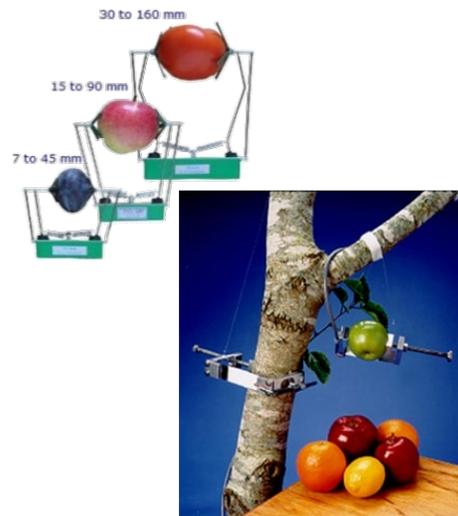
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(Fruit dendrometers)

Trunk Dendrometer
(Phyttech)



Silva-Contreras C, Sellés-Von Schouwen G, Ferreyra-Espada R, Silva-Robledo H. 2012. Chilean Journal of Agricultural Research 72:

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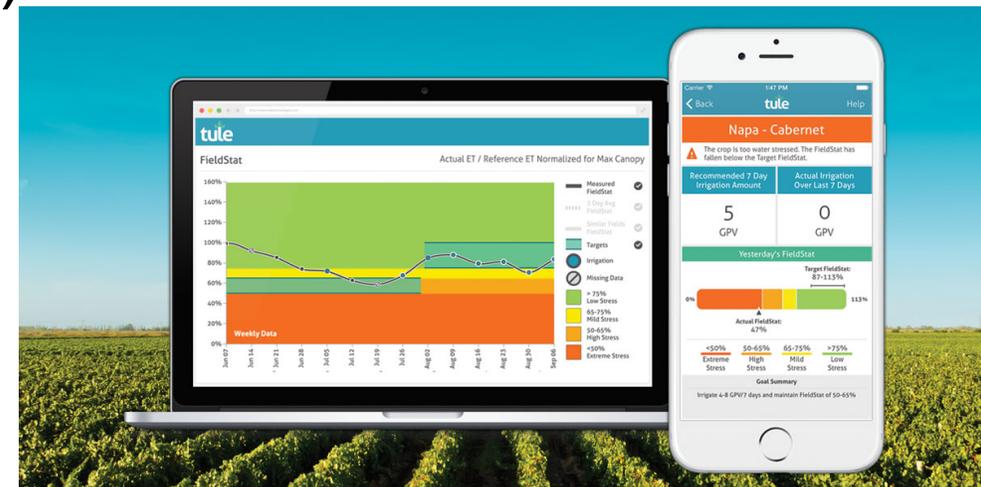
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- 2) Trunk or branch **sap flow** (e.g., Dynamax)
- 3) Canopy **ET** (e.g., Tule)



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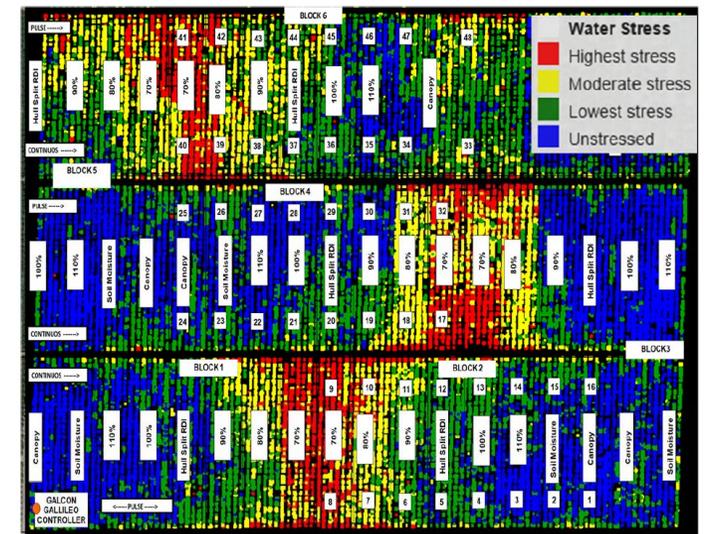
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- 4) Leaf or canopy **temperature** (evaporative cooling)/ remote sensing (e.g., CERES)



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- 5) Leaf, trunk, branch **water content** (too many to list)
- 6) Others.....

The main advantage of SWP is that we have some guidelines/recommendations:

- ‘Wet soil’ (baseline) conditions: 6-12 bars, depending on the weather (temperature, RH).
- Hull split: 14-18 bars.
- Significant stress (‘closed for business’): around 30 bars.
- Survival: 60 bars and ‘not dead yet,’ (but no yield next year).

Whether a sensor is direct or indirect, in order to be useful for irrigation management it needs to:

- 1) Measure specifically whether the trees need water or not.
- 2) In time to make an irrigation decision.
- 3) Hopefully have a close relation to overall tree health/productivity, or at least some processes that we think should be related to productivity (e.g., photosynthesis).

Whether you consider a sensor 'cheap' or 'expensive' depends on how valuable the information is to you!



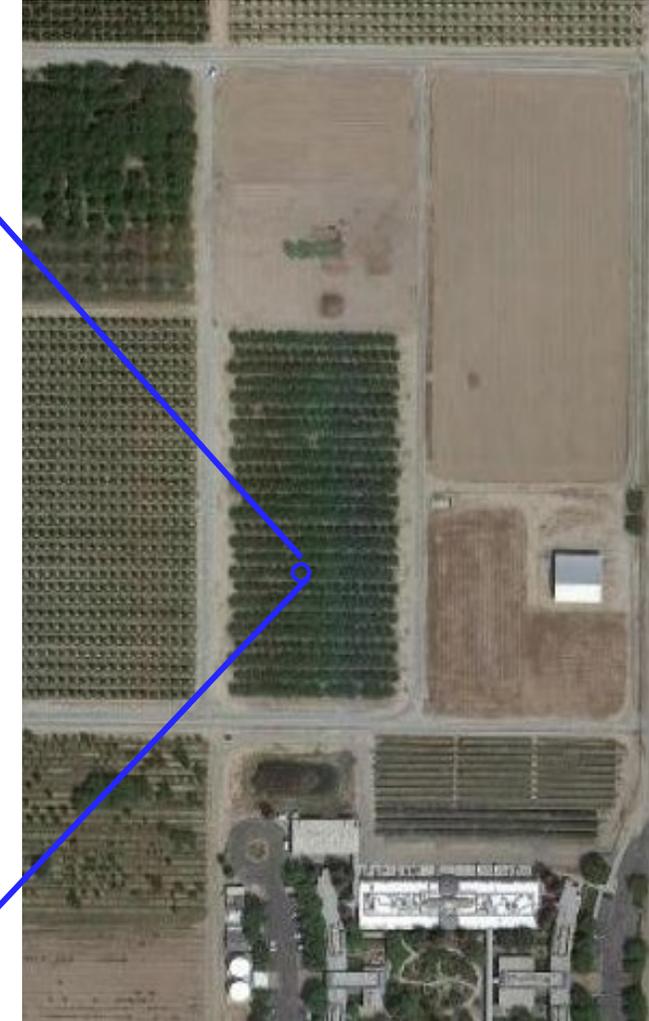
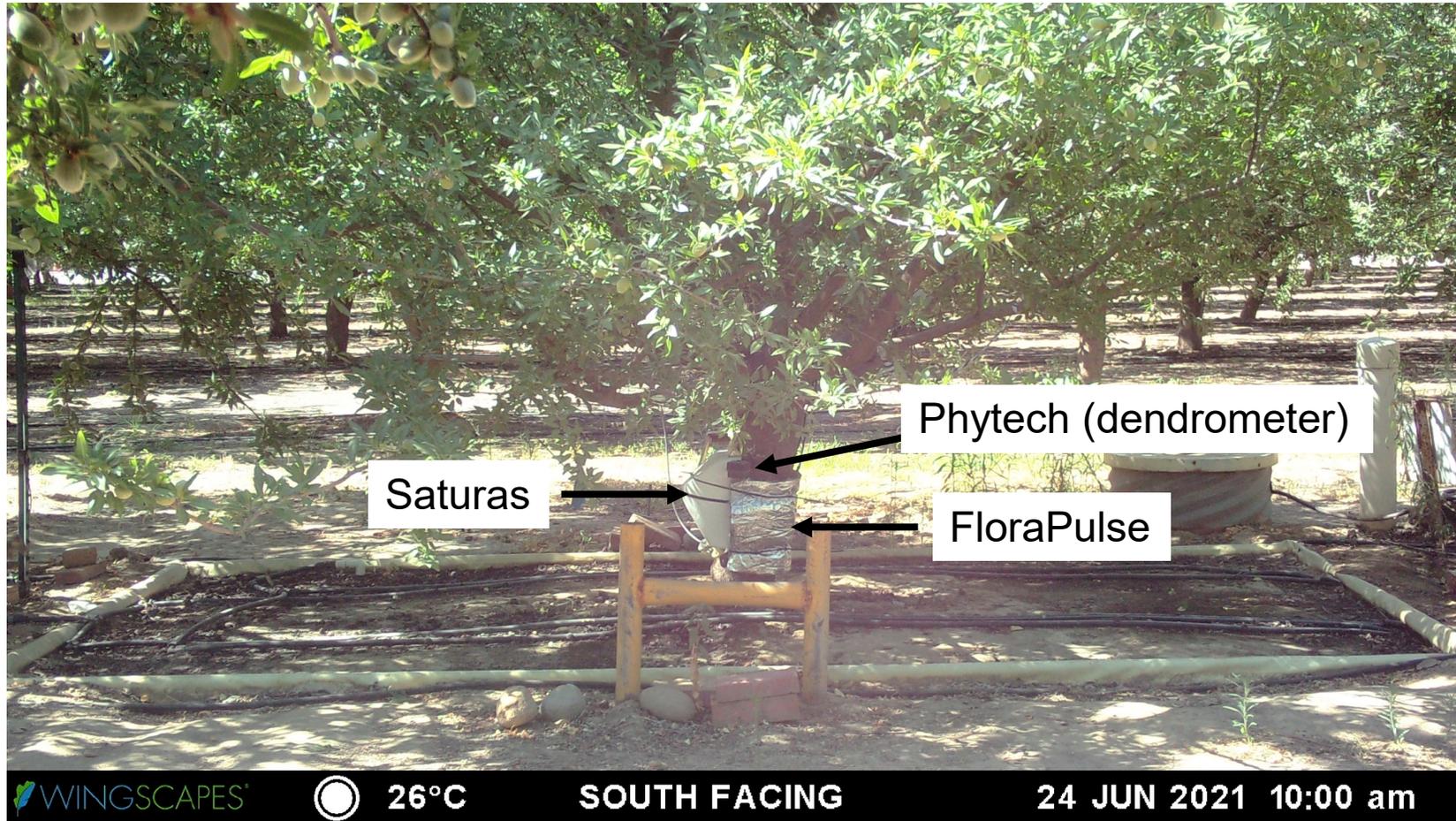
So, how does your irrigation approach affect the tree?

A few (19) 'days in the life.'



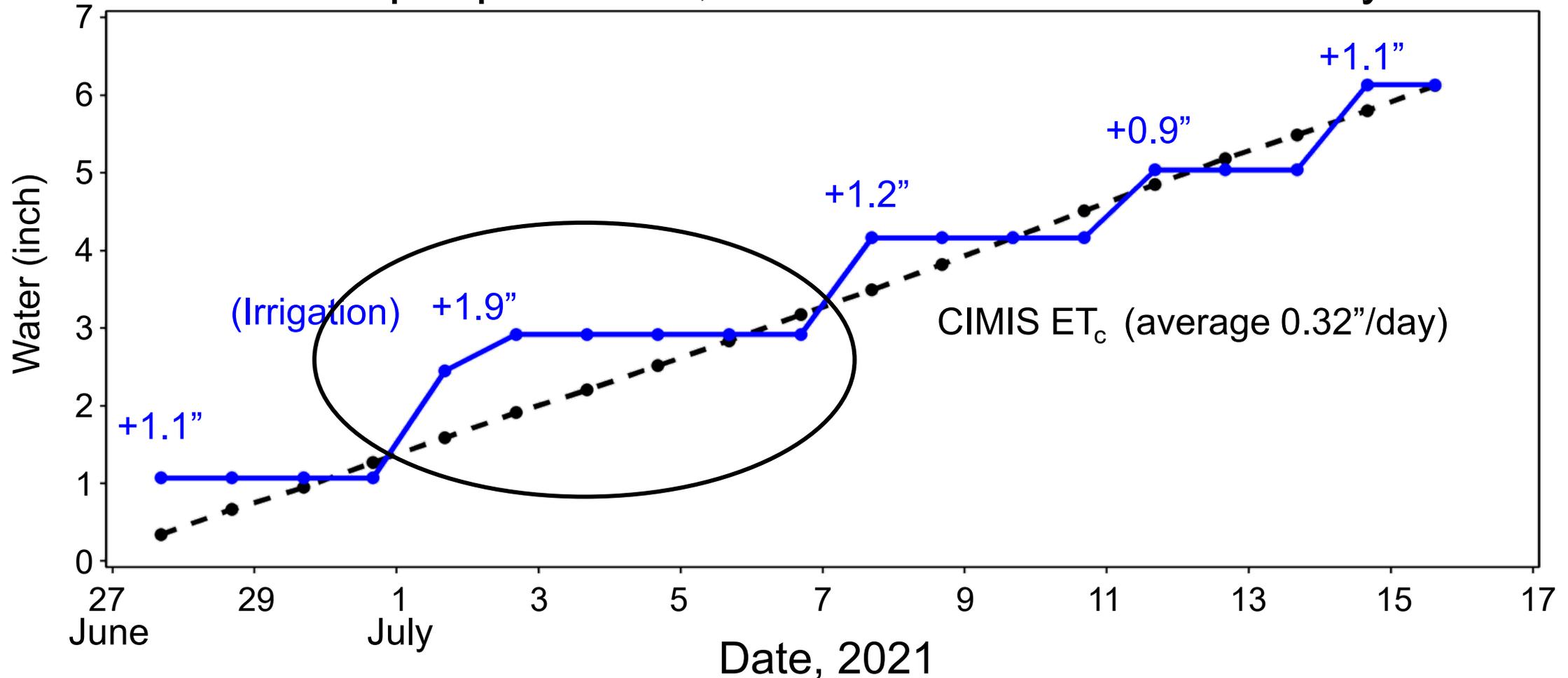
3 acre almond orchard in Parlier, CA

Tree in a lysimeter for accurate measurement of water use (ET_c), installed with commercial water stress sensors

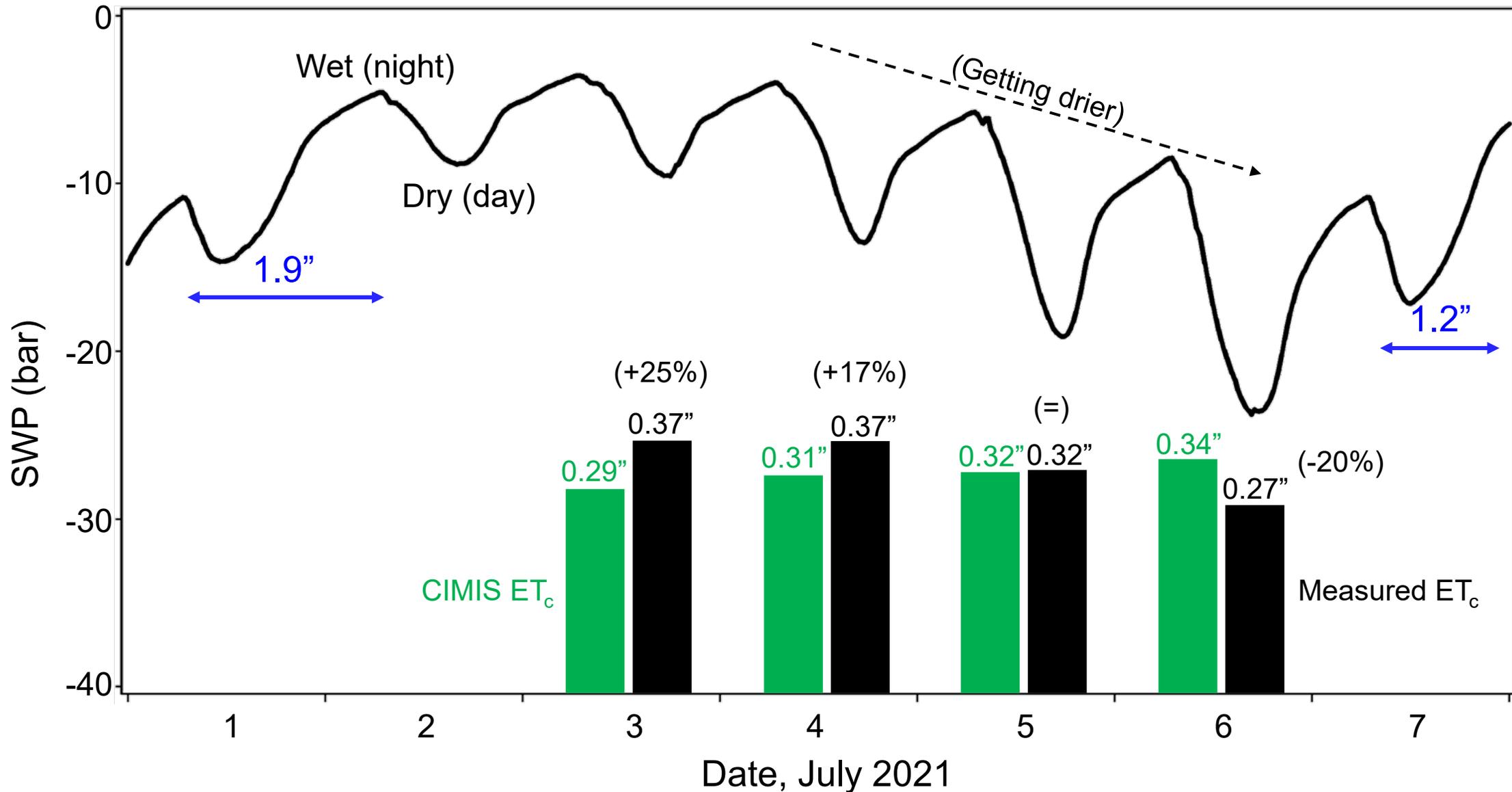


Almond ET and irrigation in Parlier, June 27 – July 16, 2021.
 (double line drip on a deep and a very well drained
 Hanford sandy loam soil)

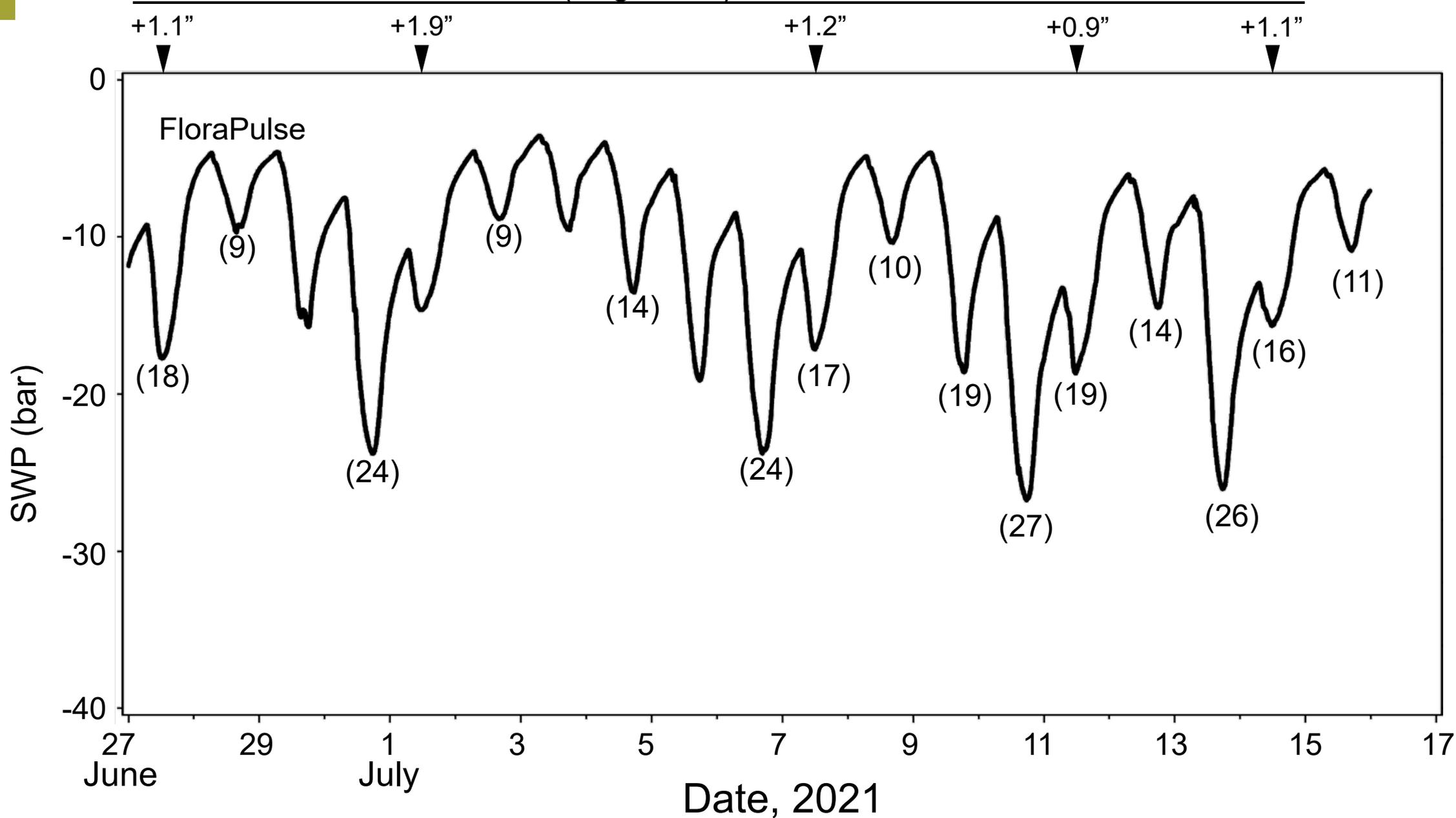
We 'kept up' with ET, but what did the sensors say?



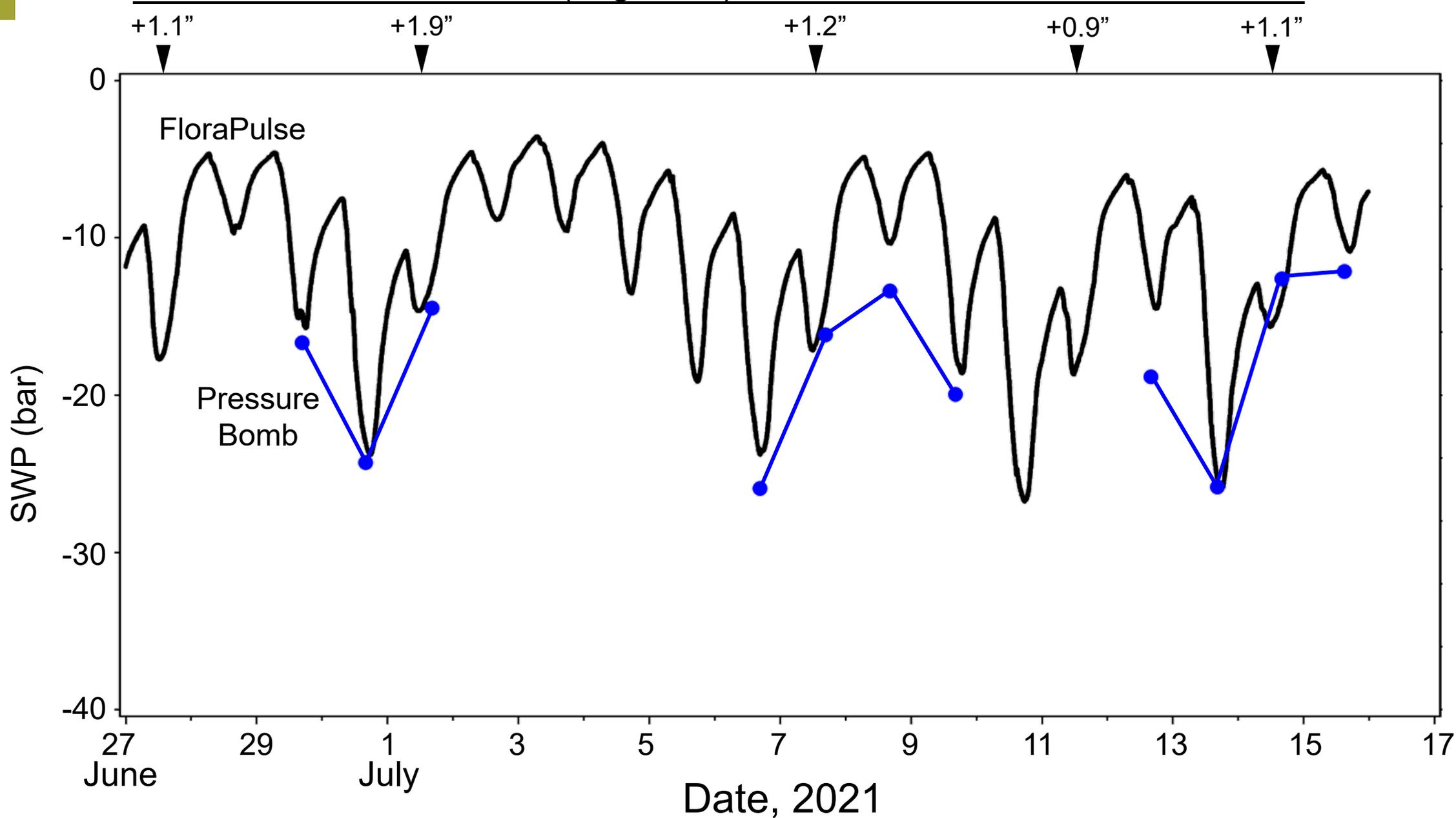
24/7 SWP according to FloraPulse sensor: the 'heart beat' of the tree



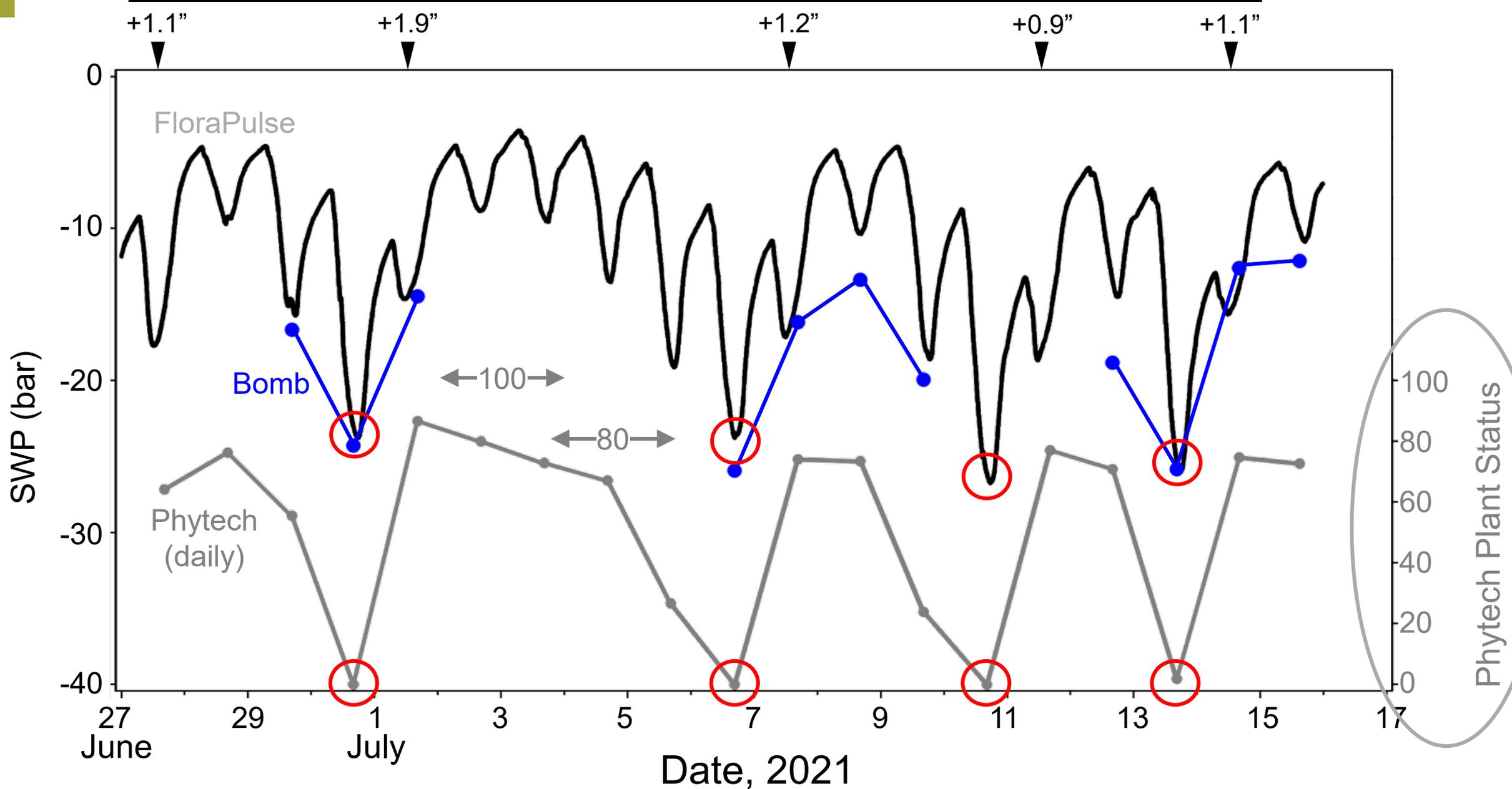
(Irrigations)



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Summary:

- 1) Daily sensor (or pressure bomb) measurements on 1 or 2 'typical' trees per irrigation block can inform irrigation management decisions for the whole block.
 - a) The pressure bomb will continue to be useful for 'roaming' spot checks.

Diagnosing plant physiological activities and drought stress effects



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•Stress-responses: hormones, transcripts, metabolites

•Growth rate

•Growth direction and orientation

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- On this deep, sandy-loam soil, daily SWP readings showed that trees go into significant stress within a few days after irrigation.

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- **Recommendation:** measure SWP soon after irrigation to confirm recovery, and again just before the next irrigation to check for significant stress.

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- On this deep, sandy-loam soil, daily SWP readings showed that trees go into significant stress within a few days after irrigation.
- Recommendation: measure SWP soon after irrigation to confirm recovery, and again just before the next irrigation to check for significant stress.
- **More work will be needed to determine if this is less of a problem on heavier soils.**

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Thank You

Rooted
IN SUCCESS :: 2021
the almond conference



T-REX

Advancing towards Precision Irrigation

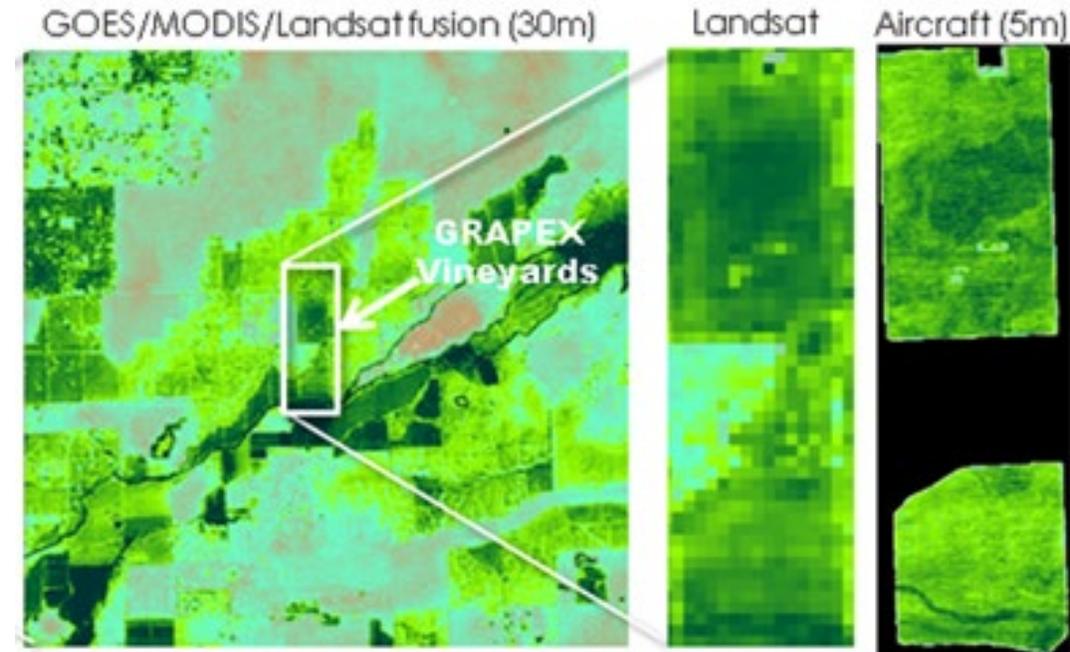
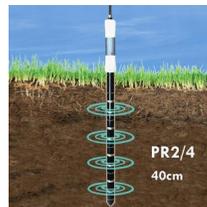
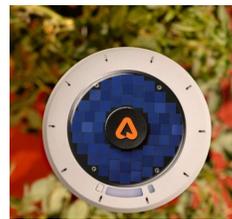
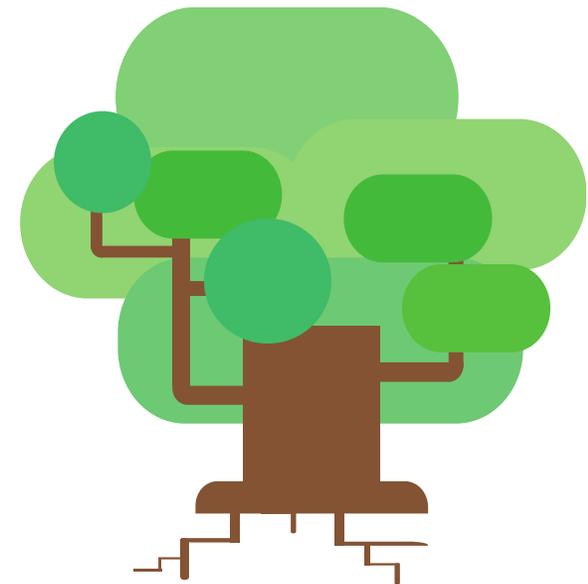
12 DEC 2021/ NICOLAS BAMBACH



∴ MOTIVATION

More almonds per drop...a journey to fine-tune irrigation

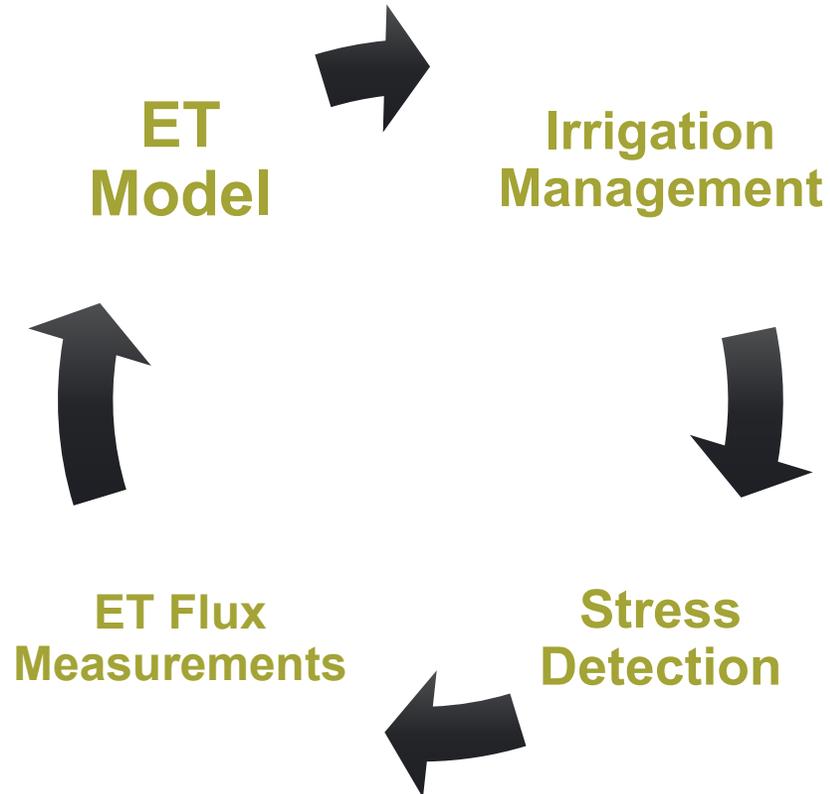
When, how much, and where to deliver water?



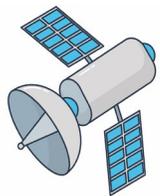
OUR PROJECT - OBJECTIVE



Test and refine ET models to support precision irrigation management decisions.



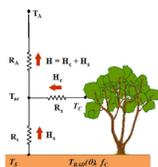
OUR PROJECT - APPROACH



Transpiration



Evaporation



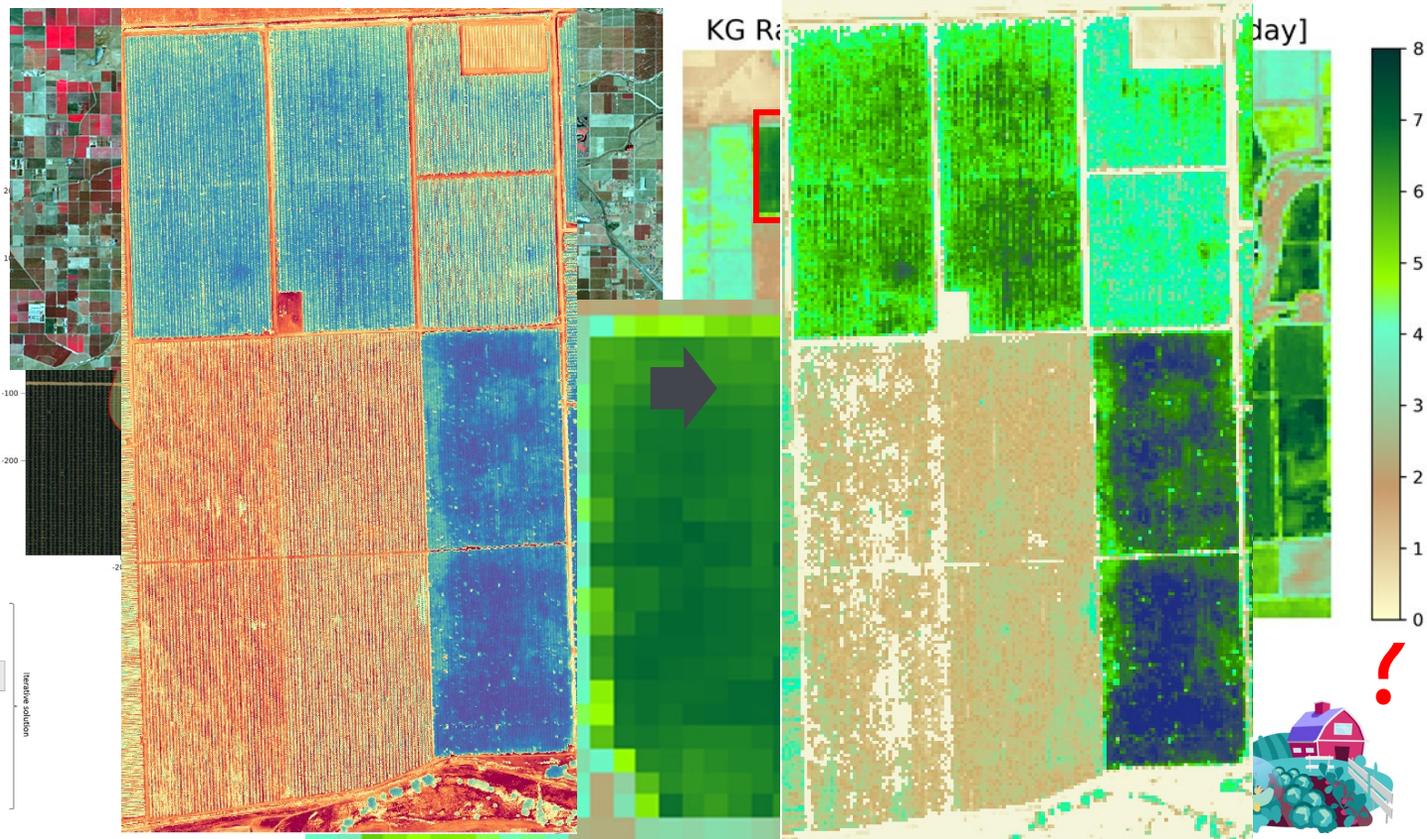
Norman and Kustas, et al. (1995)

- System, soil, canopy budgets
 - $R_n = H + \lambda E + G$
 - $R_{n,c} = H_c + \lambda E_c + G$
 - $R_{n,s} = H_s + \lambda E_s + G$
- Two-source approximation
 - $T_{soil}(0)^+ = f_s(0) T_s^+ + [1 - f_s(0)] T_s^0$
- Temperature constraint
 - $H_c, H_s, R_{n,c}, R_{n,s}, G$
- PT, PM or LUE R_n model
 - λE_c
- Residual
 - $\lambda E_s = R_n - H - G - \lambda E_c$



Tree crop Remote sensing of Evapotranspiration eXperiment

Direct Remote Sensing estimates based on the variance



PLAN

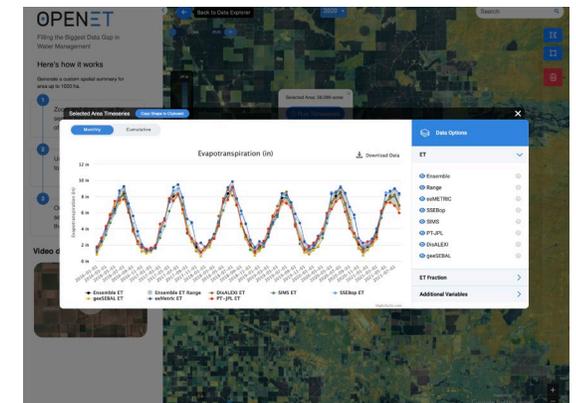
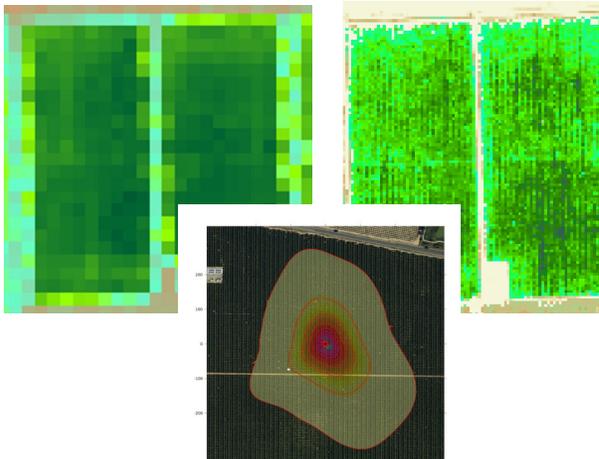
Ground-Truth
and Refine
Models



Identify Stress



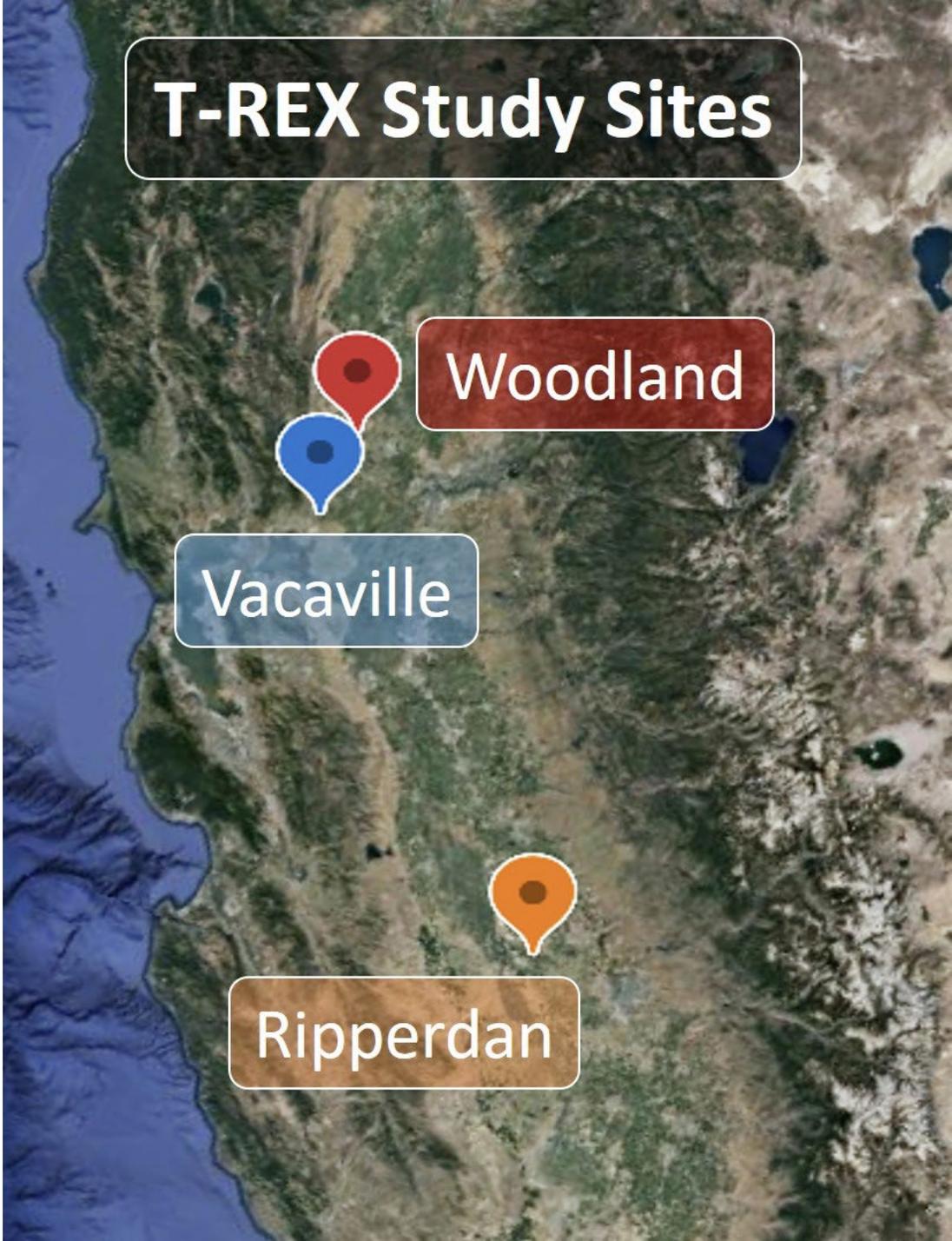
Data integration
and decision
support tools.



GROUND TRUTH EFFORTS



T-REX Study Sites

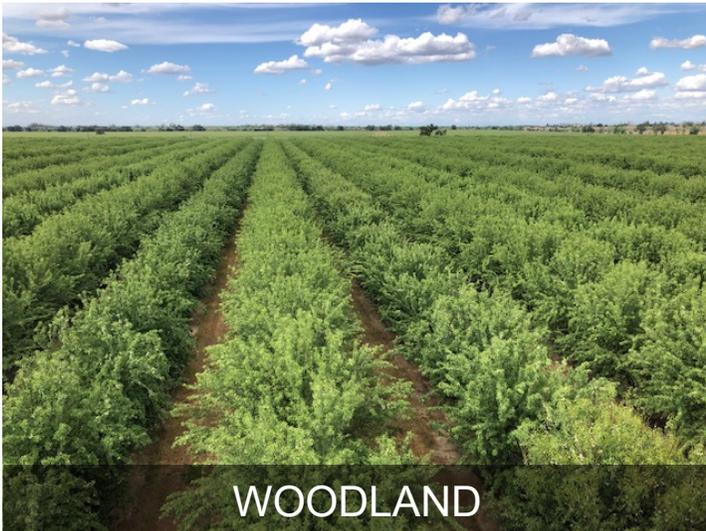
A satellite-style map of California with three study sites marked by colored location pins. A red pin is located in the northern Central Valley, a blue pin is in the northern Sierra Nevada region, and an orange pin is in the southern Central Valley. Each pin is accompanied by a text box containing the site name.

Woodland

Vacaville

Rippperdan

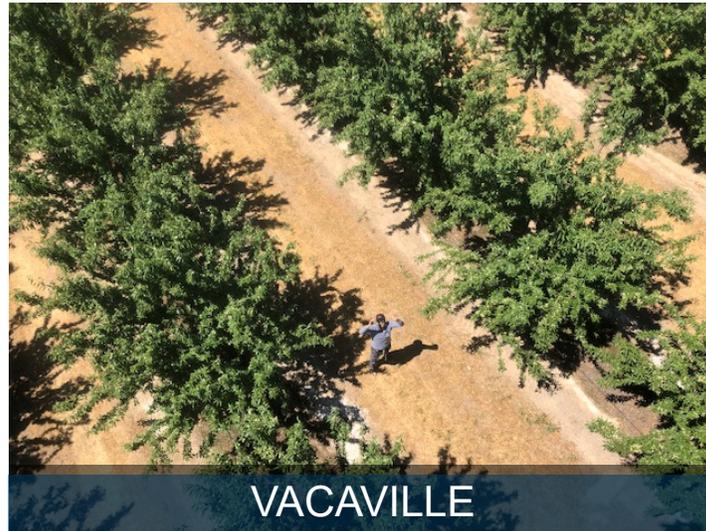
GROUND-TRUTH EFFORTS



WOODLAND

9th leaf

Non-pareil-50% | Monterey,
Butte & Carmel-17%
Heavy clay vertisol



VACAVILLE

7th leaf

Independence -100%
Silty clay loam soil



RIPPERDAN

8th leaf

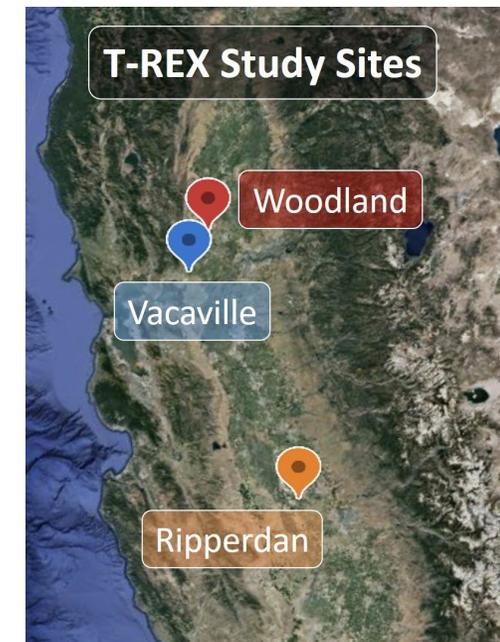
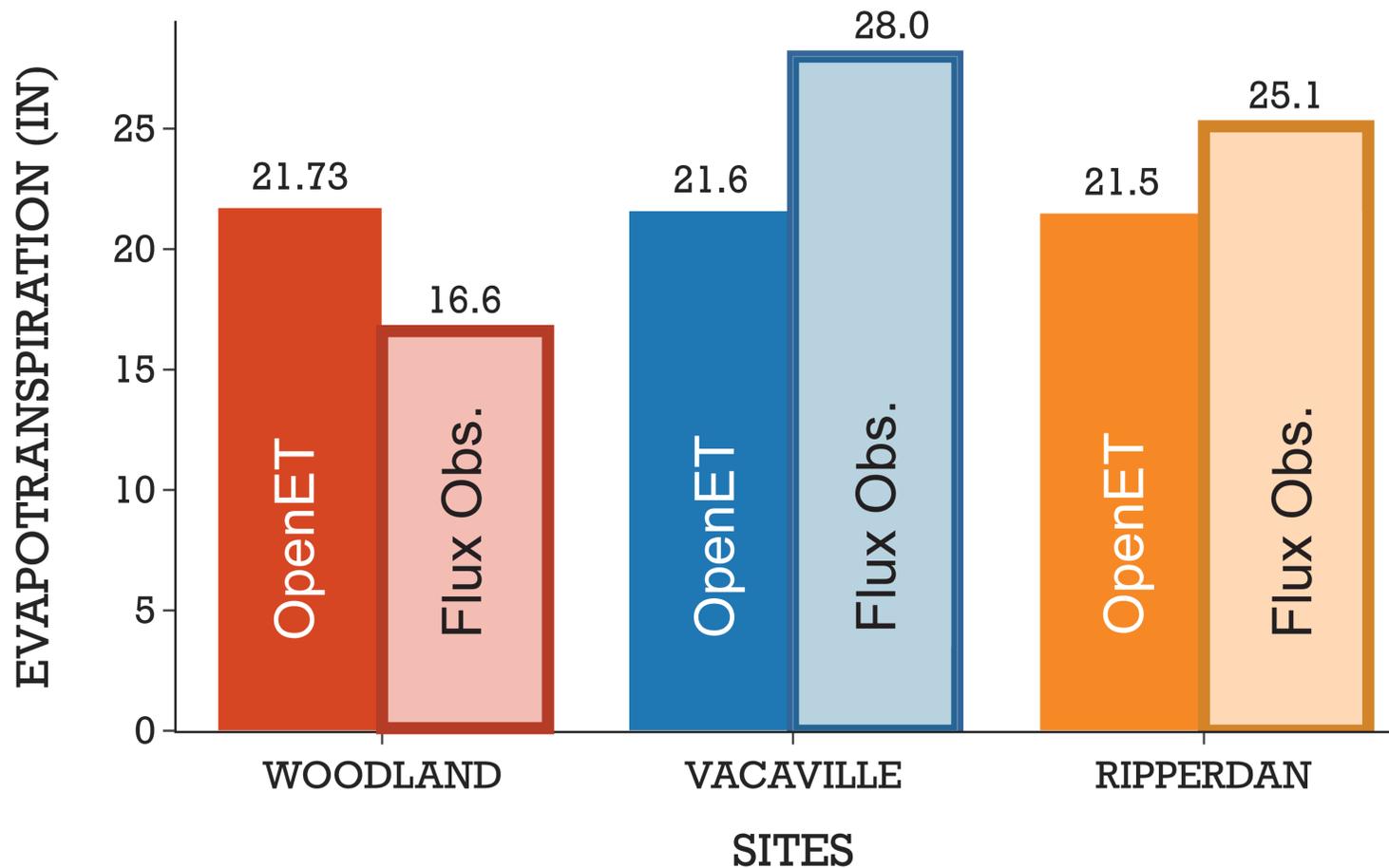
Non-pareil-50%, Wood Colony-37%,
Supareil-13%
Sandy loam soil

∴ Actual ET - ET_a

Quantity of water that is actually removed from a surface due to the processes of evaporation and transpiration.

- Paired along atmospheric demands can help to understand water stress. (Actual ET/ Potential ET)
- Sensitive to local environmental conditions, soil characteristics and management.
- No need for crop coefficients.

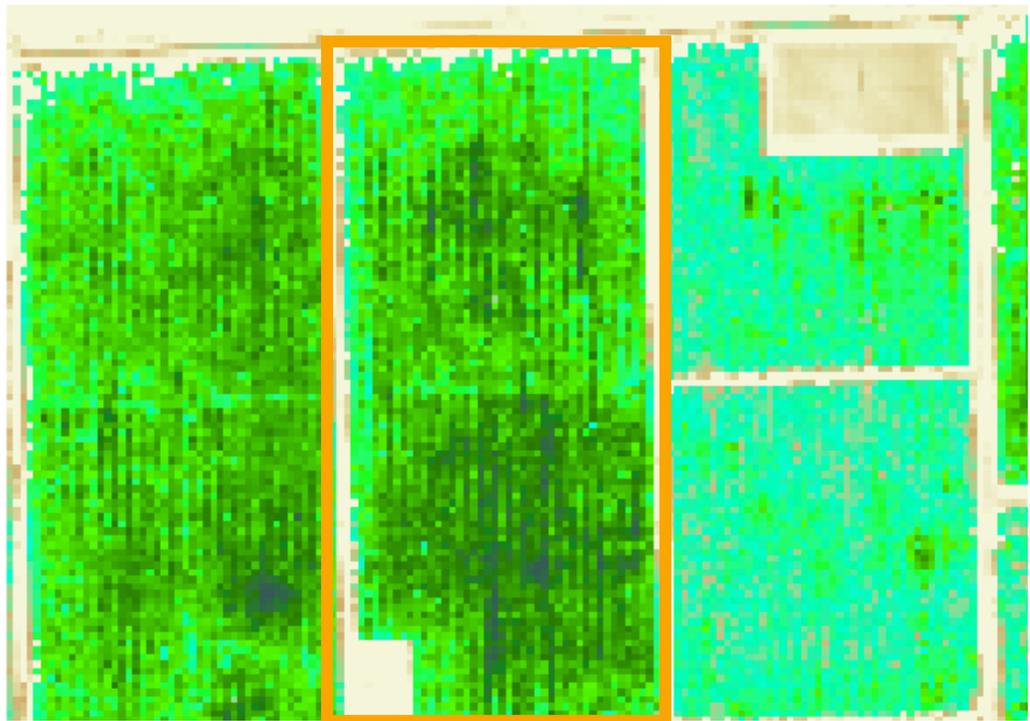
PRELIMINARY RESULTS



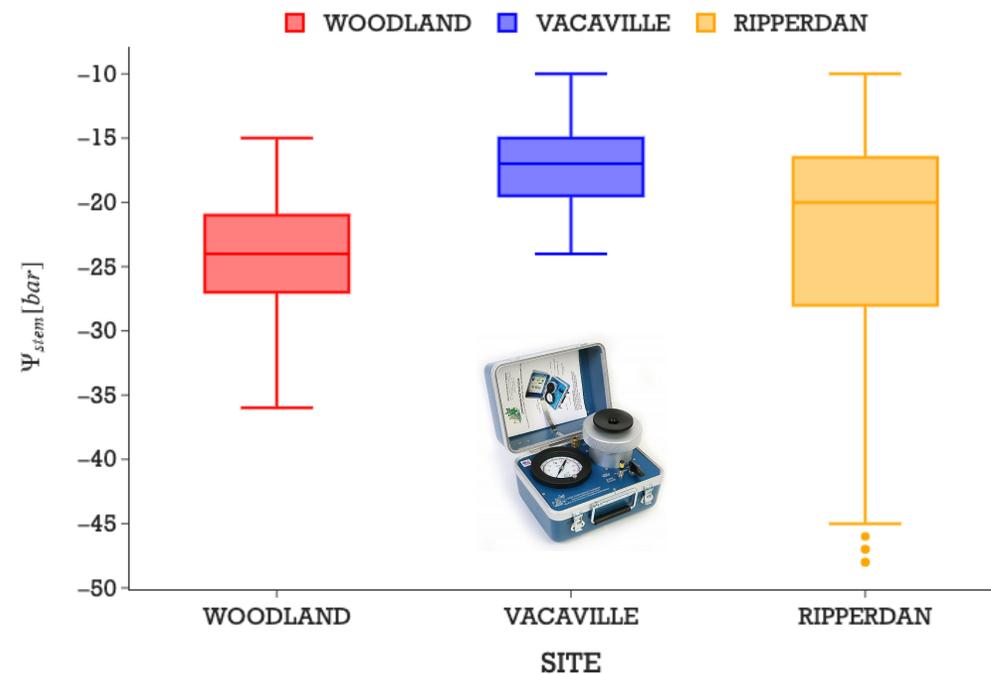
PRELIMINARY RESULTS



ET (mm/day)



STEM WATER POTENTIALS (July – August)

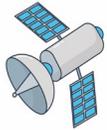




Tree crop Remote sensing of Evapotranspiration eXperiment

CORE TEAM

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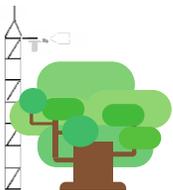
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California State University
MONTEREY BAY



INDUSTRY PARTNERS



FUNDING AGENCIES



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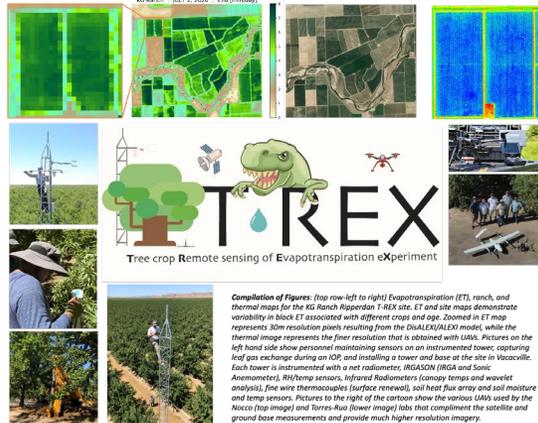
Summary

Accurately, and spatially resolved evapotranspiration (ET) and crop stress data are needed to inform irrigation management decisions. High-value perennial crops, like vinegrapes and almonds, are major water users in California, and growers will need better tools to improve water-use efficiency to remain economically viable and sustainable during periods of prolonged drought. Building on the success of our GRAPEX project (Grape Remote Sensing Atmospheric Profile and Evapotranspiration eXperiment), our team of government, university and industry partners are evaluating a multiscale remote sensing-based modeling system as an irrigation management tool for almond orchards. Starting in the Fall 2020 and continuing through the 2021 growing season, we identified grower cooperators, selected study sites, installed and instrumented flux towers, and collected micrometeorological, biophysical, and physiological data in three commercial orchards in the Central Valley of California. On several satellite overpass days throughout the growing season, additional ground based measurements were collected to fine tune and validate the ET modeling system and paired with drone-based hyperspectral and thermal imagery; these intensive observational periods (IOPs) will be used in subsequent seasons to represent different tree phenological stages and varied management practices (i.e. imposed stress during hull split). Here we present an introduction to the project team, objectives, and eventual products associated with the ET toolkit.

Background and Objectives

Agricultural water use, and almond growing in particular, has been severely scrutinized as competition for limited water resources intensifies in dry growing regions like California's Central Valley. Evapotranspiration (ET) from an orchard results from the plant canopy-atmosphere exchange, and represents the primary driver of agricultural water demands. Reliable, real time ET and stress data are needed by growers to precisely match crop water demands and trigger irrigation tied to crop water status. Grower-friendly tools emerging from remote sensing show great promise to fill this need. One such tool, the newly developed OpenET platform, will provide low-cost, accessible, and spatially distributed data at sub-field resolutions based on an ensemble of ET models. The T-REX project aims to test and validate ET models embodied within OpenET using ground truth data collected in several commercial almond orchards. T-REX builds upon the foundation of GRAPEX, where we successfully tested an ET model based on satellite thermal imagery and accurately quantified daily ET for commercial vineyards at 30m resolution. The ultimate goal of T-REX is to provide nut orchard growers with the tools needed to generate high-resolution ET data that can be used to guide water management decisions. The model at the core of T-REX differentiates between water used by the soil/cropland cover and almonds (see details of TSEB in Fig X). T-REX will also demonstrate the utility of very high-resolution imagery collected via unmanned aerial vehicles (UAVs) at critical times during the growing season to assess in-field variability and facilitate precision management.

Figure 1: Schematics of how Two Source Energy Balance (TSEB) model partitions water use between the soil and trees



Completion of Figures: (top row-left to right) Evapotranspiration (ET) ranch, and thermal maps for the KG Ranch Ripperdan T-REX site. ET and site maps demonstrate variability in block ET associated with different crops and age. Zoomed in ET map represents 30m resolution pixels resulting from the QUALIM/ALLEX model, while the thermal image represents the finer resolution that is obtained with UAVs. Pictures on the left hand side show personnel maintaining sensors on an instrumented tower; capturing leaf gas exchange during an IOP, and installing a tower and base at the site in Woodland. Each tower is instrumented with a net radiometer, RGA50N (RGA and Sonic Anemometer), 800µm sensors, infrared Radiometers (canopy temps and soil moisture analysis), fine wire thermocouples (surface renewal), soil heat flux array and soil moisture and temp sensors. Pictures to the right of the cartoon show the various UAVs used by the Nocco (top image) and Torres-Rua (lower image) labs that complement the satellite and ground base measurements and provide much higher resolution imagery.

Future Directions

- Growers require information on how much, when and where to irrigate. ET estimates can provide data on the quantity of water lost via ET from crop surfaces. Ground-truthing efforts are needed for remotely sensing based estimates of ET from energy balance approaches. We have begun this validation for our almond sites, and results to date are promising for using both satellite and UAV based imagery to map crop water use and stress.
- We will maintain T-REX flux towers at these three sites over the next few years to gather sufficient data to validate and refine these models. These efforts will include numerous IOPs involving additional ground based methods to assess stress to trigger irrigation and track stress as well as water use.
- We will continue to coordinate our efforts with the larger single tree harvest project to leverage resources and intensively study each site.

Water16: Bambach-McElrone   

T-REX Study Sites

Site Details

Westwind Farms	Sharma Independence	Olam KG Ranch
<ul style="list-style-type: none"> • 9th leaf in 2021 • Non-pareil-50% • Monterey, Butte & Carmel- 17% • Heavy clay vertisol 	<ul style="list-style-type: none"> • 7th leaf in 2021 • Large orchard of self-pollinating variety Independence • Silty clay loam soil 	<ul style="list-style-type: none"> • 8th leaf in 2021 • Non-pareil-50% • Wood Colony-37% • Supertel-13% • Sandy loam soil

Figure 2: Map of the three T-REX sites (left) and individual blocks (above) being used at each site. Tower locations are designated with red stars with the corresponding prevailing wind represented with blue arrows. Orchard details for each block are described on each plot.

Acknowledgments: We appreciate our growers partners for allowing us to conduct the work in their commercial orchards, funding from the Almond Board of California, CDFASpecialty Crops Block Grant Program, and USDA-CRIS base funds that supports this work; Castano Albujaqueque, Mina Momayyez, Pater Tolentino and other members of the McElrone lab for help with maintenance of sensors array and physiological data collection; and our larger collaborative team, especially Sat Darshan and Patrick Brown, for efforts to consolidate study sites for our myriad of efforts, and Isaya Kisekha, Troy Magney, and Yufang Jin.

Determining Almond Tree Water Use and Stress using Surface Energy Balance Models with Unmanned Aircraft Systems

Alfonso Torres-Rua¹, Nicolas Bambach², Lawrence Higgs¹, Andrew McElrone^{2,3}, William Kustas³, Hector Nieto⁴, John Prueger⁵, Joseph Alfieri⁵, Kyle Knipper⁵, Mallika Nocco²
 1 Utah State University, 2 University of California – Davis, 3 Agricultural Research Service – US Department of Agriculture, 4 COMPLUTIG – Universidad de Alcalá, 5 US Department of Agriculture AMES

Project ID: WATER16ATR

Abstract

Water management of California almonds require tools that ensure a sustainable operations under tighter water use regulations (SQMA) coupled with changing climatic conditions. While irrigation efficiency has improved dramatically with the widespread adoption of drip, micro-sprinkler, and variable rate irrigation systems, there is limited information that advises growers, orchard managers, and extension practitioners on actual orchard evapotranspiration (ET) and tree stress that is cost-effective, reliable, readily accessible, near real-time, and spatially resolved. The project builds on our previous 6+ year efforts using UAV technology for consumptive water use in California vineyards (Grape Remote Sensing Atmospheric Profile and Evapotranspiration eXperiment – GRAPEX) for almond orchards. And in collaboration with ABC and USDA, we are part of the "Tree crop Remotely-sensed Evapotranspiration eXperiment," T-REX led by Co-PI McElrone

Activities

Early this year, an intense effort was put to implement equipment and start data collection at different times during the season. An Intense Observation Period (IOP), set in late July – early August, allowed the different collaborators of T-REX to visit the Olam KG Ranch, southwest of Modesto, CA. This ranch has significant variability in almonds' variety and age, providing a unique setting to study water use and stress. In this project, the Utah State University AggieAir UAV technology (<https://uav.usu.edu/aggieair/>) was flown over 426 acres (0.66 sq miles). The technology used is an experimental fixed-wing UAV, with optical, infrared, and thermal scientific sensors at an elevation of 400m above ground. AggieAir Drones, ground control points and temperature control points (1476 ft), thanks to an FAA Certificate of Authorization to flight in this area. The area was flown under 20 min and at three times: satellite Landsat overpass (~10:30 AM), at solar noon (~12:30 PM), and mid-afternoon (~3:30 PM). These times were considered for their relationship with changes in almond transpiration during a diurnal cycle. An example of the AggieAir UAV imagery is shown on the figure on the right. While ground, UAV, and other information of this session are being analyzed, preliminary estimation of tree water use and stress using UAV indicates that methodology and algorithms developed for vineyards in California for the GRAPEX project can be transferable to almonds and nut tree environments.

Future activities

After this year's significant efforts for sensor installation and spatial data collection at Olam and other two sites in Central Valley, Year 2 will focus on intense collaborative and coordinated data collection efforts (Intensive Observation Periods - IOPs) by the different research groups in the T-REX project. Discussion over completed ground data collection efforts for ground, LAI, satellite, and UAV from all T-REX members will be conducted in early 2022 (T-REX annual meeting). A major undertaking in 2022 will be related to Intense Leaf Area Index measurement and its identified challenges due to almond phenology and canopy dimensions during the season. 2022 IOPs will also be an opportunity to understand orchard characteristics documented in collected information in 2021, as shown in the image below for the Olam Ranch KG Ranch. Green Chlorophyll index map for Olam KG Ranch around the Eddy Covariance tower for August 5, 2021. Note the almonds trees in 5 lines with a higher index values, which does not occur in the rest of orchard. Some of this may be related to the variation and differential watering that was occurring at the time of the IOP as Olam KG was trying to induce hull split for some varieties during this time. These tree lines seem not related to temperature (not different than other trees temperature), but that other trees seem to have a slightly higher ET rate.

Tools and References

Nieto, H. (2014) TSEB Model: Two-Source Surface Energy Balance model for high resolution imagery. <https://github.com/hedemontology/TSEB>

Nieto, H., et al., 2019. Evaluation of TSEB turbulent fluxes using different methods for the retrieval of soil and canopy component temperatures from UAV thermal and multispectral imagery. *Irrigation Science*, 37(3), pp.389-406.

Gao, R., et al., 2021. Evapotranspiration partitioning assessment using a machine-learning-based leaf area index and the two-source energy balance model with UAV information. In *Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping VI* (ed. V17, 477-478), International Society for Optics and Photonics.

Project goals

This project enables critical UAS technology into the T-REX project to rigorously validate tree-scale water use and stress mapping for California's almond farms.

Goal 1. Incorporate emerging and UC Davis UAS technologies in T-REX towards monitoring water use using UAS.

Goal 2. Validate and refine an UAS-based almond-tree ET Toolkit for partitioning E and T using UAS and T-REX ground information (Flux Tower, RT waveli, lysimeter, other).

Goal 3. Validate and compare almond water stress estimation using tree-scale transpiration.

Goal 4. Incorporate Goals 1-3 products into T-REX, UC Davis, and ABC's almond water stress, carbon, photosynthesis, productivity research, and extension.

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Acknowledgments: Funded by the Almond Board of California, California Department of Food and Agriculture (CDFA) Specialty Crops Block Grant Program, and USDA-CRIS base funds. We appreciate the McElrone lab for help with sensors array and physiological data collection and AggieAir Service Center for UAV data collection and processing of the different flights in 2021.



Future Directions

- **Test model parameters and sensitivity** to improve ET estimates from satellite and UAV remote sensing.
- Expand ground-truthing efforts.
- **Identify key relationship** with known parameters used to support irrigation management (SWP).
- Work with industry partners and Ag. Tech. companies to translate our research into applications and **data integration**.



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Exploring Irrigation Technology

12/09/2021 Pat Biddy



Exploring Irrigation Technology

01. INTRODUCTION

02. TYPES OF AG TECHNOLOGY

03. COMMUNICATION TYPES

04. GROWER CHEKLIST





EXPLORING IRRIGATION TECHNOLOGY

TYPES OF AG TECHNOLOGY





☼☼☼ Weather Stations

Weather stations have been some of the most common technology installed by growers. These allow you to monitor many field variables such as:

1. Frost conditions
2. Wind speed/direction for spray applications
3. Growing Degree Days (GDD)
4. IPM and disease models
5. Rain accumulation
6. ETo

Most common mistakes:

1. Installing in-field above canopy
2. Installing on concrete or dirt
3. Installing next to running pump equipment
4. Not level
5. Wind sensor pointed in the wrong direction

Plant Based Sensors

Manual pressure bomb readings have been around since the 1960's. These have been well researched, and guidelines have been documented by crop type. Automated plant-based sensors are becoming more common place some of these have well researched an have guidelines. Plant based sensors can help growers:

1. Identify stress
2. Measure fruit growth
3. Watch nutrient flow in sap
4. Localized NDVI
5. Stomatal conductance

Most common mistakes:

1. Installing in the wrong part of the plant
2. Fruit sensors not on an average fruit or fruit is damaged
3. Incorrect irrigation model
4. "Wounds" have healed
5. Sensors need to have regular maintenance or replaced annually



Soil Sensors

Manual methods of estimating soil moisture have been around since farming began. These have been well researched, and guidelines have been documented by soil type. Soil sensors can help growers:

1. Identify stress
2. Establish desired root zone
3. Monitor soil temperature
4. Monitor fertilizer movement through soil profile
5. Monitor soil moisture

Most common mistakes:

1. Installed out of root zone/wetted area
2. Installed in wrong soil type
3. Wrong technology for crop type
4. No infield verification
5. One sensor “covering” too many acres





Remote Data

Remote data can come from multiple sources. These sources include satellite, fixed wing, or drone. This data allows you to monitor many field variables such as:

1. Normalized Difference Vegetative Index (NDVI)
2. Soil water content
3. Soil variability
4. Compare different seasons
5. Consumptive water use (ETa)

Most common mistakes:

1. Not enough flights
2. Cloud or smoke coverage
3. Miss interpretation of data
4. Comparing two separate fields to one another
5. Cover crop skewing data

Automation and Control

Automation and control can be achieved through various ways like telemetry, pressure switch, or a manual timer. In some form, most growers have incorporated these into their day-to-day farming practices. Automation and control can help growers:

1. Reduce labor
2. Irrigate during off-peak
3. More accurately inject fertilizer or amendments
4. Increase irrigation efficiency
5. Utilize reservoirs more effectively

Most common mistakes:

1. Poor calibration
2. Little or no maintenance
3. No training provided to field staff
4. No infield verification
5. No feedback or lack of feedback sensors



EXPLORING IRRIGATION TECHNOLOGY

COMMUNICATION TYPES





⋮ Cellular

Cellular data transmission is the most stable way to get your data out of the field.

Pros:

1. Can be upgraded as technology advances
2. Very reliable and California has great coverage
3. Signal can be boosted
4. Can be used in combination with other communication types
5. Majority of the telemetry providers have a cellular option
6. Can be installed below canopy

Cons:

1. May not be upgradable with some telemetry providers
2. Can be expensive
3. May not read in a metal pump house
4. You are at the mercy of big cellular companies

Radios

Radios have been utilized to cover more acreage at a lower cost. These are normally installed as a hub and spoke or mesh network.

Pros:

1. Lower hardware cost than cellular
2. Low to no annual subscription
3. Can be used with other communication types
4. Can be used where cellular signal is spotty
5. Low power consumption

Cons:

1. Must be installed above canopy
2. Must have a gateway or base station, these can be very expensive
3. Does not have a long range between stations
4. Interference can interrupt readings very easily
5. Can require lots of service
6. Be weary of using radios for automation or control



LoRaWAN

Newer technology that uses radios for long range communication.

Pros:

1. Lower hardware cost than cellular
2. Low to no annual subscription
3. Can be used with other communication types
4. Can be used where cellular signal is spotty
5. Low power consumption
6. Can be installed below canopy or underground

Cons:

1. Must have a gateway or base station, these can be very expensive
2. Base stations or gateways have a large footprint and 110v
3. Third party networks are not very common. You must create your own
4. Can require lots of service
5. Be weary of using for automation or control





Bluetooth

Bluetooth has been around for years and over 4 million BLE chips are made each year. BLE 5 provides “long range” integration for Ag applications.

Pros:

1. Lower hardware cost than all other options
2. Low to no annual subscription
3. Can be used with other communication types
4. Can be used where cellular signal is spotty
5. Low power consumption
6. Can be installed below canopy
7. Can cover large acres at a very low cost

Cons:

1. Must have a gateway or base station, these can be very expensive
2. Does not have a long range between stations (+/- 500')
3. Interference can interrupt readings very easily
4. Can require lots of service
5. Be wary of using Bluetooth for automation or control

Wi-Fi

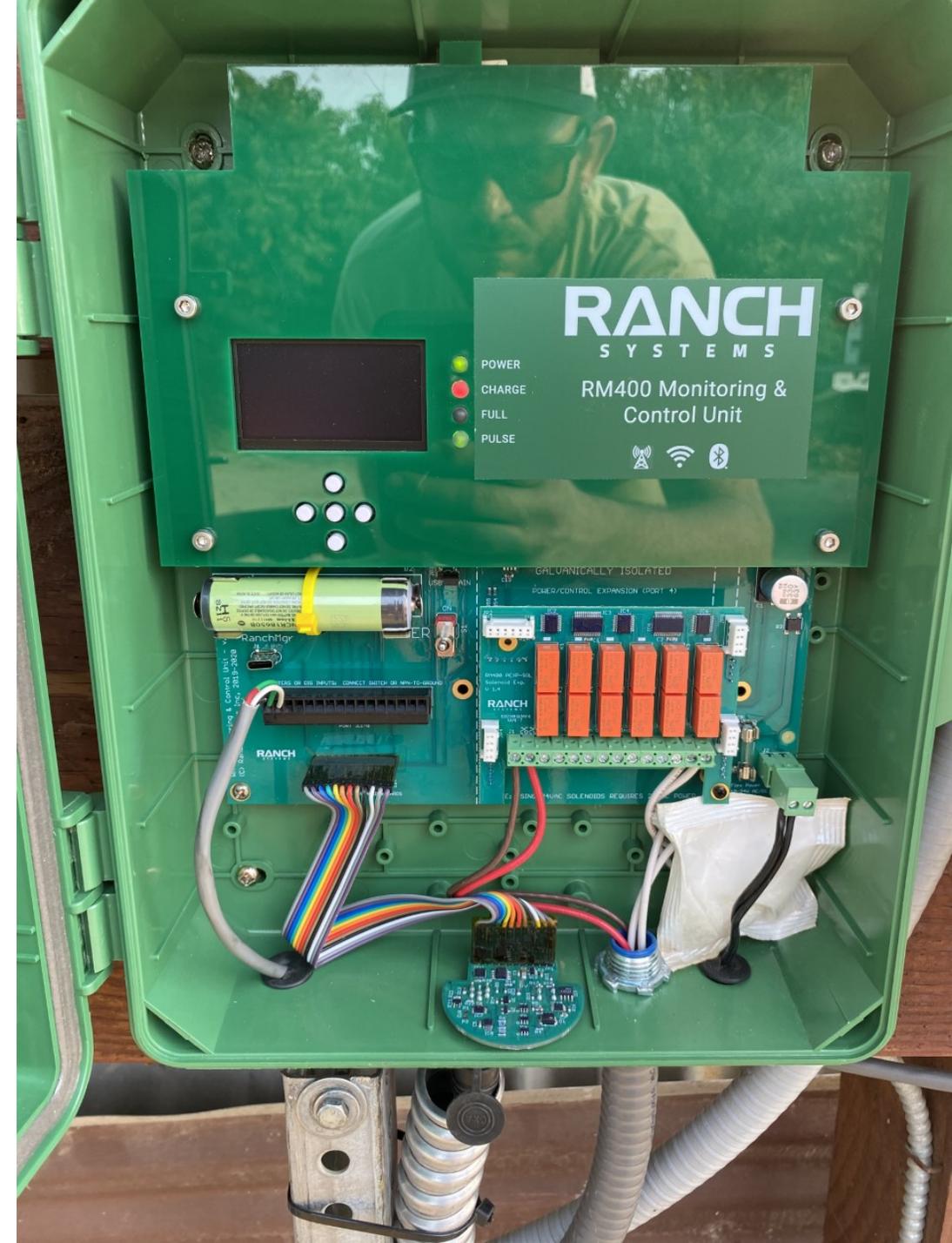
Wi-Fi networks have become more common place in field. These can be easily expanded and connect field crews to valuable apps.

Pros:

1. Lower hardware cost than cellular
2. Low to no annual subscription
3. Can be used with other communication types
4. Low power consumption
5. Can cover large acers at a very low cost

Cons:

1. Must be installed above canopy
2. Not very stable
3. Does not have a long range between stations
4. Interference can interrupt readings very easily
5. Can require lots of service
6. Be weary of using Wi-Fi for automation or control
7. Very little to no savings in annual fees





EXPLORING IRRIGATION TECHNOLOGY

GROWER CHECKLIST



∴ EXPLORING IRRIGATION TECHNOLOGY

Grower checklist

1. Where are you today and where do you want to be in 5 years?
2. Are they backwards compatible?
3. Can their hardware expand and adapt to the fast pace of technological advancement?
4. What is their expertise?
5. Are they a one trick pony?
6. Does the company have **local** support?
7. Are they financially stable enough to stand on their own?
8. Who has access to YOUR data?
9. Are you solving a problem or just buying hardware?
10. Are you a Guinea pig?
11. Do they give you action an item or charts and squiggly lines? Are these action items being directed by more than just one type of sensor?



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Novel Technology for Weed Control

Lynn M. Sosnoskie

Assistant Professor of Weed Ecology and Management in Specialty Crops

Phone:315-787-2231 Email:lms438@cornell.edu

Cornell **CALS**

College of Agriculture
and Life Sciences

Cornell **AgriTech**

New York State Agricultural
Experiment Station

Weeds are direct competitors with crops that result in yield loss

But wait! There's more!

Reductions in harvest efficiency

e.g. Palmer amaranth

Parasitism of crops

e.g. dodder, mistletoe, broomrape

Host for pests and pathogens of crops

e.g. tree of heaven and spotted lanternfly

Dangerous, noxious, poisonous, toxic, hazardous

e.g. poison ivy, giant hogweed

Ecosystem disruption and aesthetics

e.g. medusahead and fire cycles, kudzu



Palmer amaranth in almonds



Herbicides are heavily relied upon for weed control

Herbicide Use May Not Always Be Effective or Desirable in a System

- **Herbicide resistance**
 - 508 cases globally*
 - 266 species*
 - 164 herbicides*
- **Injury potential**
- **Environmental concerns**
- **Consumer perceptions**
- **Regulatory mandates**



WEED MANAGEMENT IN 2050

WESTWOOD ET AL. 2018. WEED SCIENCE 66:275-285

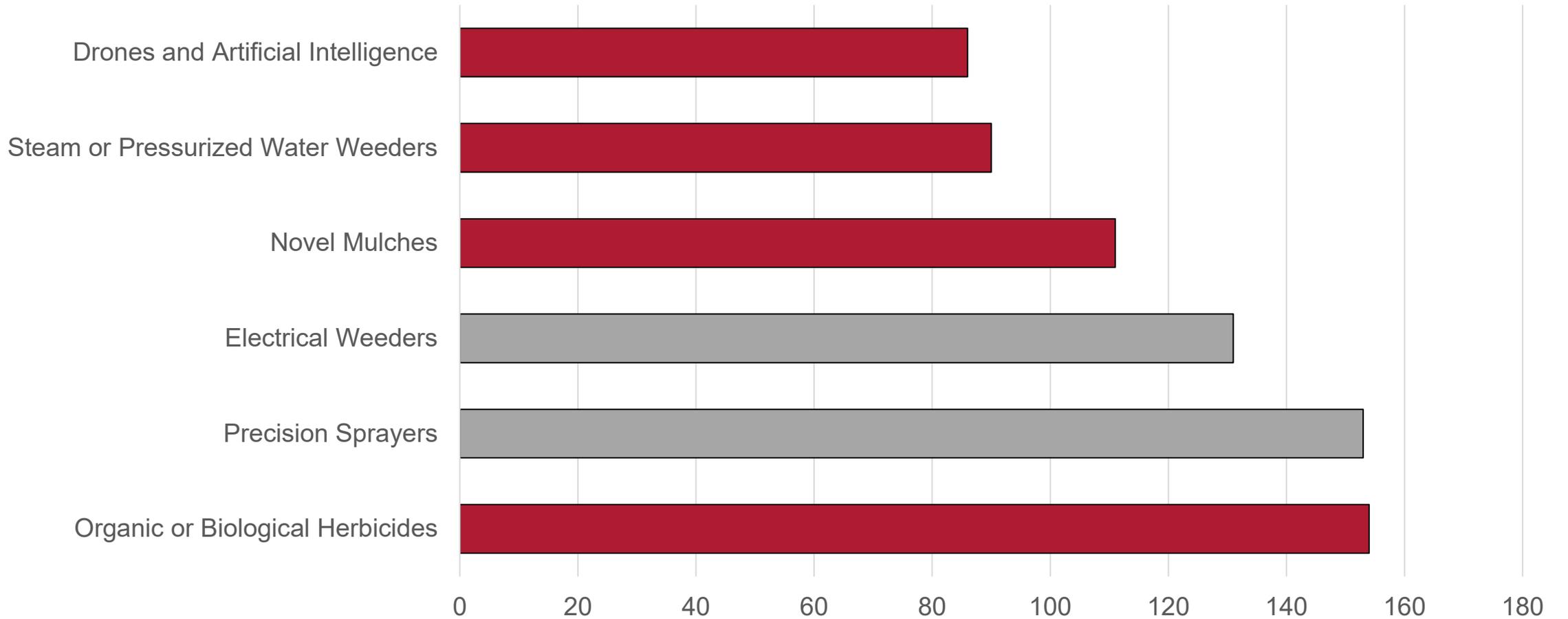
- Why 2050? That is when the planet's population is estimated to hit 9 billion and the global capacity to provide enough energy, water and food could be strained
- Meeting these needs will require improved weed control; “integrating old and new technologies into more diverse weed management systems”
- New herbicide chemistries and targets (*Note: herbicides won't go away*)
- Biological control of weeds
- Enhancing crop competitiveness
- Strategies and equipment to reduce seed inputs/deplete seedbanks
- *Novel technology for weed control, including precision agricultural tools*

Field bindweed in grapes



Nut and Fruit Grower Interest in Novel Technology (2019)

What Technologies Are You Interested In?



Automated Weeders are in Development and on the Market



Not all weeders are appropriate for all systems (i.e. annual vs perennial crops)

AUTOMATION FOR WEED CONTROL OFTEN REQUIRES DETECTION AND ACTUATION

- *Detection*
 - Differentiate the unwanted plant from the background soil
 - Differentiate the crop from the weeds (or weeds from the crop) by size differences, crop row pattern and/or machine learning
- *Actuation*
 - Spray weeds with herbicides
 - Physically remove or damage weed tissue
- *No detection and differentiation, GPS alignment to crop rows and passive removal*

CORNELL'S 2021 (AND 2022) AUTOMATED SPRAYER TRIALS

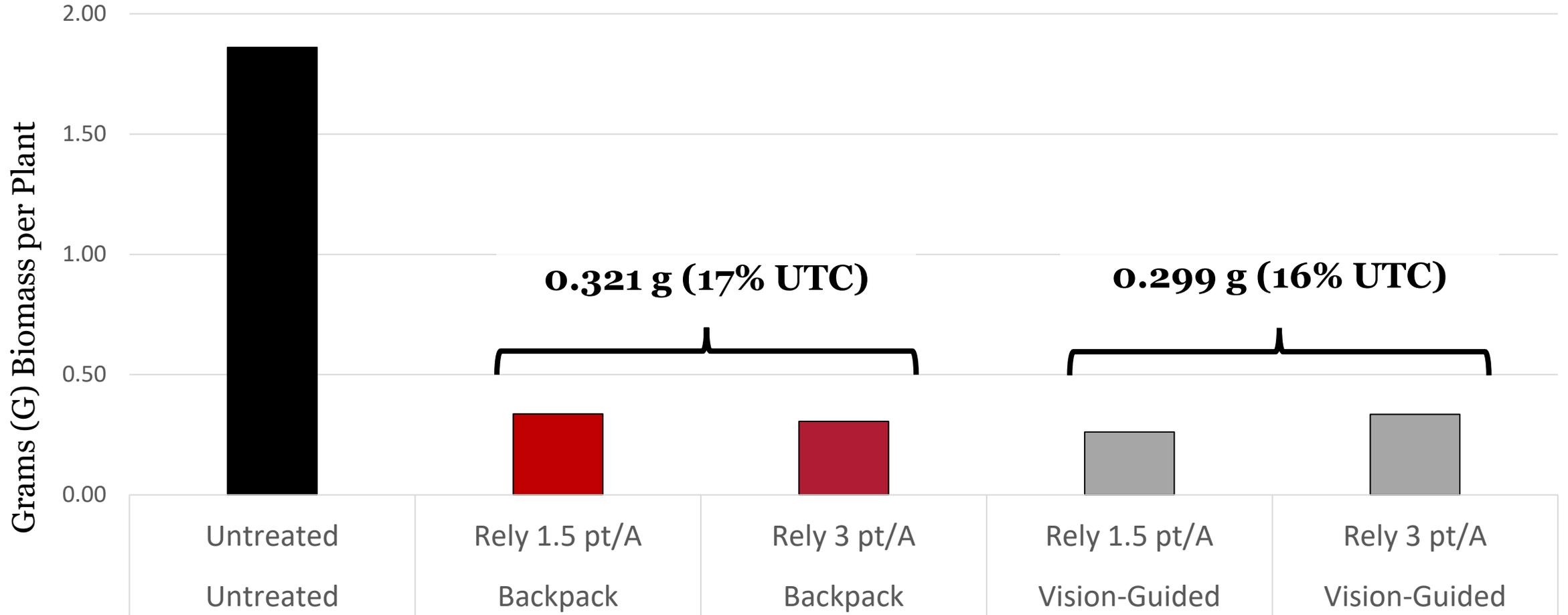
WEED-IT Quadro

WEED-IT Quadro once again sets the standards for precision spraying. Effective weed detection and elimination is becoming increasingly important in today's growing environment with less precipitation, limitations on herbicides usage and resistant weeds. To help growers combat weeds more effectively, precision spraying specialist Rometron introduces WEED-IT Quadro: the next generation spot spraying.



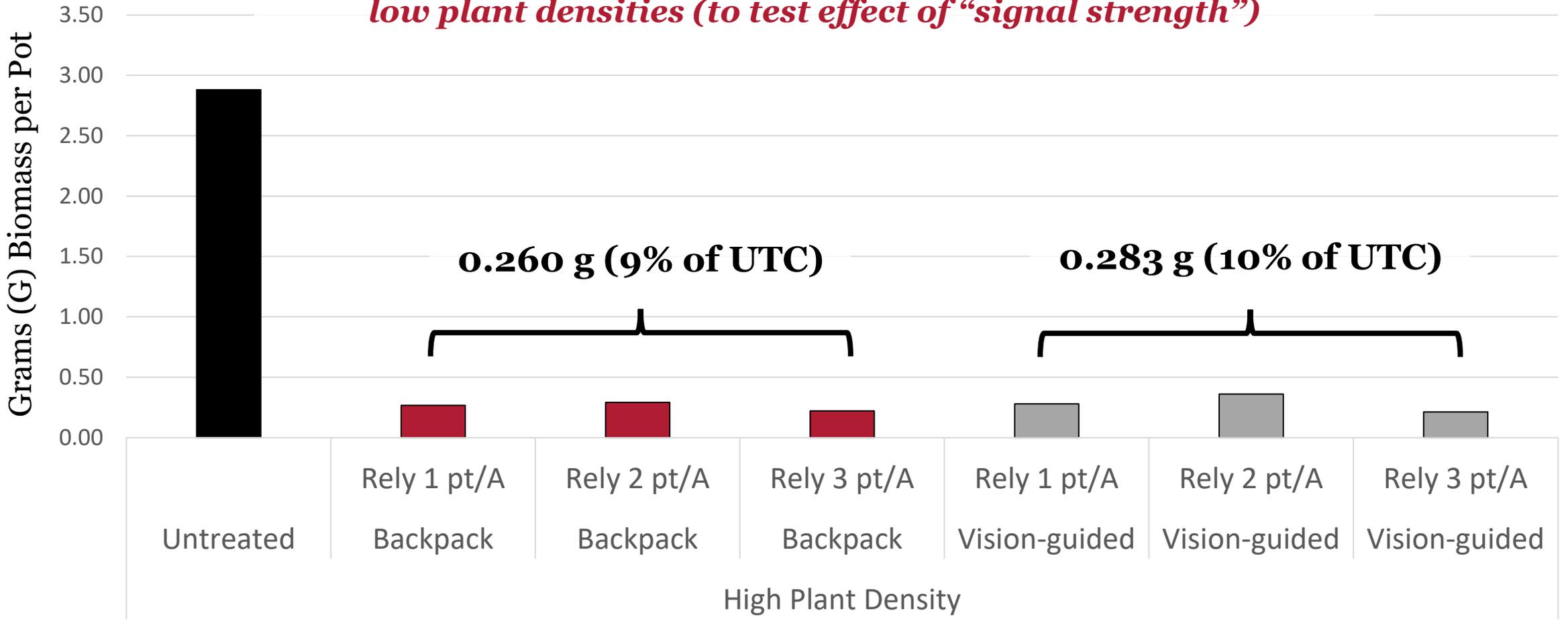
- Weed-It Quadro
- Newer iteration of “green-seeker” technology
- Green on brown by detecting chlorophyll fluorescence (no image processing)
- Detection information is relayed to solenoids that operate nozzles
- Not selective, can spray crop plants that are detected by the sensor
- Commercially available now and being used in fallow dryland production systems, examining in row crops and fruit systems

Comparison of Backpack vs Vision-Guided Sprayer Applications on Palmer Amaranth Control with Glufosinate (14 DAT)



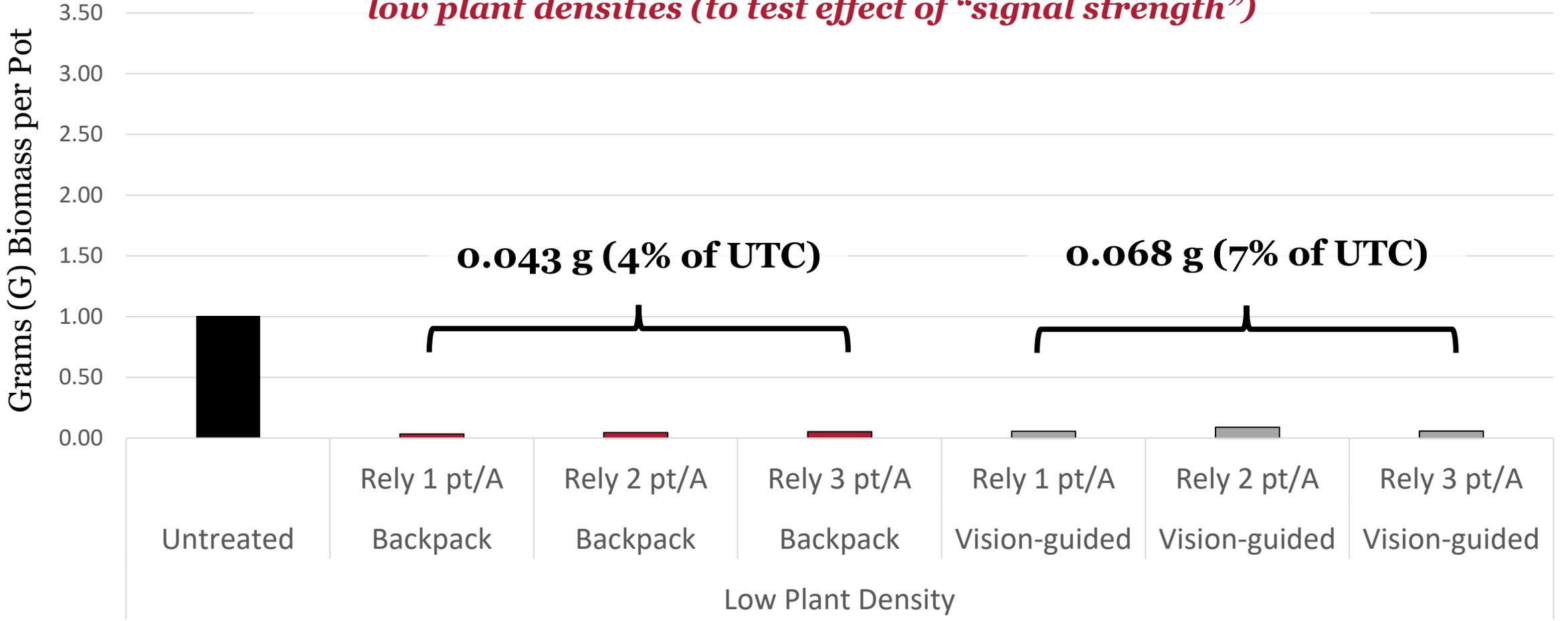
Comparison of Backpack vs Vision-Guided Sprayer Applications on Horseweed Control with Glufosinate (14 DAT)

All treatments were applied to pots with high plant densities and low plant densities (to test effect of “signal strength”)



Comparison of Backpack vs Vision-Guided Sprayer Applications on Horseweed Control with Glufosinate (14 DAT)

All treatments were applied to pots with high plant densities and low plant densities (to test effect of “signal strength”)





IT'S ELECTRIFYING!

Sosnoskie, Kikkert, Hanchar, and Brown (2020) *Managing Herbicide-Resistant and Other Difficult-to-Control Weeds in Field and Vegetable Crops Using Electrical Discharge Systems* – NYFVI (\$81,324)

Moretti, Hanson, Sosnoskie, Formiga, Brewer, and Goodrich (2021) *Performance and Economics of Electric Weed Control in Organic Perennial Crops: A Multiregional Approach* – USDA OREI (\$2,044,595)



ELECTRICAL WEED CONTROL (EWC)

Controls weeds by applying an electric current directly to unwanted vegetation

The flow of electricity through the plant generates heat, which causes water in cells to vaporize and tissues to burst and die

Touted benefits include no disturbance of the soil surface, no chemical application

First patents for electrical weed control devices were issued in the 1890's and explored in sugar beets in 1980's

Lots of recent, renewed interest because of herbicide resistant weeds and rising labor costs



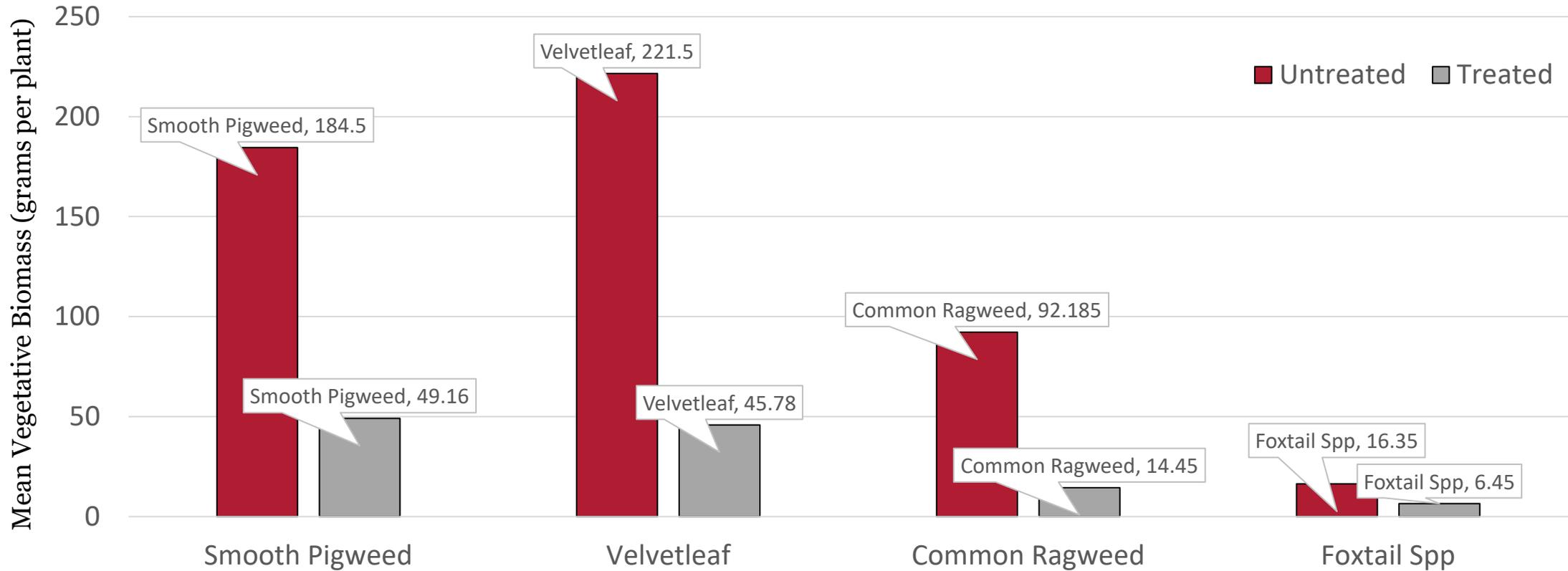
WEED ZAPPER™ IS A TRACTOR-TOWED, PTO-DRIVEN GENERATOR THAT PRODUCES 100,000+ WATTS OF ELECTRICITY
THAT CHARGES A FRONT-MOUNTED METAL BAR
WEEDS ABOVE THE CANOPY THAT CONTACT THE BAR ARE ELECTROCUTED

IN 2020 AND 2021, PARTNERED WITH THREE GROWER-COOPERATORS IN NEW YORK WHO OWN/OPERATE OR
RENT/OPERATE WEED ZAPPER™ UNITS TO EVALUATE WEED RESPONSES TO EWC

Weed Biomass (g) 7DAT with Weed Zapper Annihilator (in Soybean 2020)

61 to 84% Reduction in leaf and stem tissue biomass per plant

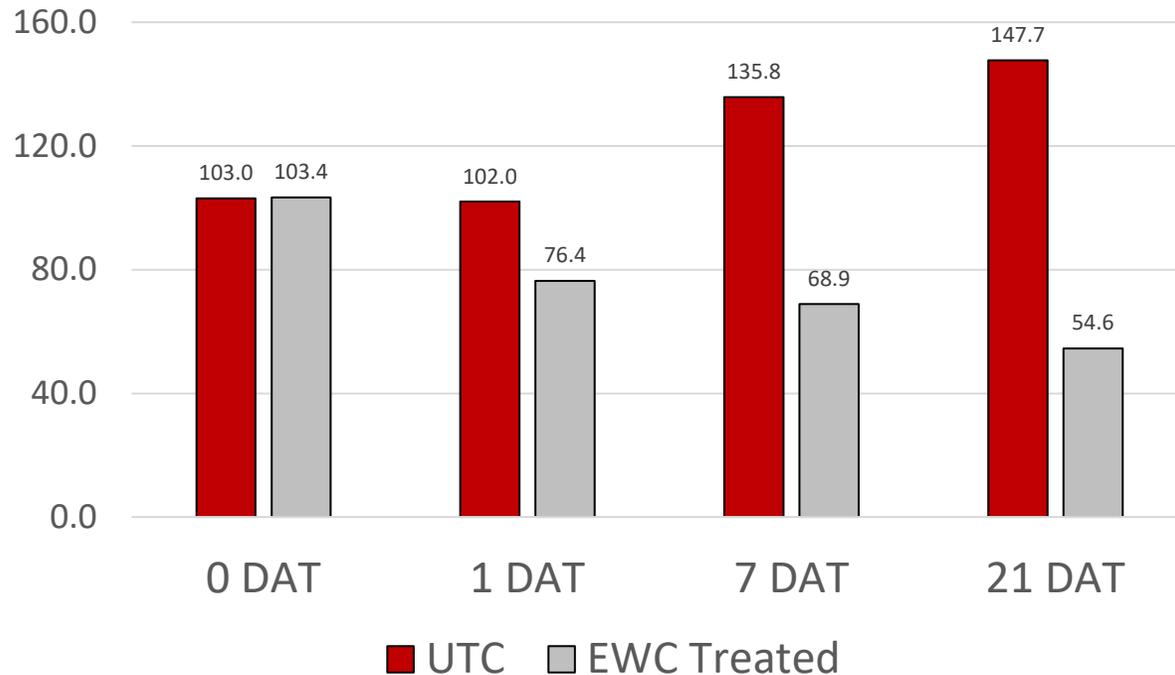
67 to 88% in reproductive output (data not shown)



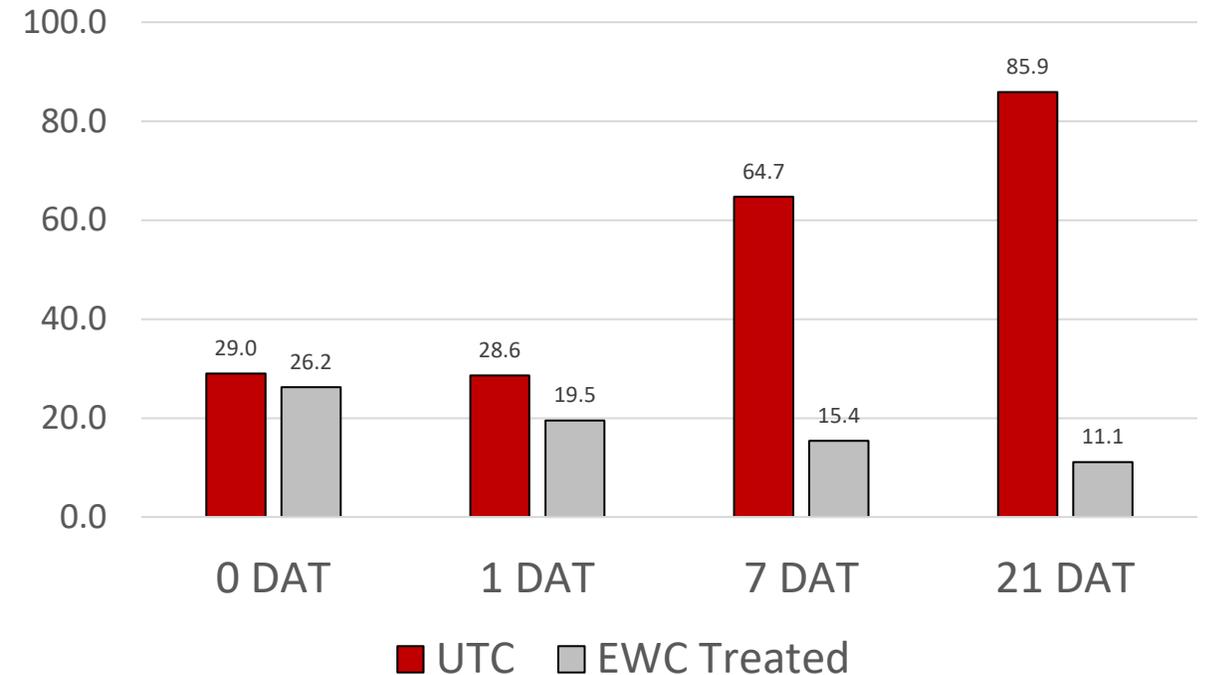
Changes in Mean Lambsquarters Height (cm) and Biomass (g) over time in response to EWC (in Beets 2021)

Lambsquarters were succulent and just beginning to flower when EWC was applied

Plant Height (cm)



Dry Biomass (g) Per Plant



Equipment (Zasso Electroherb) at Oregon State University (Lab of Dr. Marcelo Moretti)



TRANSFORMER
24,000 W
(30 KVA)

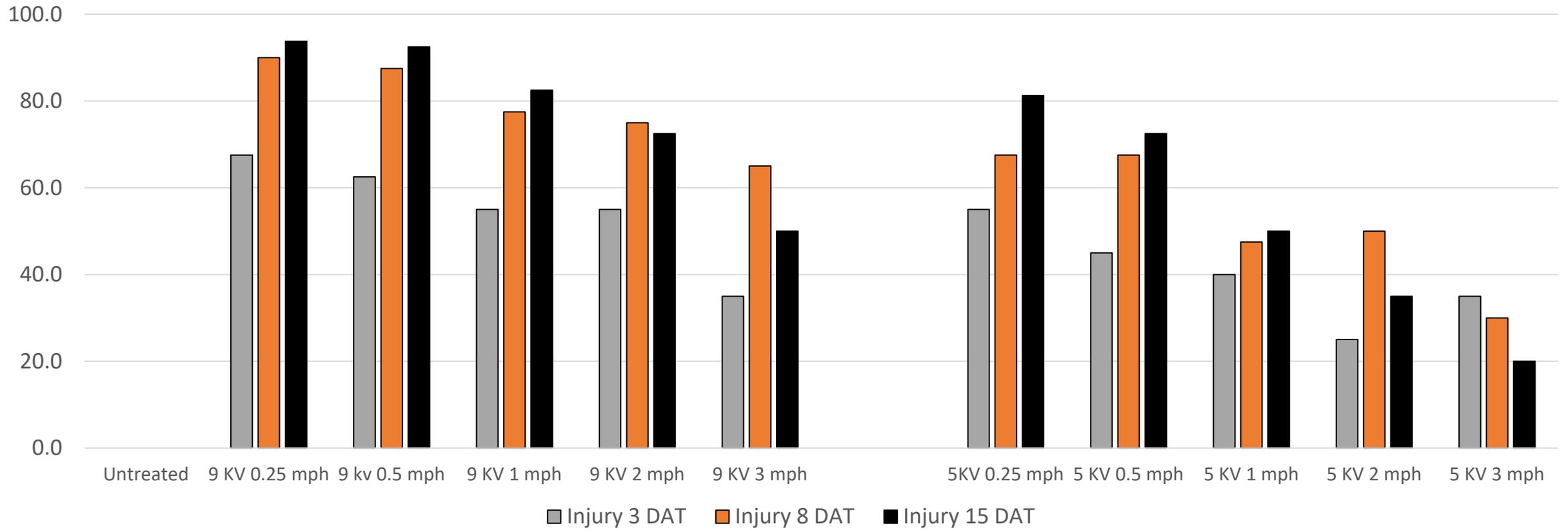
Mechanical power is generated by the tractor and a rear-mounted box containing a PTO-driven generator transfers it to high-frequency, high-voltage **transformers**

High-voltage cables and connectors

Electrical current passes through plants on the surface and down into their roots before completing the electrical circuit

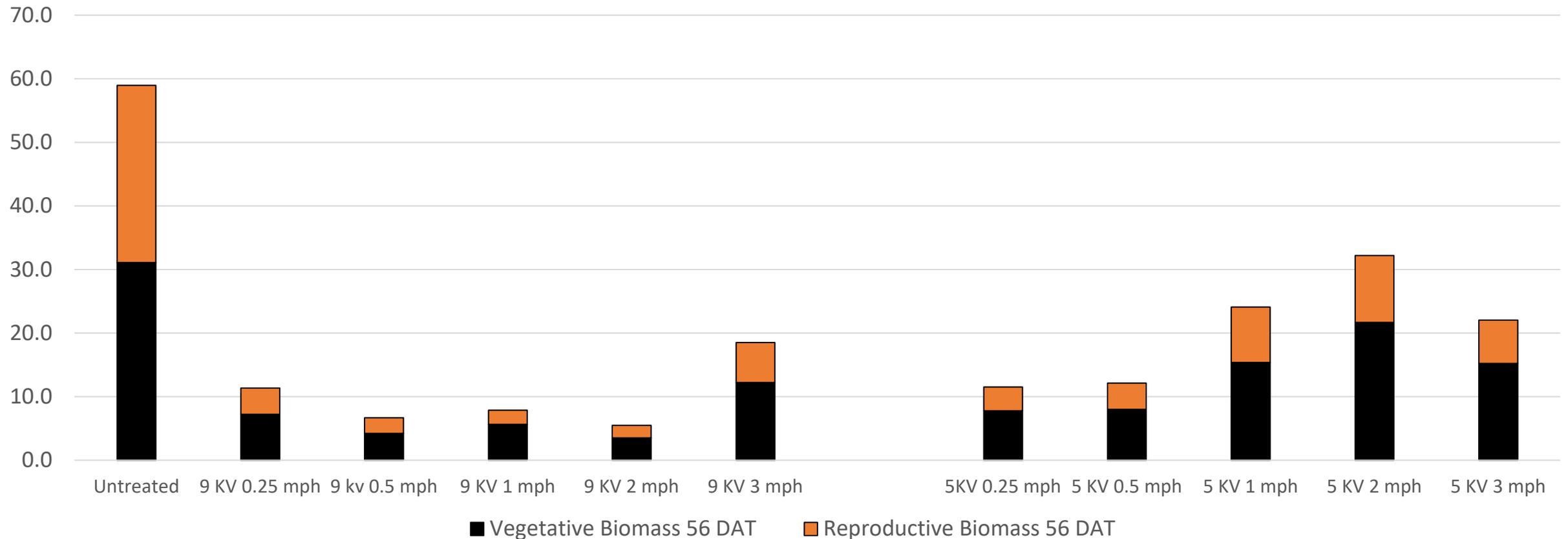
Italian Ryegrass (*Lolium multiflorum*) Injury in Response to Voltage and Travel Speed (in Hazelnuts 2021)

Lolium treated at a height of 2 feet
Initial injury observed, but damage is not instantaneous



Italian Ryegrass (*Lolium multiflorum*) Biomass in Response to Voltage and Travel Speed (in Hazelnuts 2021)

Lolium treated at a height of 2 feet
Least amount of vegetative and reproductive biomass observed with higher voltage



Research Projects In 2022 (And Beyond)

Precision Spraying

Evaluate the impacts of the following factors on weed control success

Species identity

Plant size

Plant density and arrangement

Herbicide type

Herbicide rate

Travel speed

Interference (leaves, pruning clippings)

Electric Weed Control

WEED CHARACTERISTICS: Weed type (broadleaf vs grass), life cycle (annual vs perennial), root system (fibrous vs tap), weed size, weed density and arrangement (solitary vs clustered)

EDAPHIC CONDITIONS: Soil type and moisture content on weed control efficacy and crop safety

SELECTIVE FORCES: Who survives (and why) and how does this affect drive changes in weed community composition

SYSTEM IMPACTS: Soil microbiome communities, pollinator/pest/predator interactions

Final Thoughts

Herbicides won't go away, but they won't be released as frequently as they have in the past

The nature of the products may change (i.e. plant- or microbial- based products, biopesticides)

Weed and crop biology will need to be better understood and exploited (especially under climate change conditions) to maximize weed suppression

Weed seed reduction/return to the seedbank and seedbank reductions will be crucial for weed management going forward

Technological and infrastructure advances (e.g. battery storage, processing power speed, improved cellular and broadband services)

Labor pools are getting older, more expensive, and difficult to source, but the labor needs will change (e.g. designing, building, servicing, operating novel technology, data management and analysis)



Thank You!

*Research support from FCF, IR-4, NYFVI, OREI
Local Growers and Cornell AgriTech
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