THE ALMOND CONFERENCE 2025

WELCOME!

CULTIVATING A HEALTHIER FUTURE

SOIL & IRRIGATION MANAGEMENT

Moderator

Sebastian Saa, ABC, Ag. Research

Speakers

Mae Culumber, UC ANR

Guillermo Valenzuela, WiseConn Engineering

Tom Devol, Irrigation & Technology Independent Consultant

Kyle Knipper, USDA ARS

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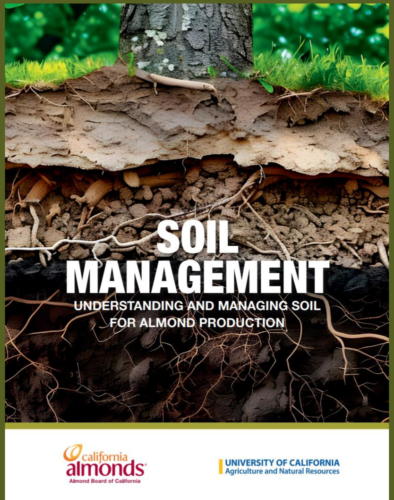
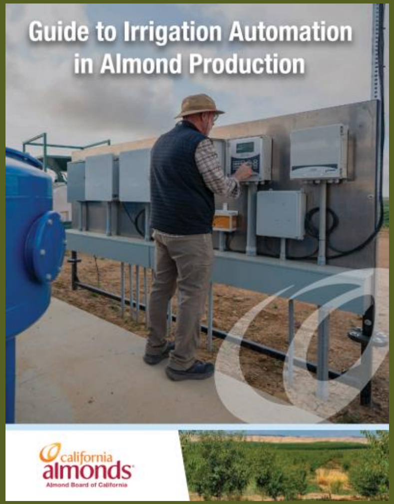
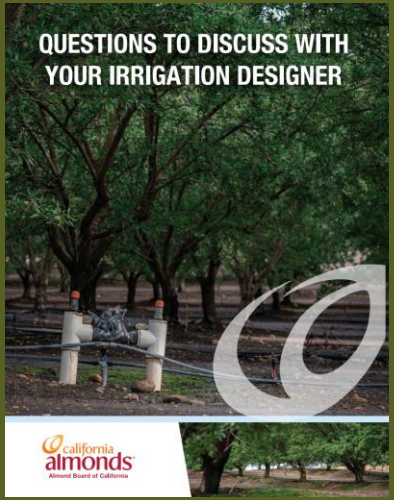
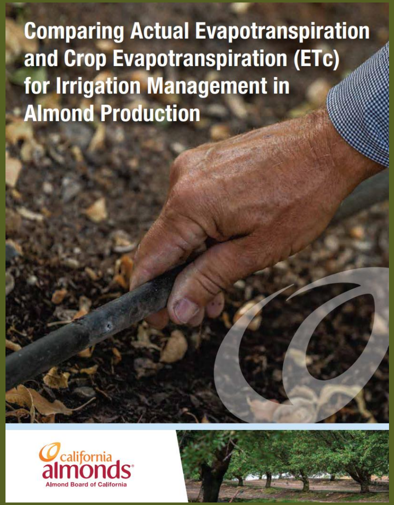
NEW RESOURCES:Q&A:









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NEW SOIL MANAGEMENT RESOURCE

MAE CULUMBER PHD

UC COOPERATIVE EXTENSION ADVISOR FRESNO -

DECEMBER 10, 2025

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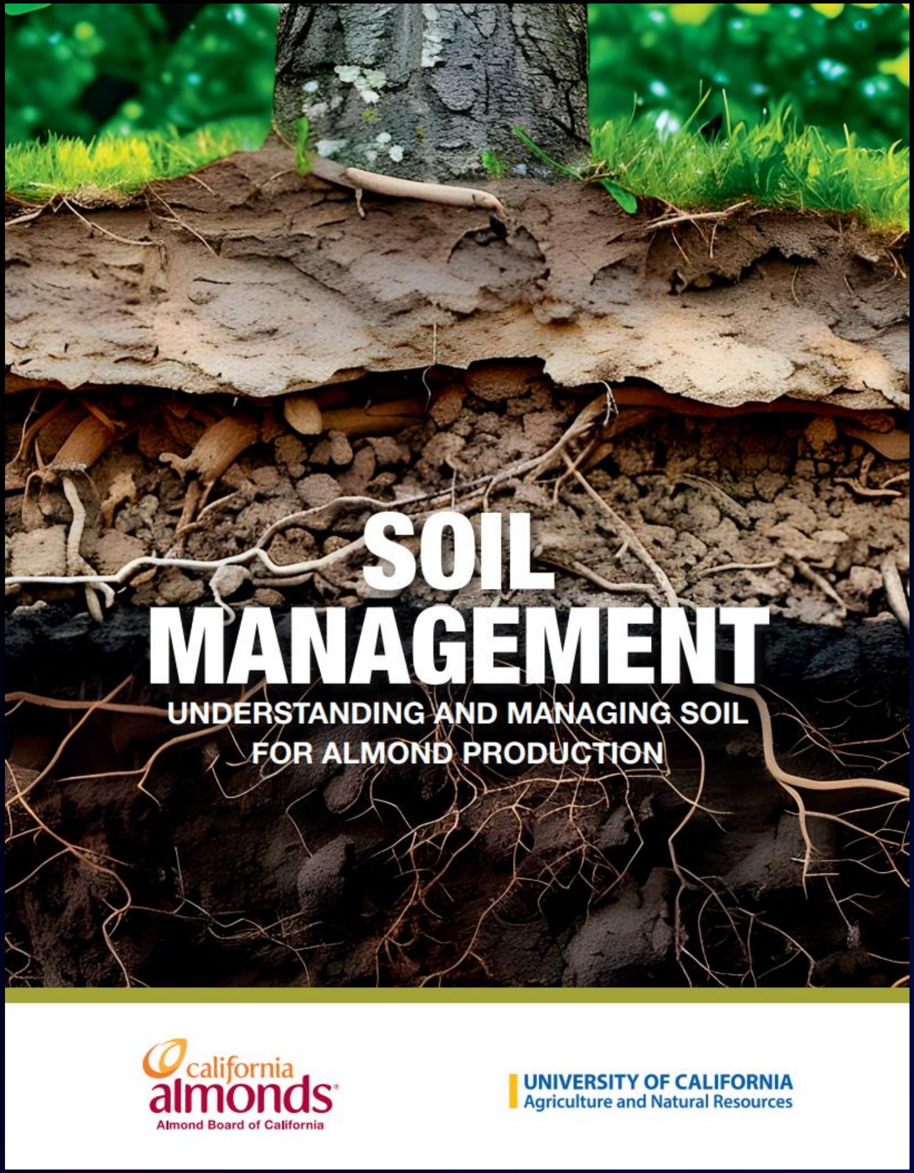

Why manage the soil?

- Reduce soil erosion
- Enhance drainage
- Boost water retention
- Increase nutrient availability
- Reduce salts
- Enhance and sustain long-term yield

https://www.almonds.org/sites/default/files/2025-11/Soil%20Management_Understanding%20and%20Managing%20Soil%20for%20Almond%20Production.pdf

The Soil Profile

- Layers of different texture, color, chemistry, and biological activity

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The Soil Profile

Topsoil: where organic matter accumulates, biological life and nutrients for growing plants reside

Subsoil: deeper layers often control water movement and root penetration

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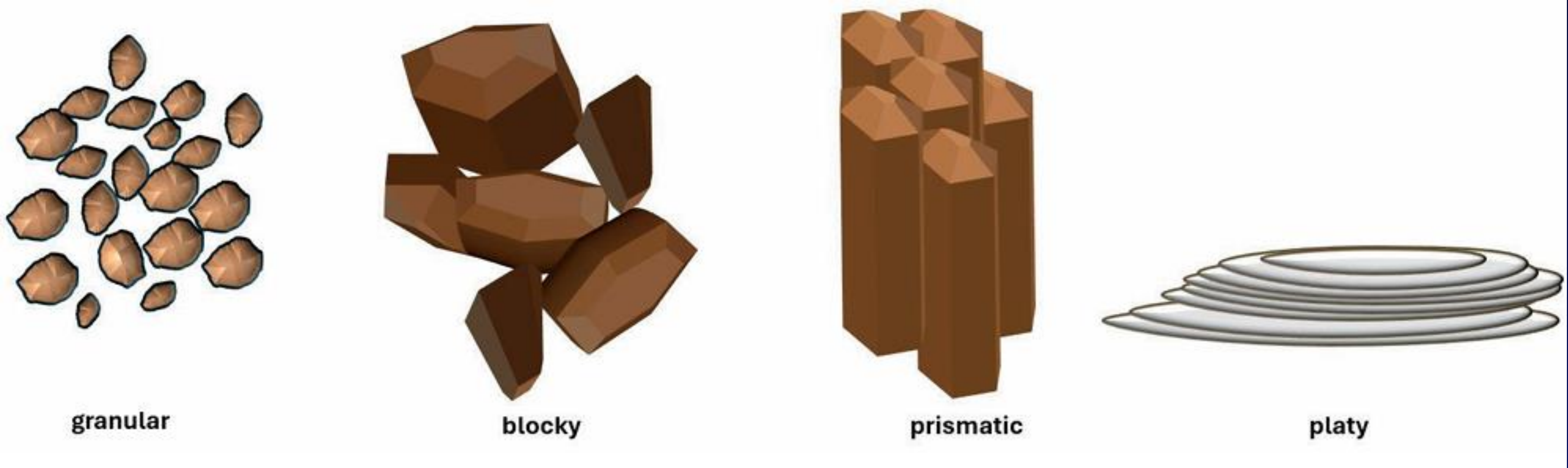
Soil aggregate forms



- Topsoil granular aggregates loosely arranged, allow water to easily infiltrate
- Subsurface blocky or prismatic aggregates larger and denser, can restrict water movement, reduce aeration, and limit root growth
- Platy structures restrict water movement and found close to the surface or in subsoil

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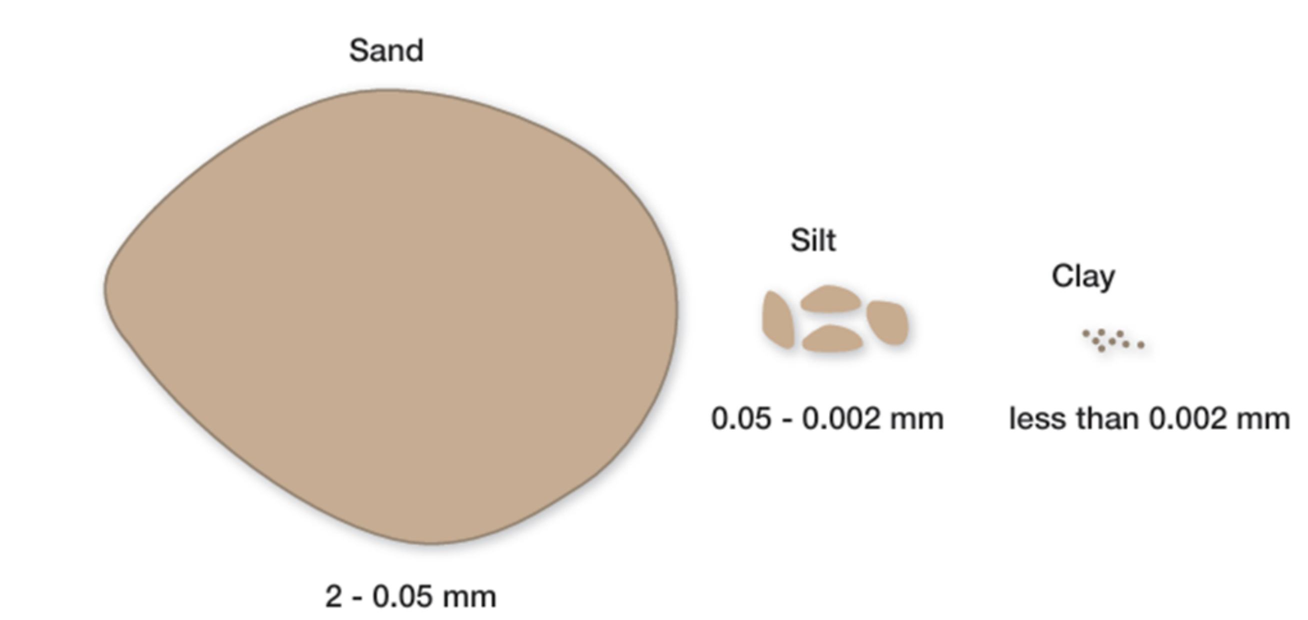
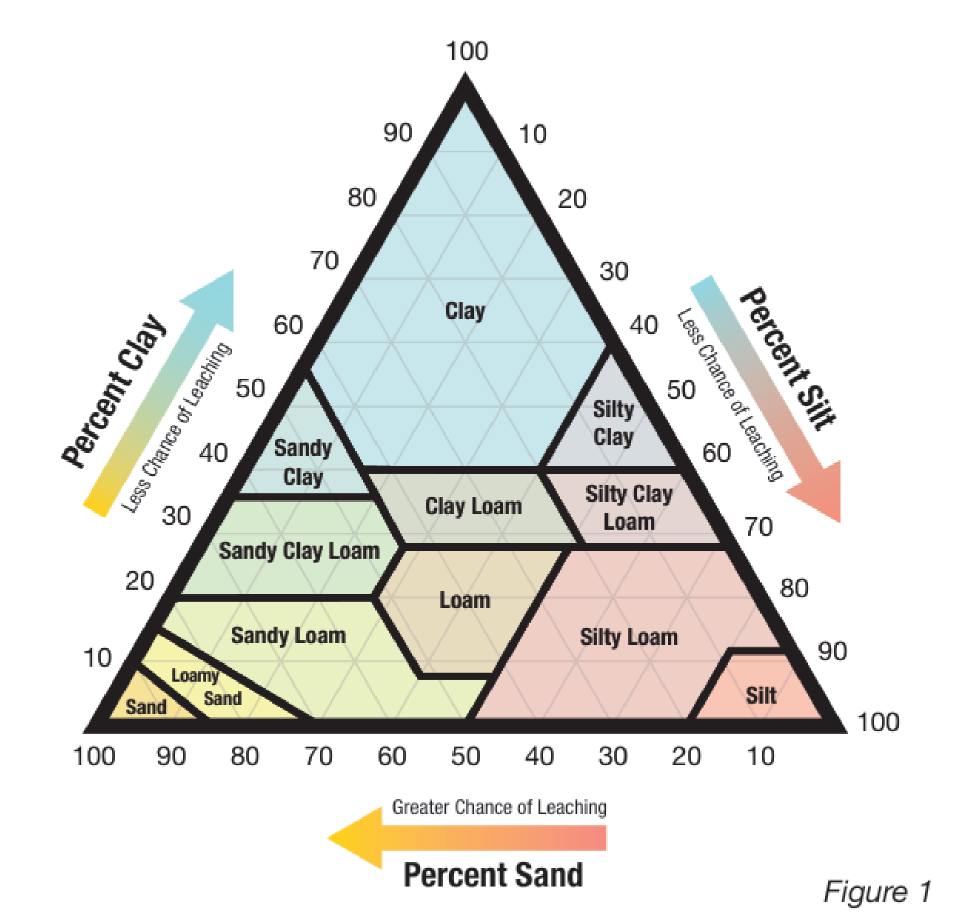
Building blocks of soil:
Sand, Silt, and Clay





Texture can change with different soil layers

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Soil Organic Matter

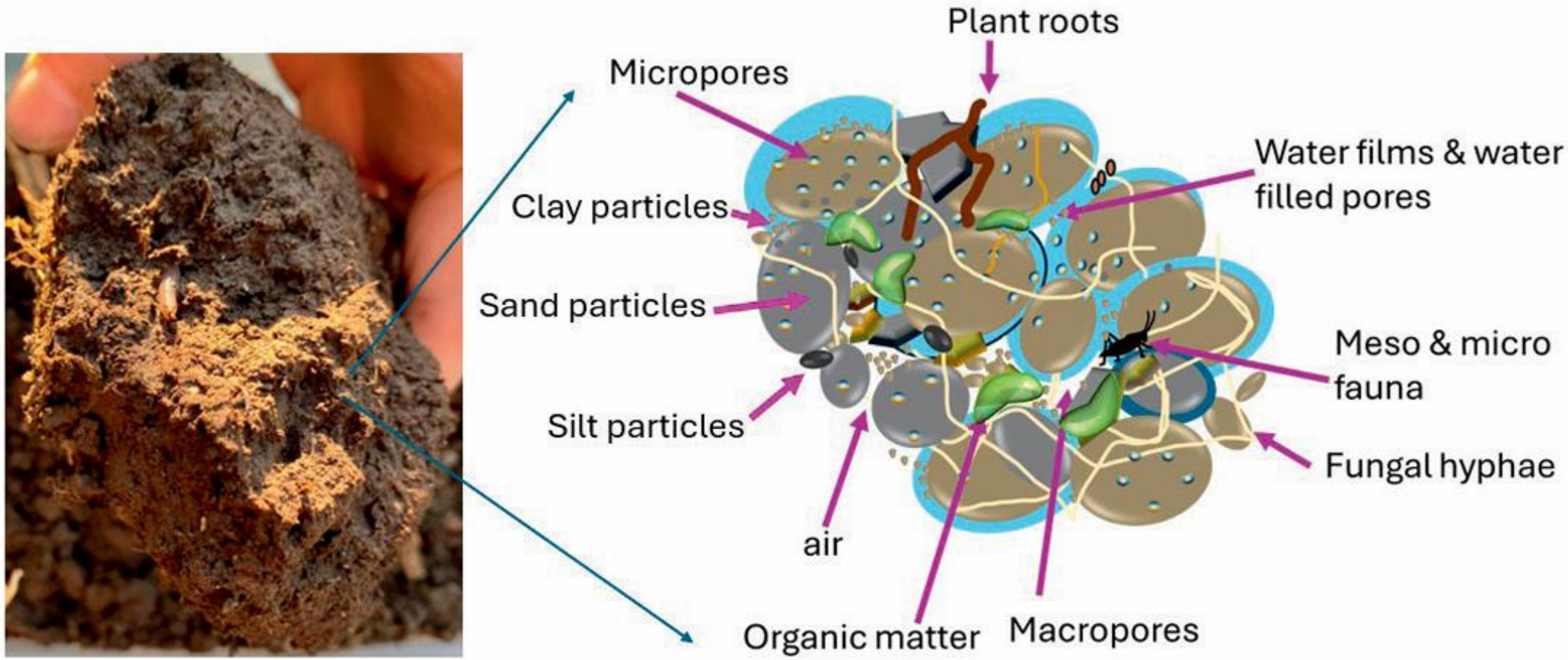

Figure 3

Living and partially decomposed plant residues, roots, and soil organisms, microbial exudates, older more slowly decomposing organic compounds mix with mineral soil to form aggregates

Meso and Micro Fauna of the Soil Food web

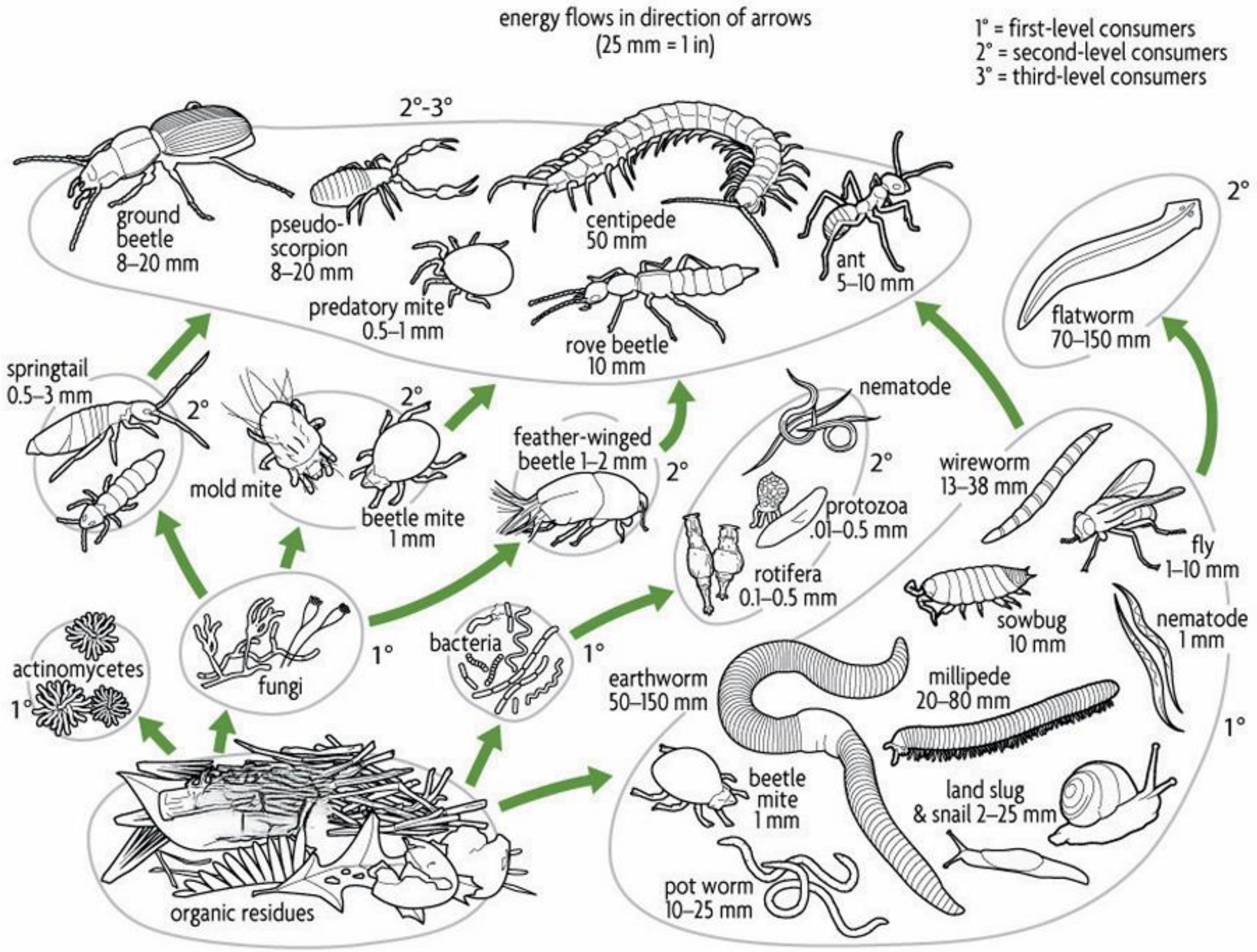

Figure 4. The soil food web. Modified from D.L. Dindal (1972). Adapted from illustration by Vic Kulihin.

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Organic materials

- Influence the balance of carbon (C) and nitrogen (N), two key elements that sustain soil biological activity
- Protect the soil and increase resilience to weather fluctuations
- Enhance soil water holding capacity
- Source of nutrients may partially substitute for chemical fertilizer without compromising yields and revenue

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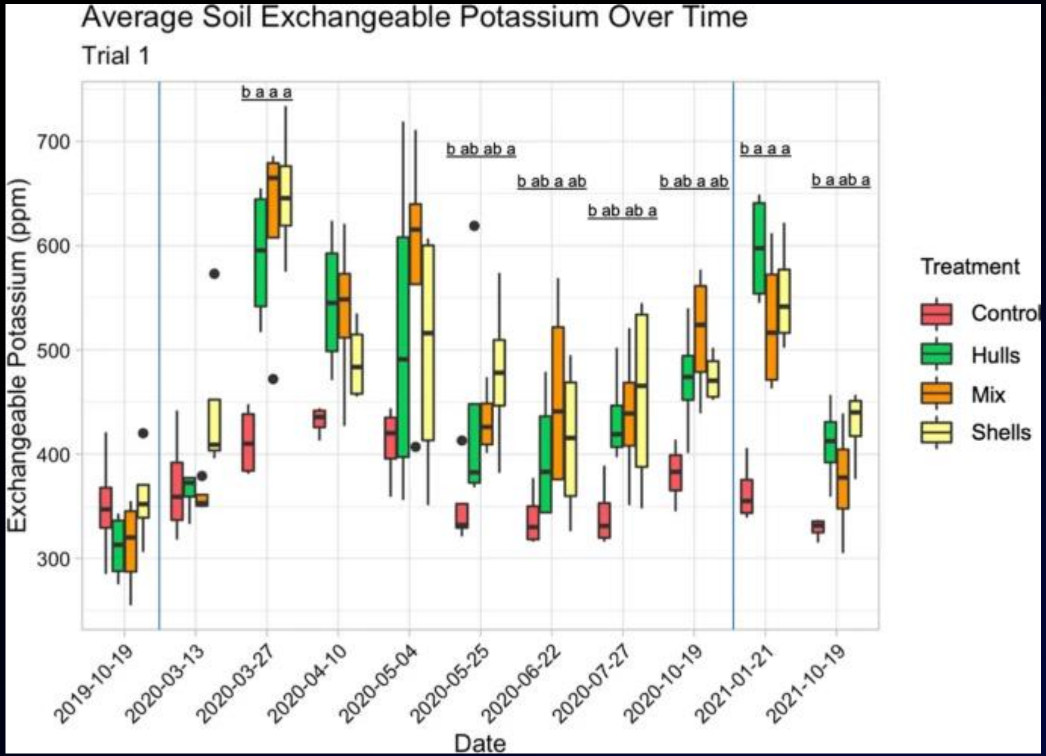
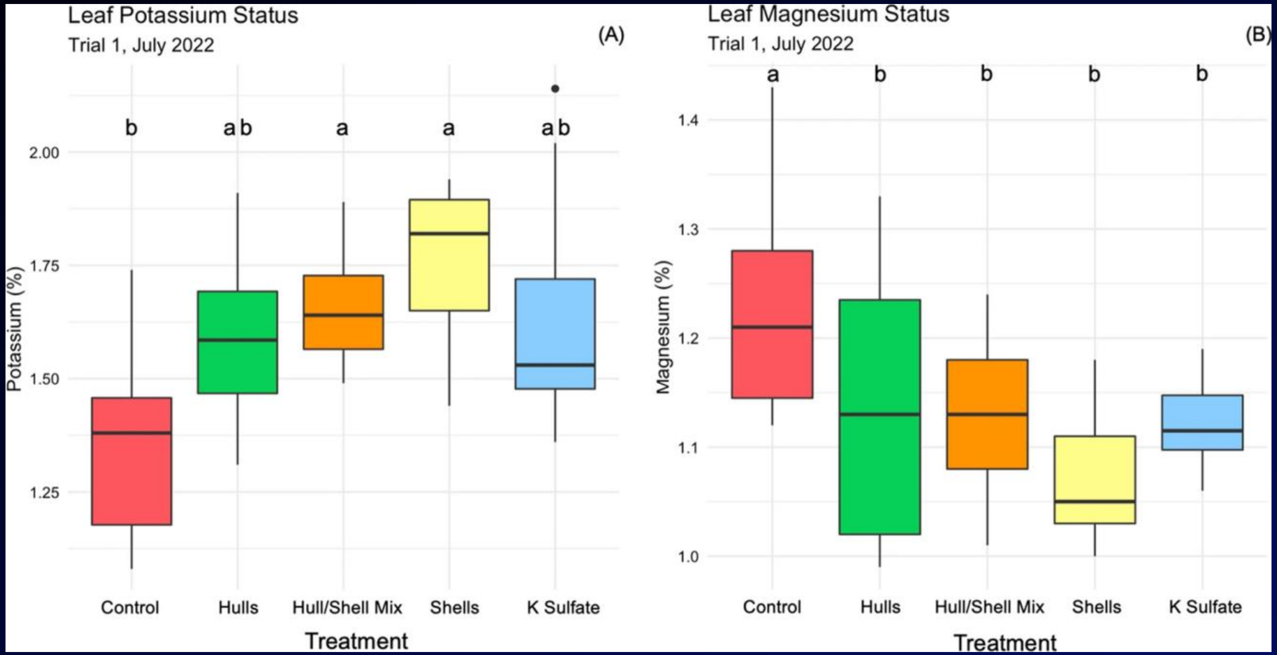
Almond hulls and shells





Andrews et al. 2024

- No risk of N immobilization with high C:N
- Higher level of soil exchangeable K in top 6 inches (2 to 7 weeks after application)
- Same leaf tissue K content compared to K-sulfate

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Organic materials potential to offset fertilizer use

Product	Rate/acre	N%	Available N lb/acre	K_2O%	K_2O lb/acre	Cost/ton	Annual cost/acre
UAN32	56 gal	32	200	0	0	$380	$112
Sulfate of potash	450 lb	0	0	50	225	$750	$170
Total			200		225	$1130	**$282**

Product	Rate/acre	N%	Available N lb/acre	K_2O%	K_2O lb/acre	Cost/ton	Annual cost/acre
Manure compost	3 tons	2.3	35*	2	120	$35	$105
Almond hulls and shells	2 tons	0.3	12	2.8	115	$45	$90
UAN32	43 gal	32	153	0	0	$380	$87
Total			200		235	$460	**$282**

- To estimate nutrient contributions from amendments, submit samples for lab analysis total N (%) and potassium oxide (K2 O, %).
- Total nutrient contribution calculated by multiplying the analysis (%) by the dry-weight application rate. Compost N reduced to 25% for the slow mineralization release of N

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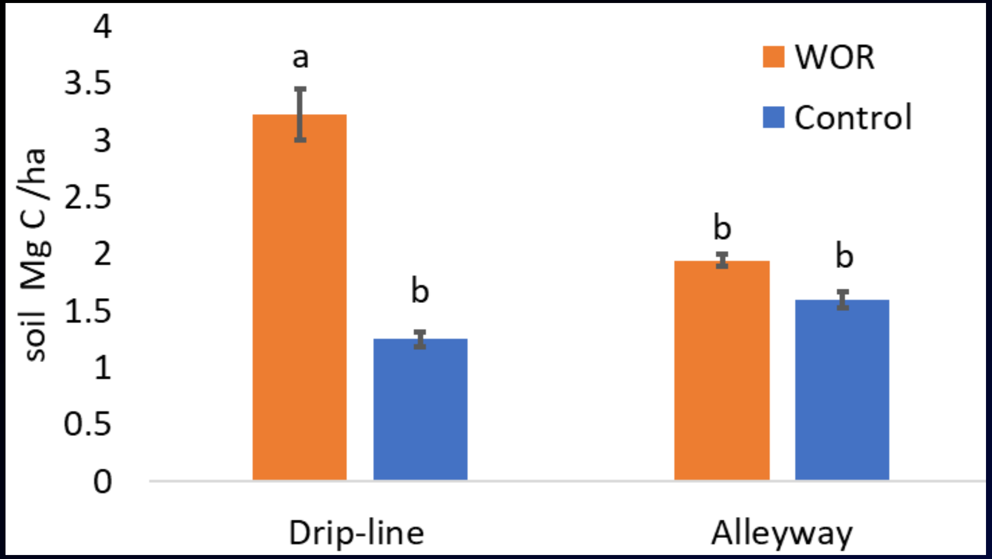
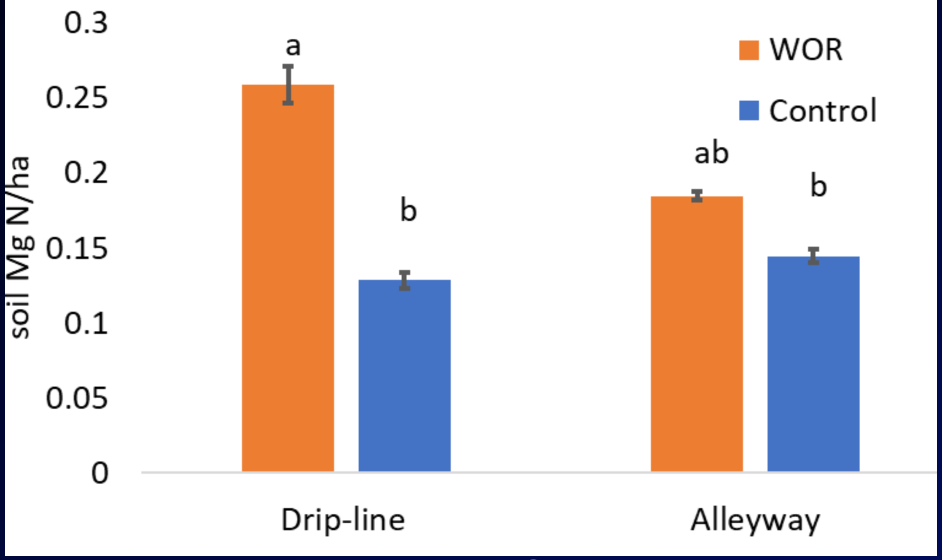
Wood Chips Impact Soil C and N in a Replanted Orchard





Culumber et al. submitted

- Soil C and N levels (< 2mm fraction) higher in WOR soils after 1 year
- Soil C stocks increase by > 880 lb C per acre in WOR treatment in 2 years
- Soil N stocks increase soil stores by 120 lb N per acre
- Suggests increased soil fertility for growing trees in WOR berms
- Little change in WOR alleyway likely due to slow biomass decomposition

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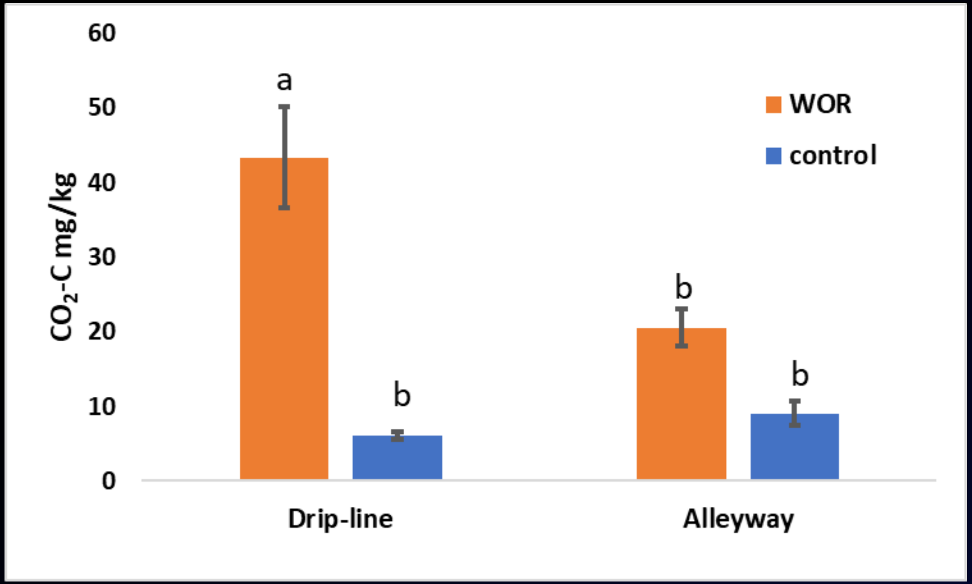
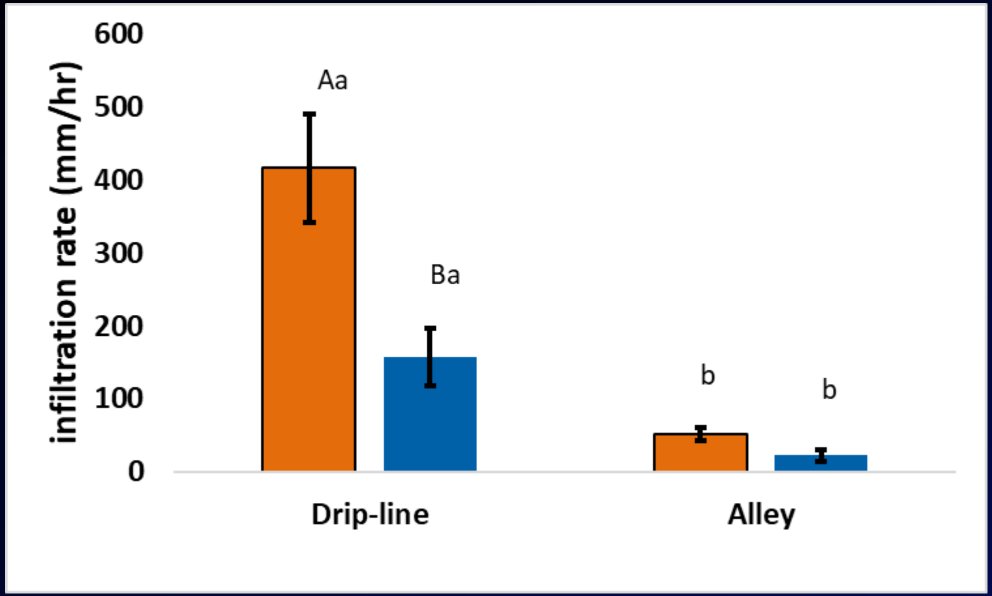
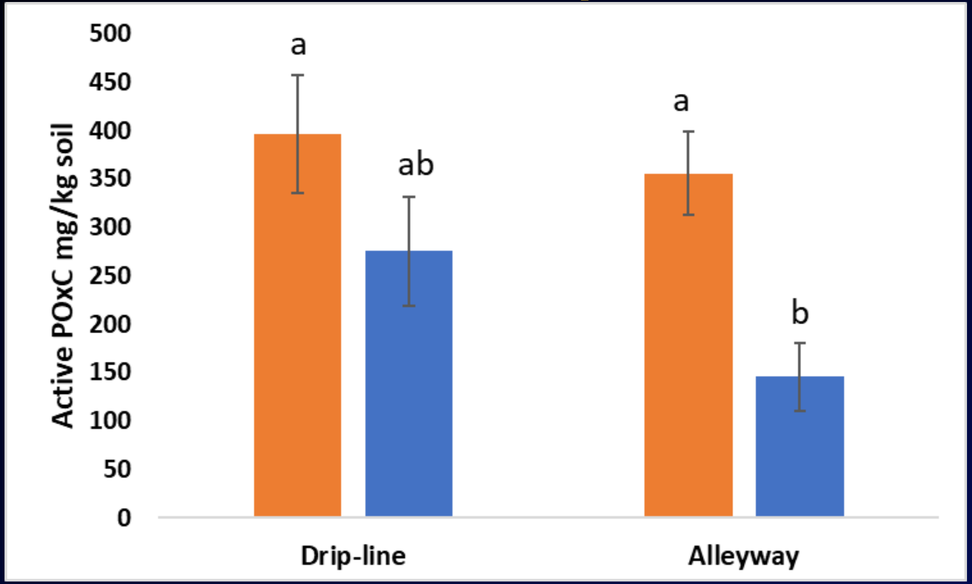
Additional Indicators of Soil Function with Wood Chips



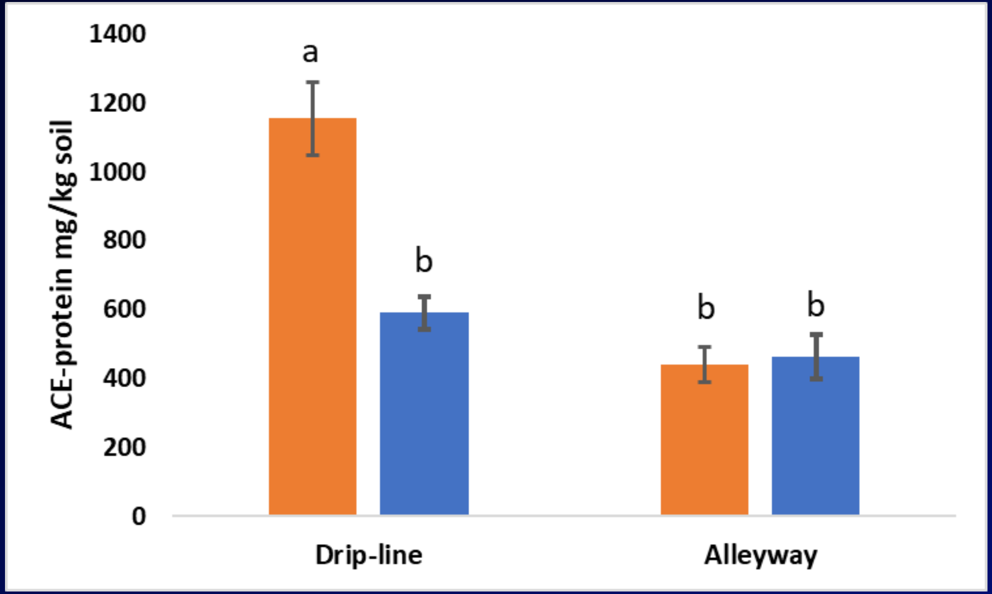
Microbial Respiration C



Water infiltration



Mineral bound and active soil C



Organically bound N proteins

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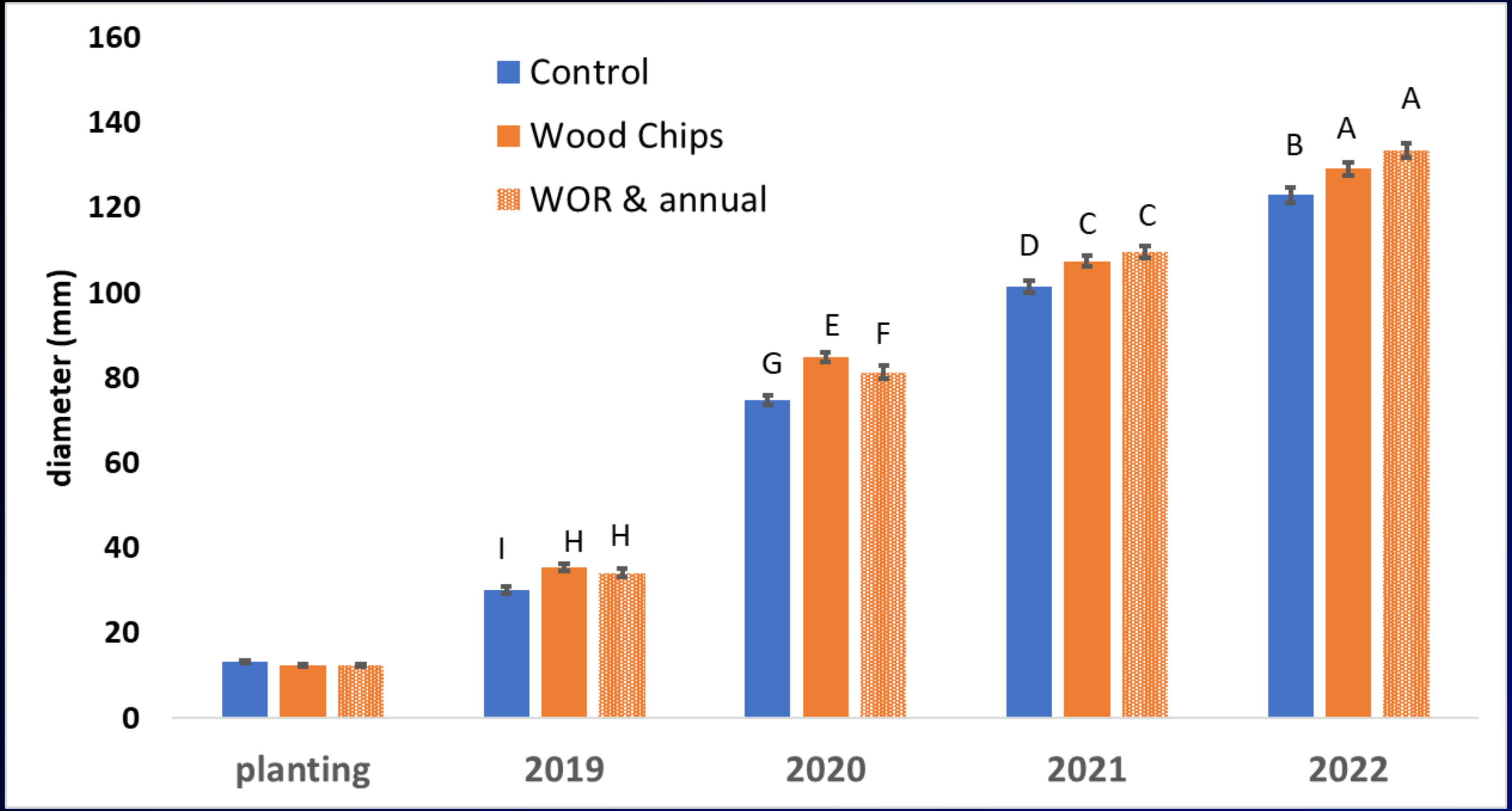
Almond Tree Growth after Wood Chips



April planting: only a 22% increase to the standard recommended rates (~5 oz N per tree or 52 kg per ha) WOR trees larger than conventional after the first season

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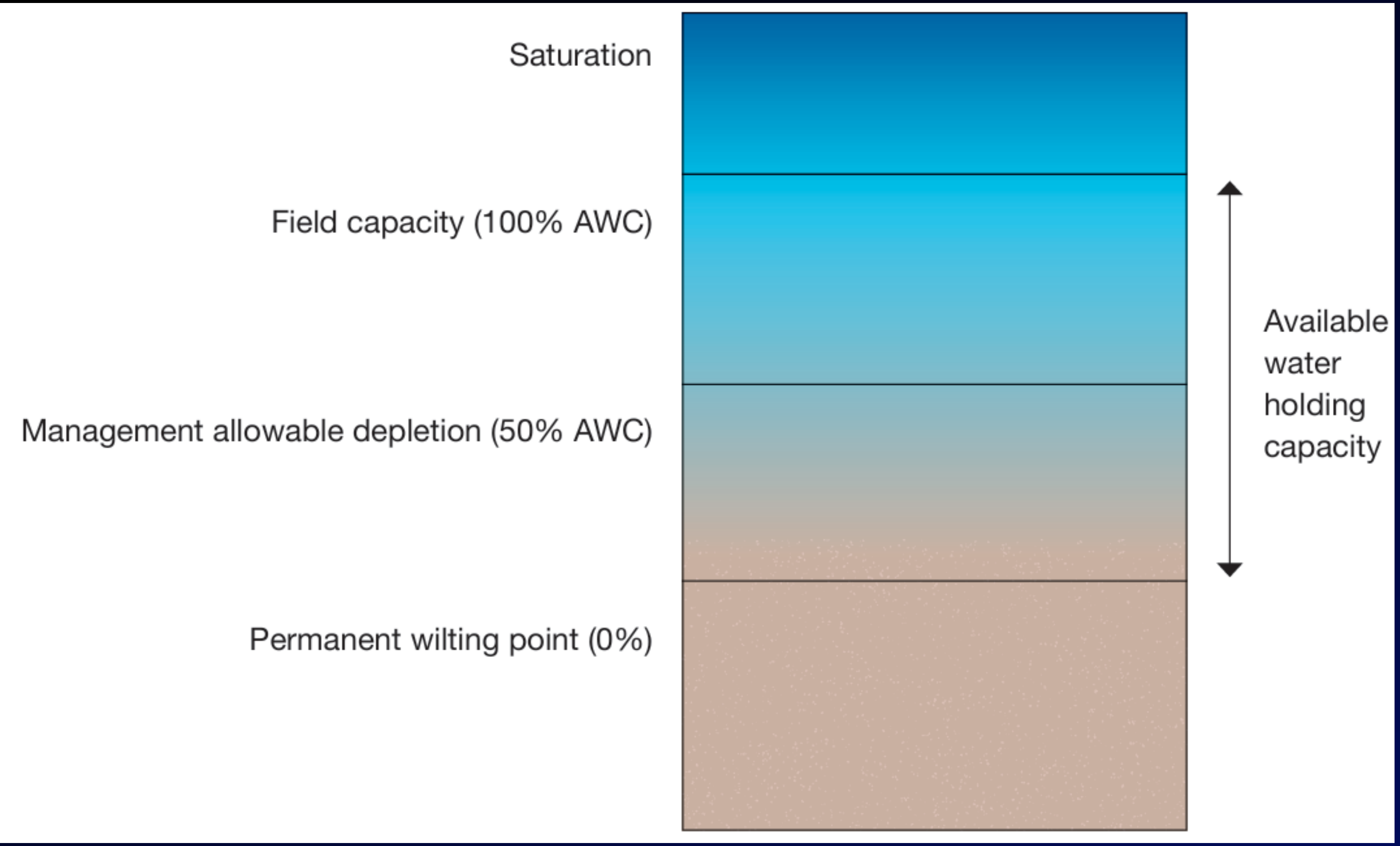
Soil texture and organic matter influence available water holding capacity(AWHC)



inches of available water per ft of soil

Some commercial labs offer site AWHC measurements, useful in orchards where SOM levels have substantially increased

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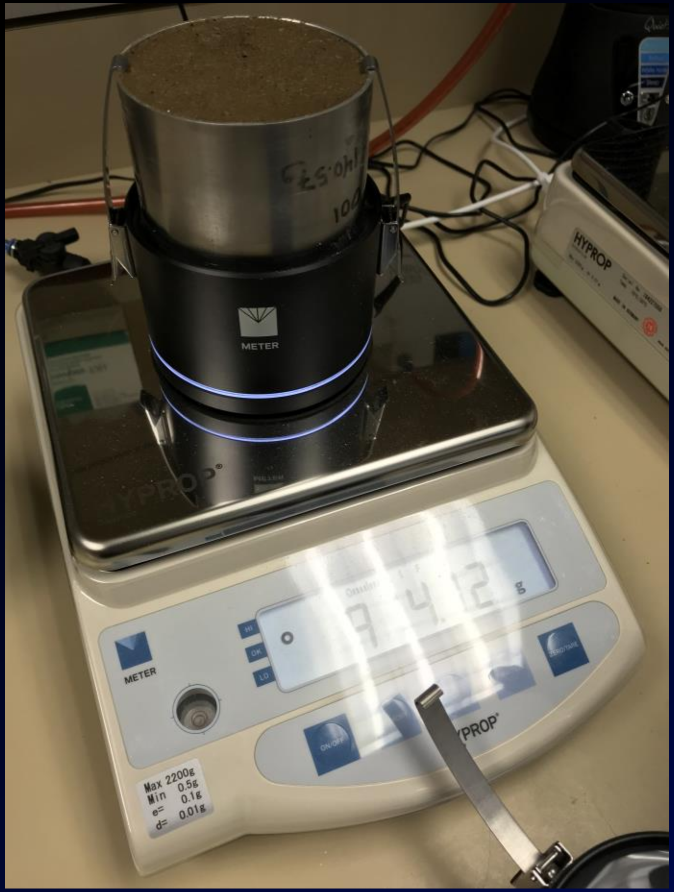
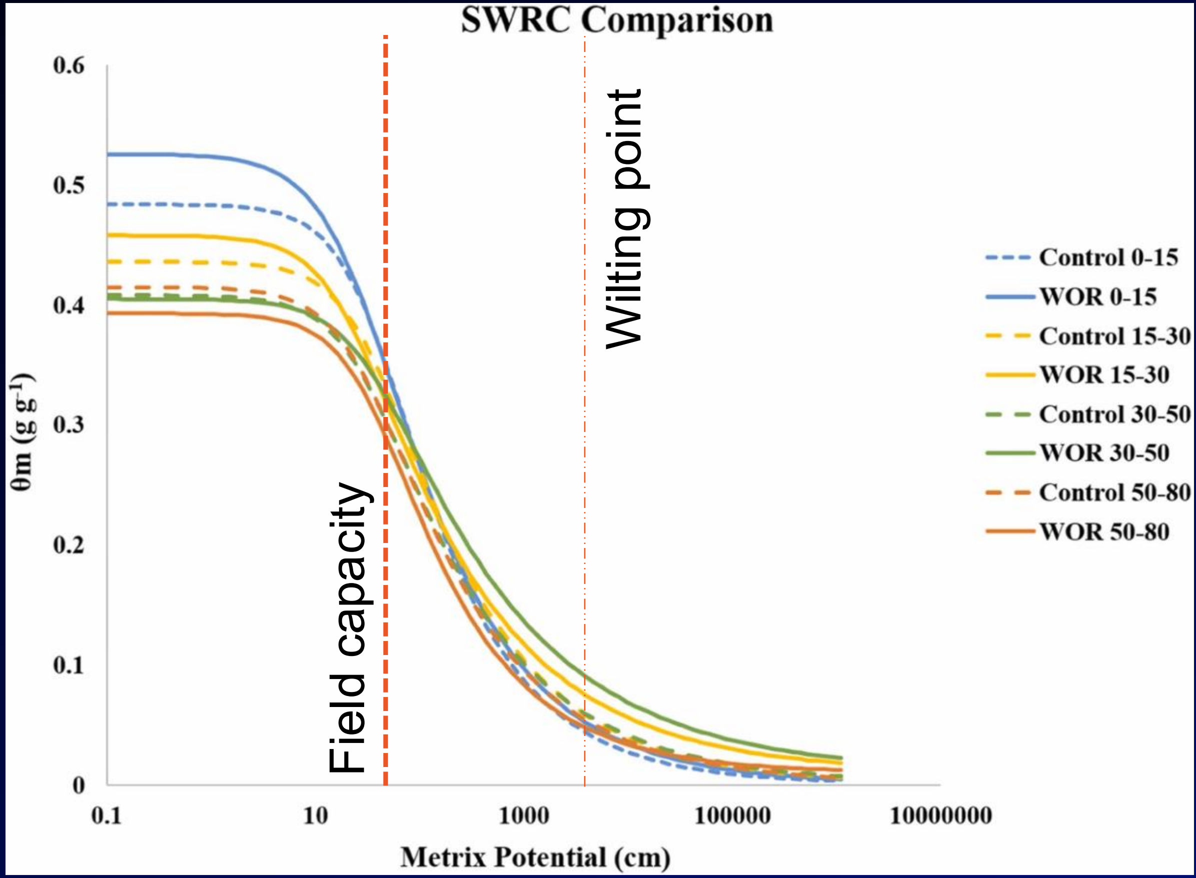
Soil water characteristic:
Wood chips vs Control by depth





Thao et al. 2024

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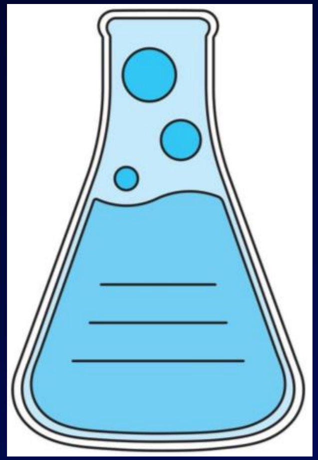
Bio-stimulant products promise:

- Improved stress resilience
- Improved yield
- Nutrient efficiency and savings
- Enhanced soil structure
- Reduced chemical footprint
- Economic savings

More field validation is needed….

Soil Evaluation: Laboratory Methods

enable quantitative comparison of orchard management practice effects on soil function over time



- SOM
- Soil texture
- Carbon to Nitrogen ratio
- Soil available nitrogen
- Soluble and extractable cations
- Electrical conductivity
- Microbial biomass abundance and diversity
- Bulk density
- Nematodes

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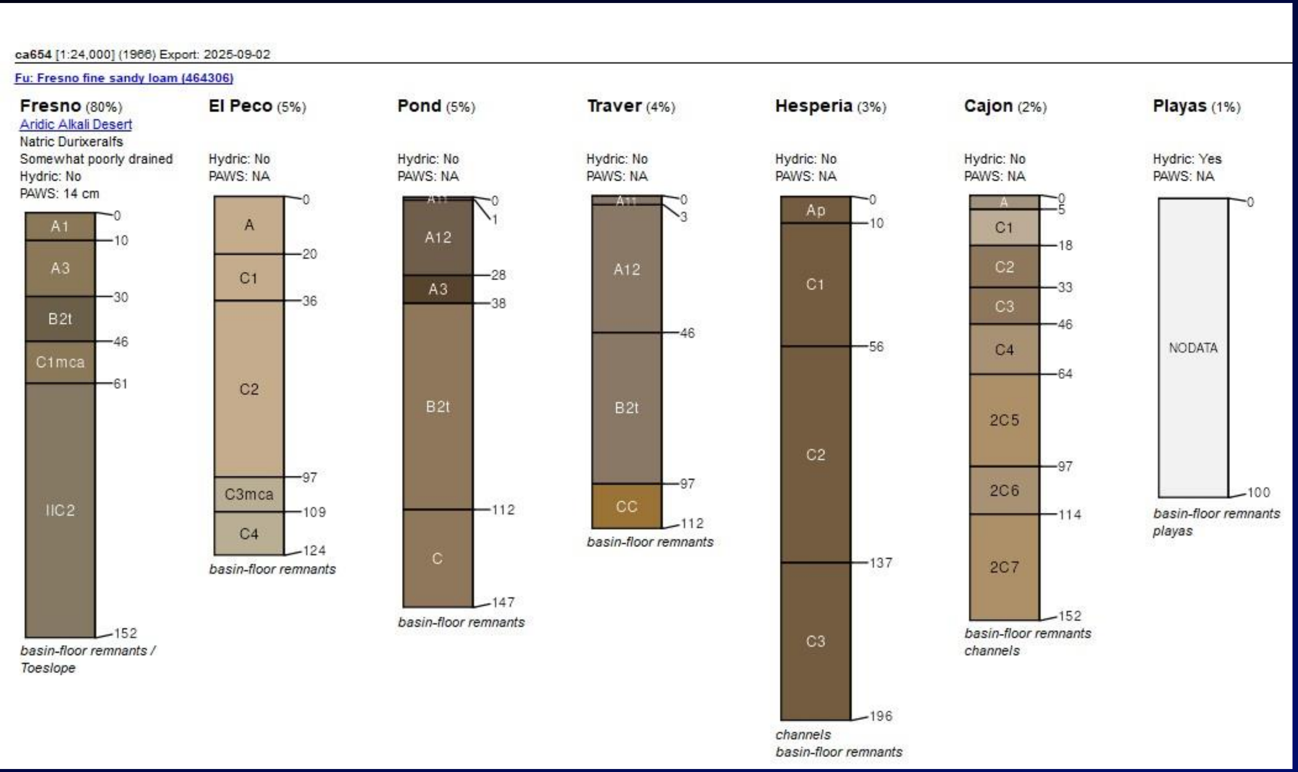
Soil Evaluation: Web Based Resources



Soil maps provide info about soil type changes across the field and useful to identify suitable locations for soil pit excavation to observe entire soil profile

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Field Methods: Texture by Feel

- Form soil into a ball, squeeze between the thumb and index finger to form a ribbon
- Length of ribbon and grittiness determine soil texture and moisture content

		Texture		
		Gritty	**Smooth**	**Neither**
Ribbon Length	**0-1”**	Sandy Loam	Still Loam	Loam
	1-2”	Sandy Clay Loam	Silty Clay Loam	Clay Loam
	2-3”	Sandy Clay Loam	Silty Clay Loam	Clay Loam

Table 1. Texture by feel soil ribbon length and texture associated with different soil types.

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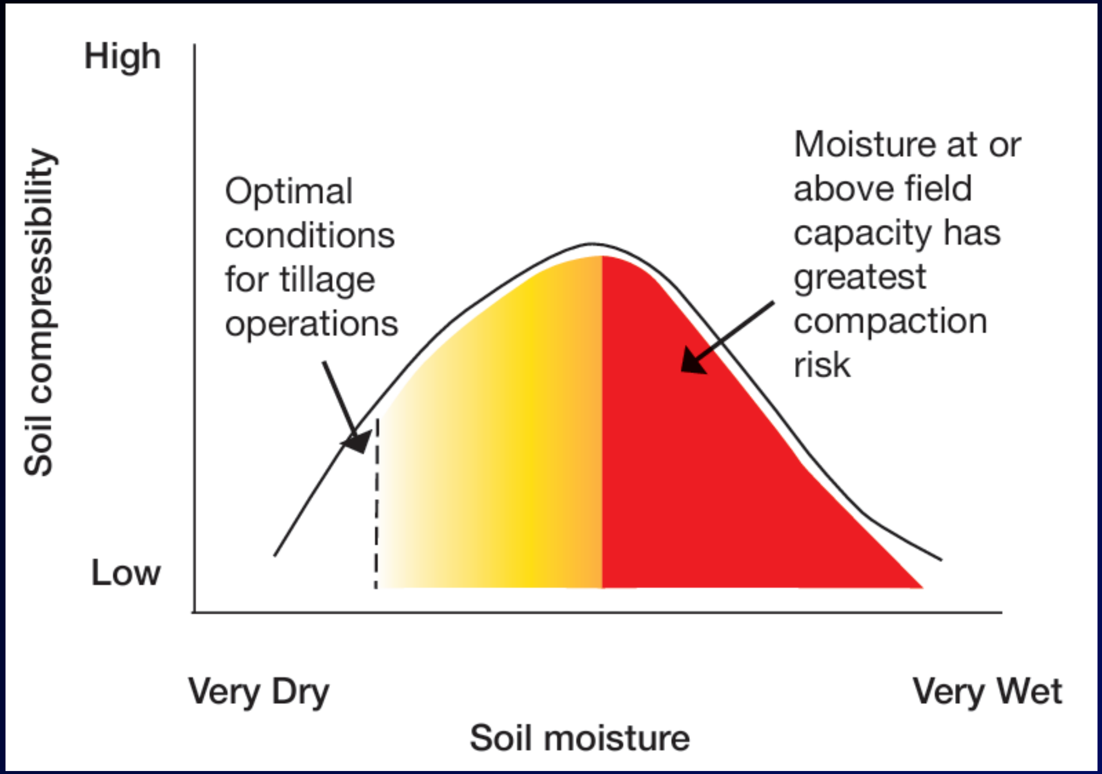
Field operations impact soil structure

- Compaction collapses pore spaces, impedes root growth, decreases oxygen, water infiltration, water holding capacity and nutrient availability
- Avoid tillage and other equipment traffic when soil moisture is at or above field capacity
- Use texture-by- feel method to assess soil moisture conditions before conducting orchard operations



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Field Methods: Infiltration rate

maximum rate water moves into the soil surface

Determine rate to:

- select drip emitters or micro sprinkler nozzles
- fine tune irrigation duration and frequency to prevent deep percolation and nutrient losses

Soil texture	Permeability Class	Inches / hour
clay	Very slow	0.1
sandy clay, silty clay	Slow	0.1 - 0.2
clay loam, sandy clay loam, silty clay loam	Moderately slow	0.2 - 0.8
very fine sandy loam, loam, silt loam, silty clay loam, silt	Moderate	0.8 - 2.5
sandy loam, fine sandy loam	Moderately rapid	2.5 - 5
sand, loamy sand	Rapid	5 - 10
coarse sand	Very rapid	>10

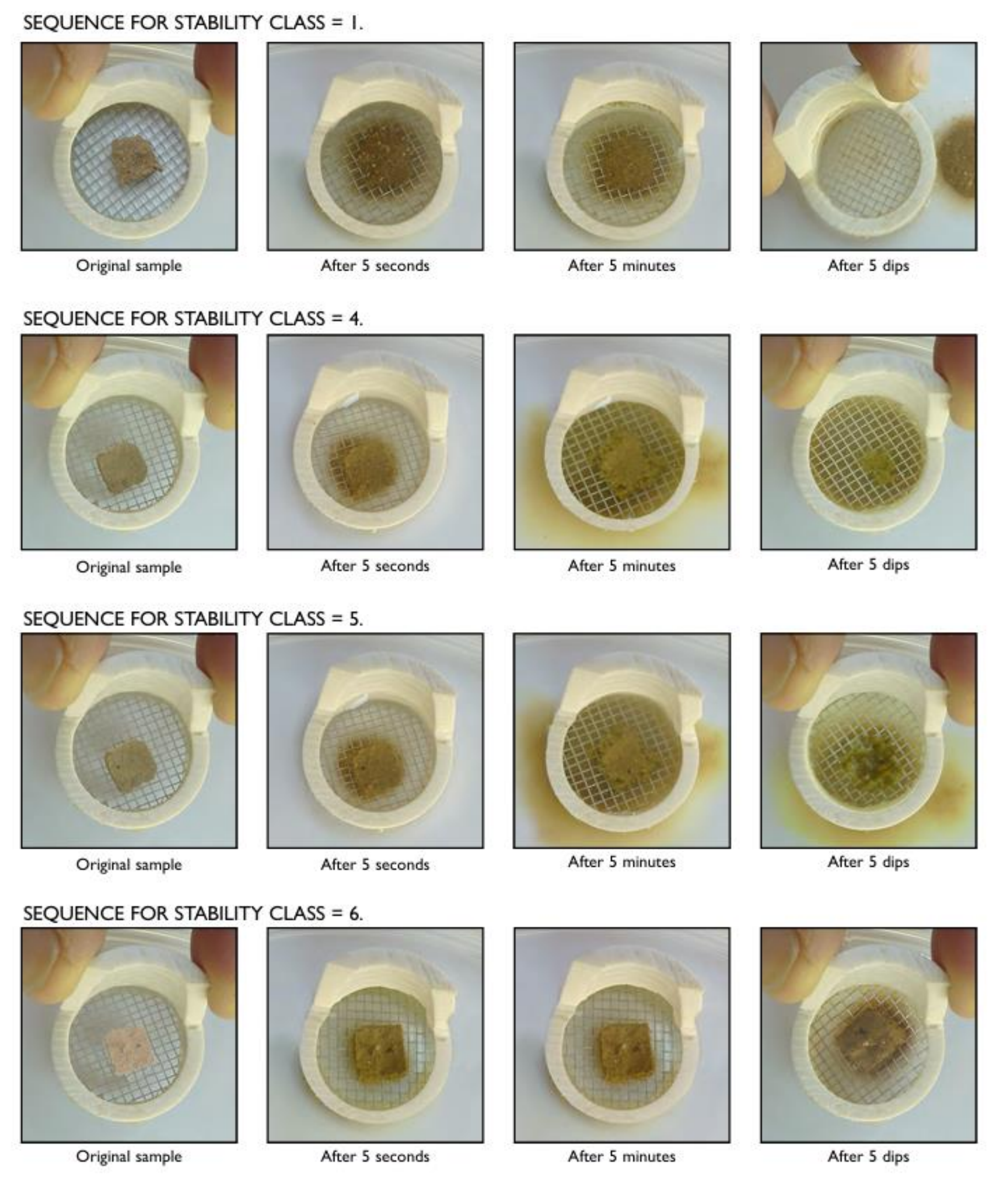
Field Methods: Slake Test

Clumps of soil with poor structure fall apart when placed into water

EVALUATION EXAMPLES		
POOR	MODERATE	GOOD
The clump of soil disintegrate and fall apart in less than 2 minutes.	The clump of soil disintegrate and fall apart in 2-10 minutes / a small portion of the clump remains intact	The clump of soil disintegrate and fall apart in > 10 minutes / a large portion of the clump remains intact


Figure 10

https://www.fao.org/fileadmin/user_upload/GSP/GSDP/Field_exercises/Aggregate_stability_EN.pdf



Field or Lab: Aggregate Stability

- 80% aggregates remaining = excellent physical quality
- 50 to 75% medium to good
- 30 to 50% medium to low
- < less than 30% poor physical quality

(https:// www.blm.gov/sites/default/files/docs/2022-04/TR_1734_8_ vol1_508.pdf).

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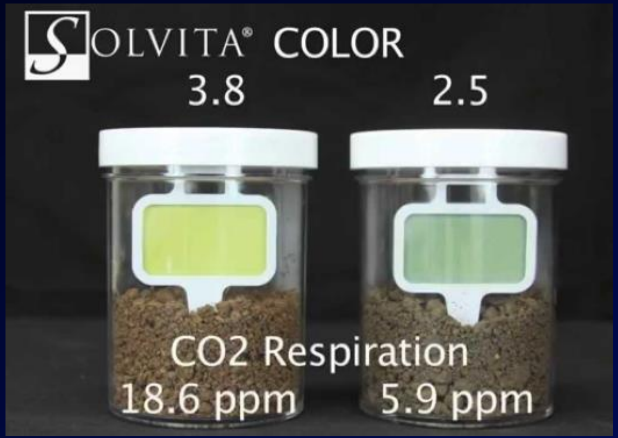
Field or Lab: Microbial biomass and activity

- Microbes metabolize carbon in organic matter to extract energy, releasing CO_2 as a byproduct.
- Higher fungal-to-bacterial ratios are linked to enhanced soil carbon storage, water retention, disease resistance, and nutrient cycling
- New field kits directly estimate CO_2 flux and microbial biomass and the relative abundance of fungi and bacteria in the soil



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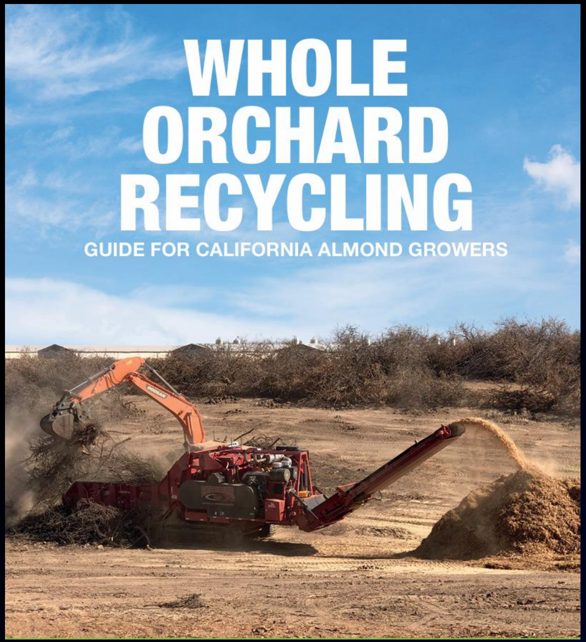
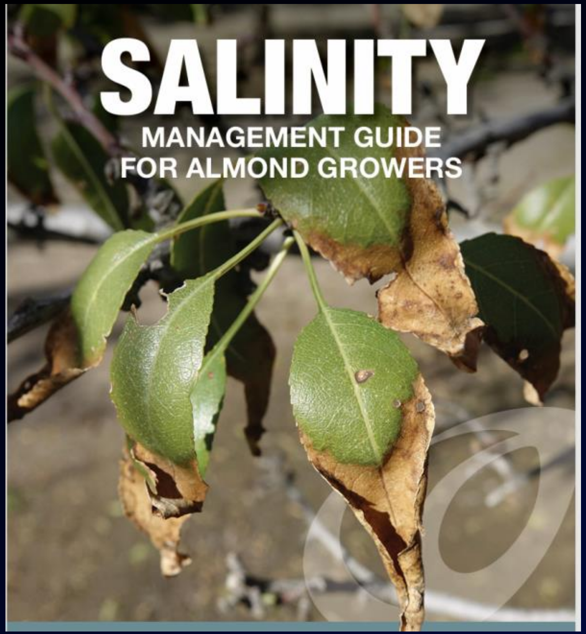
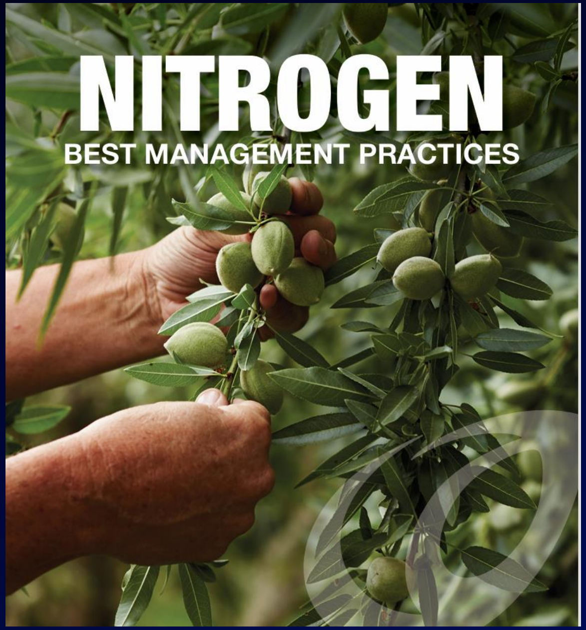
Summary

- Soil characteristics change with depth, impacting flow of water, air and nutrients through soil profile
- Field and laboratory assessments track how management practices influence soil function over time
- Organic materials, protect the soil surface, minimize disturbance, and conserve moisture can improve long-term soil function and orchard resilience
  - Potential to offset synthetic fertilizer use with a comparable budget
- Soil infiltration and water holding capacity should be considered for irrigation system design and scheduling to minimize surface runoff and deep percolation, to prevent nutrient loss from soil.


WHOLE ORCHARD RECYCLING
GUIDE FOR CALIFORNIA ALMOND GROWERS

SALINITY
MANAGEMENT GUIDE FOR ALMOND GROWERS

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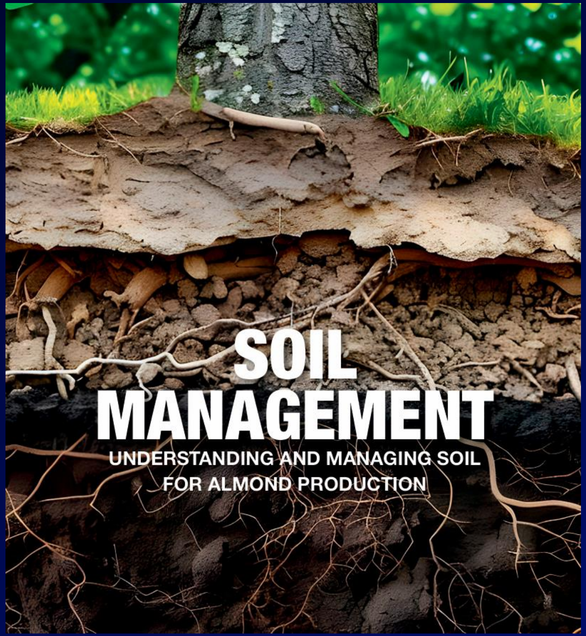
SOIL MANAGEMENT
UNDERSTANDING AND MANAGING SOIL FOR ALMOND PRODUCTION


THANK YOU!
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Overview of Soil Sensors

Guillermo Valenzuela

Wiseconn USA - g@wiseconn.com

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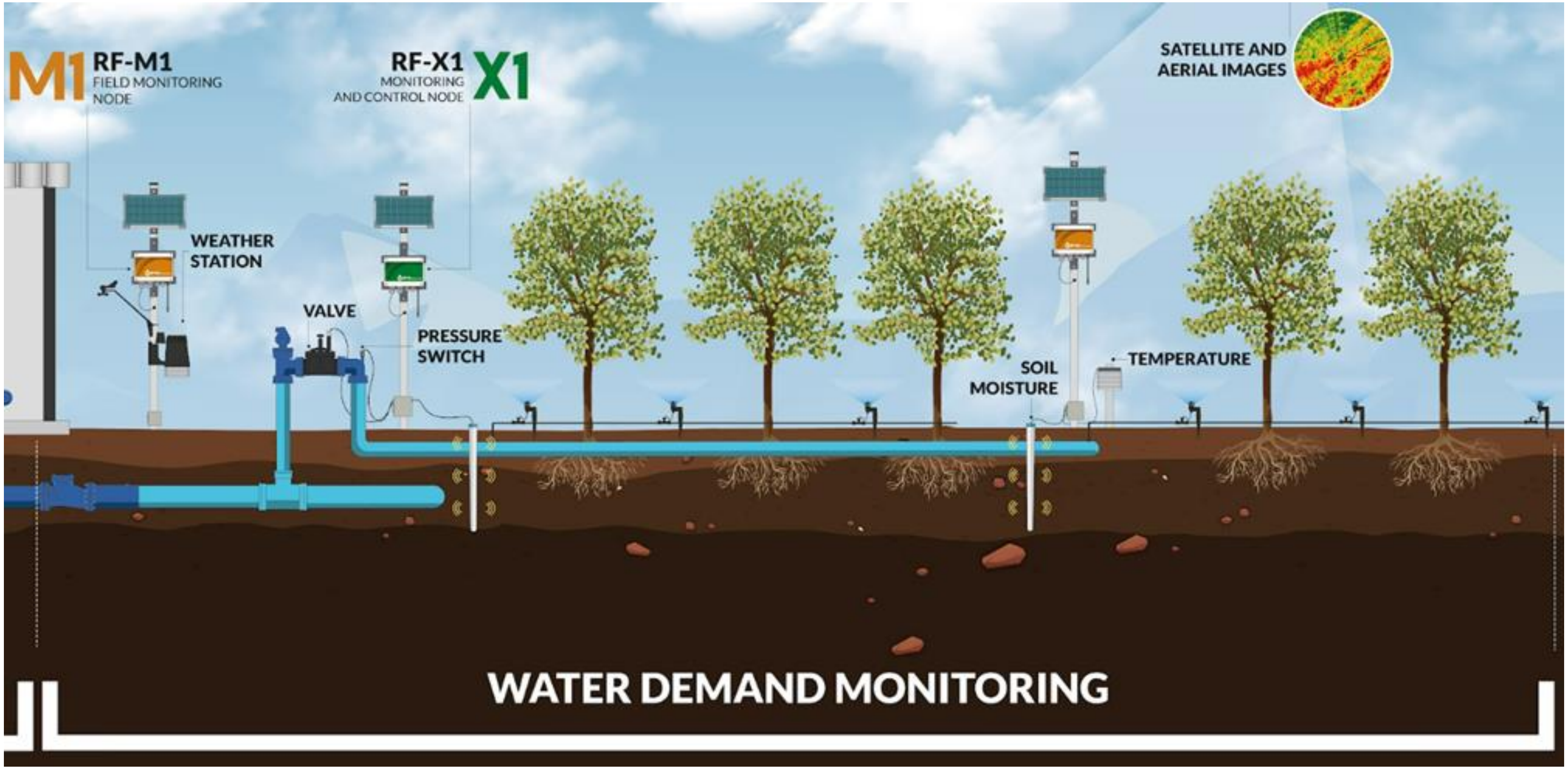
Essential component for water management:



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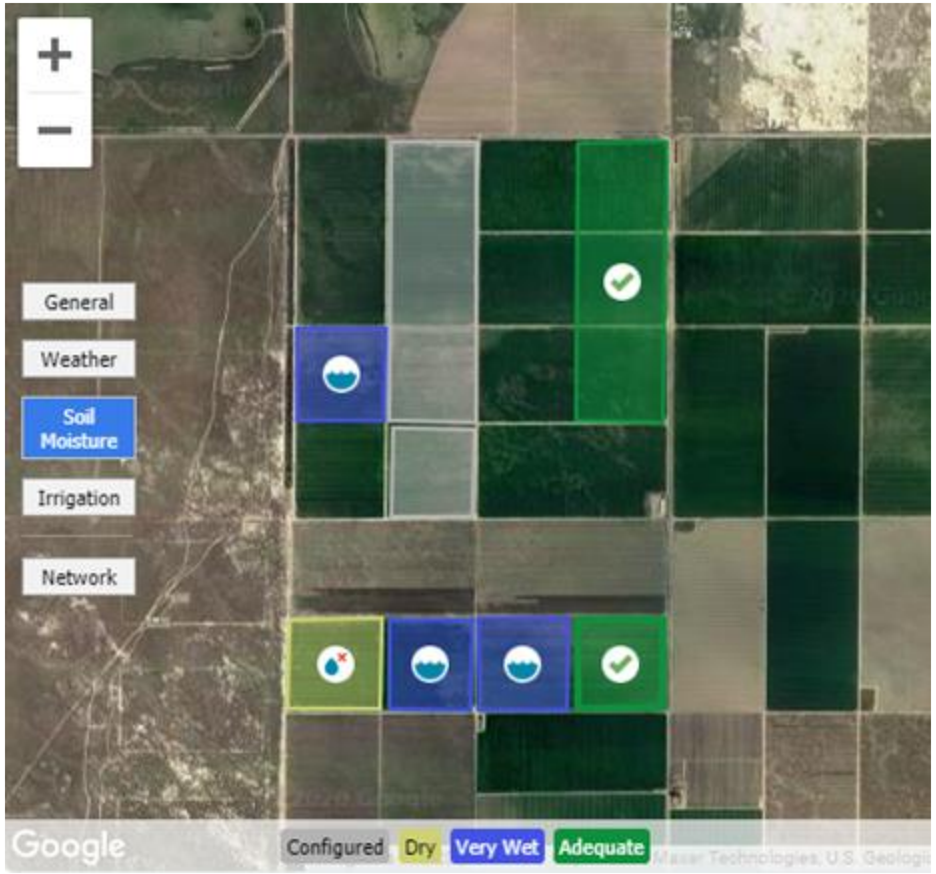
Continuous auger of the soil



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Types of sensors

Sensor	Measures What?	How?
TDR	Volumetric Water Content	Electronic signals
Capacitance	Volumetric Water Content	Electronic Signals
Tensiometer	Water Potential	Tension
Gypsum Block	Water Potential	Tension

Water Potential - Tensiometers

Ceramic Tips - usually priced higher

Tensiometer - labor intensive

Continuous - sensitive on some soils and install method

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Types of sensors

Sensor	Measures What?	How?
TDR	Volumetric Water Content	Electronic signals
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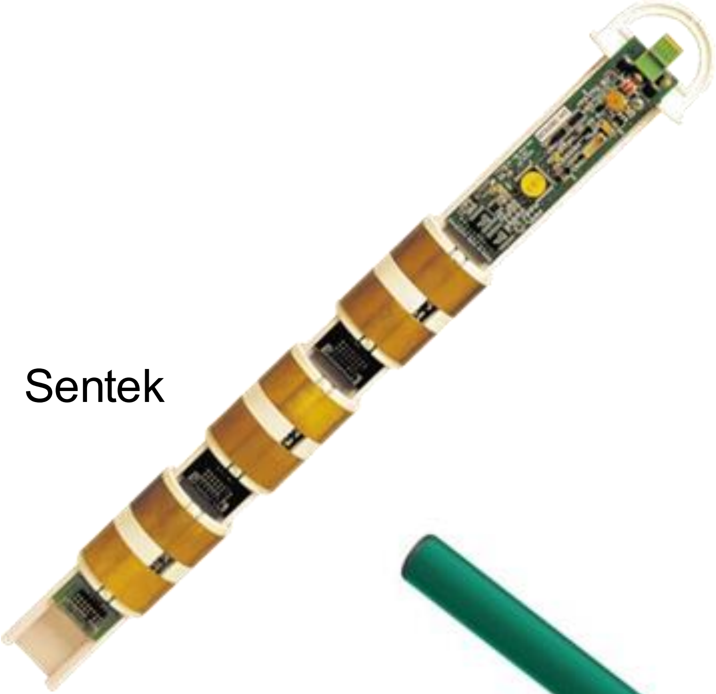
Tensiometer	Water Potential	Tension
Gypsum Block	Water Potential	Tension

Water Volume - FDR

Sentek



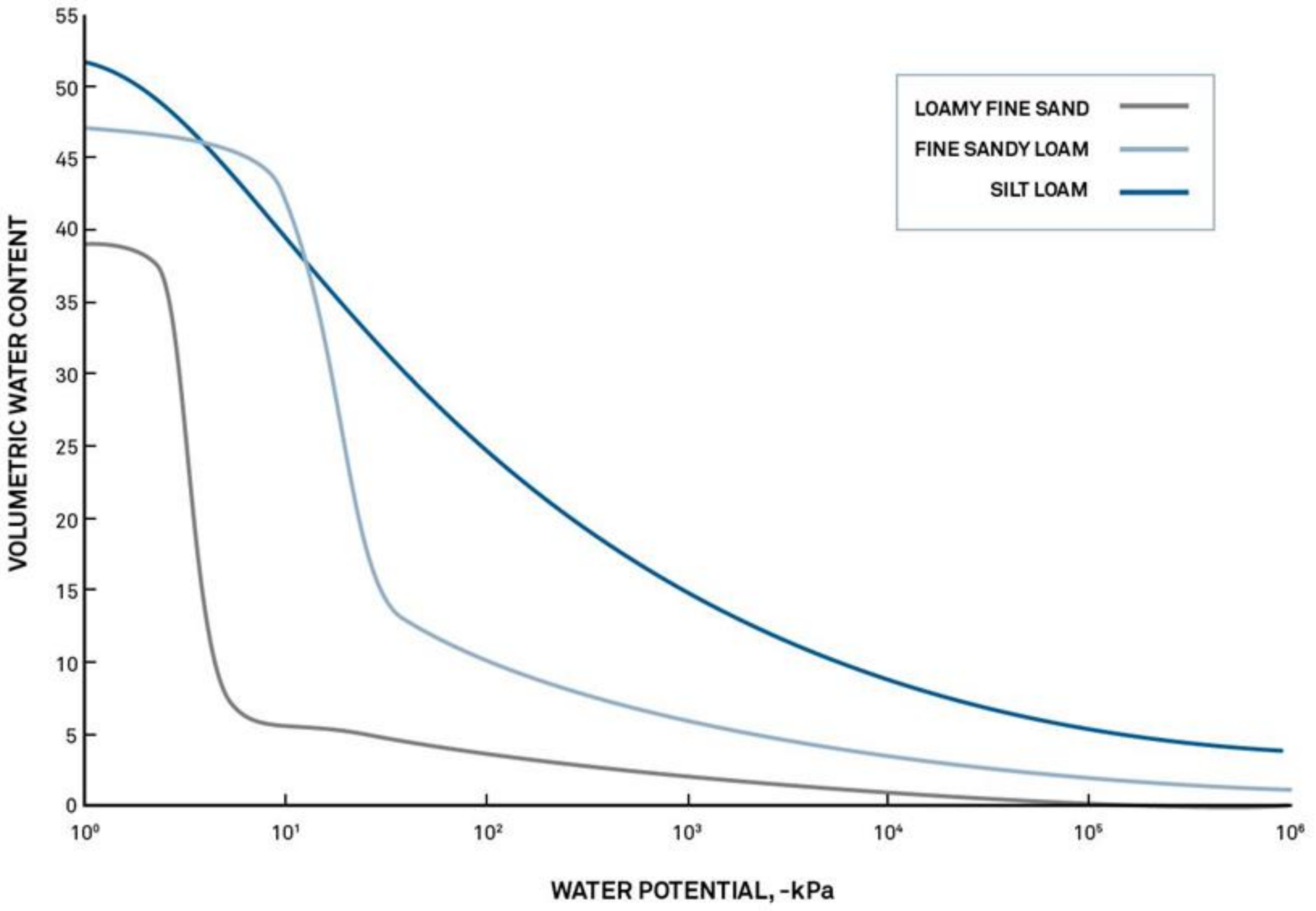
HSTI

Enviropro

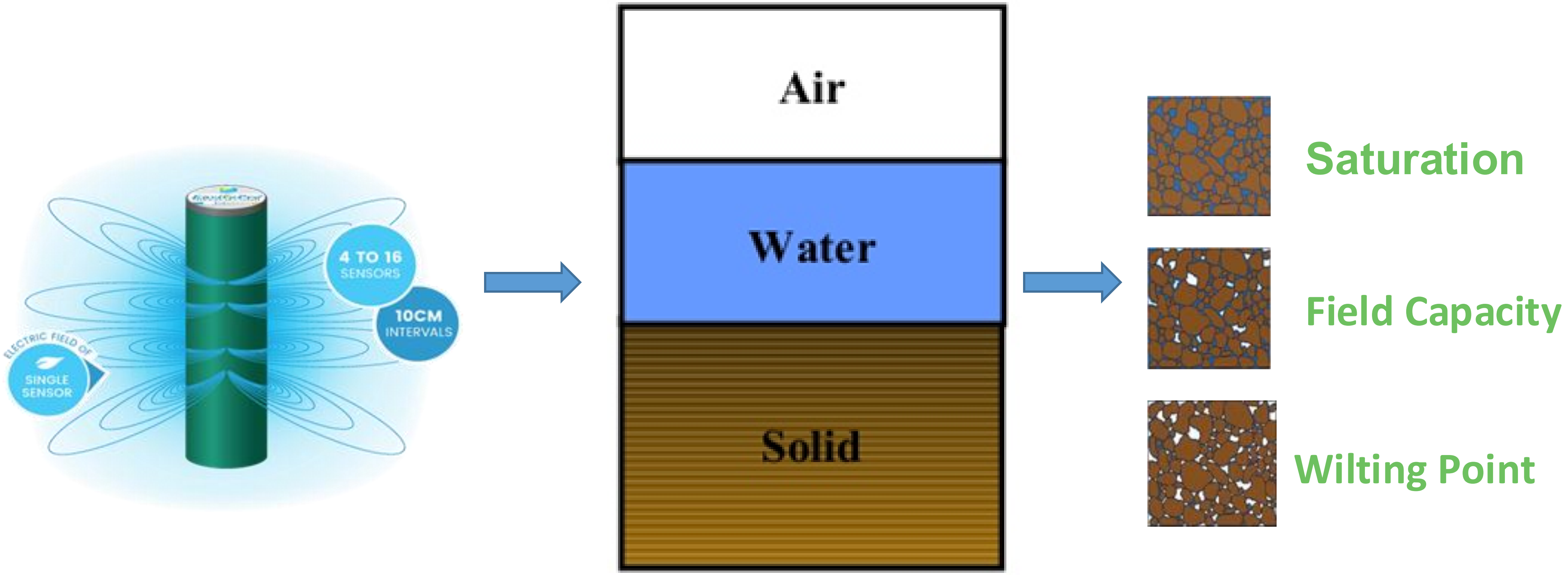
Decagon / Meter

Aquacheck

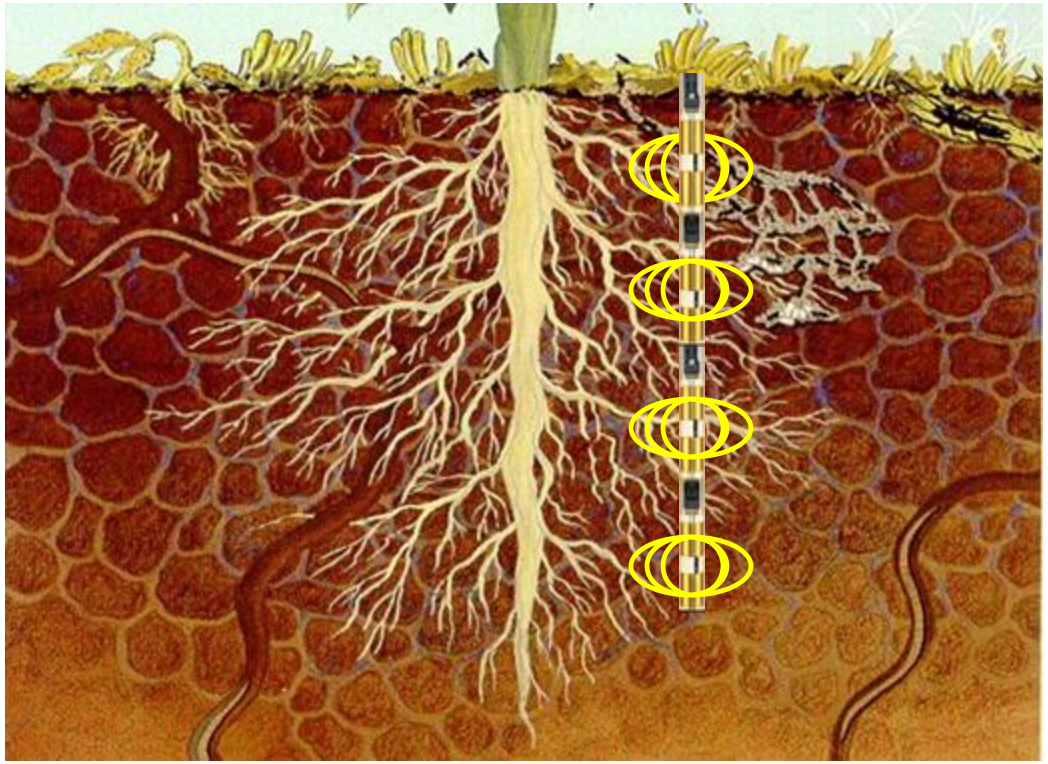
Direct Correlation

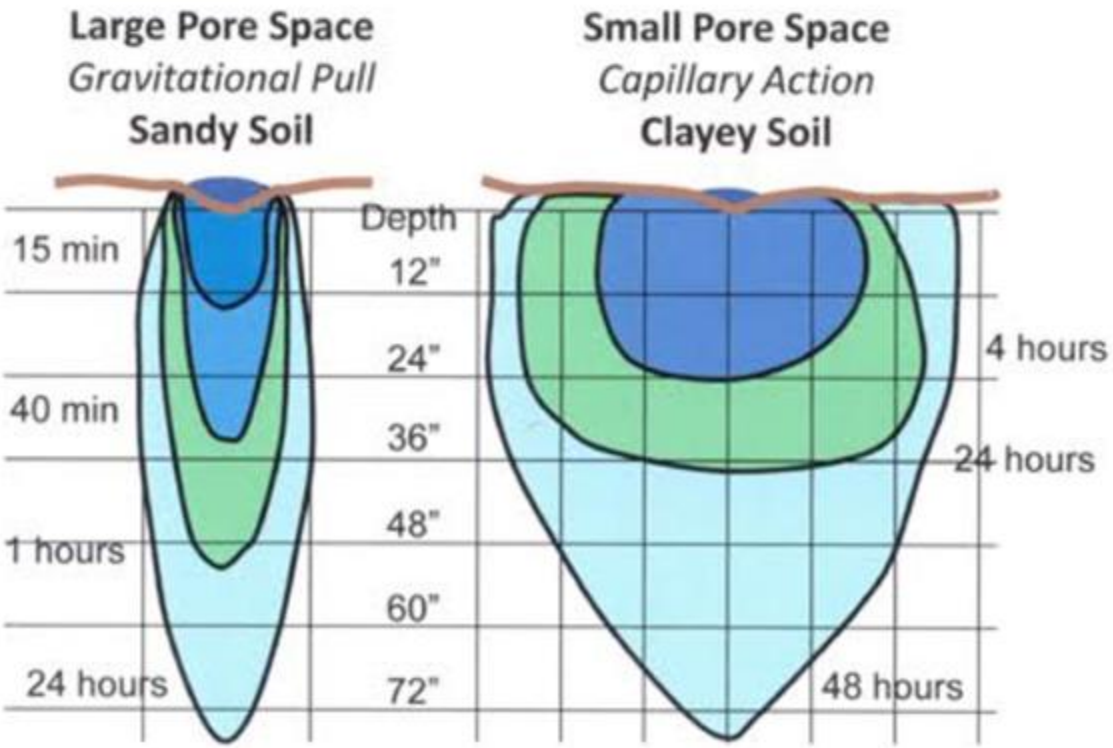


FDR - Frequency Domain Reflectometry

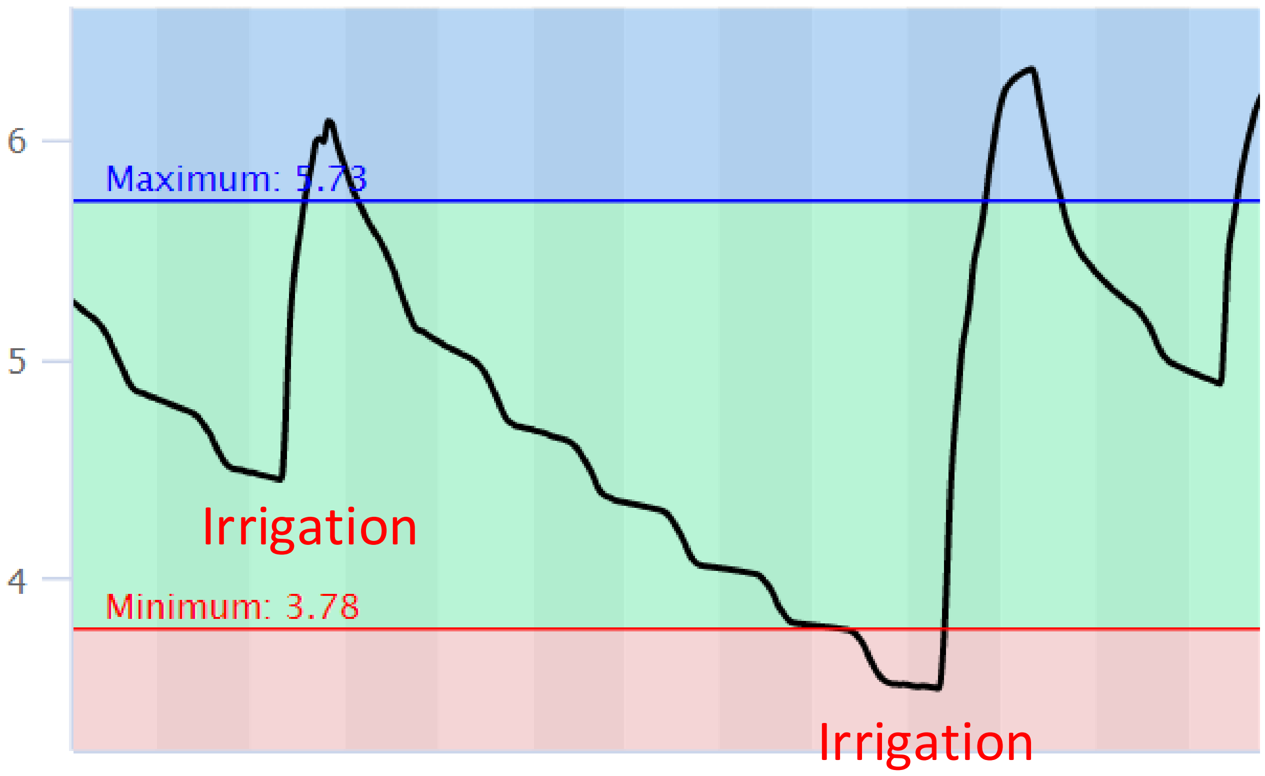


Volumetric Water Content (%)

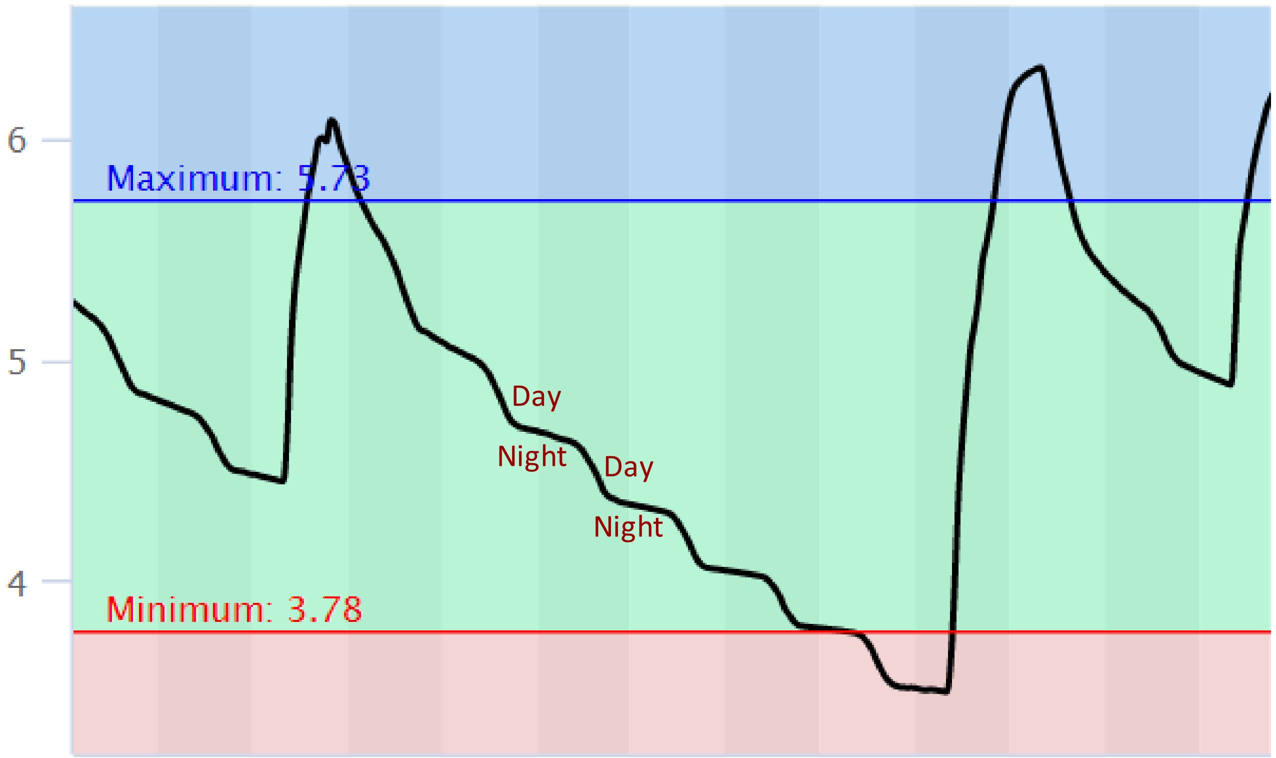


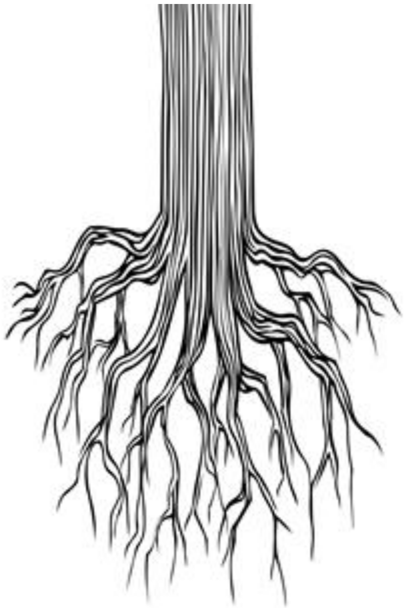


Irrigation Events

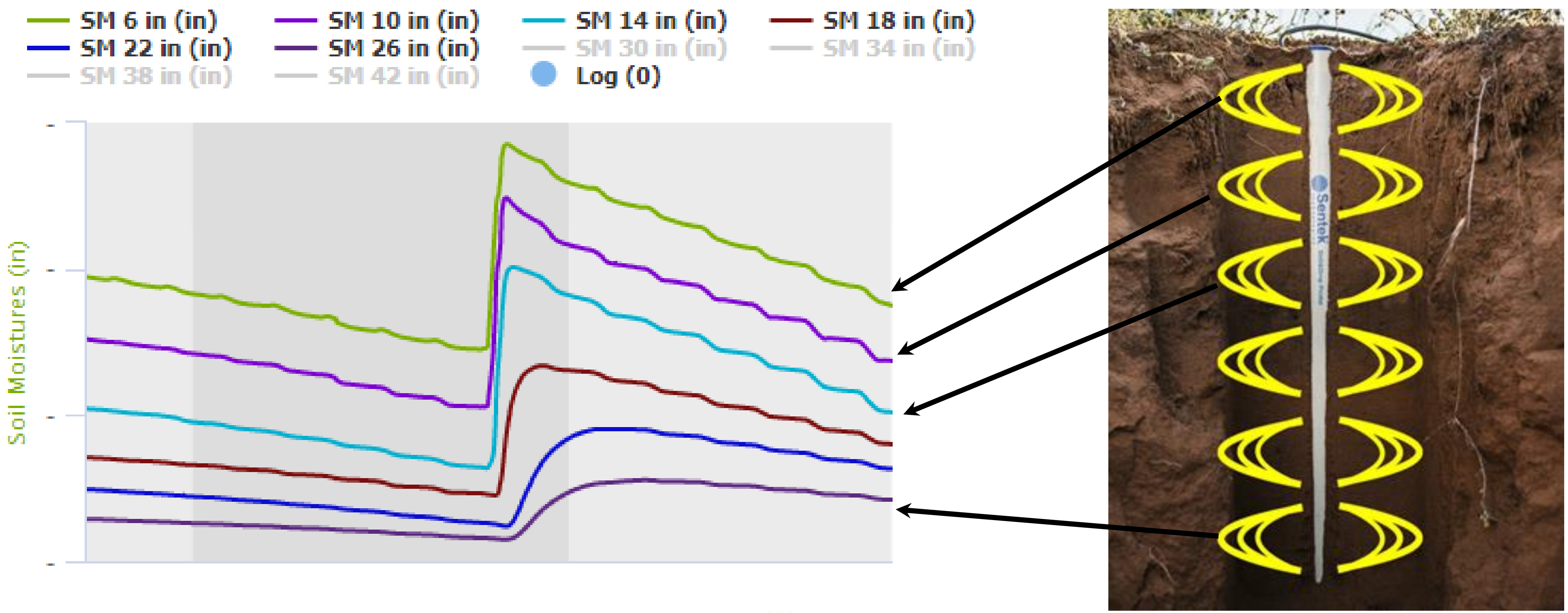


Daily/Night dynamics - root presence and activity

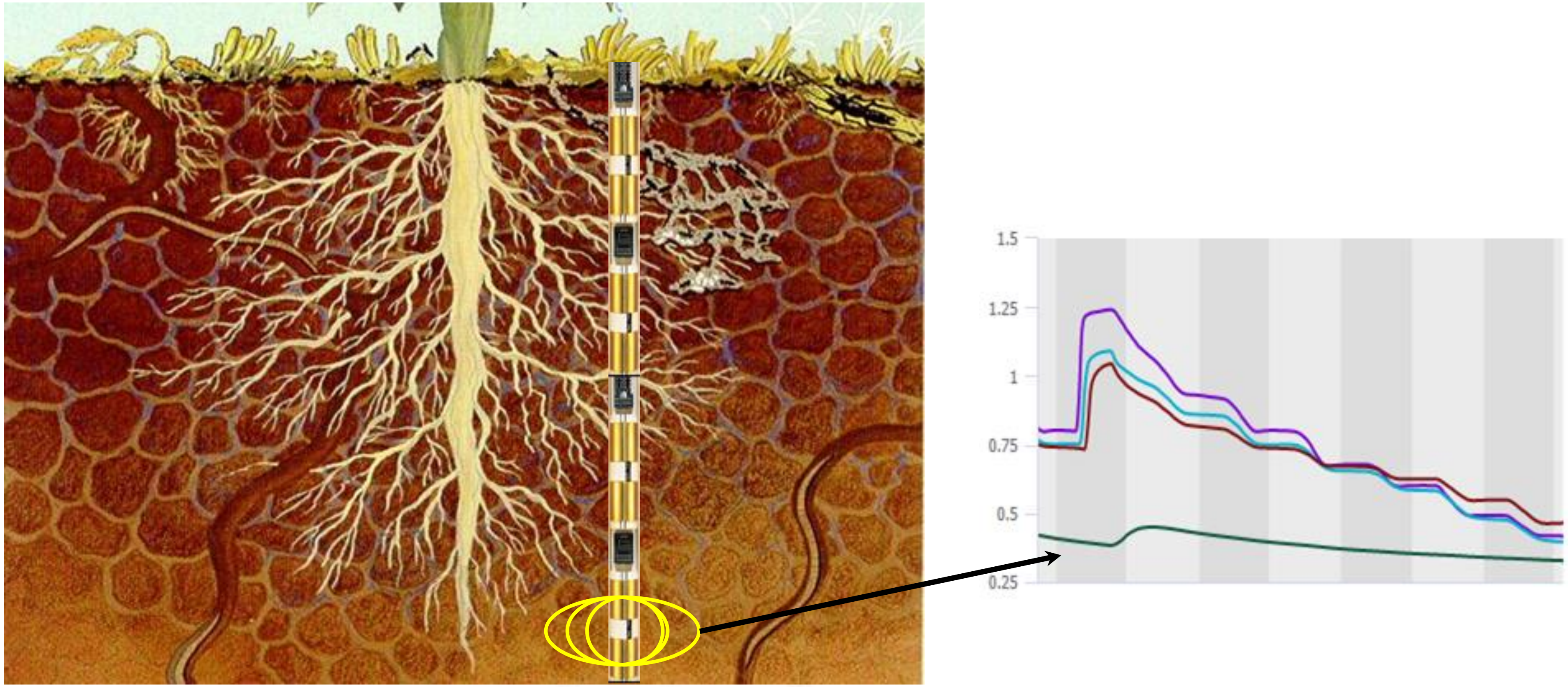




Infiltration rate and depth

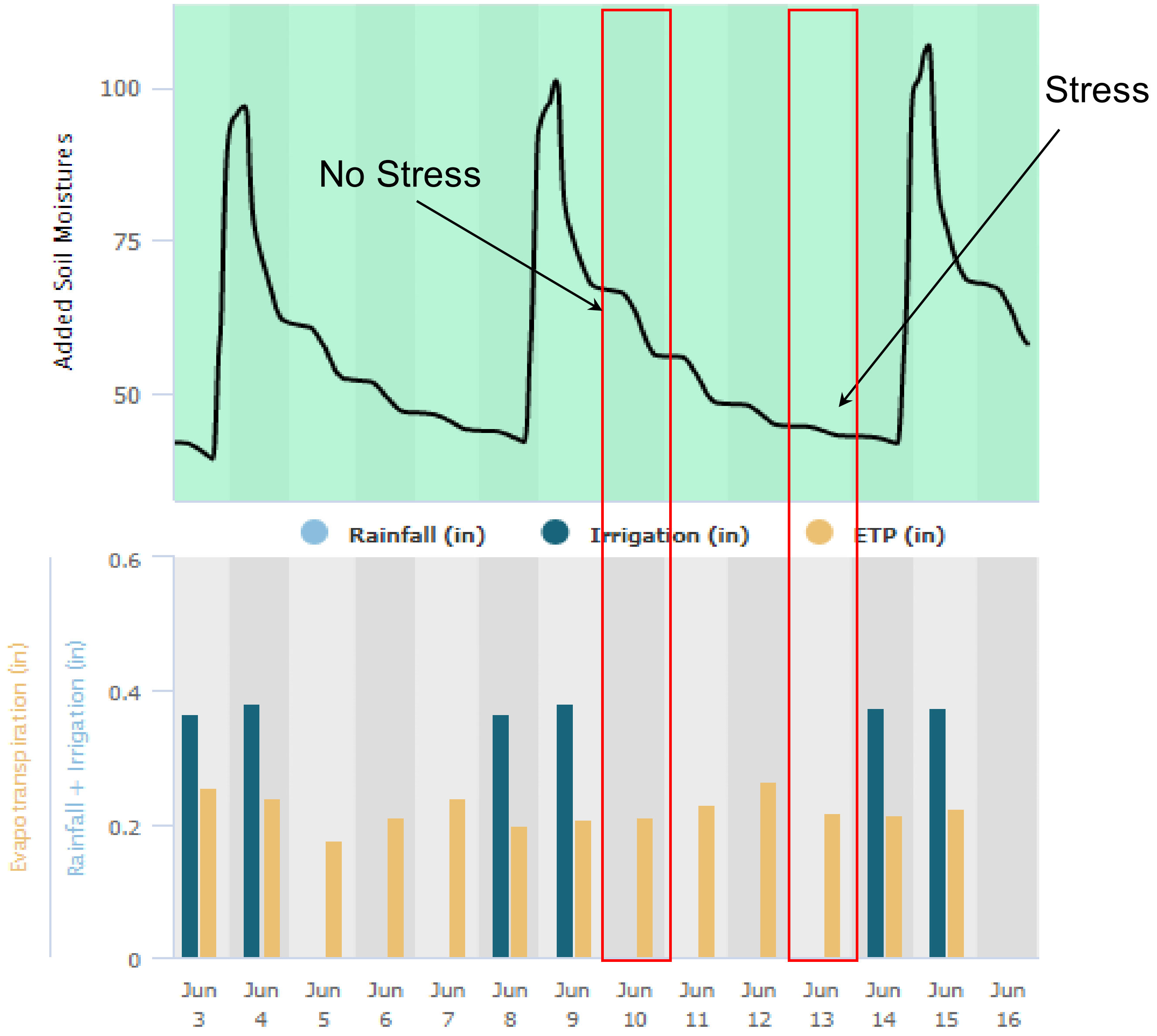


How long to irrigate?



Water dynamics in the soil

When to irrigate?



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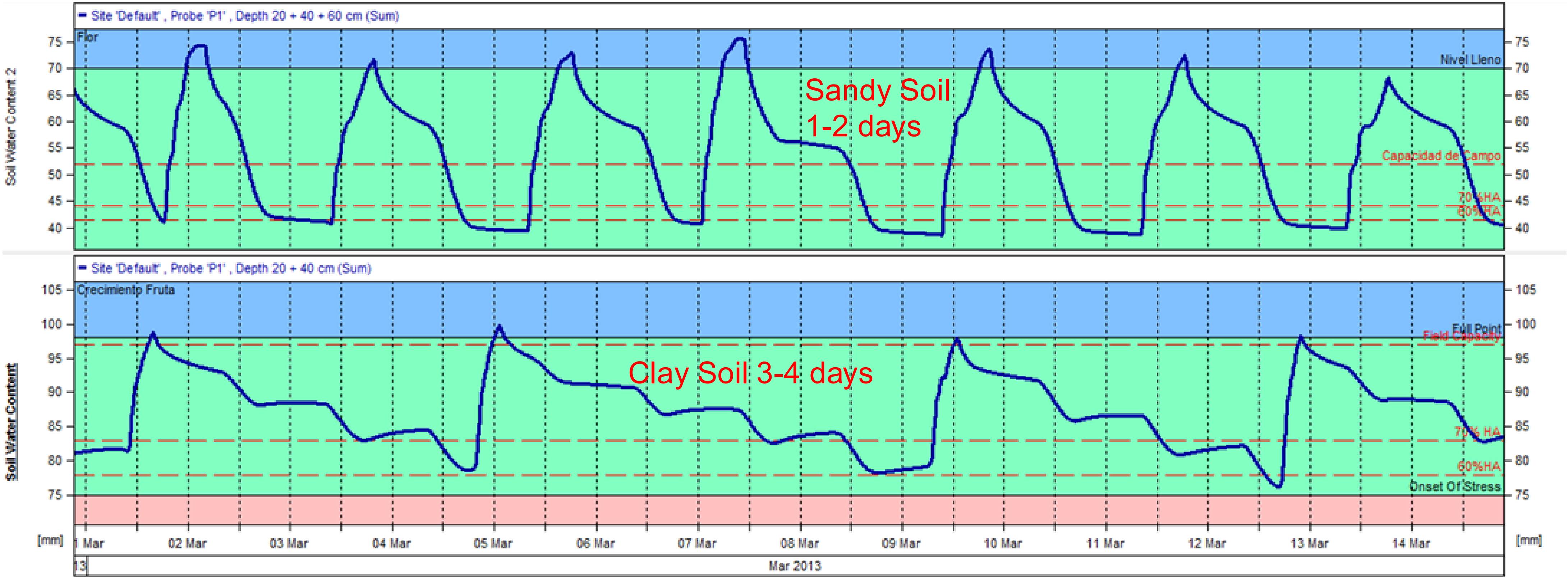
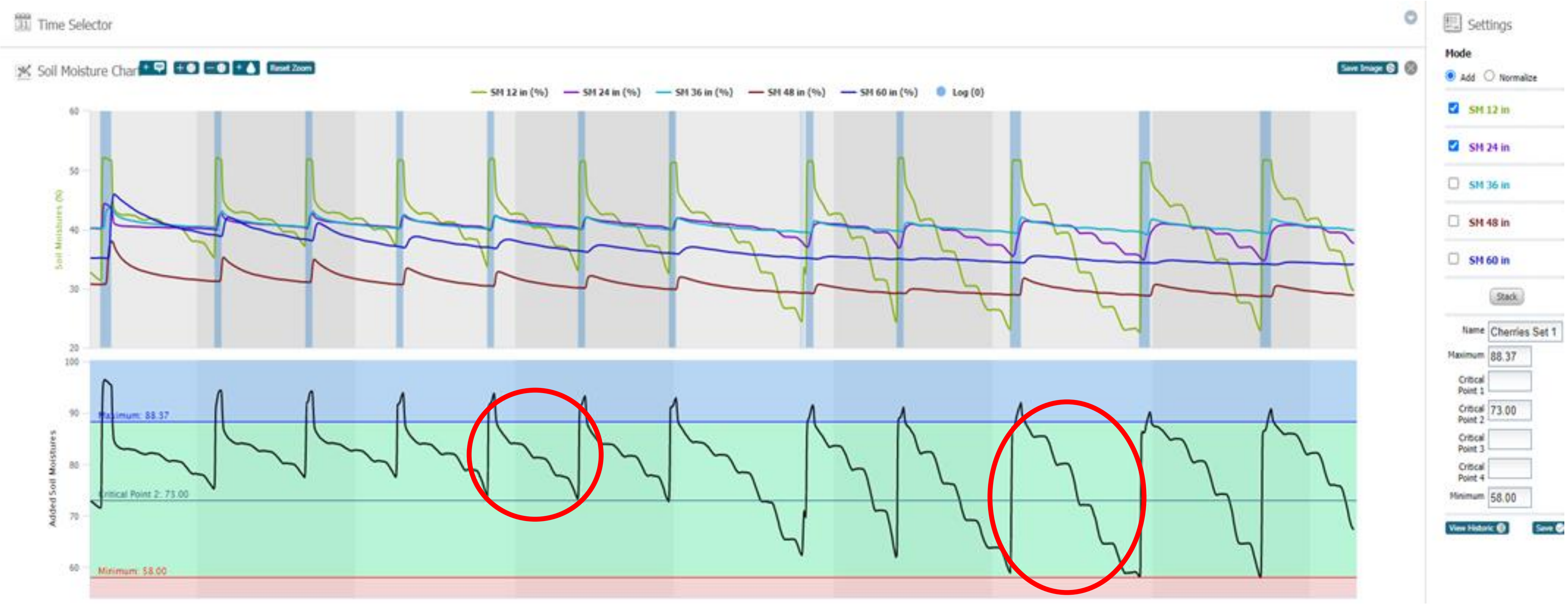
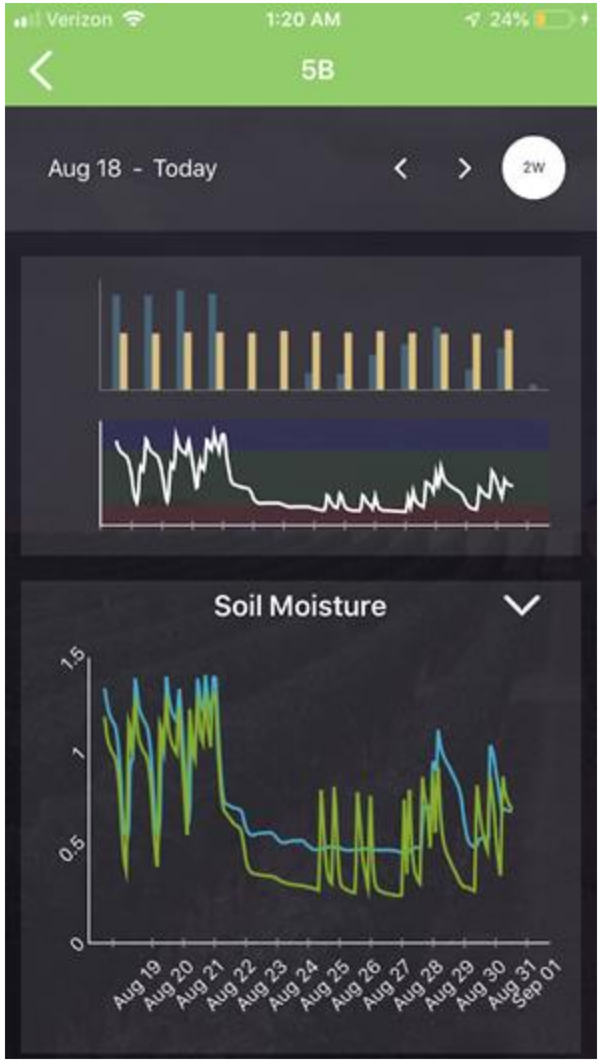
Different holding capacities of soils…



Optimize irrigation for better metabolism



Optimize your irrigation operation



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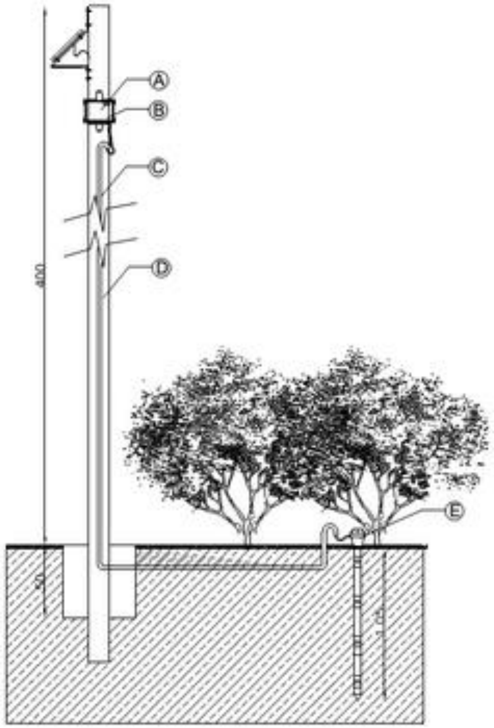
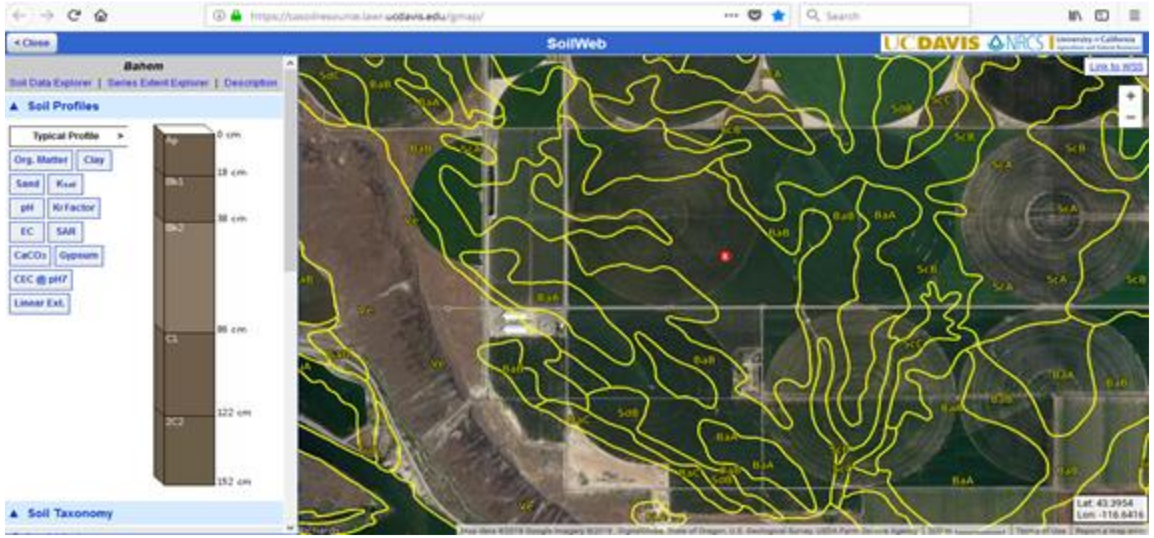
Important Considerations

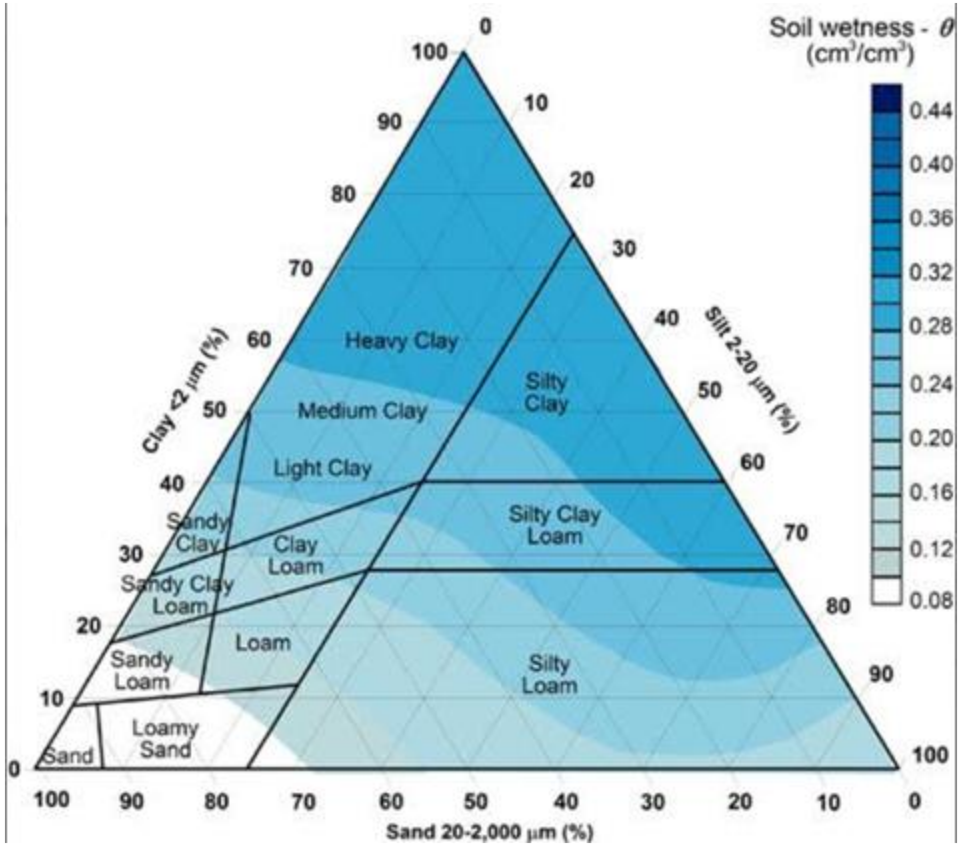
Proper installation and soil identification



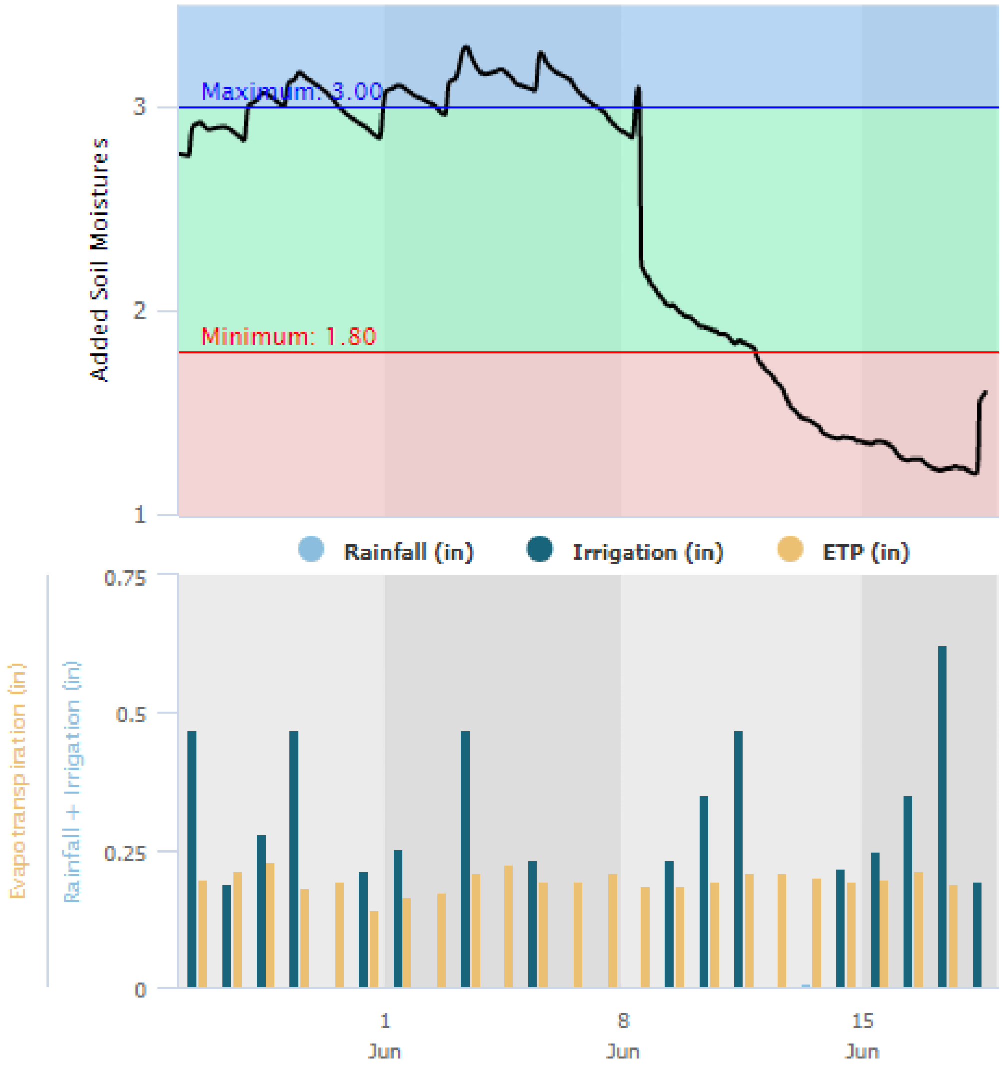


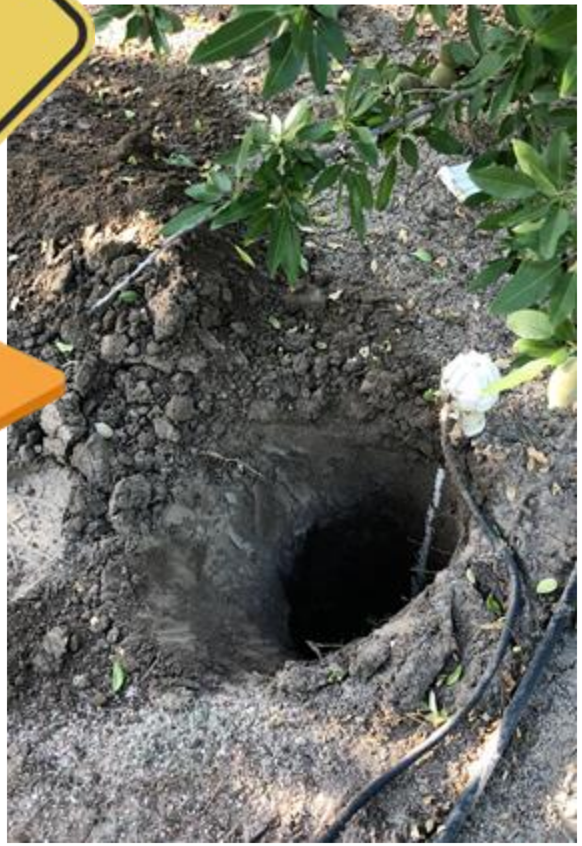
Attention to tree selection and distance from emitter

Ground truthing



Attention to the site! it is our navigation tool





Complimentary sensors

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THANK YOU!

2025 THE ALMOND CONFERENCE

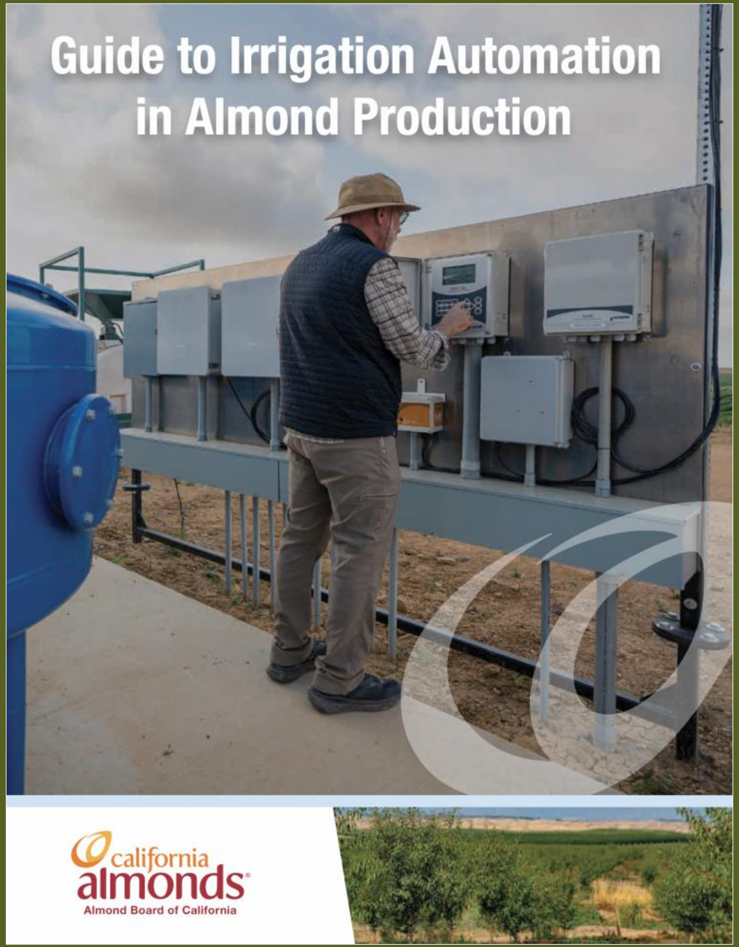
CULTIVATING A HEALTHIER FUTURE

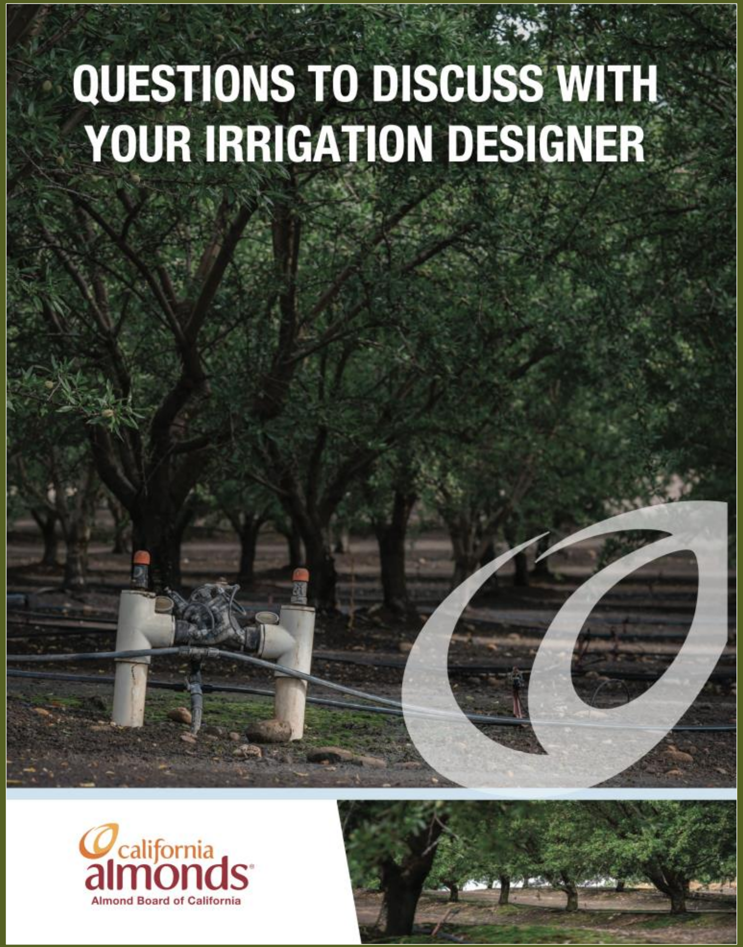
NEW IRRIGATION RESOURCES

TOM DEVOL – IRRIGATION & TECHNOLOGY CONSULTANT

12.10.2025

NEW IRRIGATION RESOUCRES





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IRRIGATION AUTOMATION

Automation of our irrigation systems is the **next step to improvements** in irrigation efficiency.

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EVOLUTION OF IRRIGATION TECHNIQUES

DRYLAND
Leave it to nature

FLOOD
Simple & low cost

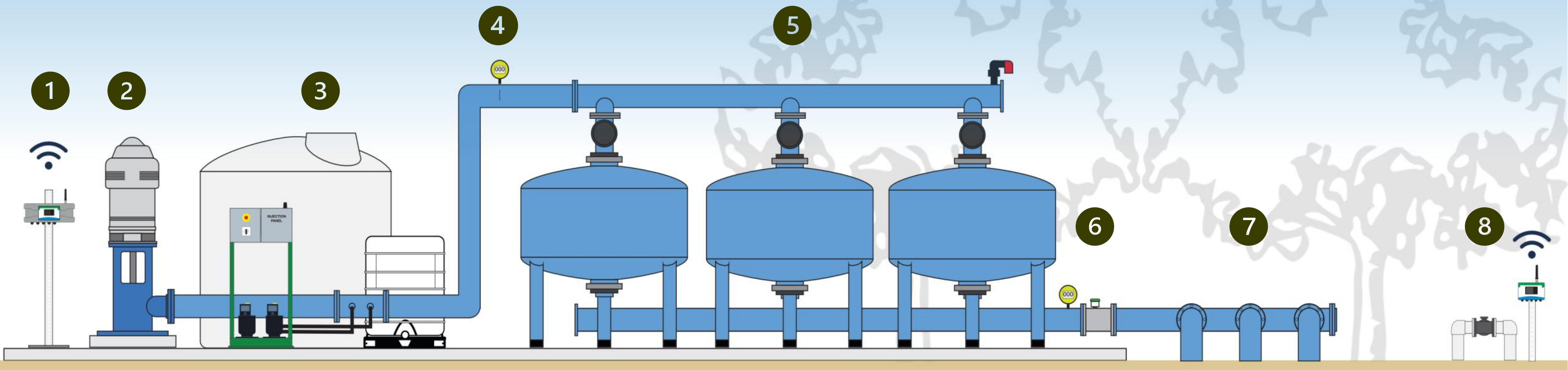
HAND MOVE SPRINKLERS
Improved uniformity, tons of work

SOLID SET SPRINKLERS
Continued improvement on uniformity without the labor.

DRIP & MICRO SPRINKLERS
Precise water supplied direct to the tree.

AUTOMATION
Matching timing to tree need and energy cost

PUMP STATION automation



1. Controller
2. Pump On/Off
3. Fertigation
4. System Pressure Pre/Post Filter
5. Filter Flush Control
6. Flow Meter Readings
7. Local Valves
8. In-Field Valves

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Irrigation automation

TORO
Simple Timeclock

WiseConn
Up to 10 Valves,
expandable to 100+.

Ranch Systems
Up to 48 Valves

Netafim
Multi-language Interface
Up to 256 Valves

Pros & Cons

Work through the **values & challenges** of different systems.

Timer-Based Systems	
Pros	**Cons**
Simple and inexpensive to install and maintain.	Inefficient if weather or soil moisture levels change unexpectedly.
Reduces labor compared to manual irrigation with irrigations starting and stopping based on schedule automatically.	Risk of overwatering or underwatering.
Does not require telemetry or connection to internet to operate.	No real-time adjustments based on plant needs and notifications.
Works well when water demand is predictable.	Requires valves to be at pump station or wired connection to field valves.

Timer-Based Systems

Fully Integrated IoT Systems	
Pros	**Cons**
Maximizes water efficiency by applying irrigation only when needed, reducing waste.	**High initial investment**, including hardware, software, and installation costs.
Optimizes yield potential by maintaining ideal soil moisture levels.	**Requires reliable internet or cellular connectivity** for seamless real-time operation.
Reduces labor costs by automating irrigation scheduling and adjustments.	**User training is necessary** to fully utilize system capabilities and avoid operational errors.
Allows remote access, enabling users to monitor and adjust irrigation from anywhere.	**Ongoing costs,** including cellular data fees, service visits, and software subscription costs for cloud-based services.
Integrates with AI-powered predictive analytics, improving long-term water management.	
Enhances record-keeping for regulatory compliance and farm management decisions.	

Fully Integrated Systems

HOW DOES IT FIT IN

Table of Departmental Needs			
Irrigation Automation for Almond Production			
Department / Role	**Responsibilities**	**Needs / Requirements**	**Benefits of Automation**
Project Champion	Acting as the lead user and internal advocate for system adoption.	Comprehensive training, authority to coordinate across teams, communication tools, service contact responsibilities.	Smooth implementation, better adoption, bridge between technology providers and farm staff.
Farm Management / Ownership	Strategic planning, budgeting, investment decisions.	ROI analysis, cost-benefit studies, system scalability, alignment with long-term orchard goals.	Reduced costs, improved yields, sustainable resource management, long-term profitability.
Irrigation / Water Manager	Overseeing irrigation schedules & water allocation.	Training on controllers, access to soil moisture/weather data, other monitoring tools.	Compliance with water restrictions, optimized scheduling & efficient water use.
Field Operations / Orchard Crew	Executing irrigation tasks, monitoring system operation, responding to field issues.	Training on valve/pump operations & easy-to-use interfaces.	Reduced manual labor, better coordination with farm activities.
Fertility / Nutrition Manager	Overseeing fertilizer applications & nutrient management.	Integration with fertigation systems, precise control of application rates, training on injection equipment.	Improved nutrient efficiency, reduced waste, consistent tree nutrition.
Maintenance / Service Team	Maintaining pumps, filters, valves, and sensors.	Notifications of system issues, diagnostic tools, training for troubleshooting and preventative care.	Less downtime, extended equipment life, reduced emergency repairs.
Finance / Administration	Managing budgets, reporting, and compliance with cost-share programs.	Usage reports for groundwater & surface water use, access to rebate/funding opportunities, system usage reports.	Improved financial planning, potential grant/rebate funding, measurable ROI documentation.

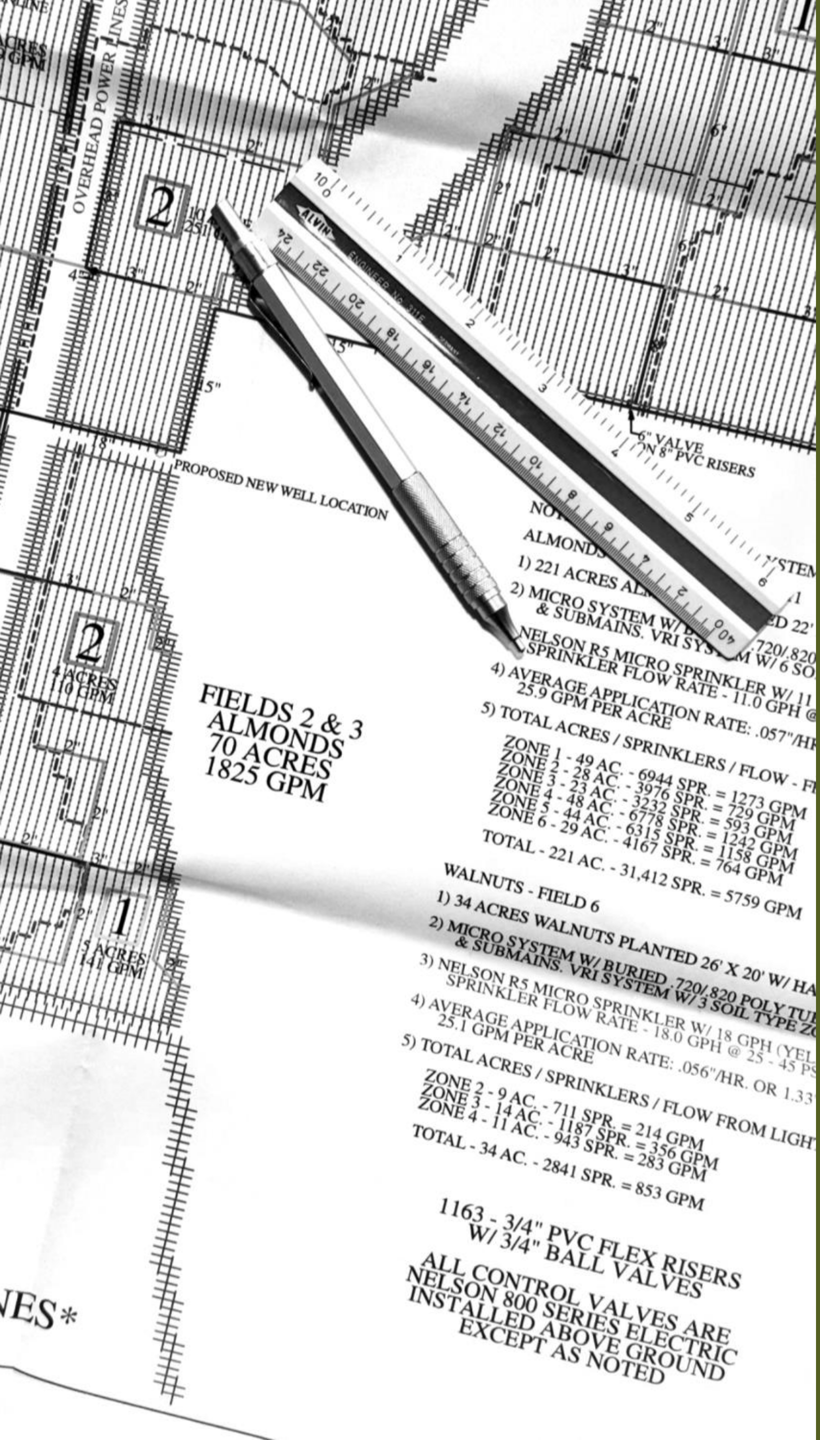
Automation has **different implications to different people** in the organization. Walk through how it fits for your teams.

RETURN ON INVESTMENT

Understanding the **Return on Investment** (ROI) is critical to success with automation.

Work through the areas and opportunities for maximizing the ROI.

Cost Savings	Increased Yield & Quality
Labor Reduction	**Automated Labor Costs**
• Less need for manual valve adjustments and monitoring. • Lower labor costs over time, especially during peak irrigation periods.	• Consistent watering reduces plant stress, leading to higher yields. • Improved kernel quality due to steady nutrient uptake.
Water Savings	**Better Nutrient Delivery**
• Precision irrigation reduces overwatering and waste. • Potential reduction in water costs, especially in areas with tiered pricing.	• Automation improves fertigation efficiency, reducing fertilizer waste and increasing nutrient absorption.
Energy Efficiency	
• Reduced pump operation times lower electricity or fuel expenses. • Automation can optimize irrigation timing to avoid peak energy rates.	
Risk Reduction	**Sustainability**
Frost & Drought Protection	**Environmental Benefits**
• Automated systems can react faster to temperature extremes. • Reduced risk of yield loss due to drought stress or frost damage.	• Reduced runoff and leaching. • More sustainable farming practices improve industry reputation and may open up sustainability incentives or certifications.
Regulatory Compliance	
Improved reporting and tracking of water usage for compliance with SGMA and other regulations.	



QUESTIONS TO DISCUSS WITH YOUR IRRIGATION DESIGNER

Designing an orchard irrigation system is a **20+ year decision**. As the grower, you should be the one **leading the conversation**.

Use this resource as a guide to the key talking points that will help shape your long-term planning.

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YOU R PLAN

ORCHARD PLANNING

IRRIGATION METHOD

FROST PROTECTION

FILTRATION

OPERATIONAL COSTS

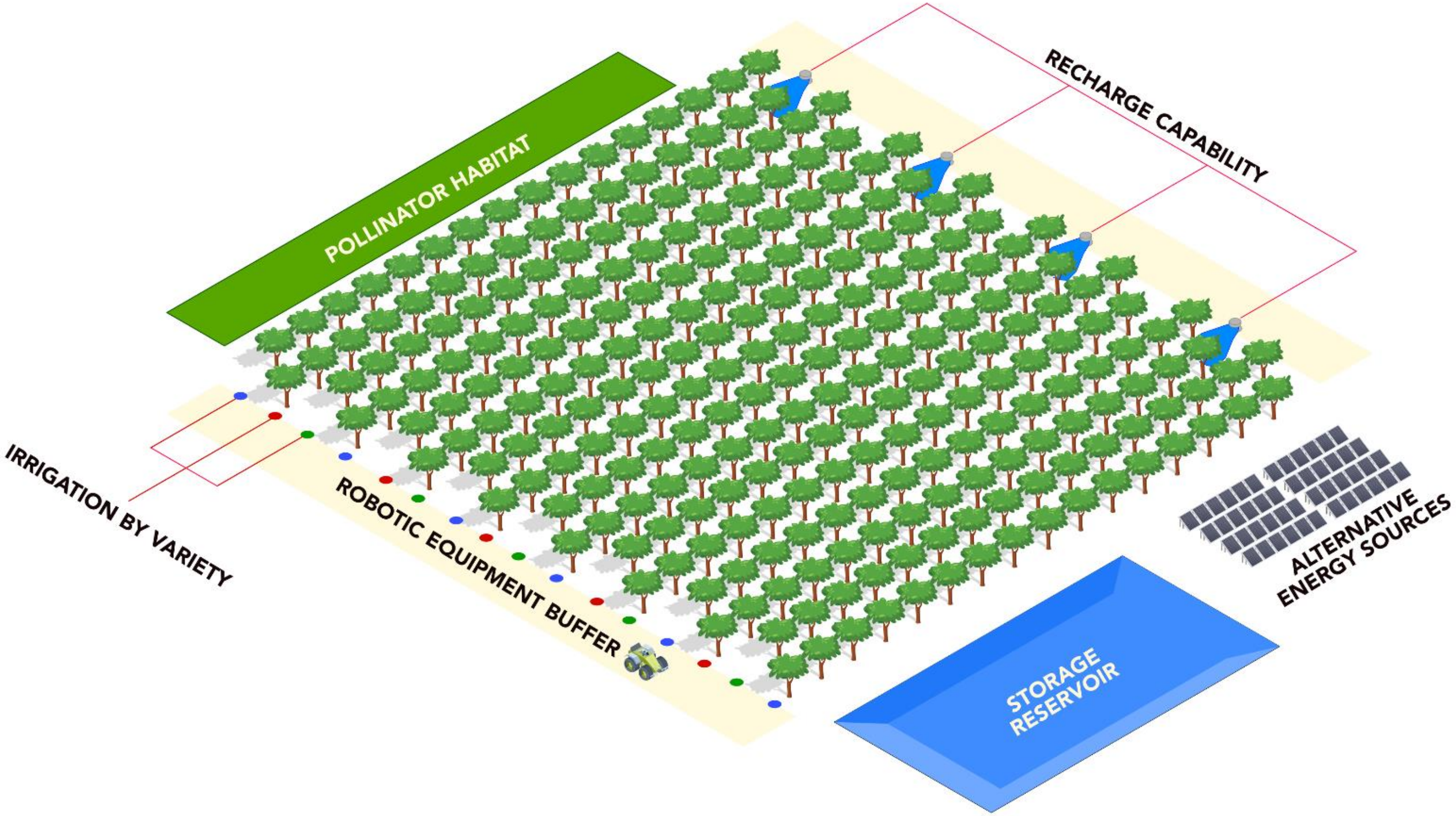
AUTOMATION & TECHOLOGY

WARRANTIES

INCENTIVES

ORCHARD PLANNING

- Harvest Direction
- Spacing
- Elevation
- Water Source & Volume
- Drive Roads
- Buffer Zones



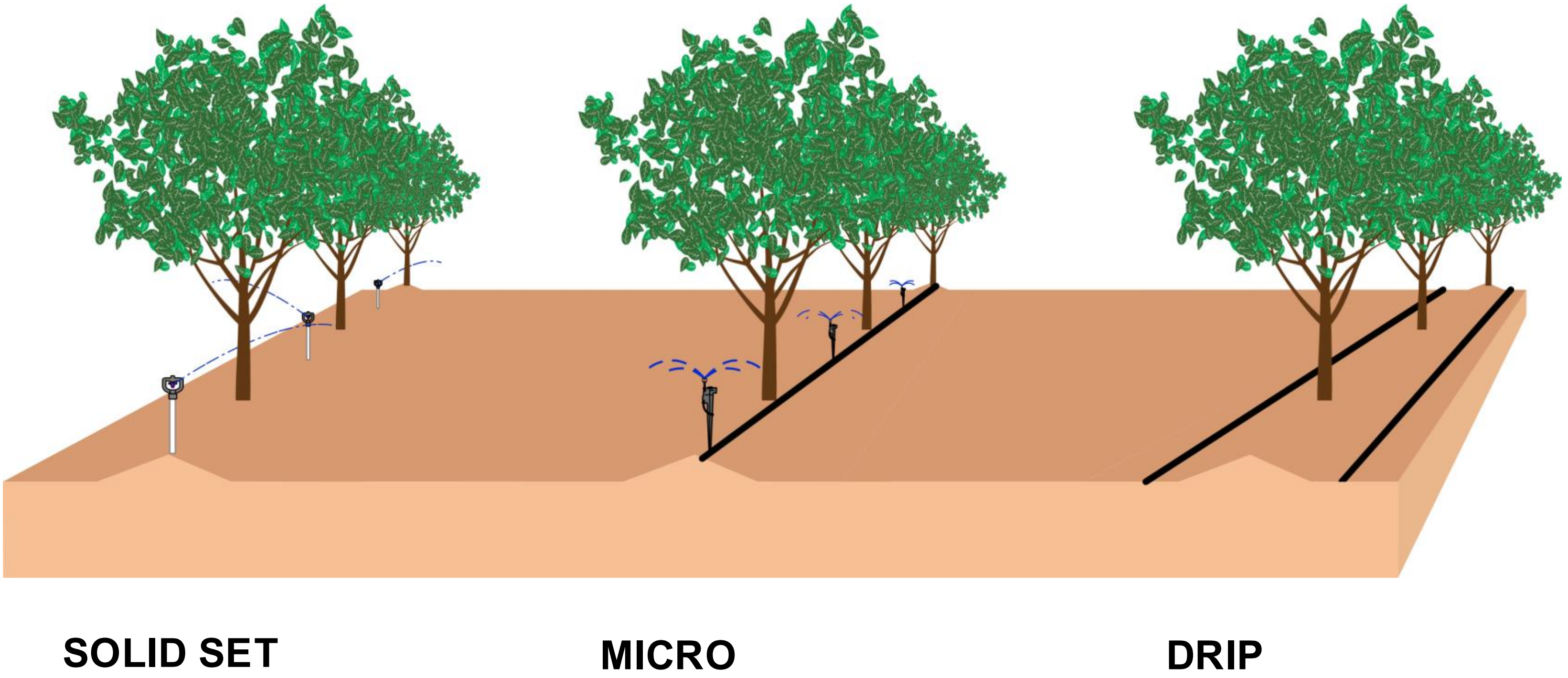
IRRIGATION METHOD

System Type

- Solid Set
- Drip
- Micro-Sprinkler
- Dual Systems

Special Needs

- Frost Protection
- Flood for Recharge



FILTRATION

Screen Filter

Image – Morrill Industries

Automated Screen Filter

Image – Morrill Industries

Sand Media Filter

Image – Fresno Valves

Disk Filter

Image – Rain Bird

ENERGY COSTS

What is it going to cost to run the system?

- Outline the **total energy cost**.
- Options for upsizing pipelines, will it **lower long-term cost**?
- Options for more **efficient pumps and motors**.

PUMP DATA CALCULATOR- COPYRIGHT TALLEMENCO PTY LTD 2018 Rev13 © www.talle.biz rob@talle.biz

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METRIC LEGEND 0.92 Active cell

PUMPING COSTS - ELECTRIC 93.94 Derived data (protected)

kWh/ML=	2.73	x	m head	refer	www.talle.biz/data.html		for derivation		
	pump η	x motor η	x drive η		www.talle.biz/pumpunits02.pdf				
				NOTE: η = efficiency					
$/yr =	kWh/ML	x	$/kWh	x	ML/yr				
			m head		$/kWh		ML/yr		$/yr
$/yr =	**2.73**	x	70	x	0.280	x	1,400	=	100,687
			pump η	x	motor η	x	drive η*		kWh/ML
			0.8		0.93		1.00		256.85
			NOTE: η = efficiency						$/ML
			* If pump is belt driven, inset **0.9** for this value						71.92
			If pump is gear driven, inset **0.95** for this value						kWh/yr
									359,597
									Flow rate l/s
	CALCULATING kVA								22
									ML/hr
	l/s		m head						0.08

AMORTISED COSTS - ELECTRIC PUMPING

	ELECT	NPV	
	7.00%	3.50%	Inflation
$/yr	100,687		

Year	Annual Cost	NPV	Year
1	100,687	97,282	1
2	107,735	197,854	2
3	115,277	301,827	3
4	123,346	409,316	4
5	131,980	520,440	5
6	141,219	635,322	6
7	151,104	754,088	7
8	161,681	876,871	8
9	172,999	1,003,806	9
10	185,109	1,135,033	10
11	198,067	1,270,698	11
12	211,931	1,410,951	12
13	226,767	1,555,946	13
14	242,640	1,705,845	14
15	259,625	1,860,813	15

CARBON EMISSIONS - ELECTRIC PUMPING

359,597 kWh/yr

kg CO_2-e/kWh	State	Tonne CO_2/yr
0.84	NSW*	302.06
1.09	VIC*	391.96
0.78	QLD*	280.49
0.53	SA*	190.59
0.68	WA*	244.53
0.12	TAS*	43.15
0.67	NT*	240.93
0.67	**Ave**	
0.80	other	287.68
0.10	**NZ low	35.96
0.64	**NZ high	230.14

For Australia:

National Greenhouse Account Factors - Aug 2016

technology

What options for **integrating technology** in the design are there?

- **Monitoring**
- **Control & Automation**

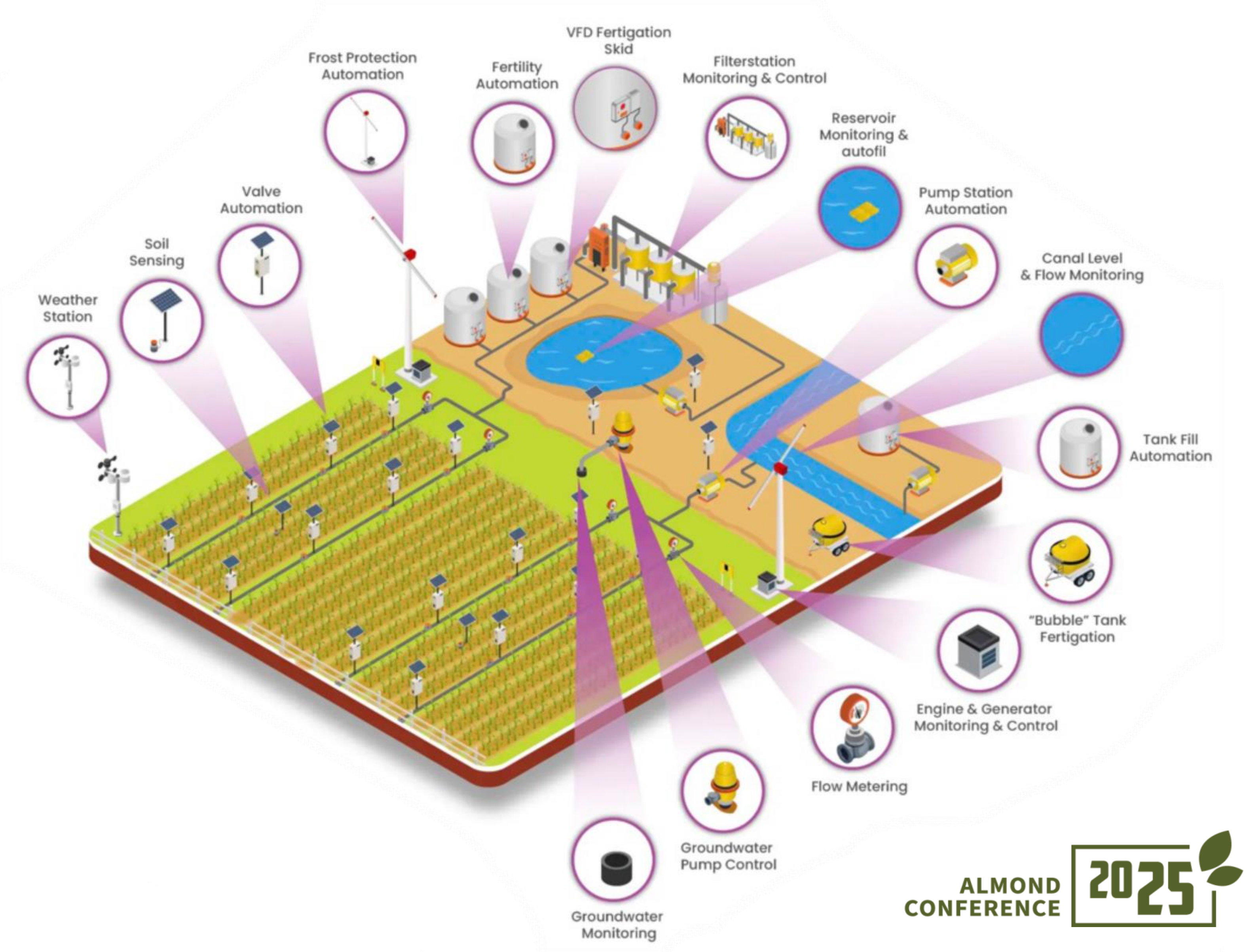

Image provided by **HotspotAG**

WARRANTIES

Often **overlooked but so important** & best to know at the start.

It's not just the hardware, **how is labor covered**?

Who provides warranties and what is covered?		
Item	**Yrs Covered**	**Provider**
Irrigation pipeline components		
Filtration components		
Air vents		
Filtration components		
Air vents		
Control valves		
Automation		
Installation		

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incentives

FIND A SUPPLIER | US

california almonds

Why Almonds | Almond Industry | Tools & Resources | About Us | Search

← Grower Tools

Incentive Opportunities

Financial support for almond growers, processors, and farm-related businesses is available from a variety of federal, state, and local agencies and from non-governmental organizations. Incentive programs are offered for a variety of focus areas. Start your search in the chart below. Deadlines are variable; please check the funding provider's website for details

Learn more about NRCS Programs here.
Learn more about USDA programs and local offices at Farmers.Gov.

FILTER BY: CLEAR ALL FILTERS

Agency | Focus Area | Eligibility

Agency	Program	Focus Area	Equipment/Practices	Eligibility	Incentive	Deadline
USDA Natural Resources Conservation Service (NRCS)	Restore Grant Program	• Emissions Reduction • Soil Health	• Cover Crops • improve soil health • Sequester carbon	Growers	Grants	Variable
California Department of Conservation	Sustainable Agricultural Lands	• Easements	• Agricultural Land Conservation • restoration and habitat	Growers	Grants	Variable

almonds.com/incentives

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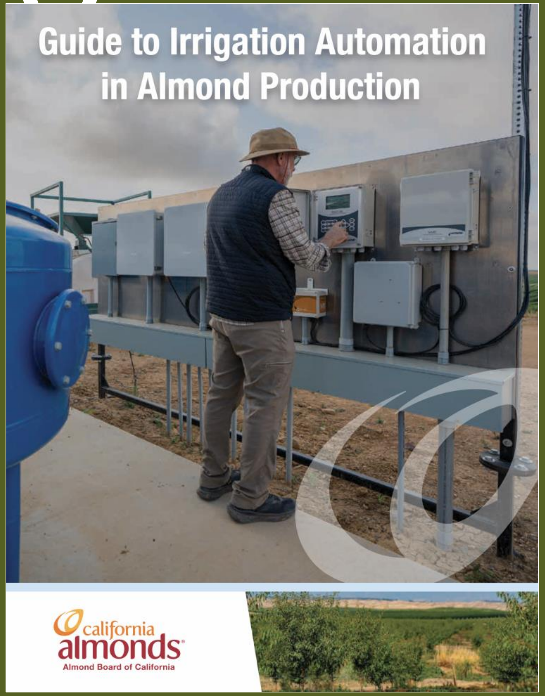
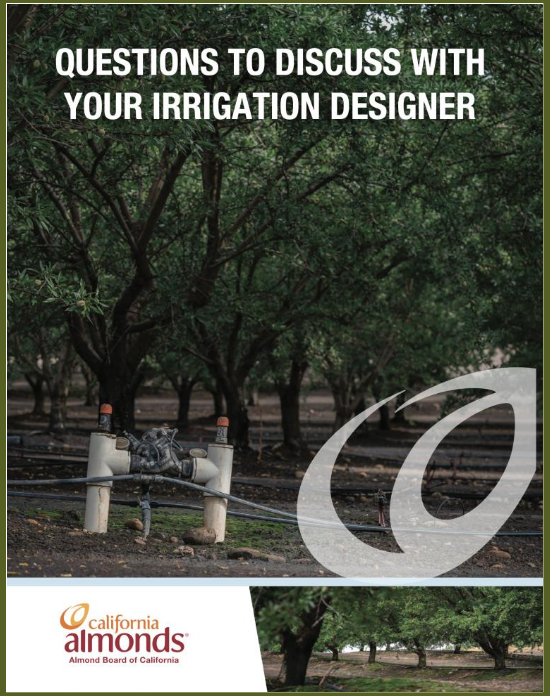
NEW ABC RESOURCES ONLINE FOR YOU





THANK YOU!

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CULTIVATING A HEALTHIER
FUTURE

T-REX RESEARCH UPDATES

NEW IRRIGATION MANAGEMENT RESOURCES & THE USE OF ACTUAL EVAPOTRANSPIRATION

Kyle Knipper, PhD

Remote Sensing Scientist

Co-Lead of Crop Sensing Group

USDA ARS, Davis, CA

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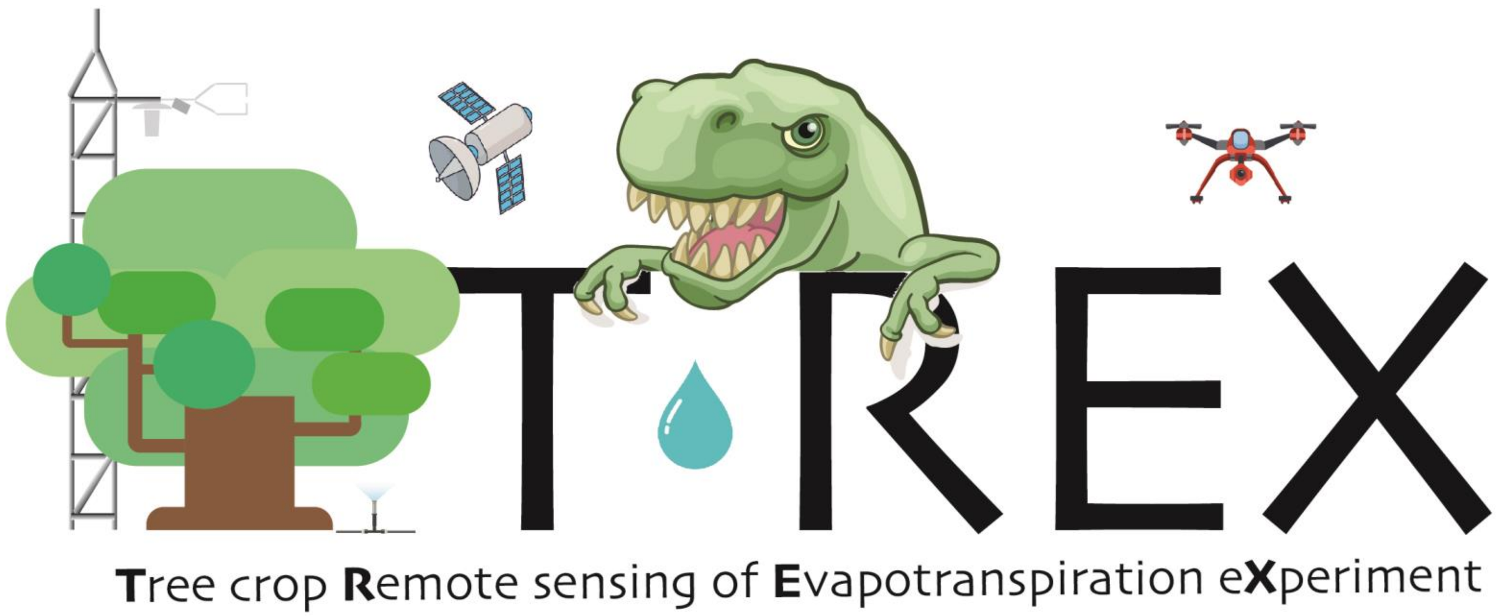
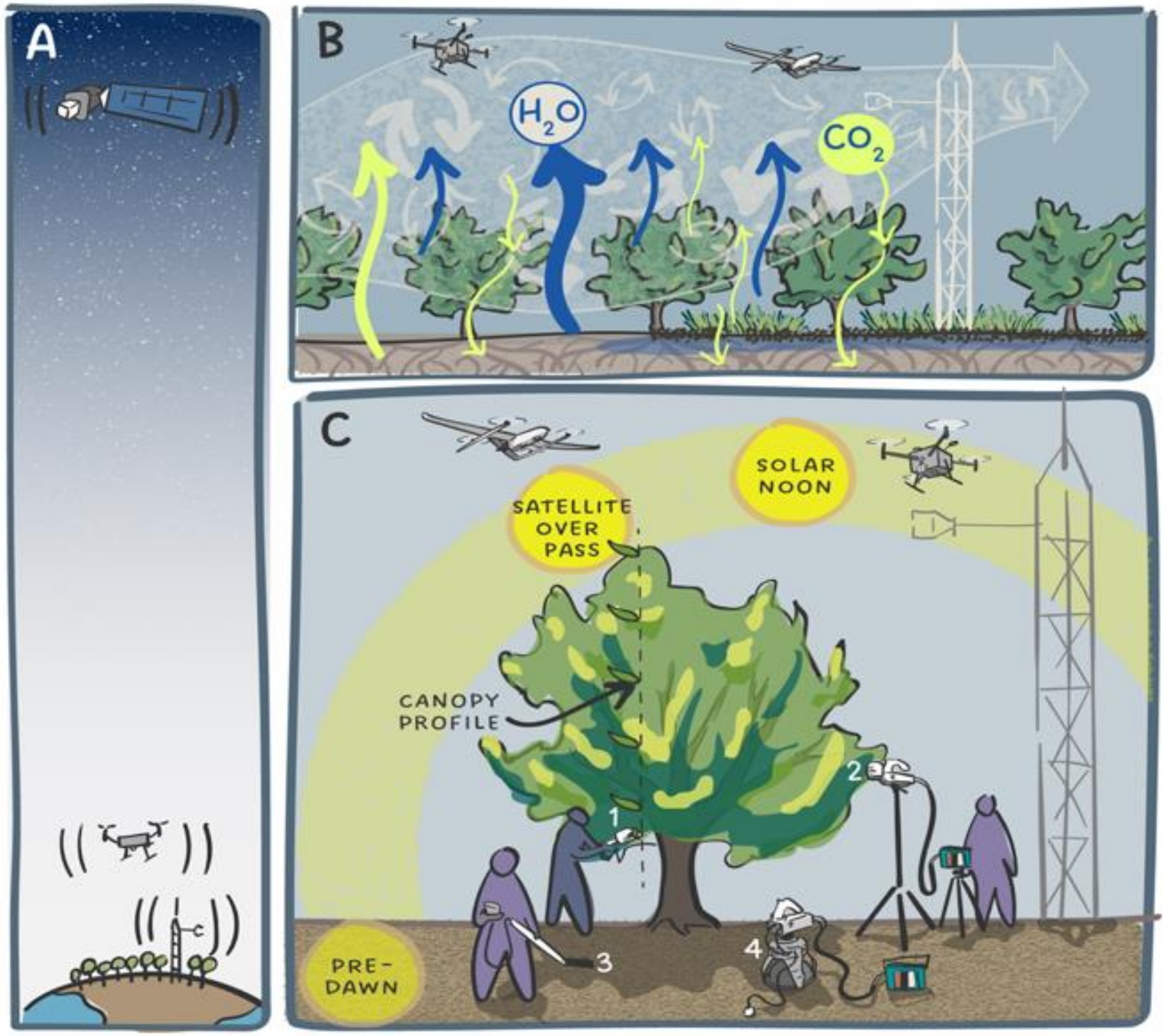
BACKGROUND


T-REX
Tree crop Remote sensing of Evapotranspiration eXperiment

BACKGROUND



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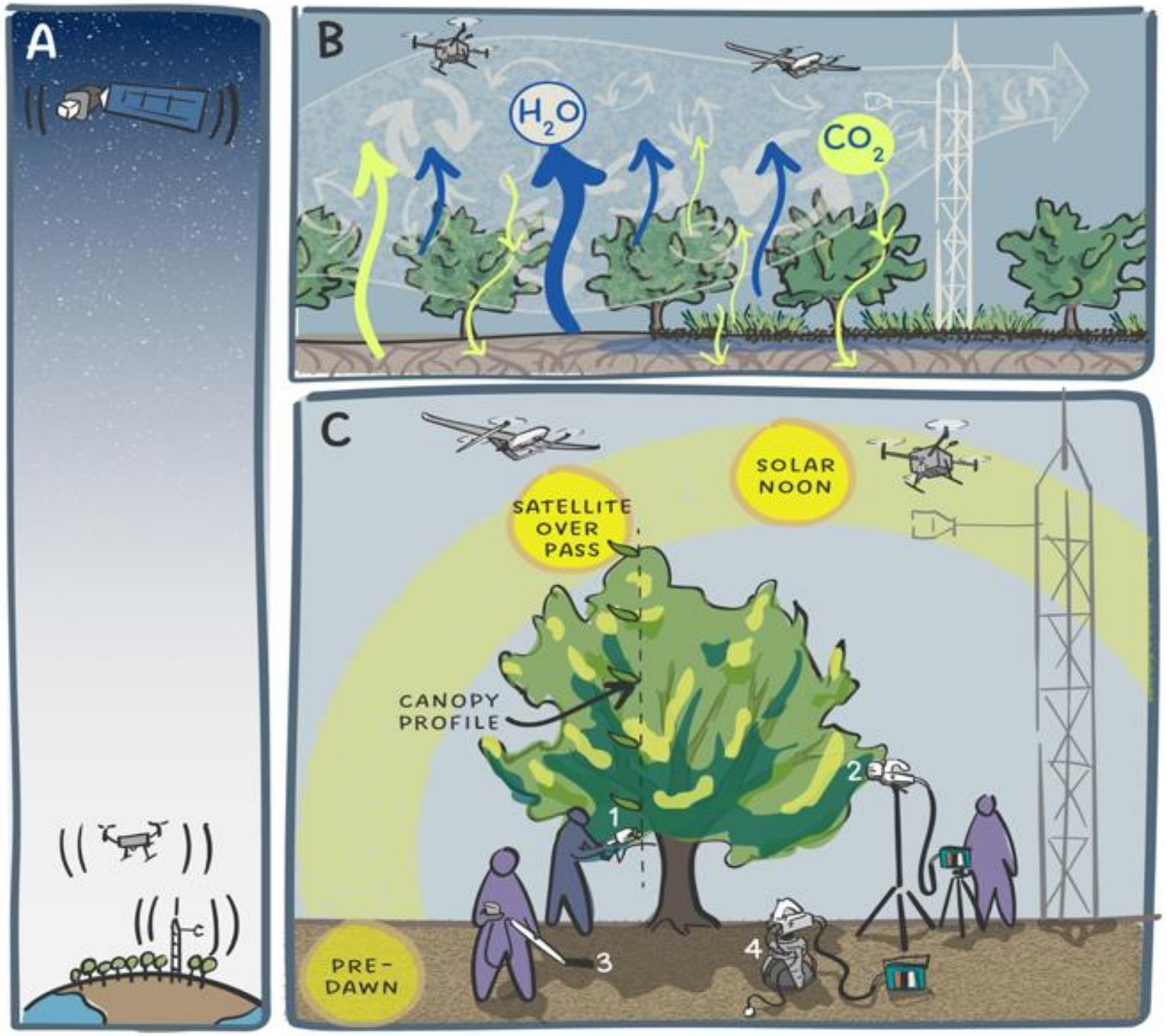
BACKGROUND



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BACKGROUND

BAMS Article

The Tree-Crop Remote Sensing of Evapotranspiration Experiment (T-REX)

A Science-Based Path for Sustainable Water Management and Climate Resilience

Nicolas Bambach, Kyle Knipper, Andrew J. McElrone, Mallika Nocco, Alfonso Torres-Rua, William Kustas, Martha Anderson, Sebastian Castro, Erica Edwards, Moises Duran-Gomez, Andrew Gal, Peter Tolentino, Ian Wright, Matthew Roby, Feng Gao, Joseph Alfieri, John Prueger, Lawrence Hipps, and Sebastian Saa

KEYWORDS:
Carbon cycle;
Evapotranspiration;
Surface fluxes;
Remote sensing;
Agriculture;
Water resources

ABSTRACT: Water scarcity threatens agriculture in California. During the last two decades, historically severe droughts have led to severe water shortages. Under projected changes in climate, droughts of greater severity and duration will exacerbate this situation. California produces 80% of the world's almonds, which require consistent water supplies for irrigation. Almonds are the most commonly grown crop in California, covering nearly 1.4 million acres over about 8,000 farms. In response to these challenges, almond growers are considering a myriad of management strategies to save water and mitigate climate change. The Tree-Crop Remote Sensing of Evapotranspiration Experiment (T-REX) aims to identify water and orchard management opportunities to maximize water use efficiency and carbon sequestration in almonds and other woody perennial tree crops. The project combines satellite, uncrewed aerial vehicles, and proximal sensing technologies to retrieve key variables used to model surface fluxes and biophysical properties. We aim to advance our understanding of water management and cultural practices on water–carbon relationships in tree-perennial agroecosystems. Through new methods, such as evapotranspiration-based irrigation scheduling, even a modest 10% decrease in almond orchard irrigation across the state equates to about a third of the water in Lake Oroville, California's second-largest reservoir, at average levels. From a carbon perspective, almond orchards could sequester 8% of the state's current greenhouse gas emissions by transitioning toward climate-smart practices. As such, the almond industry is uniquely positioned to curb water use and contribute to climate change mitigation while maintaining economic viability of almond production. An overview of initial results related to evapotranspiration observational and modeling uncertainty and carbon sequestration potential are presented in this article.

BACKGROUND

The Tree-Crop Evapotranspira

A Science-Based Path fo

Nicolas Bambach, Kyle Kr
Alfonso Torres-Rua, William
Moises Duran-Gomez, An
Feng Gao, Joseph Alfieri, J

KEYWORDS: Carbon cycle; Evapotranspiration; Surface fluxes; Remote sensing; Agriculture; Water resources

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Using ALEXI-DisALEXI for estimation of satellite-derived water use in a California almond orchard under spatially heterogeneous conditions

K. Knipper[1], N.E. Bambach[2], M.C. Anderson[3], Y. Yang[4], W.P. Kustas[3], A.J. McElrone[5,6], M.A. Nocco[2], A. Torres-Rua[7], F. Gao[3], C. Hain[8], S.J. Castro[5], O. Crompton[3] and S. Saa[9]

[1]USDA, ARS, Sustainable Agricultural Water Systems Unit, Davis, CA, USA; [2]University of California, Davis, Department of Land, Air, and Water Resources, Davis, CA, USA; [3]USDA, ARS, Hydrology and Remote Sensing Lab, Beltsville, MD, USA; [4]Mississippi State University, Department of Forestry, Mississippi State, MS, USA; [5]University of California, Davis, Department of Viticulture and Enology, Davis, CA, USA; [6]USDA, ARS, Crops Pathology and Genetics Lab, Davis, CA, USA; [7]Utah State University, Department of Civil and Environmental Engineering, Logan, UT, USA; [8]NASA Marshall Space Flight Center, Huntsville, AL, USA; [9]Almond Board of California, Agricultural Research, Modesto, CA, USA.

Abstract

A study was carried out to evaluate modifications to the ALEXI (Atmosphere-Land Exchange Inverse) and DisALEXI (associated disaggregation technique) modeling framework to estimate water use equivalent to actual evapotranspiration (ET_a) for a drip-irrigated almond orchard located in the Central Valley Region of California, USA. Modifications included the creation of a "synthetic" ALEXI ET_a by redistributing coarse resolution (4 km) ALEXI ET_a to higher spatial resolutions (2, 1, 0.5 km) using leaf area index derived from Harmonized Landsat and Sentinel-2 data sets. This was done to provide more representative estimates of ET_a for DisALEXI when applied over thermally heterogeneous landscapes. For the estimation of ET_a using ALEXI/DisALEXI, 26 satellite images (Landsat 8 OLI/TIRS and Landsat 9 OLI-2/TIR-2) acquired during clear sky days were used during 2022. The performance of synthetic ALEXI and subsequently DisALEXI was evaluated using measurements of ET_a from an Eddy covariance system (EC). Analysis indicated that synthetic ALEXI provided more representative ET_a estimates when applied over a region where a 4 km ALEXI pixel included mostly barren land and a small percentage of irrigated agriculture. The synthetic ALEXI version at 1 km performed best when used in DisALEXI and compared to observed ET_a. However, the difference in mean absolute error remained <0.2 mm day^{-1} between approaches, suggesting Landsat-scale input to DisALEXI remains the most important factor in the ALEXI/DisALEXI modeling scheme.

Keywords: remote sensing, satellite, evapotranspiration, advection, T-REX

INTRODUCTION

Water availability is an endemic challenge for farmers in California, USA. The last decade is a prime example, with several drought years leading to the current unprecedented water shortages. Climate-induced drought of greater severity and length will likely continue to exacerbate these shortages. This lack of water availability is already causing thousands of

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BACKGROUND

The Tree-Crop
Evapotranspira
A Science-Based Path fo
Nicolas Bambach, Kyle Kr
Alfonso Torres-Rua, William
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KEYWORDS:
Carbon cycle;
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Using ALEXI-Dis
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K. Knipper[1], N.E. Bambach
M.A. Nocco[2], A. Torres-Rua

[1]USDA, ARS, Sustainable Agric
Department of Land, Air, and W
Beltsville, MD, USA; [4]Mississippi
of California, Davis, Departmen
Genetics Lab, Davis, CA, USA; [7]U
UT, USA; [8]NASA Marshall Space
Research, Modesto, CA, USA.

Abstract
A study was carried
Exchange Inverse) and
framework to estimate w
drip-irrigated almond or
Modifications included t
resolution (4 km) ALEXI
index derived from Har
provide more represen
thermally heterogeneou
26 satellite images (Lan
clear sky days were us
subsequently DisALEXI
covariance system (EC)
representative ET_a estin
included mostly barren
synthetic ALEXI version
to observed ET_a. Howeve
day^{-1} between approach
most important factor in

Keywords: remote sensing

INTRODUCTION
Water availability is a
is a prime example, with s
shortages. Climate-induce
exacerbate these shortage

Agricultural and Forest Meteorology 355 (2024) 110146

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet

ELSEVIER

A comparative analysis of OpenET for evaluating evapotranspiration in California almond orchards

Kyle Knipper [a,*], Martha Anderson [b], Nicolas Bambach [c], Forrest Melton [d,e], Zac Ellis [f], Yun Yang [g], John Volk [h], Andrew J. McElrone [c,i], William Kustas [b], Matthew Roby [a], Will Carrara [d,e], Sebastian Castro [c], Ayse Kilic [j], Joshua B. Fisher [k], Anderson Ruhoff [l], Gabriel B. Senay [m], Charles Morton [h], Sebastian Saa [n], Richard G. Allen [o]

[a] USDA ARS Sustainable Agricultural Water Systems, Davis, CA, United States
[b] USDA ARS Hydrology and Remote Sensing Lab, Beltsville, MD, United States
[c] University of California Davis, Davis, CA, United States
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[i] USDA ARS Crops Pathology and Genetics Research, Davis, CA, United States
[j] University of Nebraska-Lincoln, Lincoln, NE, United States
[k] Chapman University, Schmid College of Science and Technology, Irvine, CA, United States
[l] Universidade Federal do Rio Grande de Sul, Porto Alegre, RS, Brazil
[m] U.S. Geological Survey Earth Resources Observation and Science Center, North Central Climate Adaptation Center, Fort Collins, CO, United States
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[o] (ret) University of Idaho, Kimberly, ID, United States

ARTICLE INFO

Keywords:
Evapotranspiration
OpenET
Remote sensing
Water management
Irrigation
Almond

ABSTRACT

The almond industry in California faces water management challenges that are being exacerbated by droughts, climate change, and groundwater sustainability legislation. The Tree-crop Remote sensing of Evapotranspiration eXperiment (T-REX) aims to explore opportunities to improve precision irrigation management for woody perennial cropping systems. Almond orchards in the California Central Valley were equipped with eddy covariance flux measurements to evaluate satellite remote sensing-based evapotranspiration (RSET) models. OpenET provides high-resolution (30-m spatial and daily temporal) RSET data, synthesizing decades of research for practical water management. This study provides an evaluation of OpenET performance at six almond sites covering a large range in soils, age, and variety. It also compares OpenET ensemble evapotranspiration (ET) data with applied irrigation and precipitation records over an additional 148 almond orchards located in the Central Valley of California. Results show OpenET models, including the ensemble ET value, produced reasonable and actionable ET values, with overall coefficient of determination (R^2) and mean absolute error values of 0.73- and 0.95-mm d^{-1} at the daily time step, respectively. However, given the temporal sampling of Landsat (8-day revisit) and the interpolation methods used, the assessed ET models had difficulty in capturing short-term variability in almond ET; for example, the rapid decline in measured ET observed as a response to lack of irrigation preceding and during almond harvest. The study also drew attention to the spatial complexity in scenarios where irrigated orchards are surrounded by hot/dry areas, causing discrepancies between measured and modeled ET values. In comparison with irrigation records, OpenET ensemble ET was capable of quantifying water input (applied irrigation + precipitation) in almond orchards to within 13 % when evaluating monthly

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BACKGROUND

The Tree-Crop Evapotranspira
A Science-Based Path f
Nicolas Bambach, Kyle Kr
Alfonso Torres-Rua, William
Moises Duran-Gomez, An
Feng Gao, Joseph Alfieri, J

KEYWORDS: Carbon cycle; Evapotranspiration; Surface fluxes; Remote sensing; Agriculture; Water resources

Using ALEXI-Dis
derived water u
under spatially

K. Knipper[1], N.E. Bambach
M.A. Nocco[2], A. Torres-Rua

Abstract

A study was carried ...

Keywords: remote sensing

INTRODUCTION

Water availability is ...

A comparative analysis of Ope
California almond orchards

Kyle Knipper, Martha Anderson, N
Yun Yang, John Volk, Andrew J. M
Will Carrara, Sebastian Castro, Ays
Gabriel B. Senay, Charles Morton, S

ARTICLE INFO

Keywords: Evapotranspiration; OpenET; Remote sensing; Water management; Irrigation; Almond

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Estimating the value of satellite-derived measurements of evapotranspiration to inform irrigation scheduling in California almond orchards

Daniel Lapidus[1] · Caleb Milliken[1] · Kyle Knipper[2] · Sebastian Saa[3] · Tom Devol[3] · William Kustas[4] · Andrew J. McElrone[5,6] · Michael Gallaher[1] · Nicolas Bambach[6] · Martha Anderson[4]

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Abstract

Advances in satellite remote sensing have led to the development of improved methods and tools for calculating evapotranspiration (ET), allowing for improved irrigation scheduling. Researchers have been working closely with industry groups for the last decade on developing an "ET Toolkit" that could be used operationally to improve irrigation scheduling for specialty crops in California's increasingly drought-prone Central Valley. A unique collaboration between government and academic researchers and the Almond Board of California aimed to develop and refine the ET Toolkit to improve water use efficiency through irrigation scheduling for almond growers. In this study, the monetary value of applying the ET Toolkit to improve water use efficiency through irrigation scheduling for almonds is estimated. Benefits are valued by comparing existing irrigation scheduling methods, which rely on calculating crop ET in grower fields based on nearby weather station measurements, to future adoption of a field-scale satellite-based actual ET tool. As publicly available field-scale information has only recently come on-line through OpenET, the benefits estimated are *prospective*. Two valuations are conducted: one that captures private benefits to farmers, and another that captures the economic value for all water users based on the price that buyers are paying in active California water markets. Given assumptions on scaling pathways and drought's impact on values of water, the average *annual* water savings are estimated to be 241,000 acre-feet, and value to farmers is estimated to be \$45.5 M, while economic benefits reach \$127.6 M over the period 2028–2033.

Keywords Remote sensing · Actual evapotranspiration · Irrigation scheduling · Water efficiency · Economic valuation · Agriculture

Extended author information available on the last page of the article

Springer

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BACKGROUND

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High-Resolution Actual Evapotranspiration in Almond Orchards by Integrating Physiological and TSEB Models

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Abstract

Spatial and temporal high-resolution thermal infrared (TIR) remote sensing systems are emerging as valuable tools for monitoring crop water use and stress. Thermal cameras onboard small uncrewed aerial systems (UAS) provide high spatial and temporal resolution TIR. Reliable high-resolution TIR imagery is a crucial input for remote sensing-based land surface energy balance models in mapping instantaneous actual evapotranspiration (ET_a). Therefore, evaluating UAS-acquired TIR temperature correction and ET_a upscaling method is needed to improve the accuracy of instantaneous and daily ET_a, respectively. In this study, we applied a novel physiological-surface energy balance-based TIR temperature correction, a key input for the two-source energy balance (TSEB) model, in combination with a daily ET_a upscaling method, to estimate high-resolution ET_a at almond orchards in California. A coupled physiological model was developed and compared to in-situ physiological measurements of net CO_2 assimilation rate (A_n), stomatal conductance (g_s), and leaf temperature (T_l). The TSEB Priestley-Taylor (TSEB-PT) and contextual approach (TSEB-2T) models were applied to UAS imagery and proximal tower data, and their performance was compared with eddy covariance (EC) measurements. For ET_a to be useful for irrigation scheduling, upscaling methods based on solar radiation (R_s) and hourly LE based on TSEB-2T were evaluated using EC measurements. Results showed that the coupled physiological and surface energy balance model predicted T_l in good agreement with observed canopy radiometric surface temperature (T_{rad}), with the highest R^2 (0.92 - 0.98) and the lowest RMSE (0.84-1.6°C). Applying physiological-surface energy balance-based TIR temperature correction to UAS-acquired TIR imagery improved LE estimates, reducing the MAE by 18.3%. The hourly LE based on the TSEB-2T upscaling method performed best when using instantaneous LE values between 11:00 and 13:00, with RMSE of 0.02 - 0.65 mm day^{-1}. This study demonstrates the potential to enhance the accuracy of high-spatial-resolution ET_a estimates in cropping systems, supporting precision irrigation.

Keywords: Evapotranspiration, TSEB model, Almond orchards, TIR, UAS, Eddy covariance

1. Introduction

Increasing drought frequency has intensified the spatiotemporal disconnects between water supply and demand in many vital agricultural regions, raising concerns surrounding the future of food and water security (Scanlon et al., 2023; Boser et al., 2024). Irrigation constitutes the largest use

CURRENT FOCUS

- *Improve* remotely sensed modeling approaches in almond orchards

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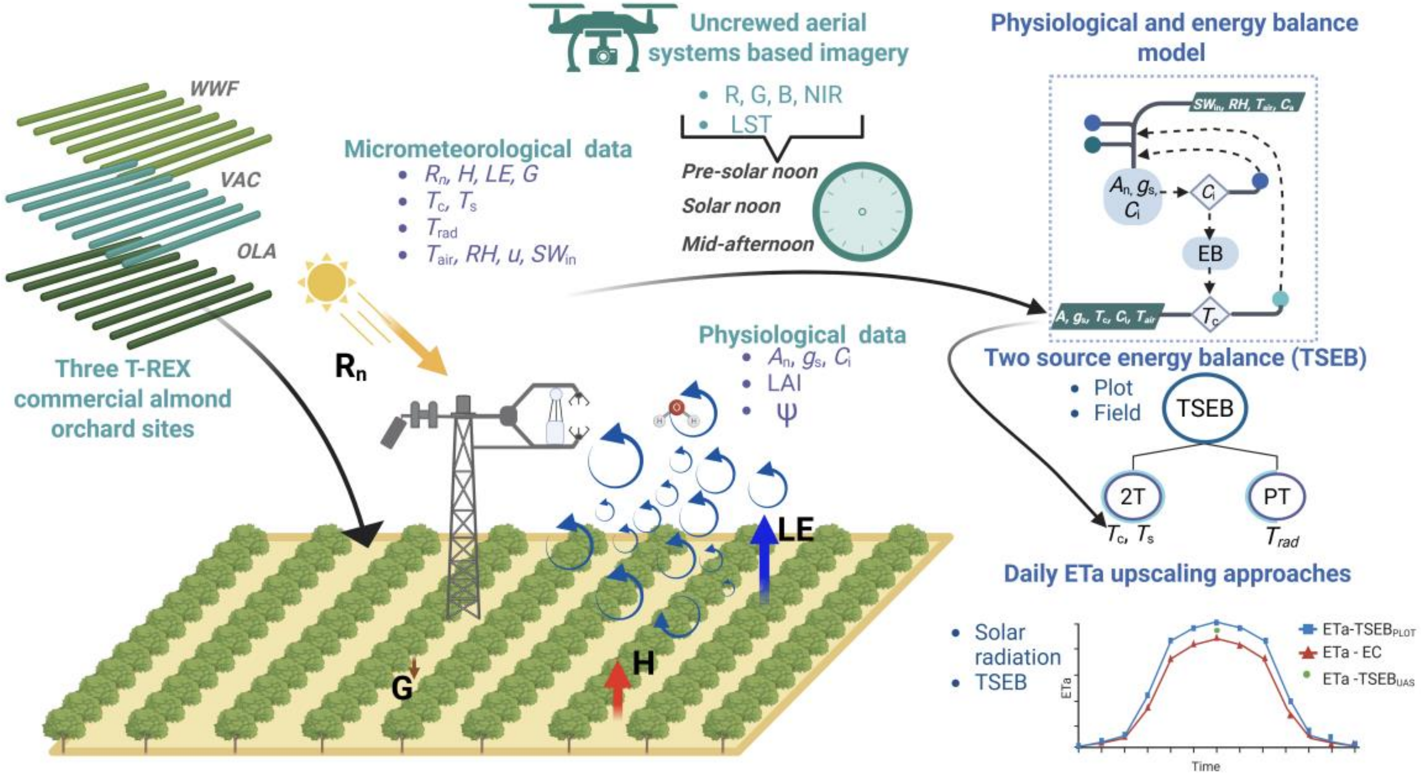
- *Forecast* almond water use (actual ET) out 1 to 2 weeks

CURRENT FOCUS

- *Improve* remotely sensed modeling approaches in almond orchards
- *Forecast* almond water use (actual ET) out 1 to 2 weeks
- *Deliver* decision-ready irrigation information to growers through early adopters

IMPROVE

"High-Resolution Actual Evapotranspiration in Almond Orchards by Integrating Physiological and TSEB Models"



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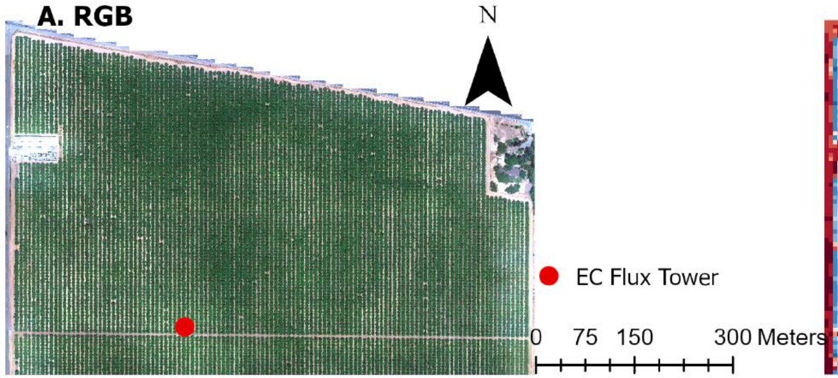

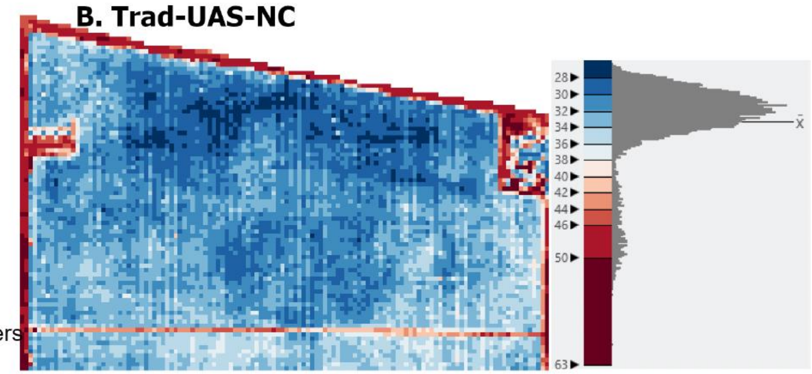

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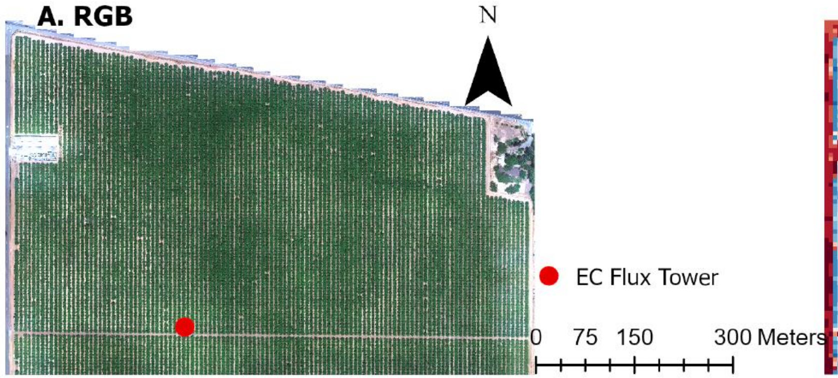

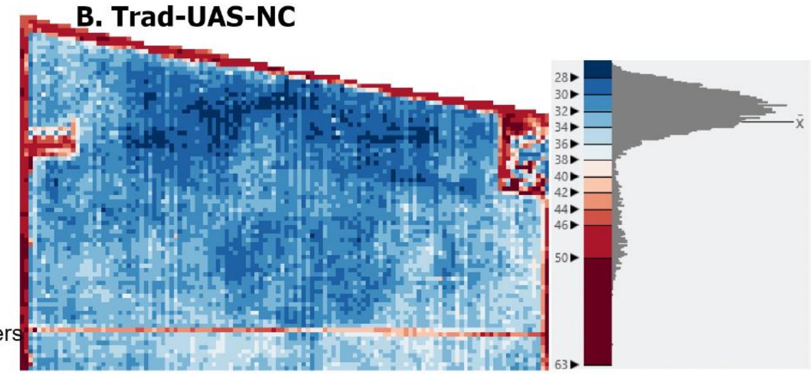

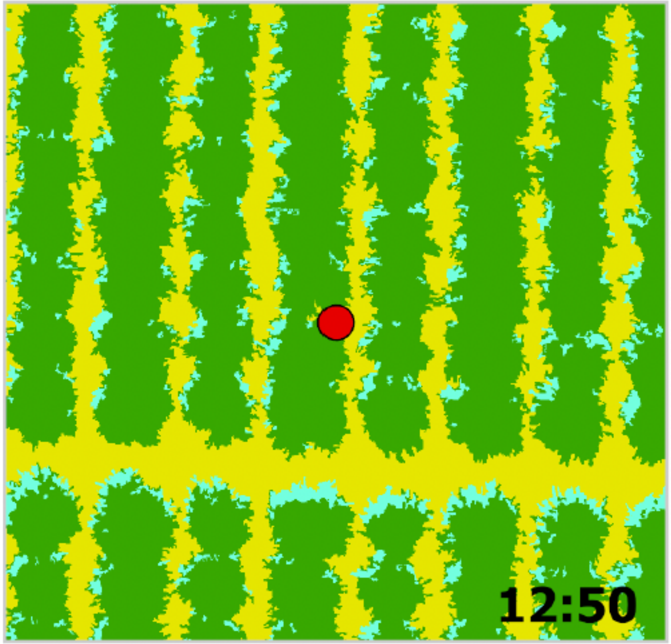

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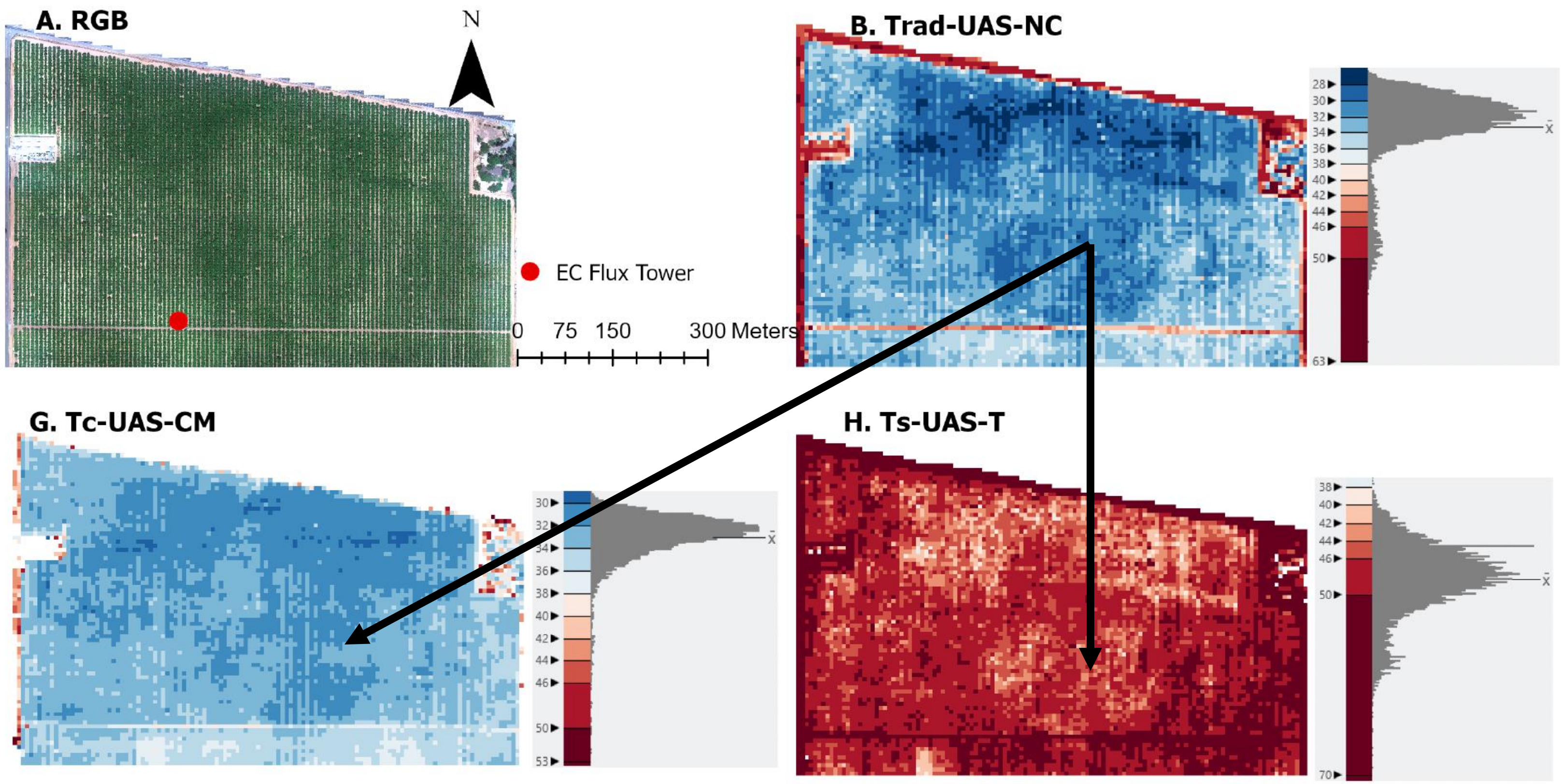

Apply correction that includes:

1) Net Leaf Photosynthesis
2) Stomatal Conductance
3) Leaf Temperature

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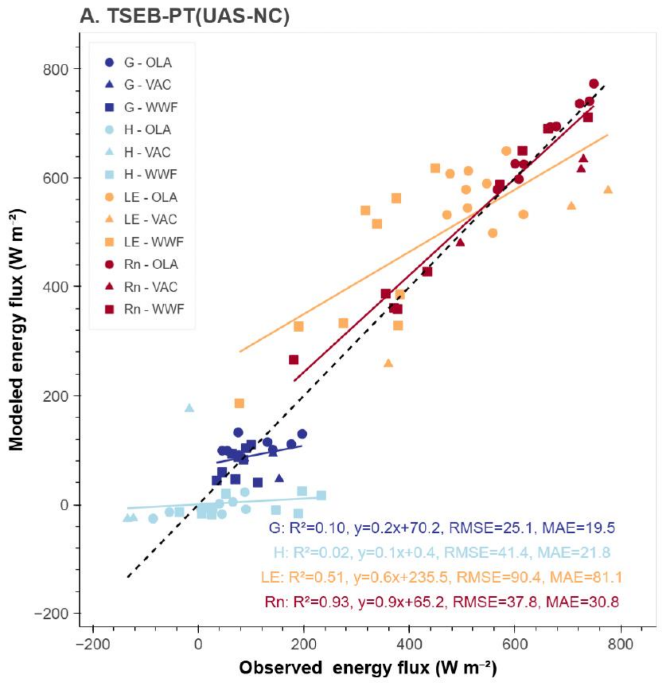

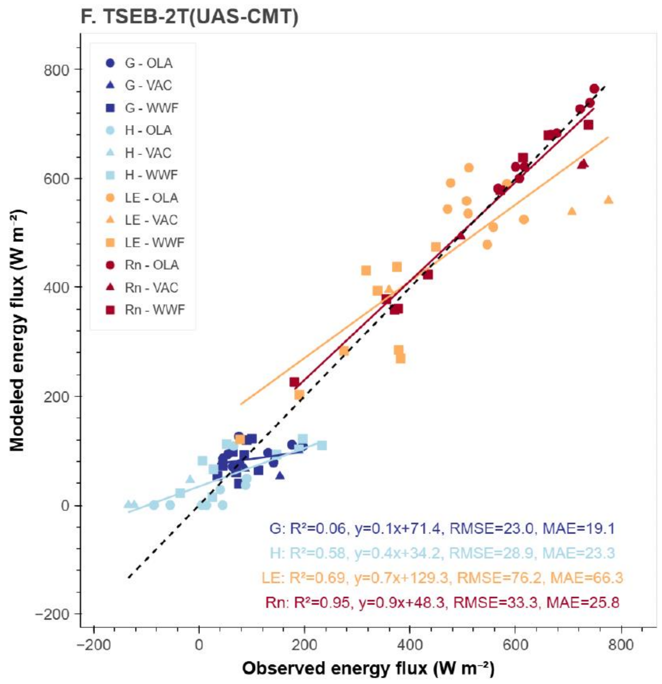

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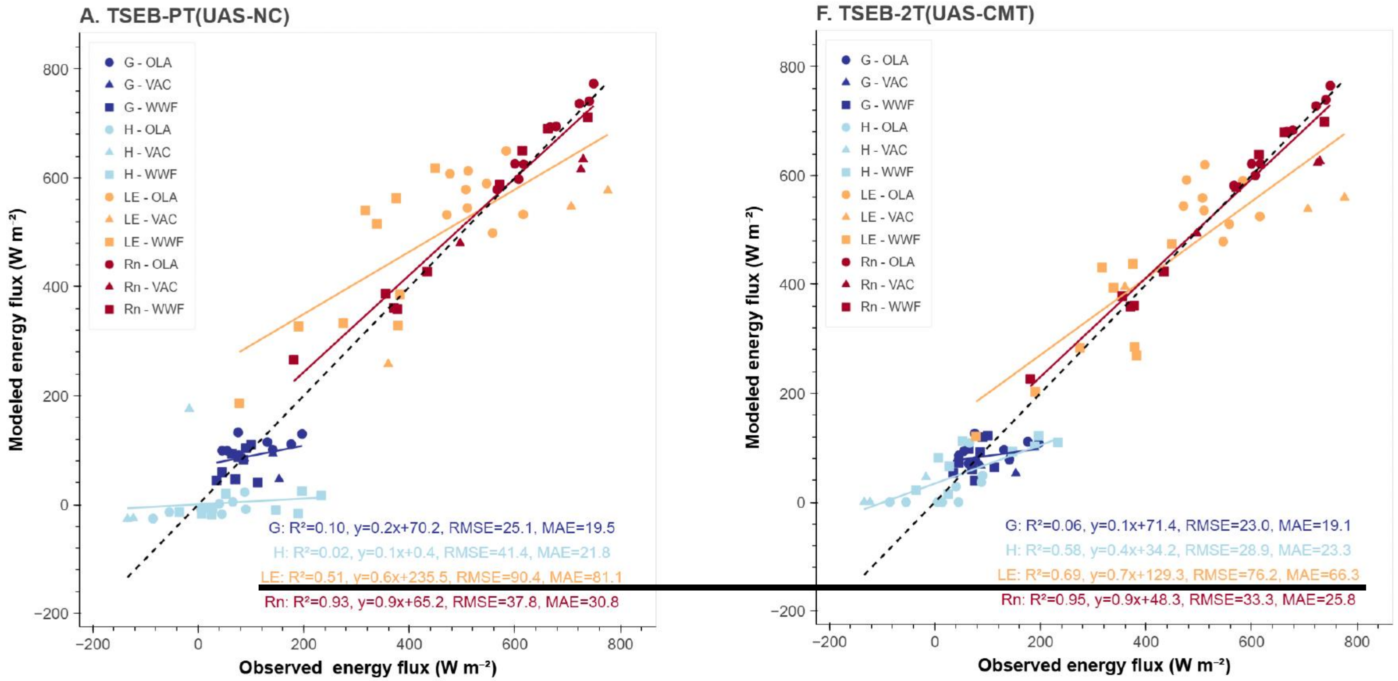

↓ **MAE by 18.3%**

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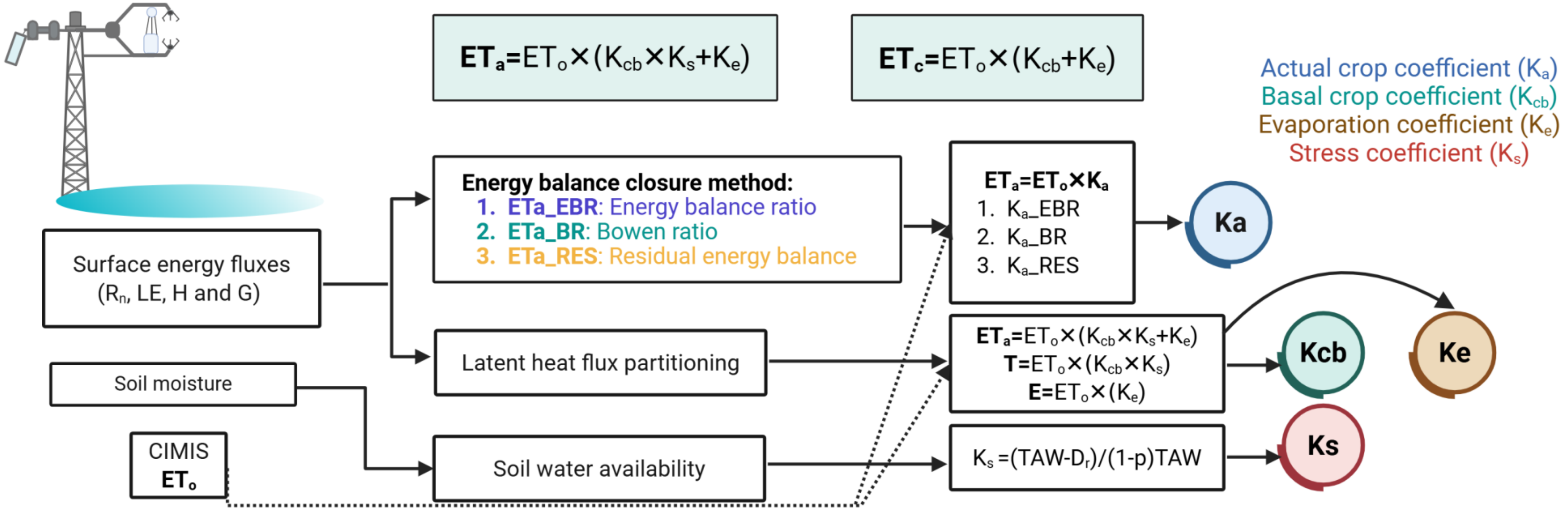
"Evaluating Energy Balance Closure Adjustments for Estimating Actual Evapotranspiration and Crop Coefficients"



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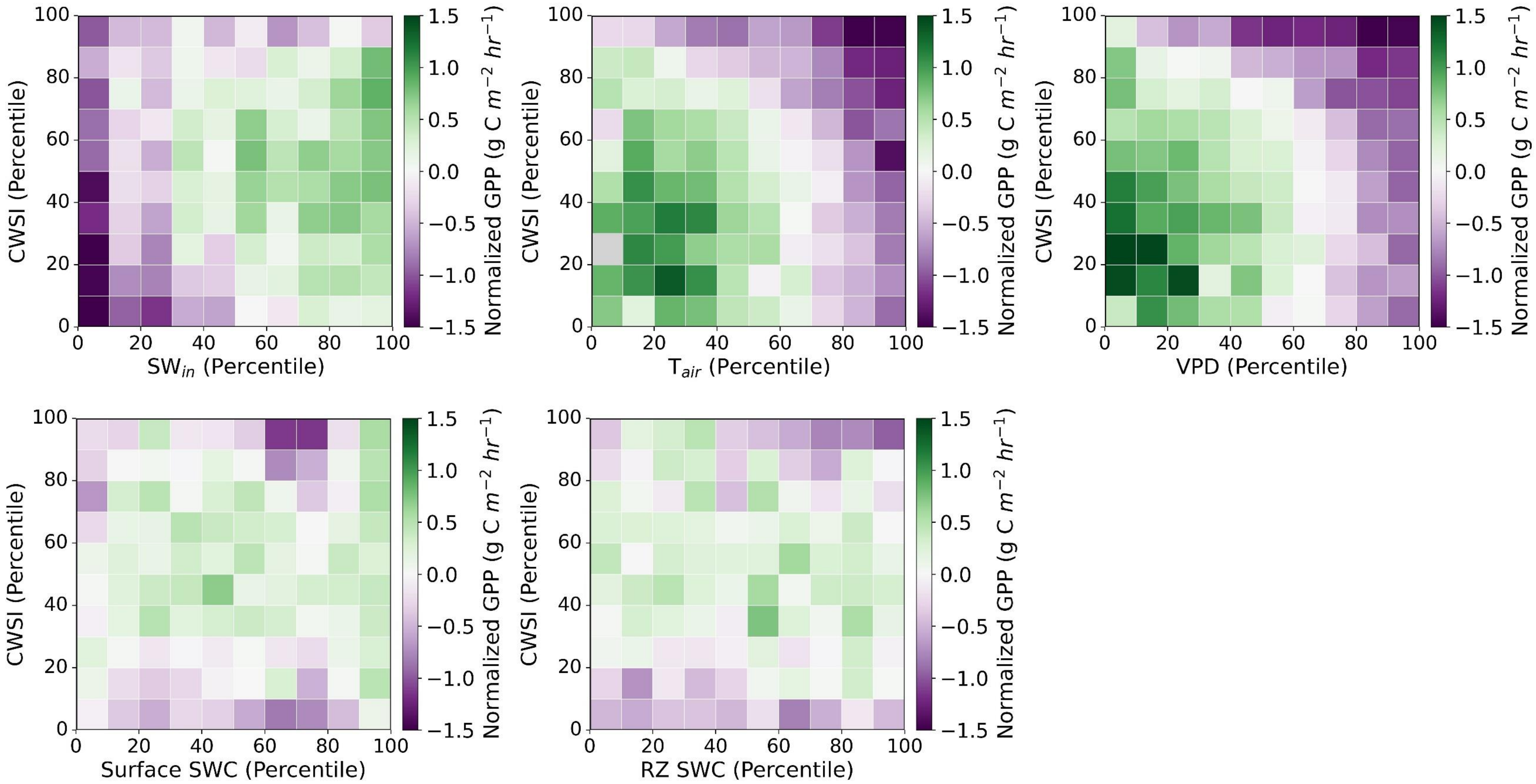
"Independent Impacts of Climatic Drivers on GPP for Multiple Crop Water Stress Scenarios"

Saroj Dash, PhD



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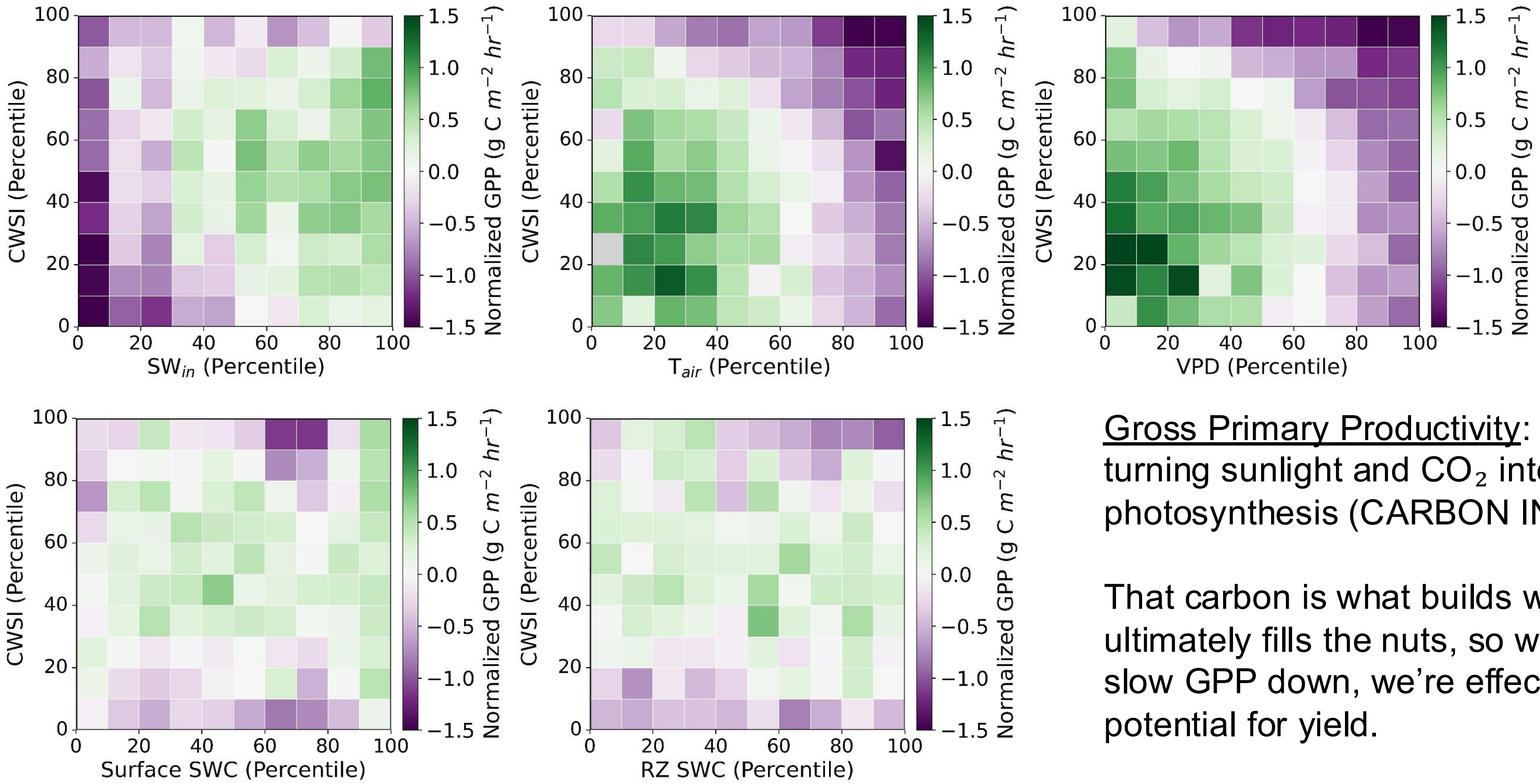

<u>Gross Primary Productivity</u>: how fast the trees are turning sunlight and CO_2 into sugars through photosynthesis (CARBON IN).

That carbon is what builds wood, leaves, and ultimately fills the nuts, so when weather or stress slow GPP down, we're effectively shrinking potential for yield.

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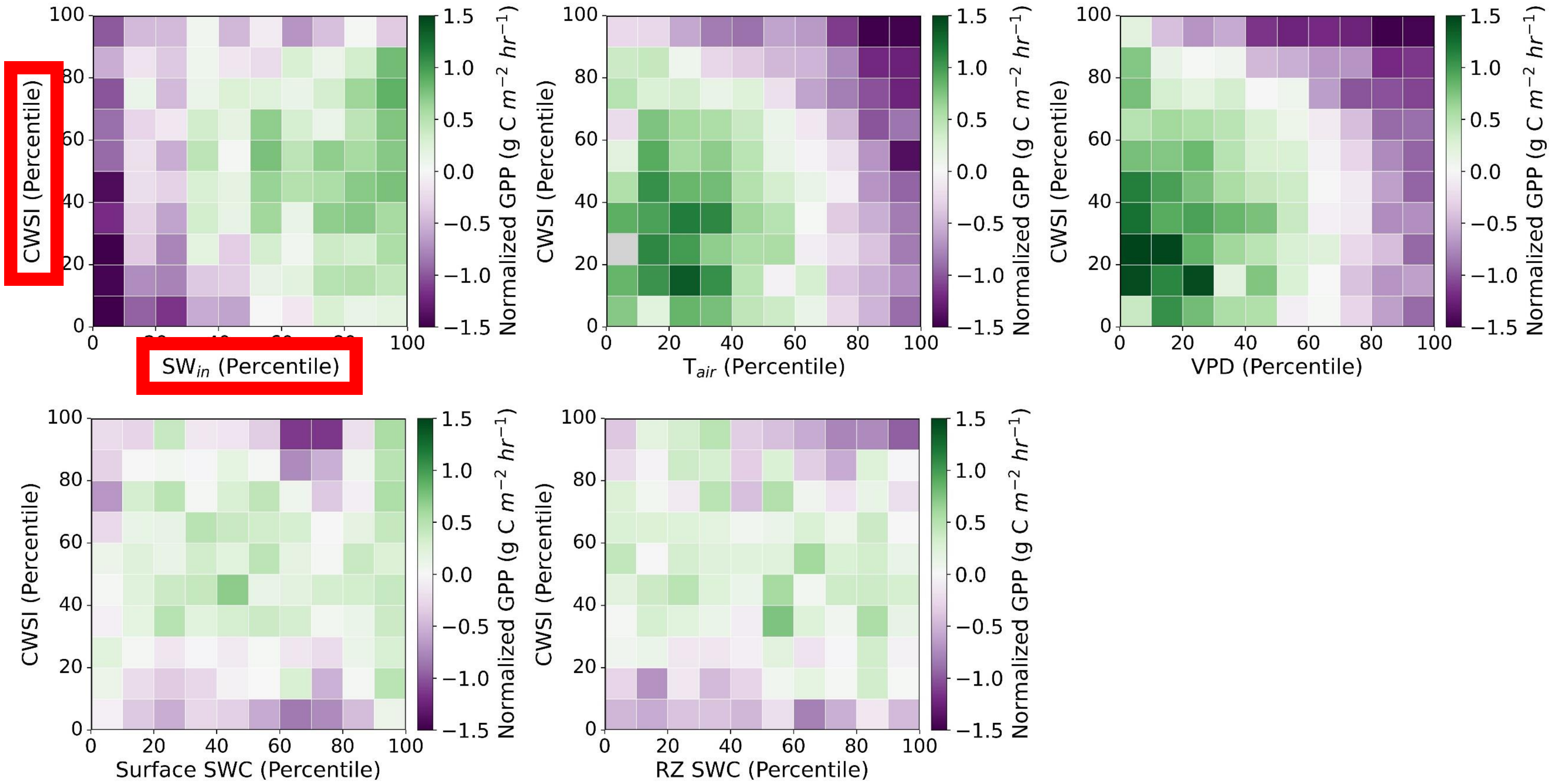
“Independent Impacts of Climatic Drivers on GPP for Multiple Crop Water Stress Scenarios” *Saroj Dash, PhD*



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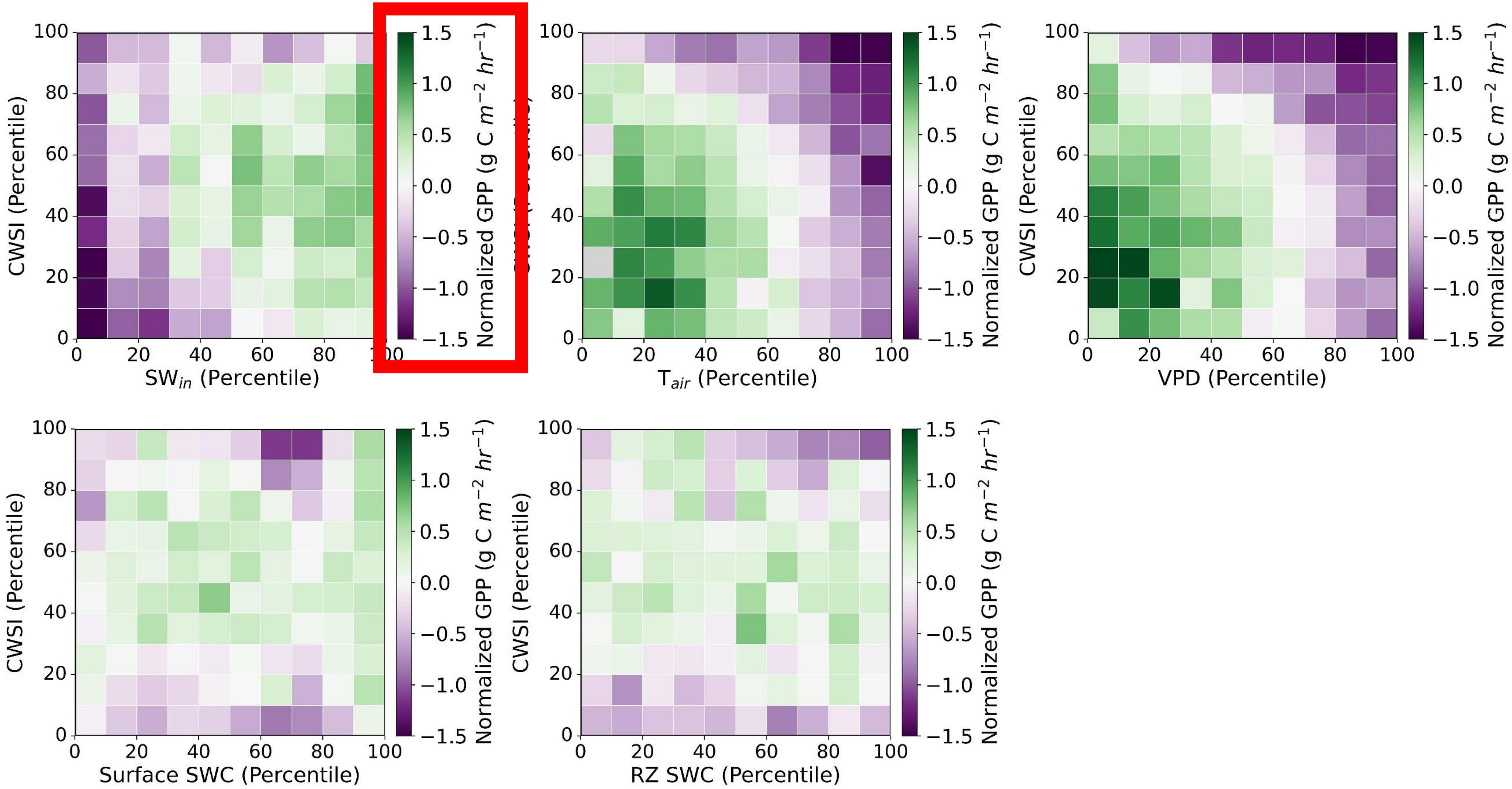

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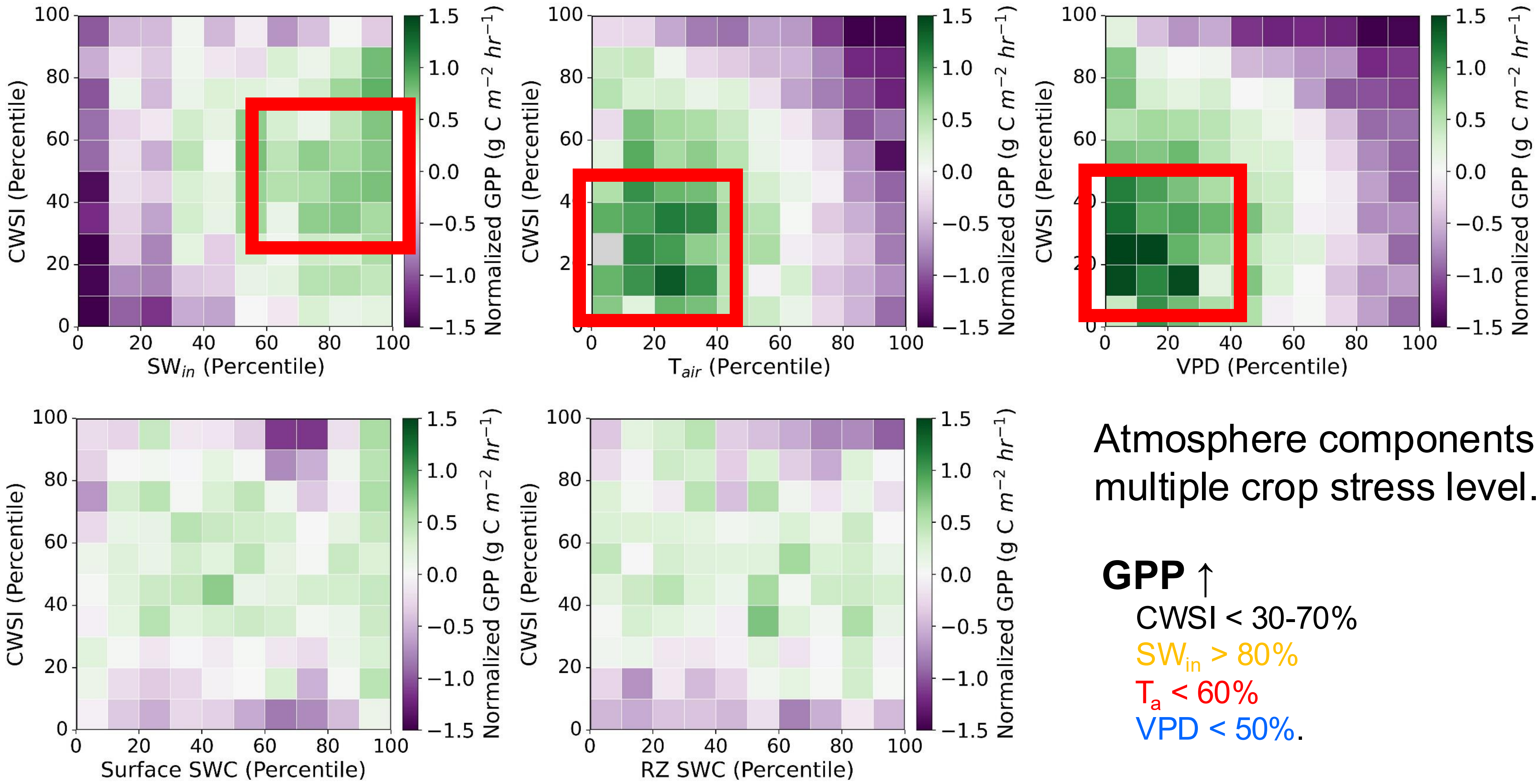

Atmosphere components enhances GPP at multiple crop stress level.

GPP ↑

CWSI < 30-70%

SW_{in} > 80%

T_a < 60%

VPD < 50%.

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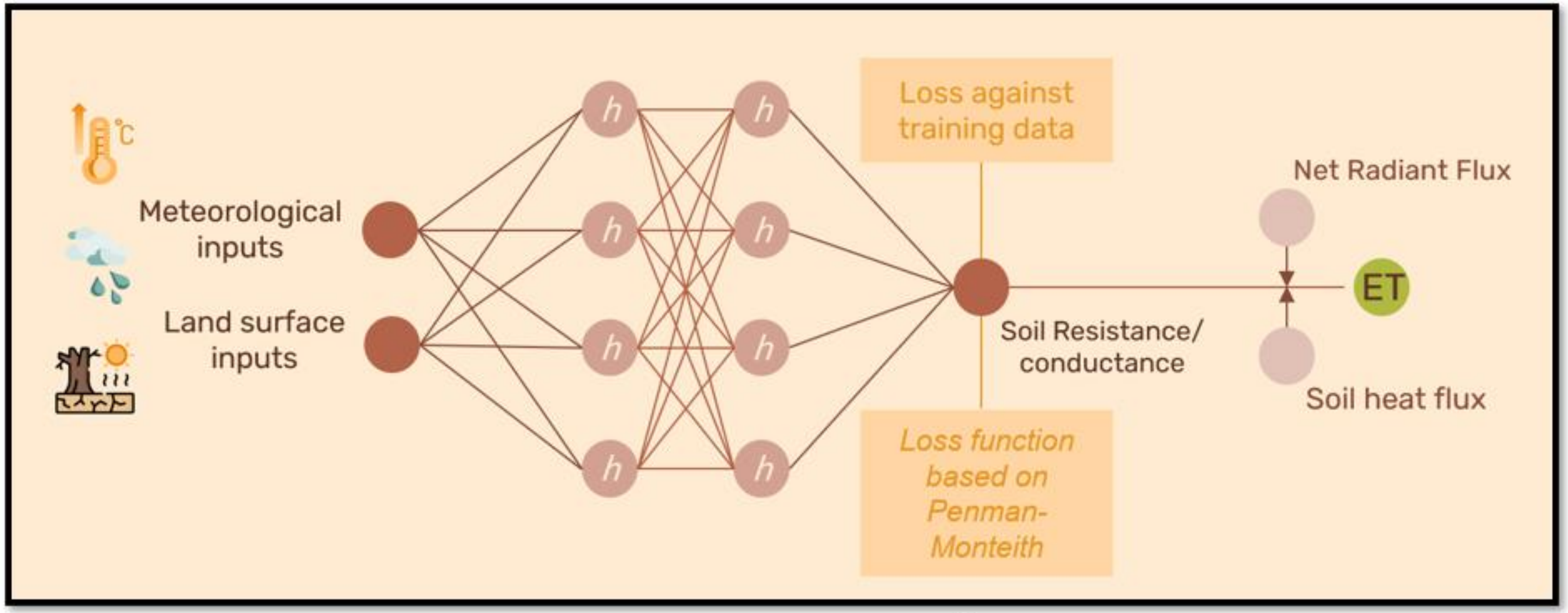
FORECAST

“Forecasting Actual Evapotranspiration with Deep Learning and OpenET: A Cast Study in California Almonds, Olives, and Vines”



Apoorva Jha

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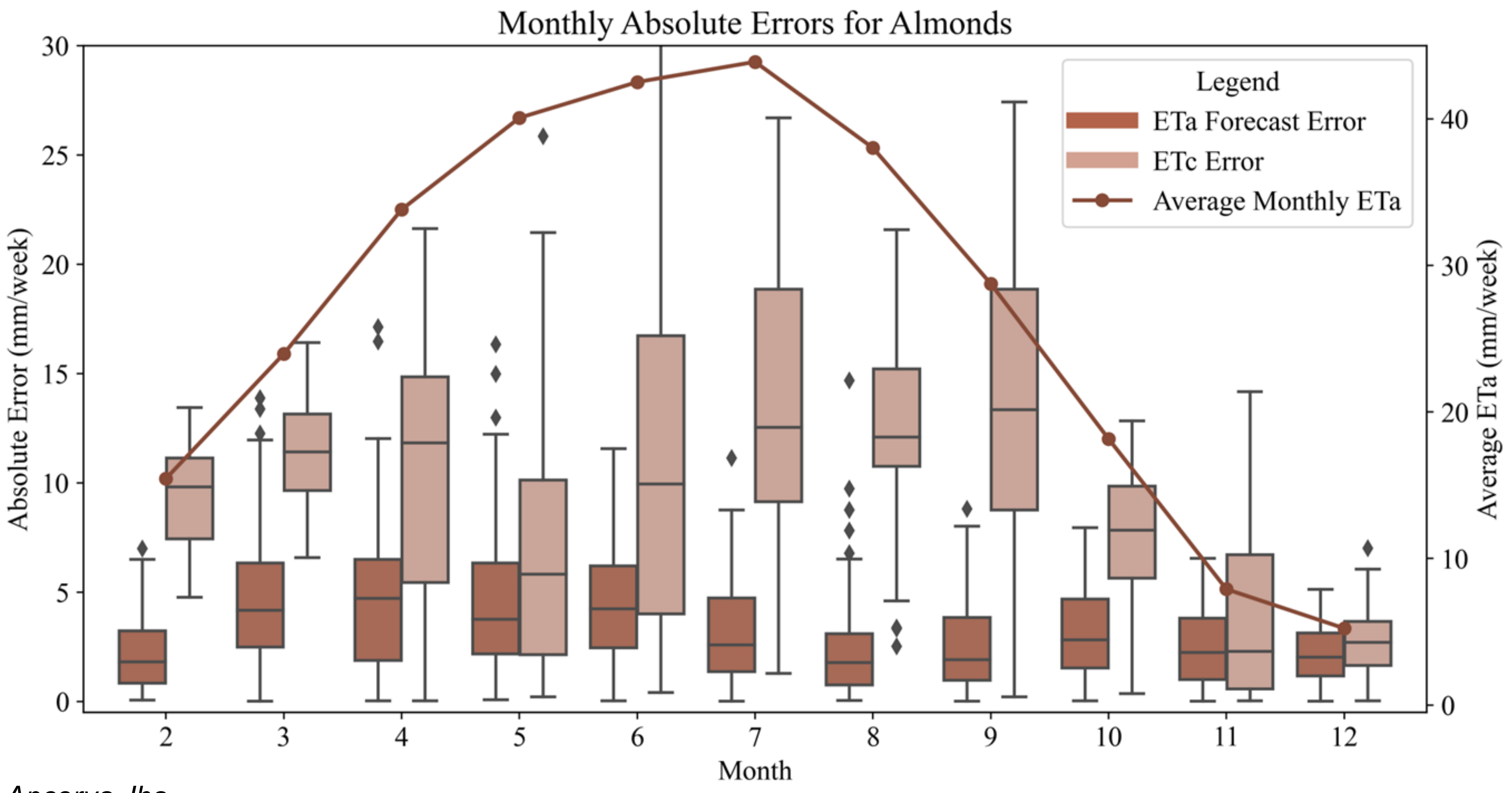

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FORECAST

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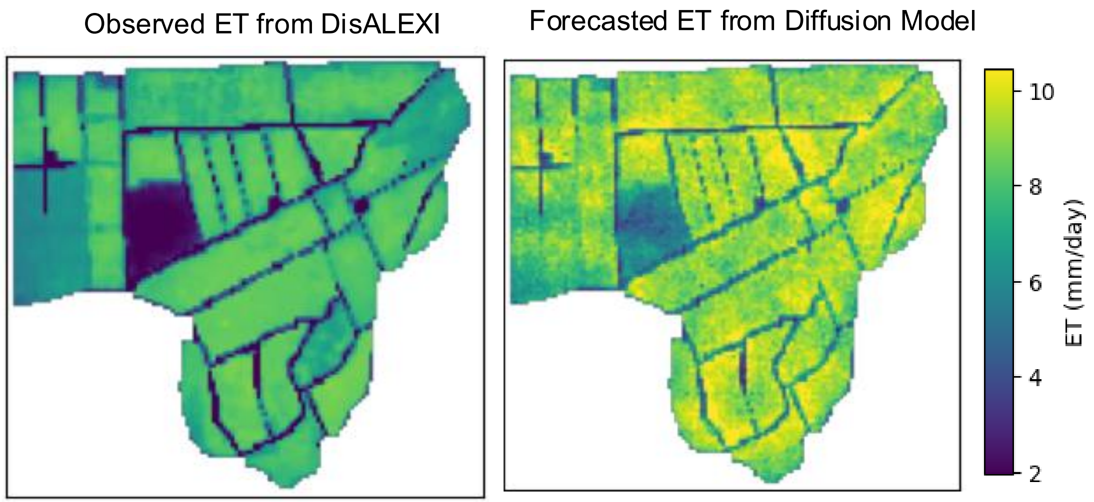
DisALEXI ET + NDVI
(aligned, masked, normalized) — INPUTS

↓

Conditional DDIM
(2D UNet Backbone) — DEEP-LEARNING MODEL

↓

ET_a Forecasts (7-days out) — OUTPUTS



Observed vs. Forecasted ET for 2024-07-21 (+7-day lead) at OLA

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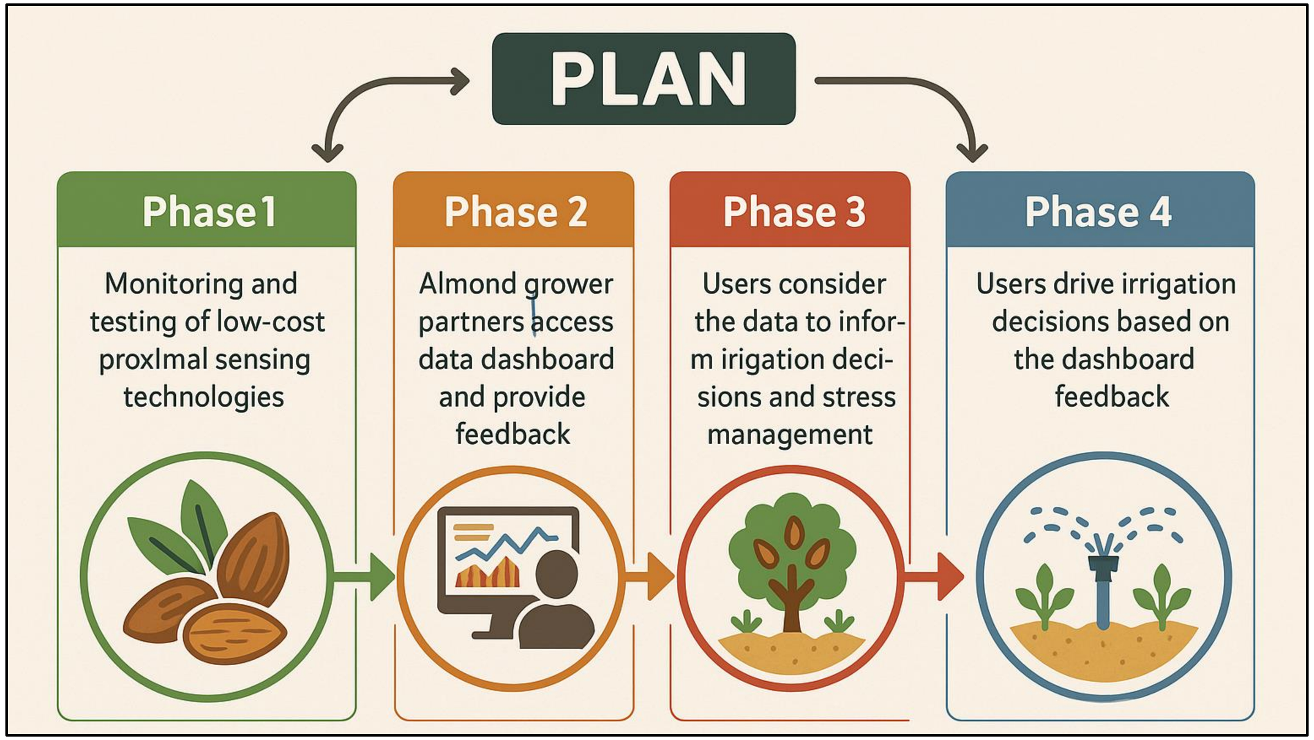
DELIVER

WET (Wavelet Evapotranspiration Tower) Network

- A tool to increase accuracy of near-real-time ET products for irrigation management



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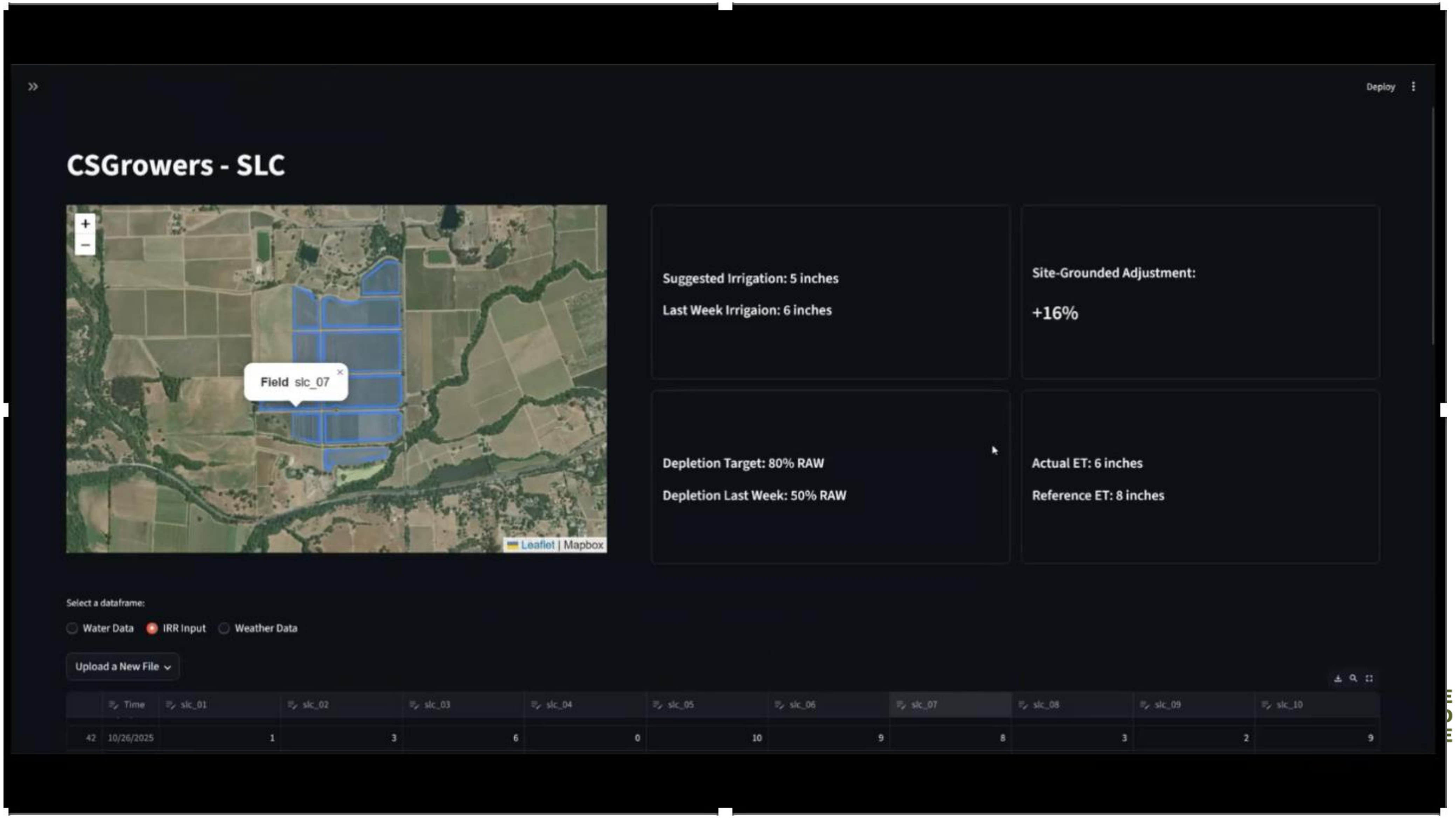
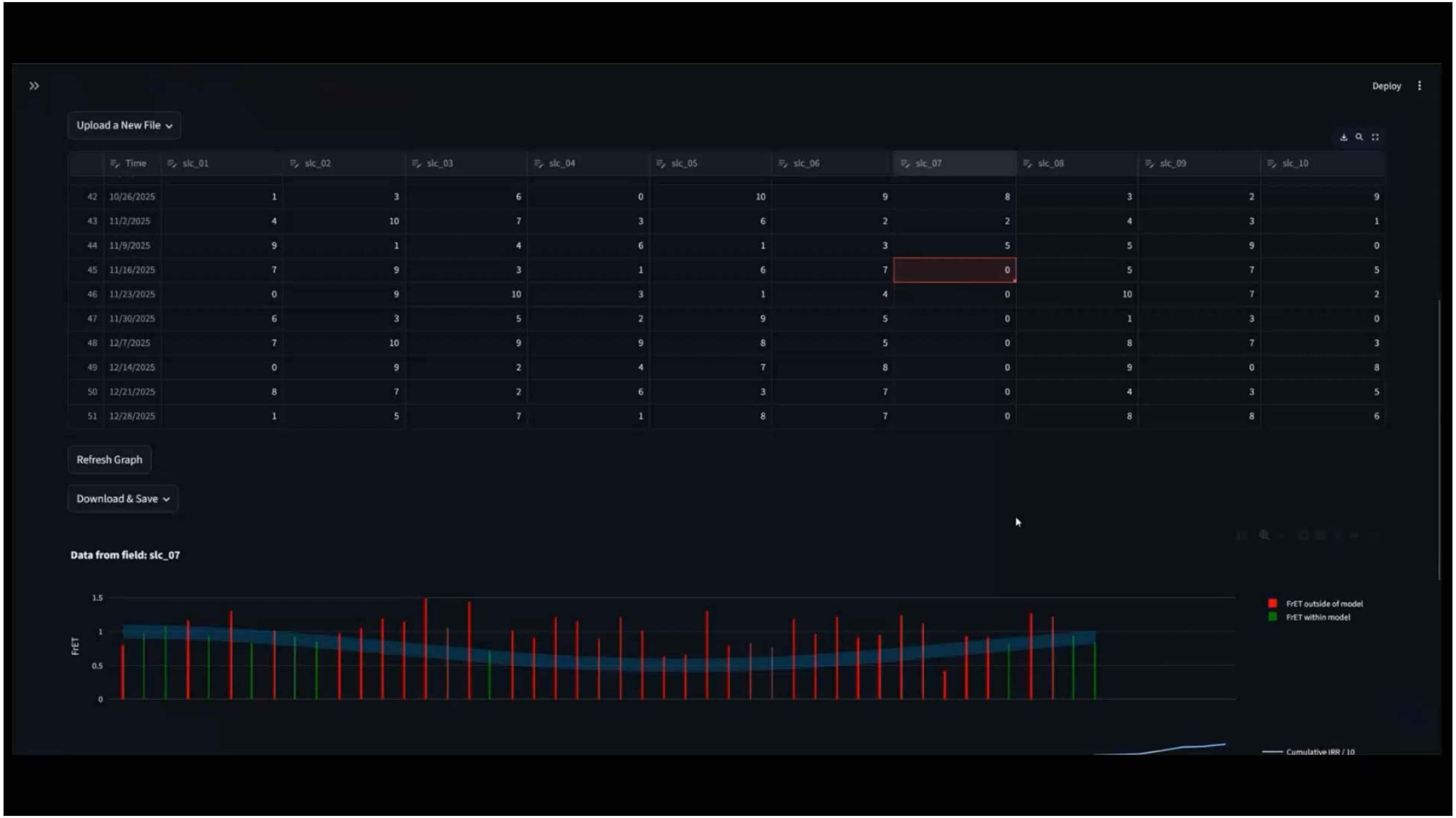
DELIVER


Deploy
CSGrowers - SLC
Field slc_07
Leaflet | Mapbox
Suggested Irrigation: 5 inches
Last Week Irrigaion: 6 inches
Site-Grounded Adjustment:
+16%
Depletion Target: 80% RAW
Depletion Last Week: 50% RAW
Actual ET: 6 inches
Reference ET: 8 inches
Select a dataframe:
Water Data
IRR Input
Weather Data
Upload a New File
Time slc_01 slc_02 slc_03 slc_04 slc_05 slc_06 slc_07 slc_08 slc_09 slc_10
42 10/26/2025 1 3 6 0 10 9 8 3 2 9

DELIVER



	Time	slc_01	slc_02	slc_03	slc_04	slc_05	slc_06	slc_07	slc_08	slc_09	slc_10
42	10/26/2025	1	3	6	0	10	9	8	3	2	9
43	11/2/2025	4	10	7	3	6	2	2	4	3	1
44	11/9/2025	9	1	4	6	1	3	5	5	9	0
45	11/16/2025	7	9	3	1	6	7	0	5	7	5
46	11/23/2025	0	9	10	3	1	4	0	10	7	2
47	11/30/2025	6	3	5	2	9	5	0	1	3	0
48	12/7/2025	7	10	9	9	8	5	0	8	7	3
49	12/14/2025	0	9	2	4	7	8	0	9	0	8
50	12/21/2025	8	7	2	6	3	7	0	4	3	5
51	12/28/2025	1	5	7	1	8	7	0	8	8	6

CROP SENSING GROUP

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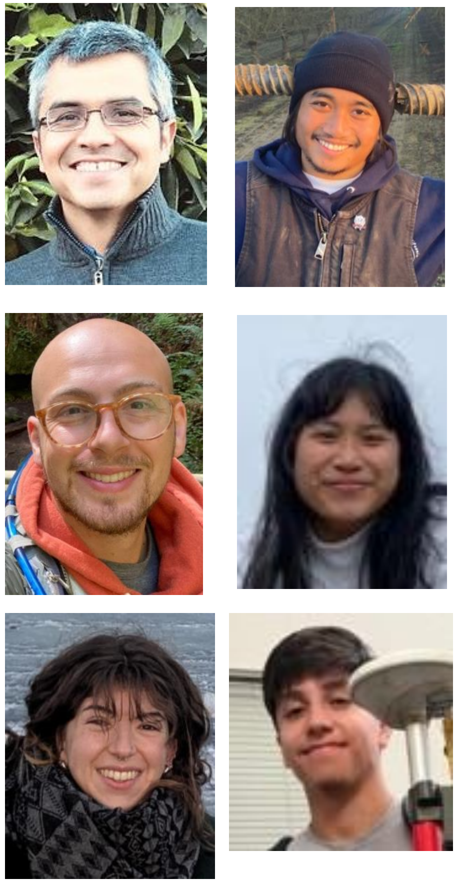
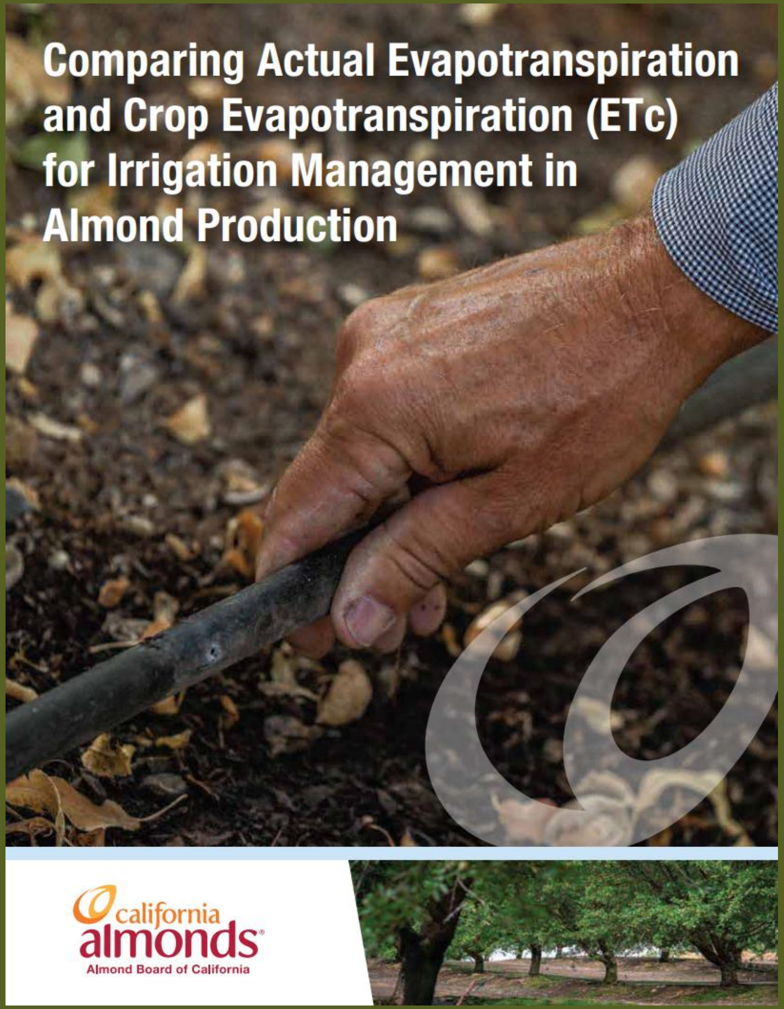


Data Science

NEW ABC RESOURCE FOR YOU



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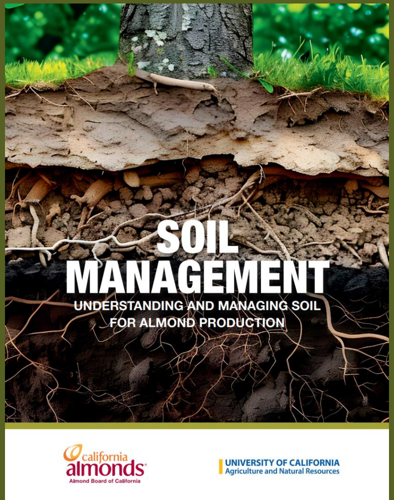
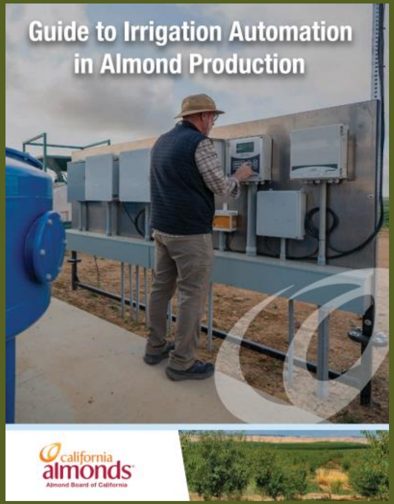
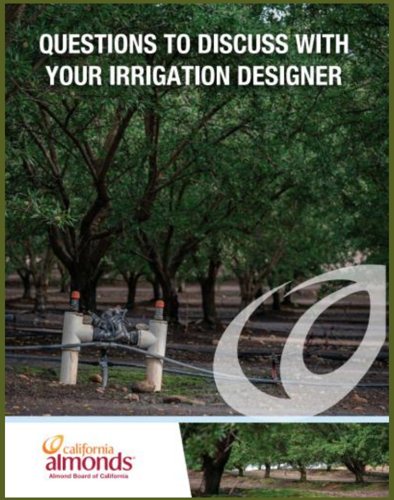
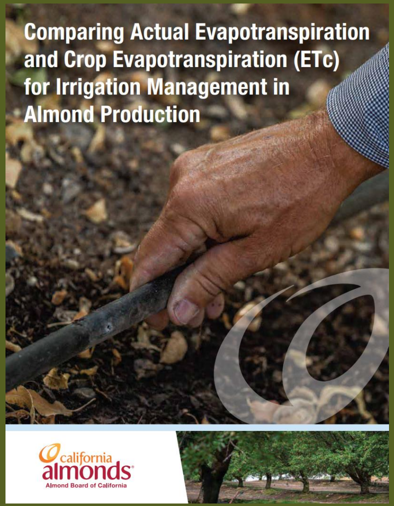
CULTIVATING A HEALTHIER FUTURE

NEW RESOURCES:Q&A:









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THANK YOU!

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