THEME 4 • VALUE CREATION

Creating Value through Agricultural Water Reuse

Lessons from Mediterranean and California systems

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Regional Workshop
"Sustainable Wastewater Operations:Lessons, Challenges, and the Roadmap"

Department of Water and Crop Production

CEBAS CENTRO DE EDAFOLOGÍA Y BIOLOGÍA APLICADA DEL SEGURA
CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

RESEARCH LINES

- Water-soil-plant-environment relationships.
- Deficit irrigation strategies.
- Efficient irrigation management through the use of sensors.
- **Use of non-conventional water for irrigation**.
- Ecophysiology of plants under environmental stresses.
- Nursery cultivation techniques.

The **Spanish National Research Council (CSIC)** is the largest public research organisation in Spain, the fourth largest in Europe and the seventh largest in the world.

CENTER FOR SOIL SCIENCE AND APPLIED BIOLOGY IN SEGURA (CEBAS)

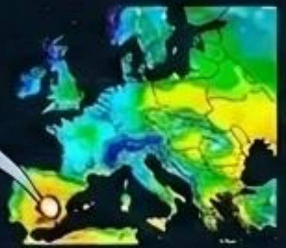
- Leading center within the CSIC in agri-food research.

Murcia: The Living Laboratory of Water Scarcity

A highly productive circular water model operating under severe structural deficit.

Metric 1: Climate

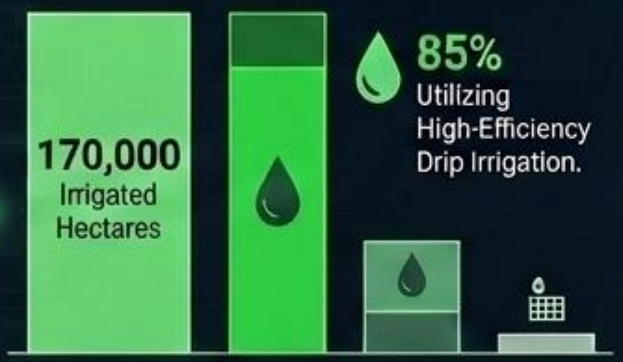
~300mm
annual rainfall.



Metric 2: Deficit

460 Hm³
structural water deficit.

Metric 3: Efficiency



170,000 irrigated hectares, with 85% utilizing high-efficiency drip irrigation.

Metric 4: Water Reuse & Non-Conventional Resalination

98% of reclaimed water is reused

15-20% of agricultural water resources are desalinated

Desalination: Significant Contribution

Torrevieja: 240,000 m³/d Águilas: 210,000 m³/d

High-quality water for agricultural integration.

THE QUESTION

What makes agricultural reuse succeed?

TREATMENT → WATER → VALUE

The project succeeds only when value reaches the field.

Farmer

Reliable supply • manageable quality • competitive cost

Utility

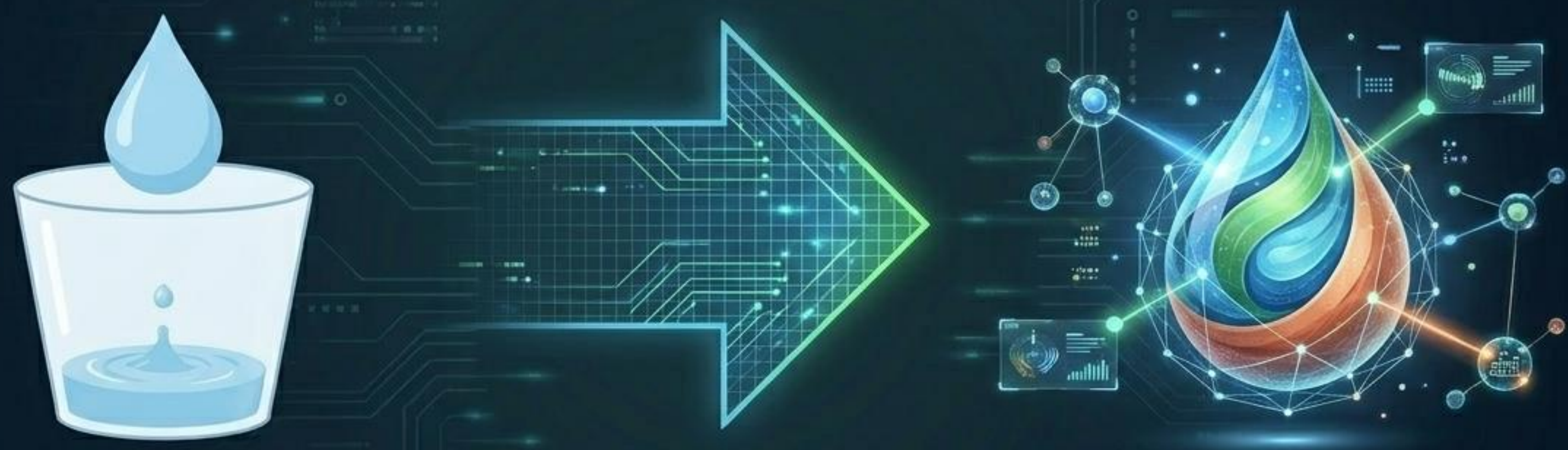
Predictable demand • resilient portfolio • viable infrastructure

Society

Aquifer relief • lower discharge • circular-economy benefits

The Paradigm Shift: We Must Stop Searching and Start Designing

The Old Paradigm | **The New Paradigm**



The Old Paradigm: Relying on the passive extraction of abundant, high-quality conventional freshwater.

The New Paradigm: The active agronomic integration of complex, non-conventional waters through smart combinations.

The future of irrigation is not about finding more water, but designing the right water for each crop, soil, and territory. Water quality is the new water quantity.

The Arsenal of Non-Conventional Waters

Reclaimed Water

Opportunity: Reliable volume; provides essential macronutrients.

Risk: Accumulation of salts, sodium, and emerging contaminants. Variable quality.

Desalinated Water

Opportunity: Exceptional reduction in total salinity (EC); acts as a dilution tool.

Risk: Severe mineral imbalances; high energy cost.

Brackish Groundwater & Drainage

Opportunity: Locally available; reduces pressure on deep freshwater aquifers.

Risk: Requires intensive management of crop toxicity thresholds and soil structure degradation.

OUR JOURNEY

Each experiment added one piece of the success equation

SAFE USE
1
Water + crop

LONG TERM
2
Soil + salinity

FIT FOR PURPOSE
3
Beyond SAR

MANAGE
4
Blend + monitor

LEGITIMACY
5
Evidence + trust

SCALE
6
California

Mediterranean experiments

California field study

Scientific trajectory summary

What 15+ Years of Reclaimed Water Research Taught Us

Key message: reclaimed water is not only an alternative water source; it is a managed agronomic input.

1. It works — but not everywhere

Field trials in citrus and woody crops showed that reclaimed water can sustain production under Mediterranean conditions.

2. Long-term monitoring changes the story

The main risk is not always immediate yield loss, but gradual accumulation of salts, Na, Cl and B in the soil–plant system.

Mediterranean lesson for California

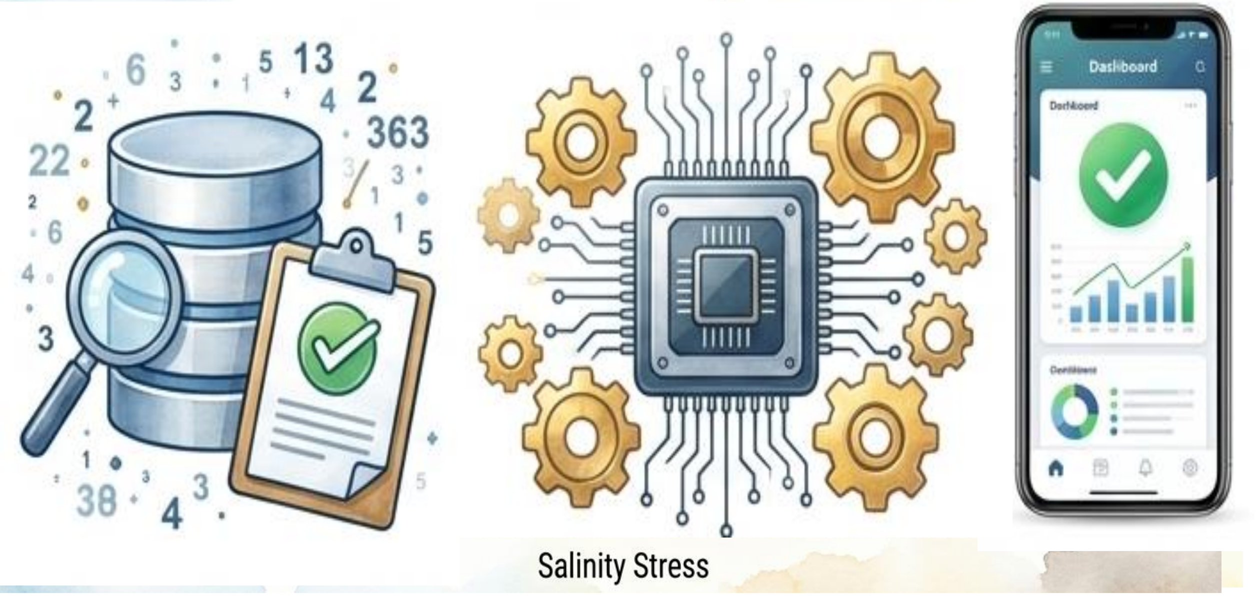
Short-term agronomic feasibility does not remove the need for long-term soil and plant monitoring.

3. Reclaimed water is also a nutrient source

Treated wastewater can contribute N, P and K, reduce fertilizer inputs (10 -15 - 100 %) can improve fruit quality parameters and support circular agriculture when quality is monitored.

4. Adoption needs tools, not only thresholds

Decision-support systems, blending, fertigation and sensors are essential to scale safe reuse on farms.



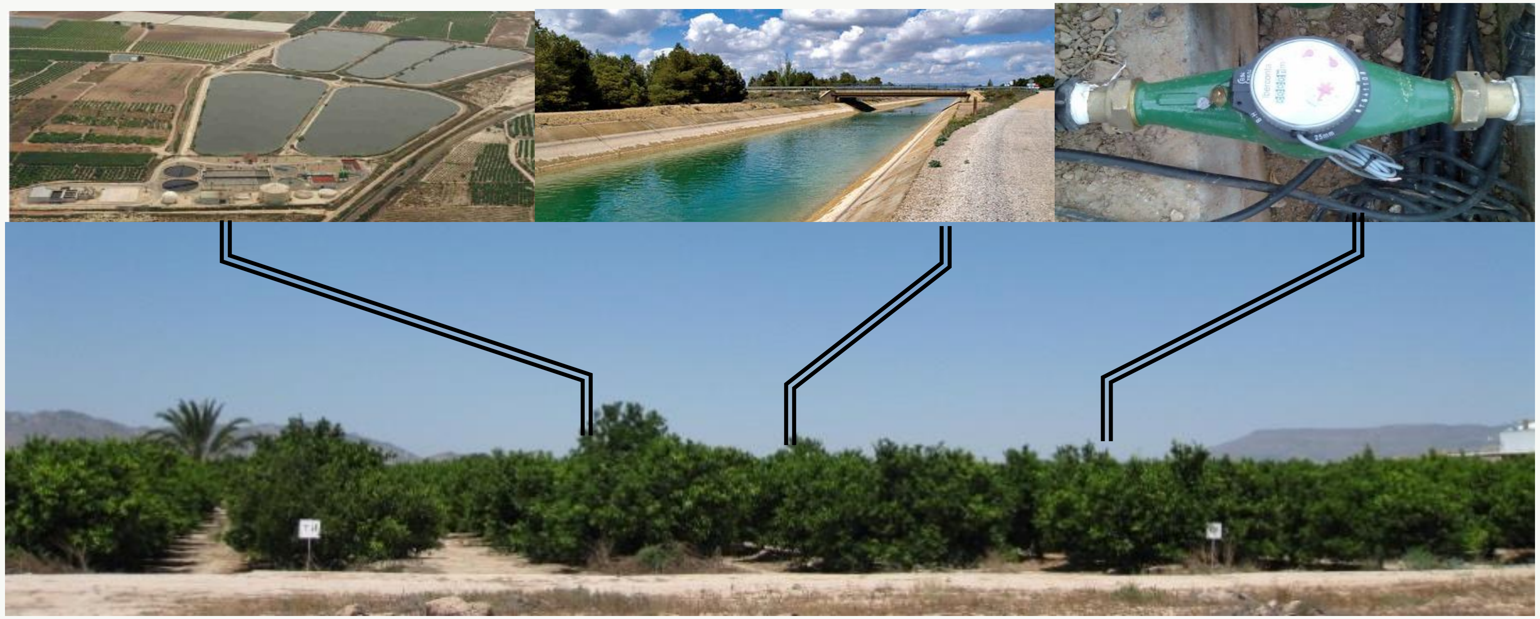
Key references: Pedrero et al. (2014, 2015, 2018, 2020, 2022); Nicolás et al. (2016); Romero-Trigueros et al. (2019); Vivaldi et al. (2021).

Safe water is necessary — but the crop closes the evidence chain

Compliance ≠ performance

The agronomic endpoint must be measured.

WATER → SOIL → CROP



First principle

Validate reclaimed water under the actual irrigation method, soil and crop.

Long-term irrigation changes the question

"Is the water acceptable?" → **"Can the system remain productive?"**

SALTS

root-zone accumulation

Na^+ / Ca^{2+} / Mg^{2+}

soil structural stability

B / Cl^-

crop-specific sensitivity

NUTRIENTS

fertilizer value + imbalance

Long-term success is a soil–water–crop balance, not a single water-quality threshold.

Beyond SAR: Multi-cation irrigation water composition affects soil structural stability and strawberry performance

Integrating soil physical and plant response under recycled water irrigation

1. IRRIGATION WATER COMPOSITION MATTERS

Synthetic recycled waters with constant salinity but contrasting cation composition

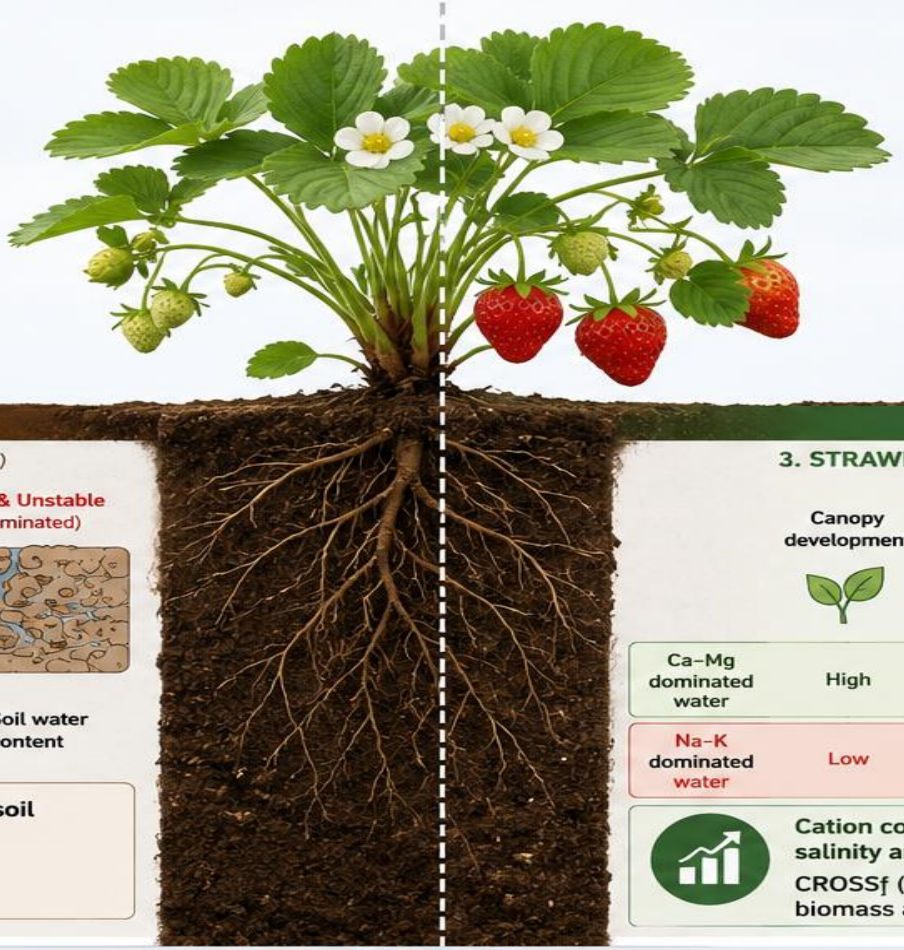
Na^+	K^+	Ca^{2+}	Mg^{2+}
SODIUM	POTASSIUM	CALCIUM	MAGNESIUM
Dispersive cation	Dispersive cation	Flocculating cation	Flocculating cation

Indices to assess sodicity and soil structural stability

SAR
Treditional index
Considers Na^+ only

vs.

CROSSf / CROSSopt
Multi-cation indices
Consider Na^+, K^+, Ca^{2+}, Mg^{2+} and their relative effects



SOIL RESPONSE

2. SOIL STRUCTURAL STABILITY *(Greenhouse Experiment)*

Flocculated & Stable (Ca–Mg dominated) → **Dispersed & Unstable** (Na–K dominated)

- ↓ Clay dispersion
- ↑ Standing water
- ↑ Reduced infiltration
- ↑ Soil water content

CROSSf showed stronger relationships with soil structural indicators than SAR.
Clay dispersion was the primary driver of soil physical degradation.

PLANT RESPONSE

3. STRAWBERRY GROWTH, YIELD & FRUIT QUALITY (Greenhouse Experiment)

	Canopy development	Biomass	Marketable yield	Fruit soluble solids (°Brix)	Tissue ion accumulation
Ca–Mg dominated water	High	High	High	Moderate	Balanced Na/K/Ca/Mg
Na–K dominated water	Low	Low	Low	High	High Na & K, Low Ca & Mg

Cation composition affected strawberry performance beyond total salinity and beyond SAR.
CROSSf (and CROSSopt) explained more variability in canopy cover, biomass and yield than SAR.

KEY MESSAGE

In recycled water irrigation, considering the full cation composition is essential. CROSS-based indices improve the prediction of soil structural risks and crop performance compared with SAR alone.

Implications

- Better risk assessment
- Improved crop management
- Sustainable use of recycled water

Aldughaishi et al. (2024). *Beyond SAR: evaluating CROSS for predicting soil structural stability under recycled water irrigation. Irrigation Science.*

Aldughaishi et al. (2025). *Multi-cation irrigation water composition affects strawberry growth, yield and fruit quality beyond SAR-based sodicity assessment.*

LESSON 3

Beyond SAR: ionic balance predicts soil response better

SAR → CROSS

Na

Na + K | Ca + Mg

$R^2 \approx 0.97$

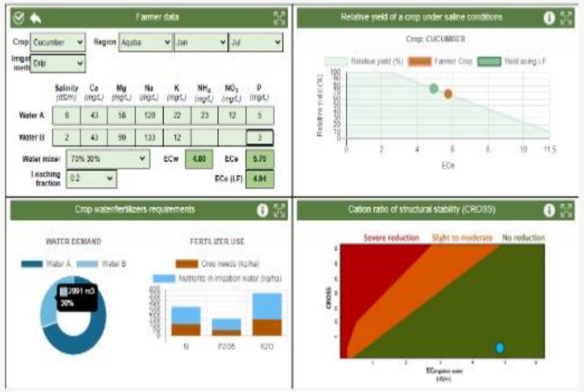
clay dispersion response
in our greenhouse study

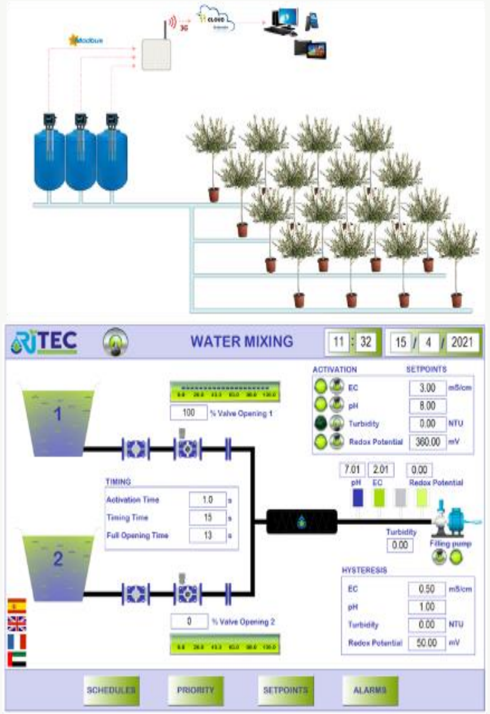
KEY RESULT

CROSS captured multi-cation effects that SAR can miss — improving the diagnosis of structural risk under non-conventional waters.

LESSON 4

Variability can be managed — if we close the loop





1 → 2 → 3 → 4

MEASURE
EC • ions • nutrients

MIX
quality target

IRRIGATE
crop requirement

LEARN
soil + plant response

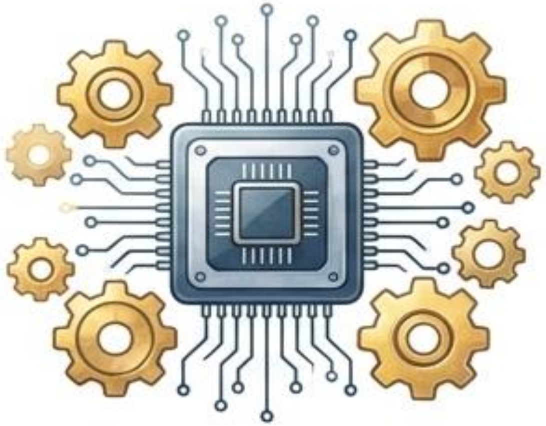
Management converts water variability into a controllable operating condition.

Digital Translation: From Complex Chemistry to Farmer Action

Input
(The Complexity)

Raw data including water analysis (high nitrogen/phosphorus from reclaimed water), localized climate data, and crop phenology.

The Engine
(QUANTUM & PROSIM DSS)



Web-based platforms running scientific algorithms. They calculate optimal blending fractions, evaluate infiltration/sodicity risks, and model crop tolerance.

Translation

Output
(Farmer Action)

Real-time, actionable blending recommendations delivered to a smartphone.

The Result: A proven 20-40% reduction in the use of chemical fertilizers by optimizing the nutrient-rich properties of reclaimed water.

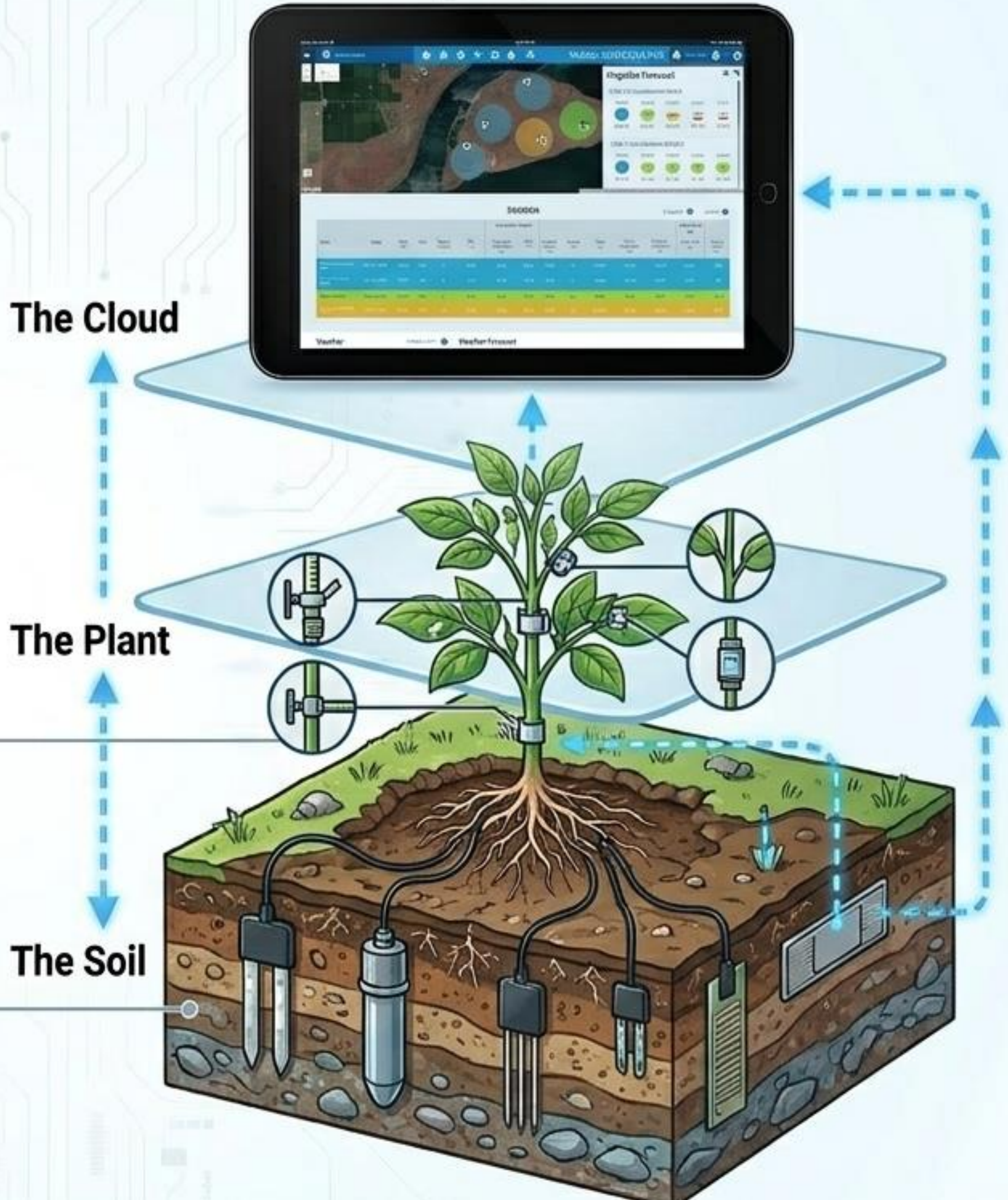
Bridging the Gap: Digital Tools & Precision Irrigation

The Challenge: Non-conventional waters introduce dynamic, real-time risks to the soil-plant system.

The Solution: Moving from static traditional irrigation ($ET_c = ET_o \times K_c$) to dynamic, data-driven **Decision Support Systems (DSS)**.

Plant Indicators: Continuous, automated monitoring via stem/leaf water potential, stomatal conductance, and sap flow to detect stress before yield drops.

Soil Indicators: TDR, capacitance sensors, and matric potential monitoring to manage salt accumulation.



FARMWISE: Closing the Loop in Mediterranean Agriculture

A circular framework integrating non-conventional water, AI-driven management, and Zero Liquid Discharge technologies for water-scarce regions.

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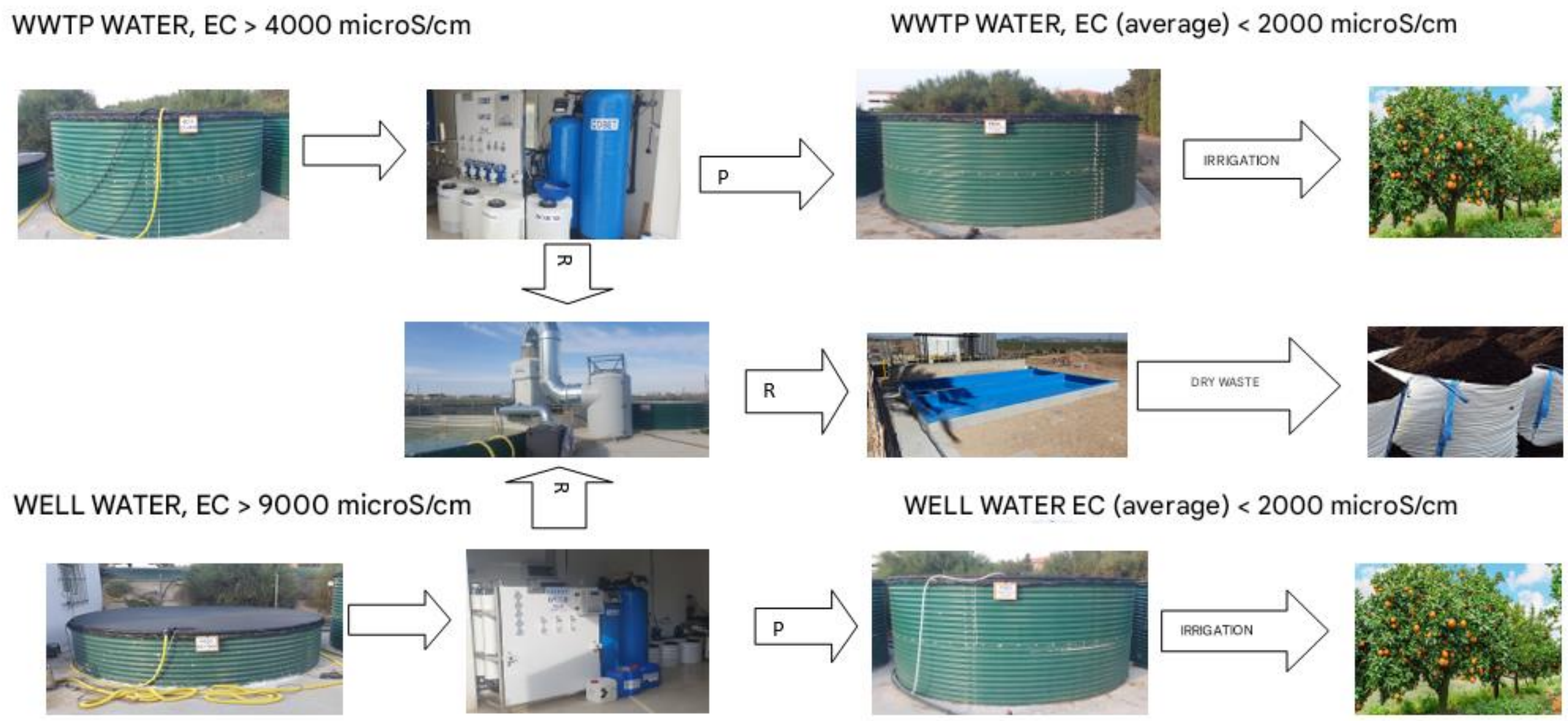

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CIRCULAR RESOURCE RECOVERY

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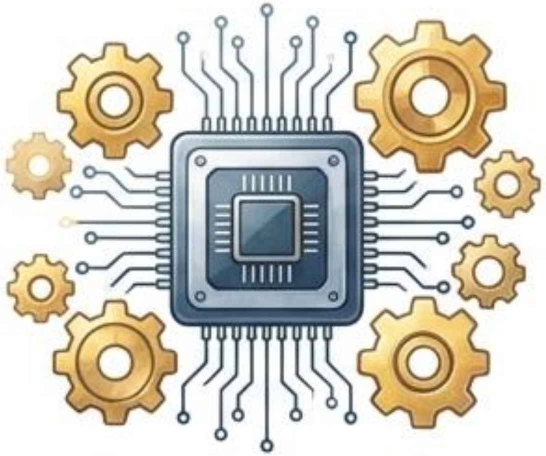

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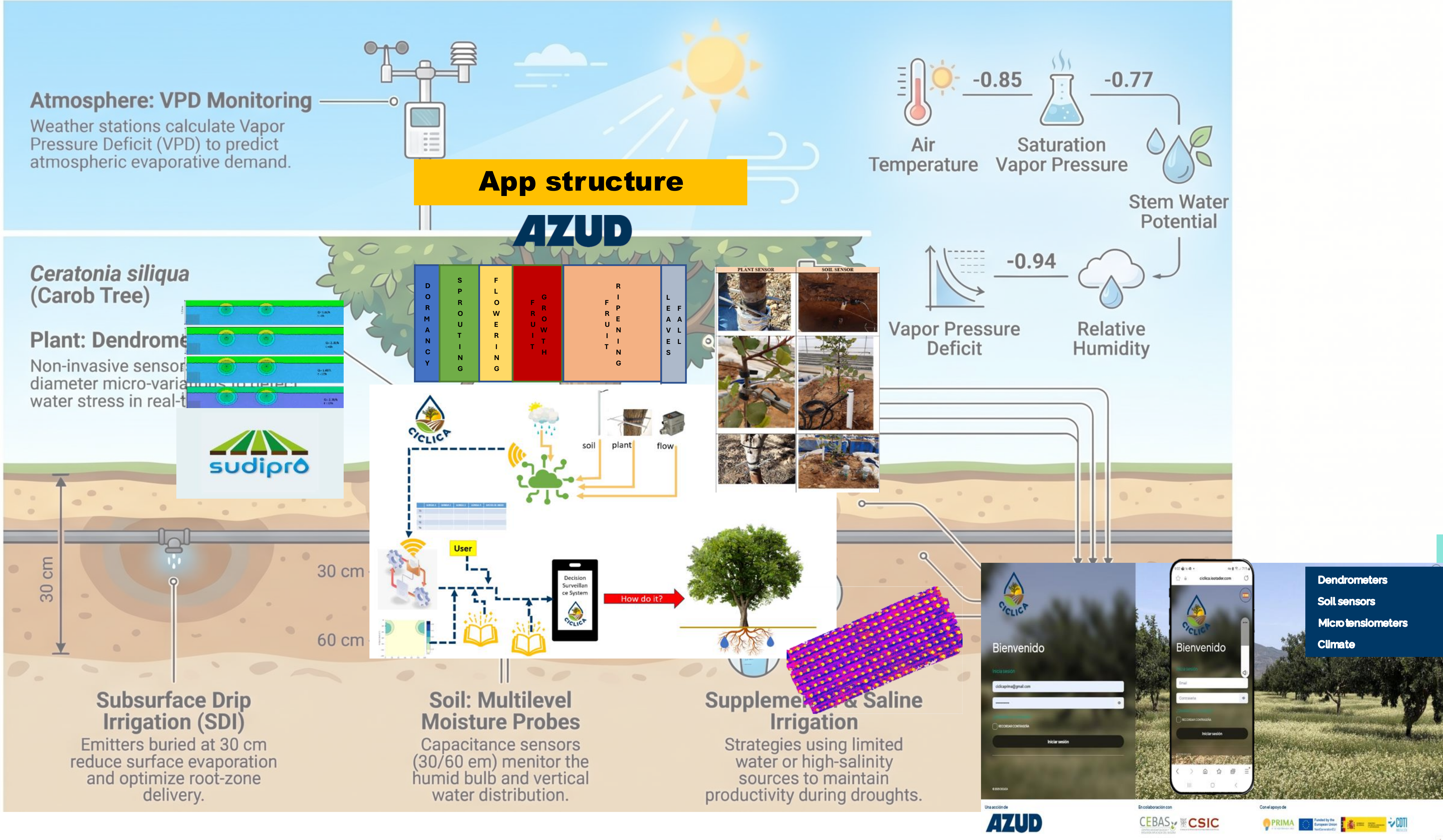
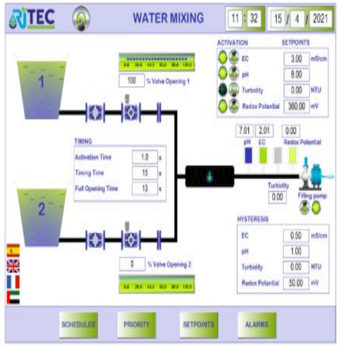
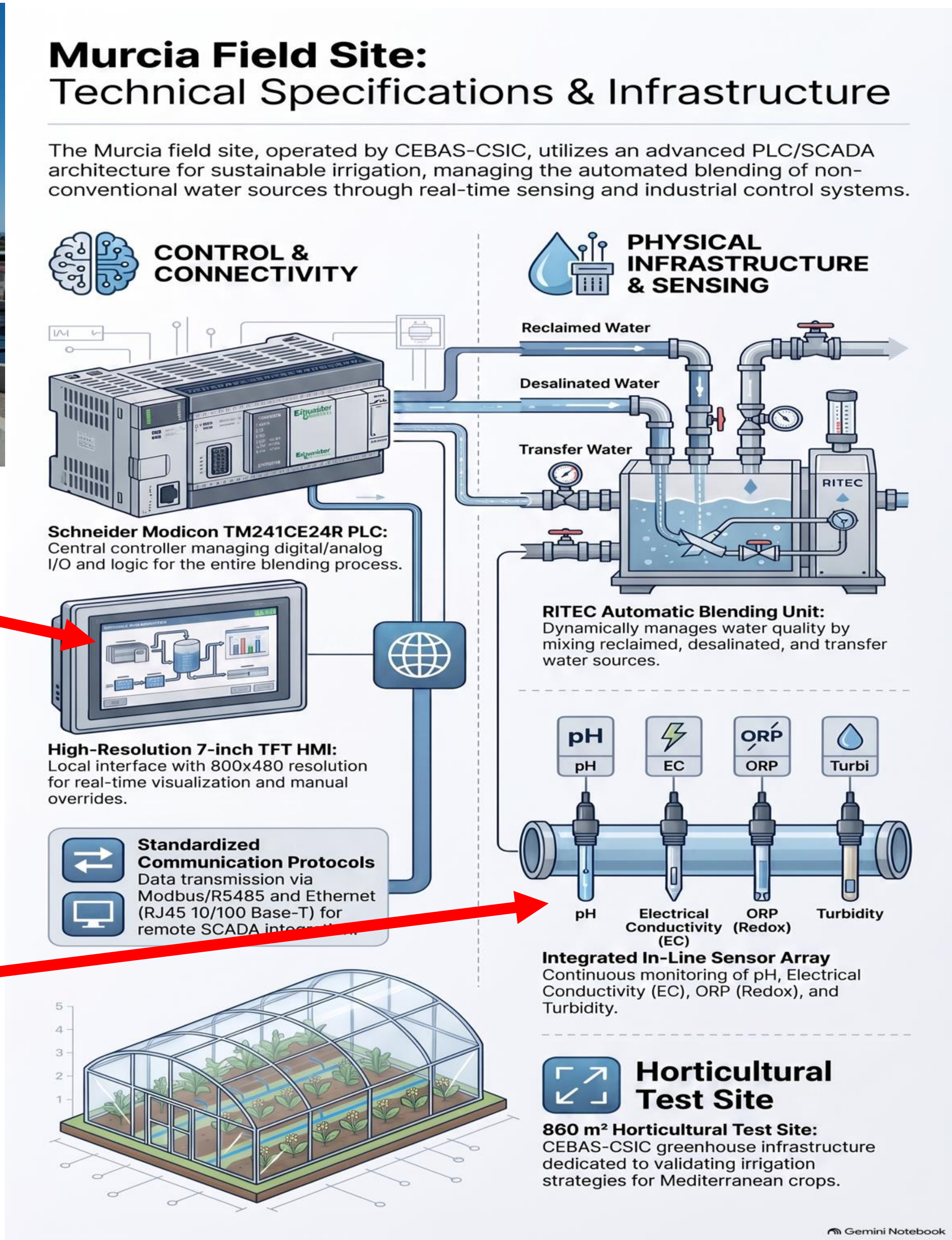
CICLICA: Precision Agriculture for Sustainable Carob Cultivation



QUALIMIX-N: from water blending to soil-aware fertigation





Six conditions repeatedly determine success

1 **SCARCITY**
A real driver

2 **FIT**
Water–soil–crop

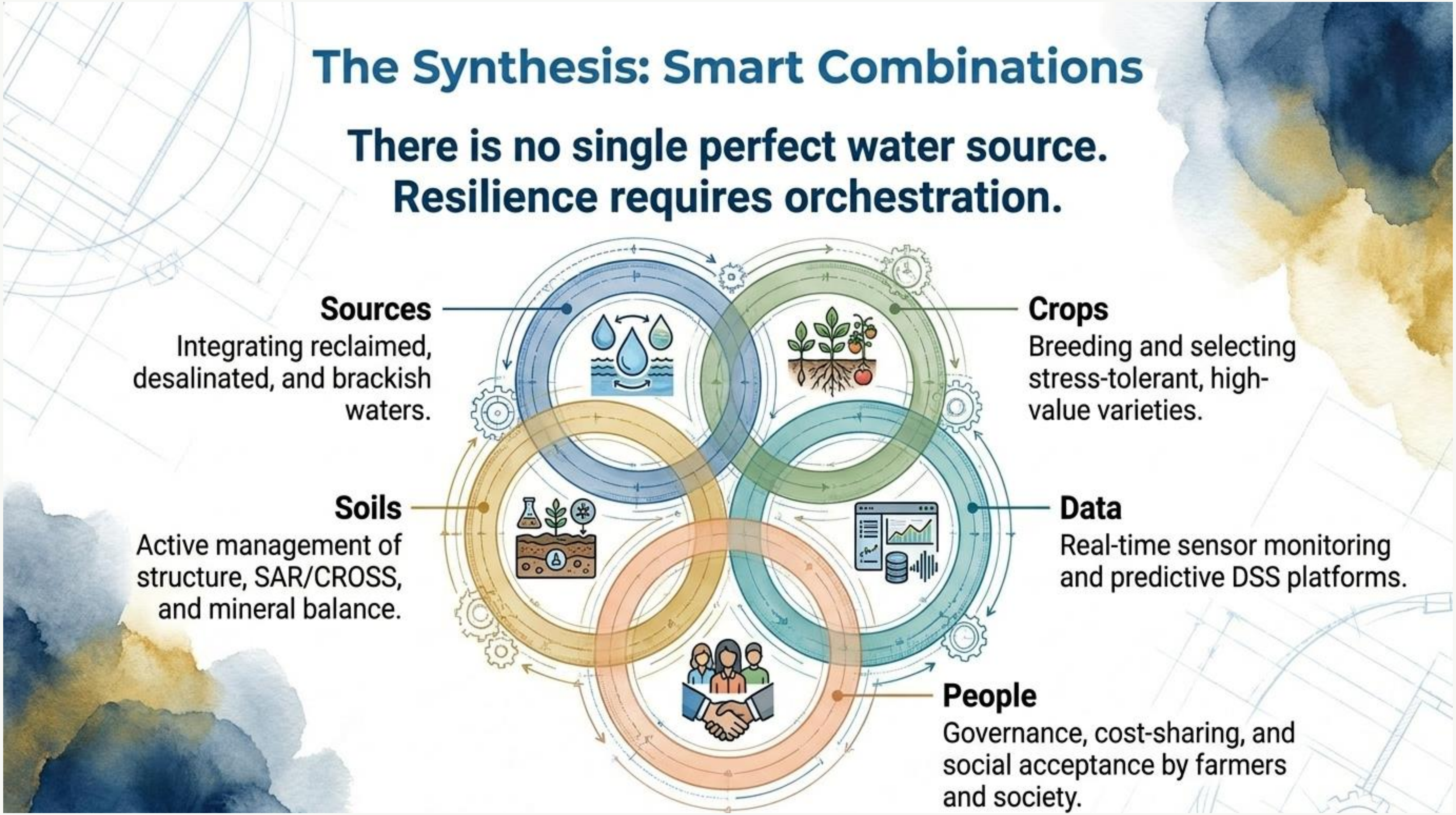
3 **MIX**
Flexible sources

4 **MONITOR**
Evidence over time

5 **FARMERS**
Co-design + trust

6 **ECONOMICS**
Competitive value

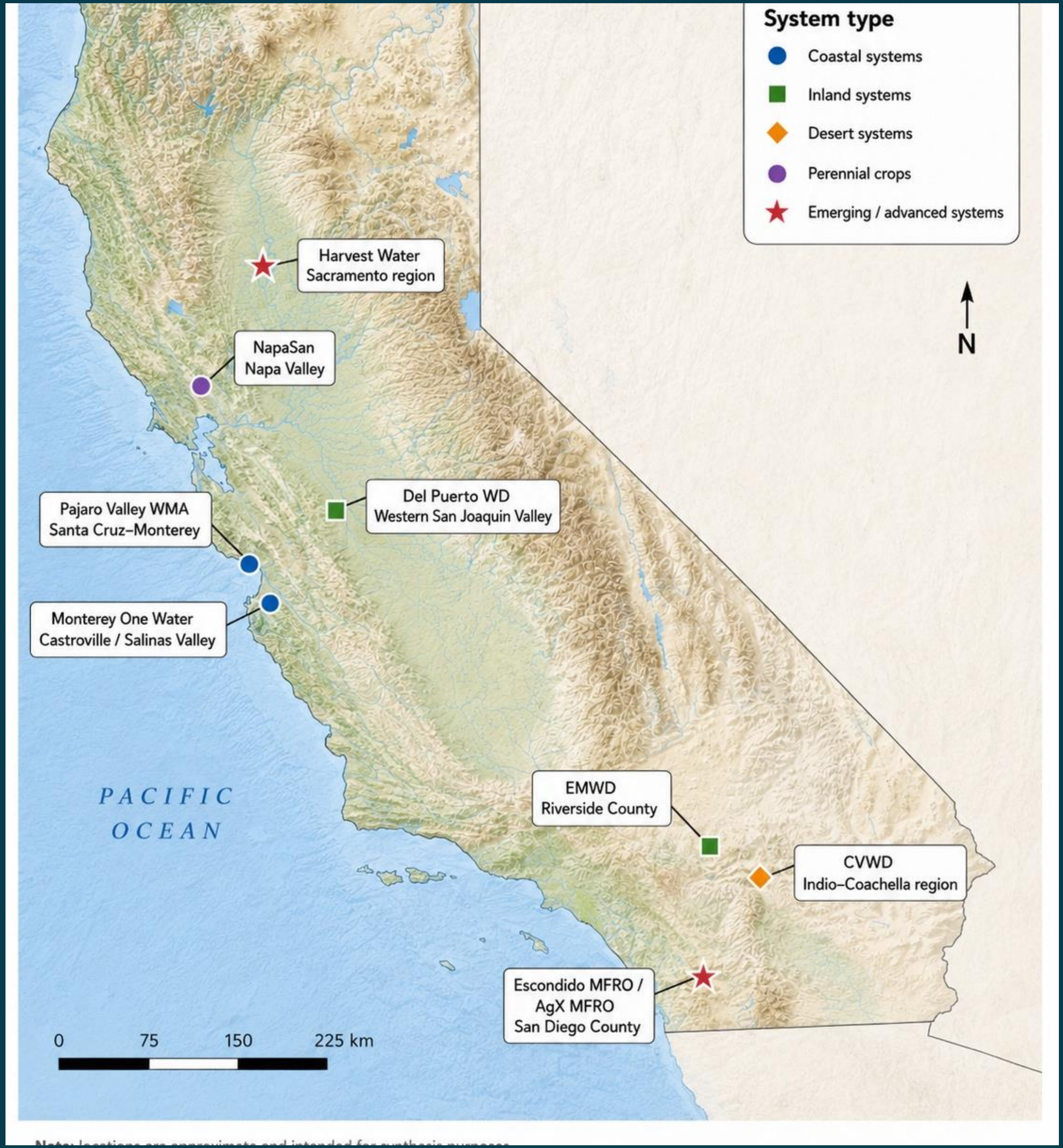
Technology is only one piece of the system


The Synthesis: Smart Combinations
There is no single perfect water source.
Resilience requires orchestration.
Sources
Integrating reclaimed, desalinated, and brackish waters.
Crops
Breeding and selecting stress-tolerant, high-value varieties.
Soils
Active management of structure, SAR/CROSS, and mineral balance.
Data
Real-time sensor monitoring and predictive DSS platforms.
People
Governance, cost-sharing, and social acceptance by farmers and society.

THEN I WENT TO CALIFORNIA…

A pioneer.
A paradox.

If the science and technology are mature,
why is agricultural reuse not expanding faster?



Large reuse portfolio — agricultural expansion remains selective

≈ 895 hm^3/yr

total recycled water reported statewide (2024)

≈ 214 hm^3/yr

agricultural irrigation (2024)

The key question is not “Can California recycle water?”

It is:

WHERE DOES AGRICULTURAL REUSE CREATE ENOUGH VALUE TO SCALE?

Source: California State Water Resources Control Board, 2024 VAR. Values converted to SI.

Four cases — four different value propositions

MONTEREY	**Food-safety confidence**	Science + institutions
NAPA / CARNEROS	**Reliability for vineyards**	Blending + dedicated conveyance
EASTERN MWD	**Cost + local supply**	Portfolio management
HARVEST WATER	**Multi-benefit design**	Agriculture + aquifer + ecosystem

Same resource. Different reason to invest.

Reliability itself has economic value

2/3 recycled water + **1/3** surface water

BLEND

≈ 14.5 km pipeline

Long-term grower experience

VALUE = **RELIABILITY**

What the grower taught us

Compare reclaimed water with the quality, cost and reliability of the alternatives actually available.

Constraint

Infrastructure financing can limit expansion even when additional agricultural demand exists.

Field interview evidence; approximate values converted to SI.

Technology is mature. Alignment is not.

- Treatment capacity ✓
- Regulation ✓
- Water scarcity ✓
- Agricultural demand ✓

- Distance / conveyance
- Seasonal mismatch
- Competing reuse pathways
- Farmer-facing evidence
- Financing
- Source control / salinity

The bottleneck has shifted from producing water to aligning place, demand, quality, economics and trust

Different institutions — the same success conditions

	MEDITERRANEAN SPAIN	CALIFORNIA
DRIVER	Structural scarcity	Scarcity + regulation + reliability
WATER STRATEGY	Managed water mix	Project-specific portfolios
AGRONOMY	Routine adaptation	Needs stronger role in new projects
FARMERS	Irrigation communities	More fragmented participation
OPPORTUNITY	Optimize every m^3	Map where reuse creates most value

Transfer the principles — not the institutional template

Pilot first — then scale with evidence

1 **SCREEN** Find the opportunity → 2 **CO-DESIGN** Farmer + utility → 3 **PILOT** Representative field → 4 **MONITOR** Water • soil • plant → 5 **ADAPT** Blend • irrigate → 6 **SCALE** Finance + contracts

Field evidence reduces technical risk — and also financing, regulatory and adoption risk

Harvest Water: up to ≈61.7 hm^3/yr design delivery; first full operational reporting anticipated later this decade.

ADD VALUE

Agricultural reuse succeeds when value reaches the field.

DESIGN FOR OUTCOMES

Fit-for-purpose water + reliable supply

PROVE PERFORMANCE

Pilots + monitoring + adaptive management

BUILD WITH USERS

Farmers participate before infrastructure is locked

The challenge is no longer producing reclaimed water It is putting the right water in the right place, for the right crop, under the right management.


Thanks for your attention
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