RESEARCH ARTICLE

Central Valley decision support tool helps predict yield and profitability response to irrigation with saline water

The effect of irrigation water salinity on yield and profits depends on soil texture and crop type.

by Floyid Nicolas, Mae Culumber, Hossein Shahrokhnia, Usama Al-Dughaishi, Jongwon Do, Sharon Benes and Isaya Kisekka

Online: https://doi.org/10.3733/001c.147883

The Central Valley has faced escalating challenges in managing salinity and sustaining agricultural productivity amid increasing groundwater reliance, recurring droughts, and declining water quality (Faunt et al. 2016; Quinn and Oster 2021). In response to these long-standing and systemic issues, California enacted the Sustainable Groundwater Management Act (SGMA) in 2014 (California Department of Water Resources 2024). SGMA implementation requires groundwater sustainability agencies (GSAs) to achieve sustainable groundwater management by 2040, which may necessitate significant reductions in agricultural water use and strategic land repurposing decisions (Quandt et al. 2023). Recycled or brackish irrigation water has been proposed to offset scarcity (Kisekka et al. 2024). However, these alternative water sources contain elevated dissolved salts that can accumulate in the root zone, potentially impacting crop yield and leading to environmental degradation if not properly managed (Nicolas et al. 2023).

Abstract

This study introduces a novel decision support web tool (doi.org/10.15140/D3J04K) to assist farmers and policymakers in managing salinity in California's Central Valley. The tool integrates agronomic, economic and spatial data to predict crop yield and profitability under varying irrigation water salinity. This resource also supports policymakers and groundwater sustainability agencies in identifying areas where saline groundwater prevents profitable farming and prioritizing those areas for land repurposing to reduce agricultural water demand. We evaluated the tool by predicting yield and profitability for alfalfa, almonds, pistachios, table grapes, and processing tomatoes under varying salinity at field and regional scales. Alfalfa maintained high yields and profitability across varying salinity levels, while table grapes showed strong economic resilience; however, almonds were most sensitive to water quality degradation. The spatial analysis indicated regional variation, with western Central Valley regions showing lower yields and profitability due to high groundwater salinity. This tool highlights the role decision support technologies can play in advancing sustainable irrigation under water quality constraints.

An almond orchard in the San Joaquin Valley. Irrigation water quality determines what can be farmed profitably in the Central Valley. *Photo:* Mae Culumber.

More than 6 million tons of salt are deposited annually in the San Joaquin Valley, worsening long-term soil and water degradation issues (CV-SALTS 2023; Quinn 2020). Welle and Mauter (2017) estimated that salinity-related yield losses resulted in an annual economic loss of approximately $3.7 billion in California's agricultural sector. Best management practices are essential to address these biophysical system concerns while maintaining economic sustainability, which highlights the need for comprehensive modeling frameworks that integrate agronomic, economic and spatial considerations (Nicolas et al. 2023).

While salinity was the dominant constraint on crop performance, spatial variability in soil texture and hydraulic properties . . . also influenced yield and profitability patterns across the valley.

Models have been developed to predict relative crop yield for various crops, soil types, and irrigation water salinities (Eldeiry et al. 2004; Skaggs et al. 2014). The primary objective of agricultural production is not merely to sustain yields, but to maximize overall profitability. Shani et al. (2007) developed the Analytical Salt-Water (ANSWER) model, which integrates biophysical parameters with economic information to predict crop yield under various irrigation water salinity levels. Kaner et al. (2019) implemented this biophysical model into a user-friendly decision support web tool, enabling users to predict crop yield and profitability by considering irrigation water salinity and costs. Nicolas et al. (2023) improved the analytical model for major crops grown in the Central Valley and developed a spatial screening component to predict crop yield and profitability across the region. This improved model included comprehensive validation against observed yield data, which enabled the model to accurately predict crop responses to irrigation water salinity stress under Central Valley conditions. The validated model provides the foundation for translating complex soil-water-plant interactions into practical decision support tools.

The objective of this study was to develop a user-friendly, spatially explicit web-based decision support tool using the validated ANSWER model. The tool is designed to (1) assist growers in estimating crop yield and profitability as functions of water salinity and quantity, and (2) support policymakers and GSAs in identifying areas unsuitable for sustainable and profitable agriculture, thereby guiding multi-benefit land repurposing efforts aimed at reducing agricultural water demand.

The ANSWER model framework

The decision support web tool we developed, the Yield-Salinity Model, is built upon the ANSWER model, which was improved and adapted for the Central Valley conditions by Nicolas et al. (2023). The one-dimensional model simulates the soil-plant-atmosphere continuum under the following four assumptions: (1) the root zone's environmental conditions can be described by two main parameters: soil water content and soil salinity; (2) these conditions are considered to be in a steady state, removing the dimension of time; (3) the climate conditions are assumed to be constant; and (4) a proportional relationship between relative transpiration and relative yield exists as shown in Equation (1):

$$Y_r = \frac{Y}{Y_p} = \frac{T}{T_p} = T_r \tag{1}$$

where Y is yield (ton acre^{-1}), T is transpiration (inches [in] day^{-1}), and subscripts r and p denote relative and potential values, respectively. Crop transpiration (in day^{-1}) is given in Equation (2):

$$T = \frac{min\left\{T_p, \left[\left(\psi_{root - \frac{\psi_w}{\left(\frac{(I-T)}{K_s}\right)^{1/\eta}}}\right)(I-T) * b\right]\right\}}{1 + \left(\frac{EC_{iw} * I * \left(\theta_r + (\theta_s - \theta_r)\left(\frac{(I-T)}{K_s}\right)^{1/\delta}\right)}{EC_{e50} * (I-T)\theta_s}\right)^p} \tag{2}$$

The parameters of Equation (2) include I, irrigation (in day^{-1}); EC_{iw}, irrigation water electrical conductivity (decisiemens [dS] m^{-1}); K_S, saturated hydraulic conductivity (in day^{-1}); ϑ_S, saturated soil moisture content; ϑ_r, residual soil moisture content; ψ_{root}, crop sensitivity to available soil moisture (in); ψ_w, air-entry head (in); δ and η, empirical soil characteristic parameters; EC_{e50}, saturated soil paste solution electrical conductivity (EC), reducing yield by 50% (dS m^{-1}); p, which governs the curve's steepness; and b, which characterizes the flow length from the soil to the crop roots.

The model integrates management factors (I and EC_{iw}), which represent user-controlled irrigation inputs; physical properties (T_p, K_s, δ, ϑ_r and ϑ_s), which characterize soil hydraulic and moisture characteristics; and biophysical processes (EC_{e50} and ψ_{root}), which capture crop-specific responses to salinity and water stress. Shani et al. (2007; 2009) and Nicolas et al. (2023) provide a more detailed model description.

Economic framework

The decision support tool integrates an economic module that estimates crop profitability by combining predicted yield (ton acre^{-1}) with user-defined economic parameters. The economic variables are crop price (US$ ton^{-1}), fixed costs (US$ acre^{-1}), and water prices (US$ acre-foot^{-1}), sometimes referred to as water rates. The economic module assumes (1) non-water costs are fixed within each crop type (including yield-dependent costs such as harvesting and processing, which are averaged based on expected yields) and (2) only water costs vary with management decisions. These simplifications reduce data requirements while preserving the dominant sensitivity of profit to salinity-induced yield loss and water price. Nicolas et al. (2023) validated both yield and profits against observed data, achieving R^2 greater than 0.9 and relatively low root mean square errors (RMSE). Equations 3, 4 and 5 were used to compute the profits, revenue and total costs, respectively.

$$\text{Profits (US\$ acre}^{-1}\text{)} = \text{Revenue (US\$ acre}^{-1}\text{)} - \text{Costs (US\$ acre}^{-1}\text{)} \quad (3)$$

$$\text{Revenue (US\$ acre}^{-1}\text{)} = \text{AdjY}_r * \text{MY (ton acre}^{-1}\text{)} * \text{Crop price (US\$ ton}^{-1}\text{)} \quad (4)$$

where AdjY$_r$ is the adjusted relative yield (unitless) and MY is the maximum yield (t^{-1} acre).

$$\text{Cost (US\$ acre}^{-1}\text{)} = \text{Fixed costs (US\$ acre}^{-1}\text{)} + [\text{water price (US\$ acre}^{-1}\text{)} * \text{Irrigation depth (acre-ft acre}^{-1}\text{)}] \quad (5)$$

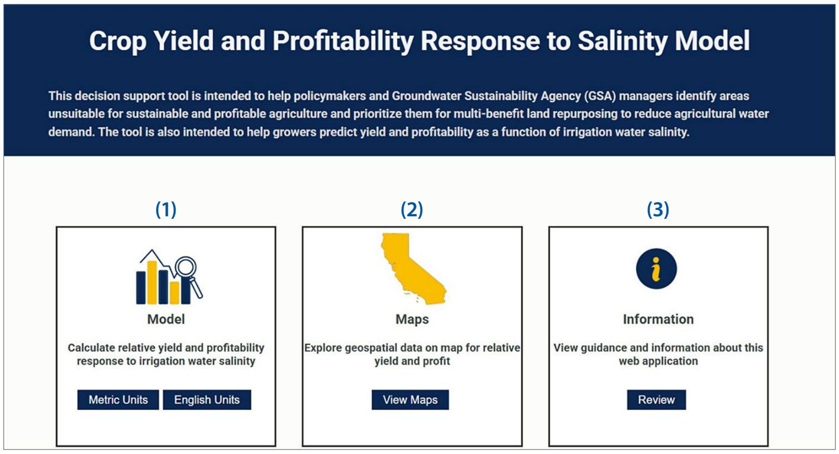
Spatial screening component

The spatial component was developed using three geospatial data layers to drive cell-level yield and profit predictions across the Central Valley at a 98-feet-by-98-feet resolution. First, soil parameters were derived from POLARIS (Probabilistic Remapping of Soil Survey Geographic Database [SSURGO]), a 98-foot probabilistic digital soil mapping product that provides depth-resolved estimates (0.2–6.5 ft) of texture, bulk density, organic carbon, and hydraulic properties (Chaney et al. 2019). Second, cropland-use data (California Natural Resources Agency n.d.) were used to assign crop types to each grid cell. Third, the regional groundwater electrical conductivity (EC) raster supplied baseline salinity conditions (California Department of Water Resources n.d.). For other EC levels, no raster was used; instead, EC$_{iw}$ of 0.5 to 5.5 dS m^{-1} were applied uniformly. For each grid node, the ANSWER model processes the POLARIS soil profile and groundwater EC, along with user-specified irrigation depths, crop market prices, and water prices, to generate spatially explicit predictions of relative yield and profit that capture soil heterogeneity across the Central Valley.

Tool architecture and interface

The tool architecture has three main sections (fig. 1), each designed to serve different user needs and applications. Section 1 computes yield and profitability in both English and metric units. Users can select from five crops (alfalfa, almonds, table grapes, processing tomatoes, and pistachios), five soil types (sand, clay, loamy sand, sandy loam, and silt loam), and specify EC$_{iw}$ (dS m^{-1}) and irrigation application rates (in day^{-1}). The interface computes relative yield using the core model equations and calculates profits by incorporating user-specified economic parameters, including water prices, field size, season length, maximum yield, price per ton, and fixed production costs (fig. 2). Both yield and profit can be plotted as functions of irrigation amount and EC$_{iw}$ levels (fig. 3).

Section 2 enables geospatial exploration of crop performance across the entire Central Valley. Users can select from six EC$_{iw}$ levels (0.5 to 5.5 dS m^{-1}), current



Crop Yield and Profitability Response to Salinity Model

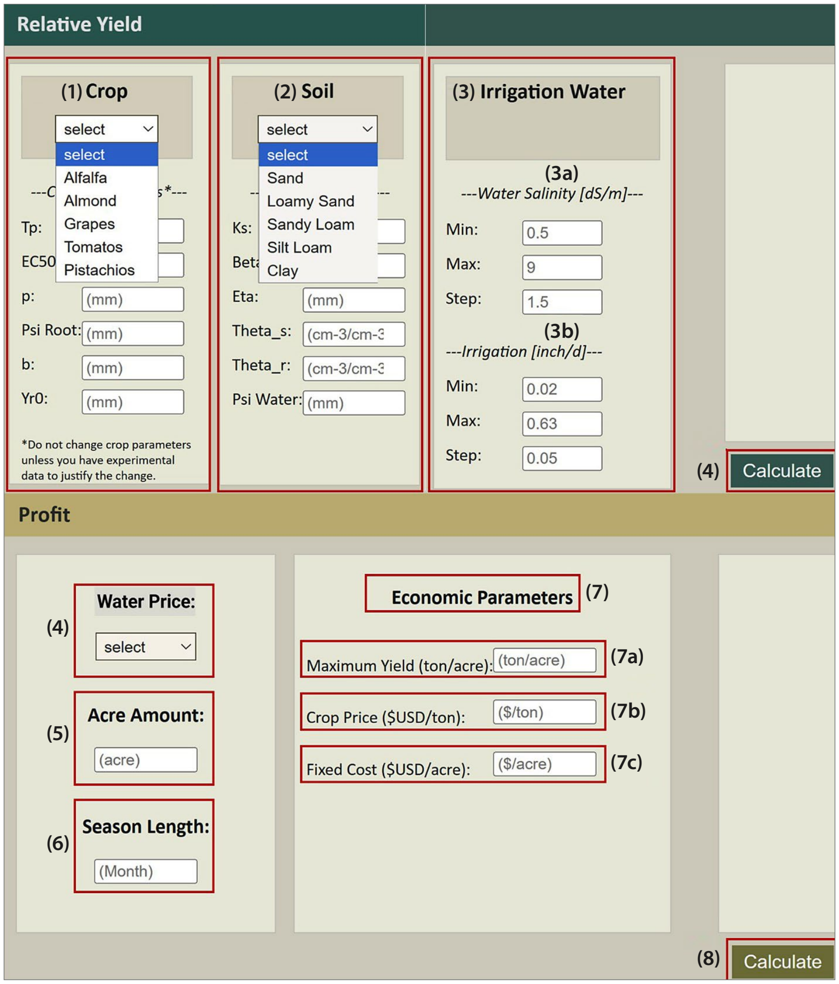
This decision support tool is intended to help policymakers and Groundwater Sustainability Agency (GSA) managers identify areas unsuitable for sustainable and profitable agriculture and prioritize them for multi-benefit land repurposing to reduce agricultural water demand. The tool is also intended to help growers predict yield and profitability as a function of irrigation water salinity.

(1) Model: Calculate relative yield and profitability response to irrigation water salinity

(2) Maps: Explore geospatial data on map for relative yield and profit

(3) Information: View guidance and information about this web application

FIG. 1. The web interface of the tool. Clicking on these squares takes the user to (1) the yield and profit calculator, which lets users calculate crop yield and profitability response to irrigation water salinity; (2) the maps viewer, which displays geospatial data showing crop yield and profit variations related to salinity across regions; and (3) the background information and guidance section, which provides details for using the salinity response decision tool.



Relative Yield

(1) Crop: select

Tp: / EC50 / p: (mm) / Psi Root: (mm) / b: (mm) / Yr0: (mm)

*Do not change crop parameters unless you have experimental data to justify the change.

(2) Soil: select

Ks: / Beta / Eta: (mm) / Theta_s: (cm-3/cm-3 / Theta_r: (cm-3/cm-3 / Psi Water: (mm)

(3) Irrigation Water

(3a) ---Water Salinity [dS/m]---

Min: 0.5

Max: 9

Step: 1.5

(3b) ---Irrigation [inch/d]---

Min: 0.02

Max: 0.63

Step: 0.05

Profit

(4) Water Price: select

(5) Acre Amount: (acre)

(6) Season Length: (Month)

Economic Parameters (7)

Maximum Yield (ton/acre): (ton/acre) (7a)

Crop Price ($USD/ton): ($/ton) (7b)

Fixed Cost ($USD/acre): ($/acre) (7c)

FIG. 2. Decision support tool inputs. Panels (1)–(3) gather agronomic inputs: crop type (1), soil texture (2), and irrigation water settings (3) with EC$_{iw}$ levels (3a) and irrigation depths (3b). The calculate button (4) generates relative yield. The Profit section includes water price (4), cultivated area (5), season length (6), and three economic parameters — maximum yield (7a), crop price (7b), and fixed cost (7c) — to compute profit (8).

Crop: Almond

Soil: Sand

---Crop Parameters*---
Tp: 7
EC50: 4.13
p: 3
Psi Root: -8000
b: 10
Yr0: 0

*Do not change crop parameters unless you have experimental data to justify the change.

---Soil Parameters---
Ks: 17000
Beta: 1.3
Eta: 4.5
Theta_s: 0.33
Theta_r: 0.03
Psi Water: -80

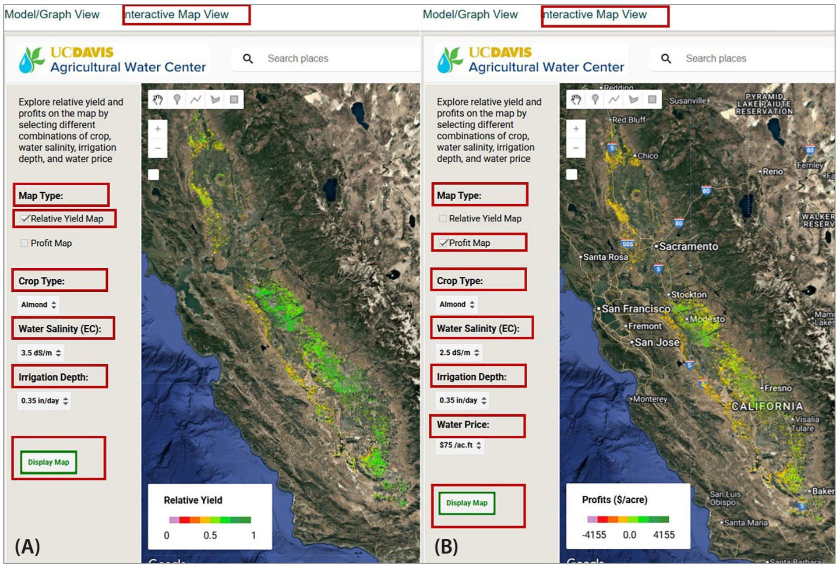
---Water Salinity [dS/m]---
Min: 0.5
Max: 9
Step: 1.5

---Irrigation [inch/d]---
Min: 0.02
Max: 0.63
Step: 0.05

Water Price: $100/ac.ft
Acre Amount: 100
Season Length: 8

Economic Parameters
Maximum Yield (ton/acre): 1.5
Revenue ($ per ton): 4500
Fixed Cost ($ per acre): 4875

FIG. 3. Web tool yield and profits calculation interface (example scenario). The upper panel collects agronomic inputs to calculate and plot relative yield for each EC_{iw} level. The lower panel uses economic inputs to compute and plot profits with irrigation amount and EC_{iw} levels.



(A)

Explore relative yield and profits on the map by selecting different combinations of crop, water salinity, irrigation depth, and water price

Map Type:
☑ Relative Yield Map
☐ Profit Map
Crop Type: Almond
Water Salinity (EC): 3.5 dS/m
Irrigation Depth: 0.35 in/day

(B)

Map Type:
☐ Relative Yield Map
☑ Profit Map
Crop Type: Almond
Water Salinity (EC): 2.5 dS/m
Irrigation Depth: 0.35 in/day
Water Price: $75 /ac.ft

FIG. 4. Interactive map view of the decision support tool. (A) Relative yield and (B) profit maps for almond under a seasonal irrigation depth of 0.35 in day^{-1}. Users can specify the map type, crop, ECiw level, and irrigation depths to display yield. Users can then select water price to display profit (US\$ $acre^{-1}$). Empty places correspond to areas with no crops or crops that have not yet been added to the tool.

groundwater EC conditions, and four irrigation depths (0.12, 0.24, 0.35 and 0.47 in day^{-1}) to visualize spatial distributions of relative yield. Profit maps can be generated for three water prices (US\$75, US\$150 and US\$350 per acre-foot). Individual pixel values can be accessed by clicking on specific locations within the interactive map (fig. 4).

Finally, section 3 provides comprehensive documentation, including research articles and data sources, that offer additional information about the model used to develop the tool.

Tool evaluation

We tested the decision support tool for four crops (alfalfa, almonds, table grapes, and processing tomatos) within loamy sand, eight EC_{iw} levels (0.5, 2, 3.5, 5, 6.5, 8, 9.5 and 11 dS m^{-1}), and daily irrigation range (from 0.01 to 0.35 in day^{-1}). We considered a planted area of 100 acres and crop-specific yields of 9 ton $acre^{-1}$ (alfalfa), 1.5 ton $acre^{-1}$ (almonds), 9.5 ton $acre^{-1}$ (table grapes), and 53 ton $acre^{-1}$ (processing tomatos). We used a 5-year average historical crop price (US\$ ton^{-1}) (USDA NASS 2024) and fixed costs (US\$ $acre^{-1}$) of production derived from University of California Cooperative Extension cost studies for alfalfa (Wilson et al. 2020), almonds (Niederholzer et al. 2024), table grapes (Fidelibus et al. 2018), and processing tomatoes (Aegerter et al. 2023). The crop yield and profits for the entire Central Valley were calculated using a salinity of 3.5 dS m^{-1} and a water depth of 0.35 in day^{-1}.

Yield response to irrigation water salinity

Relative yield rose with irrigation depth and declined with higher EC for all crops (fig. 5). Alfalfa maintained 95% potential yield at low EC (0.5 dS m^{-1}) and 85% even at high EC (11 dS m^{-1}). Table grapes and processing tomatos were moderately sensitive. Under low salinity, they plateaued near 90% of potential yield at 0.25 in day^{-1}, but their peak dropped to 60%–65% when salinity rose to 11 dS m^{-1}, despite irrigation depths above 0.30 in day^{-1}. Almonds were the most sensitive, with its relative yield reaching 80% at a moderate salinity of 3.5 dS m^{-1} and falling below 40% at 11 dS m^{-1}, even when irrigation approached 0.32 in day^{-1}. Thus, on loamy sand, alfalfa retained near-optimal yield across the salinity range, almonds dropped sharply, and grapes and tomatoes showed intermediate penalties. Alfalfa, table grapes, and processing tomatoes showed relatively similar optimal irrigation rates (0.18–0.24 in day^{-1}) at an EC_{iw} of 0.5, which may reflect the model's optimization of soil water balance under steady-state conditions rather than crop-specific physiological differences.

Profit response to irrigation water salinity

For every crop, the profit curve rose from an initial loss at 0.01 in day^{-1}, attained a distinct maximum, and then flattened or declined slightly as water applications increased further; the entire set of curves was translated downward as salinity increased (fig. 6). Peak profits per acre were US\$900 at 0.25 in day^{-1} for alfalfa, US\$1,800 at 0.27 in day^{-1} for almonds, US\$3,500 at 0.27 in day^{-1} for table grapes, and US\$550 at 0.25 in day^{-1} for processing tomatoes. Break-even salinities (defined as the lowest EC class at which profit remained negative across the full irrigation range) were not reached for alfalfa but occurred at 6 dS m^{-1} for almonds and at 9.5 dS m^{-1} for both grapes and tomatoes.

Spatial yield and profit prediction

Relative yield maps generated with a uniform irrigation depth of 0.35 in day^{-1} and cell-specific groundwater EC revealed clear differences in crop tolerance as well as strong spatial control by the underlying salinity pattern (fig. 7). Using groundwater EC, alfalfa (fig. 7A) maintained over 0.85 Y_r throughout most of the Central Valley, with only isolated pockets of moderate loss (< 0.70) where groundwater salinity exceeded 6 dS m^{-1}. In contrast, almonds (fig. 7B) displayed pronounced yield decrease (< 0.60) in the west side of the San Joaquin Valley, where shallow groundwater typically ranges from 2 to over 10 dS m^{-1}, whereas yield in the eastern upland with fresher groundwater remained above 0.75.

Table grapes (fig. 7C) followed an intermediate pattern: extensive tracts in the northern valley and Delta attained 0.70–0.85 Y_r, but fields underlain by saline groundwater corridors along the west side dropped below 0.60. Processing tomatoes (fig. 7D) maintained high productivity in the Sacramento Valley and Delta, yet exhibited significant declines (< 0.65 Y_r) across the southern San Joaquin, mirroring the distribution of elevated groundwater EC. These maps underscore the dominant influence of spatial groundwater salinity on yield potential and highlight alfalfa's relative resilience, the moderate sensitivity of grapes and tomatoes, and the pronounced vulnerability of almonds under prevailing hydro-salinity conditions.

Profitability calculated with cell-specific groundwater salinity displayed strong regional contrasts for the four evaluated crops (fig. 8). Alfalfa remained modestly profitable (US\$800 acre^{-1}) across most of the Sacramento Valley and northern San Joaquin Valley, but returns quickly turned negative in saline areas along the west side (fig. 8A). Almonds showed the widest range with profits up to US\$4,500 acre^{-1} in the eastern side of the valley, yet large areas on the western side incurred losses exceeding US\$4,000 acre^{-1} as salinity reduced yield while high production costs persisted (fig. 8B). Table grapes achieved the highest profits, surpassing US\$7,000 acre^{-1} wherever groundwater EC was below 1 dS m^{-1}; only isolated pockets with elevated EC fell below break-even (fig. 8C). Processing tomatoes retained positive margins (US\$2,200 acre^{-1}) in the Delta and northern interior basins but posted substantial deficits (> US\$1,000 acre^{-1}) in poorly drained, high-salinity tracts of the southern San Joaquin (fig. 8D).

Collectively, these maps indicate that under the specified water price and depth, table grapes offers the most robust economic performance, alfalfa and tomatoes are profitable only where salinity is moderate, and almonds are highly sensitive to groundwater EC, exhibiting large swings from strong gain to severe loss depending on location.

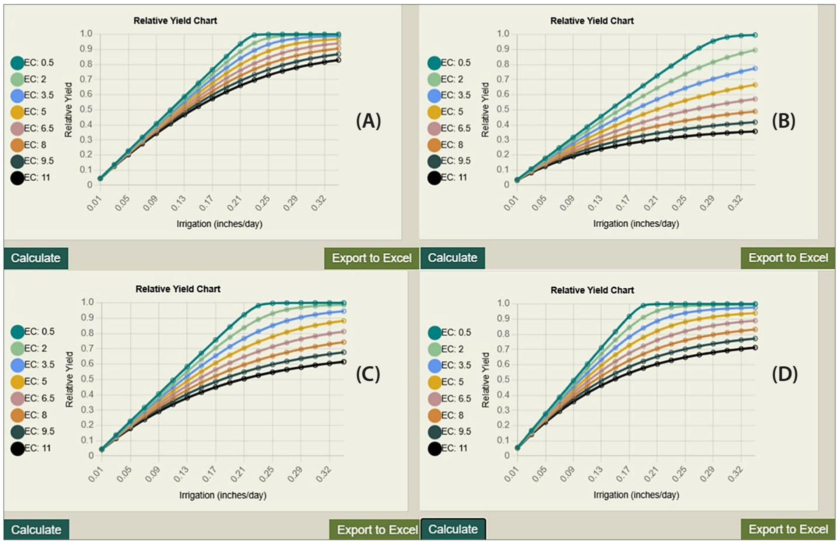


FIG. 5. Yield response to daily irrigation depth and irrigation water salinity for four crops grown on loamy-sand soil for (A) alfalfa, (B) almonds, (C) table grapes, and (D) processing tomatoes. Each curve represents a water-salinity class from 0.5 dS m^{-1} to 11 dS m^{-1}.

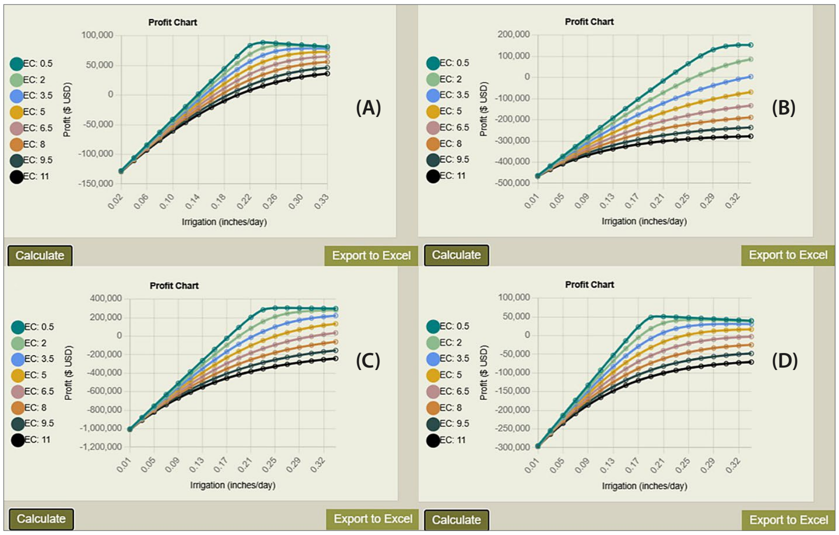
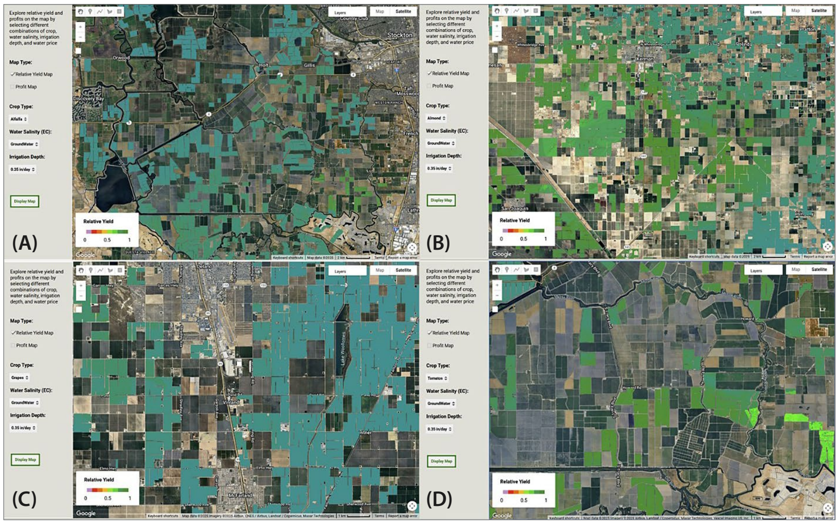


FIG. 6. Profit (US\$) versus daily irrigation depth for four crops on loamy-sand soil. Curves show eight irrigation water salinity classes (0.5–11 dS m^{-1}) for (A) alfalfa, (B) almonds, (C) table grapes, and (C) processing tomatoes.

Crop yield and profit response

The Yield-Salinity Model successfully translates the validated ANSWER model into practical technology for agricultural and water management applications. The tool's dual interface design serves distinct user communities: point-specific analysis for farmers and consultants, and spatial mapping for policymakers and GSA managers addressing SGMA implementation challenges. The results confirm the long-recognized hierarchy of crop salt tolerance (alfalfa > table grapes ≈ processing tomatoes > almonds) and show how these physiological differences translate into economic outcomes.



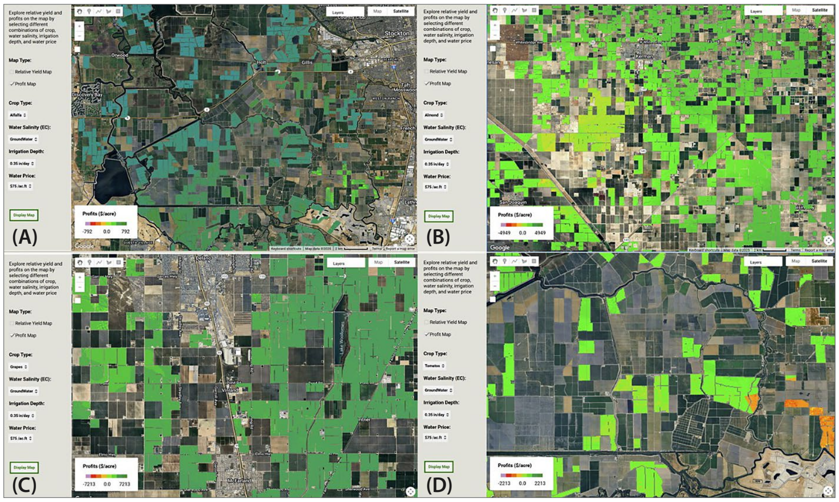
(A)
Explore relative yield and profits on the map by selecting different combinations of crop, water salinity, irrigation depth, and water price
Map Type:
✓ Relative Yield Map
☐ Profit Map
Crop Type: Alfalfa
Water Salinity (EC): GroundWater
Irrigation Depth: 0.35 in/day
Display Map

(B)
Explore relative yield and profits on the map by selecting different combinations of crop, water salinity, irrigation depth, and water price
Map Type:
✓ Relative Yield Map
☐ Profit Map
Crop Type: Almond
Water Salinity (EC): GroundWater
Irrigation Depth: 0.35 in/day
Display Map

(C)
Explore relative yield and profits on the map by selecting different combinations of crop, water salinity, irrigation depth, and water price
Map Type:
✓ Relative Yield Map
☐ Profit Map
Crop Type: Grapes
Water Salinity (EC): GroundWater
Irrigation Depth: 0.35 in/day
Display Map

(D)
Explore relative yield and profits on the map by selecting different combinations of crop, water salinity, irrigation depth, and water price
Map Type:
✓ Relative Yield Map
☐ Profit Map
Crop Type: Tomatoes
Water Salinity (EC): GroundWater
Irrigation Depth: 0.35 in/day
Display Map

FIG. 7. Spatial distribution of relative yield for (A) alfalfa, (B) almonds, (C) table grapes, and (D) processing tomatoes irrigated at 0.35 in day^{-1} with cell-specific groundwater salinity (dS m^{-1}).



(A)
Explore relative yield and profits on the map by selecting different combinations of crop, water salinity, irrigation depth, and water price
Map Type:
☐ Relative Yield Map
✓ Profit Map
Crop Type: Alfalfa
Water Salinity (EC): GroundWater
Irrigation Depth: 0.35 in/day
Water Price: $75 /ac.ft
Display Map

(B)
Explore relative yield and profits on the map by selecting different combinations of crop, water salinity, irrigation depth, and water price
Map Type:
☐ Relative Yield Map
✓ Profit Map
Crop Type: Almond
Water Salinity (EC): GroundWater
Irrigation Depth: 0.35 in/day
Water Price: $75 /ac.ft
Display Map

(C)
Explore relative yield and profits on the map by selecting different combinations of crop, water salinity, irrigation depth, and water price
Map Type:
☐ Relative Yield Map
✓ Profit Map
Crop Type: Grapes
Water Salinity (EC): GroundWater
Irrigation Depth: 0.35 in/day
Water Price: $75 /ac.ft
Display Map

(D)
Explore relative yield and profits on the map by selecting different combinations of crop, water salinity, irrigation depth, and water price
Map Type:
☐ Relative Yield Map
✓ Profit Map
Crop Type: Tomatos
Water Salinity (EC): GroundWater
Irrigation Depth: 0.35 in/day
Water Price: $75 /ac.ft
Display Map

FIG. 8. Spatial distribution of profits (US$ acre^{-1}) for (A) alfalfa, (B) almonds, (C) table grapes, and (D) processing tomatoes irrigated at 0.35 in day^{-1} with cell-specific groundwater salinity (dS m^{-1}).

Alfalfa maintained a high relative yield across all EC levels and remained profitable in all scenarios, consistent with previous studies that report minor growth penalties above 10 dS m^{-1} (Grieve et al. 2012). Conversely, almonds showed economic viability only under low-salinity conditions, becoming unprofitable above 4 dS m^{-1}, highlighting the vulnerability of high-value perennial crops to water quality degradation (Prgomet et al. 2020). Table grapes retained acceptable margins under moderate salinity, demonstrating that premium perennial crops can remain viable so long as irrigation depth is sufficient to mitigate salt stress. Tomato profitability deteriorated more rapidly, reflecting the crop's thinner cost margins and sensitivity to both water price and salinity stress (Nicolas et al. 2023).

Alfalfa, table grapes, and processing tomatoes peaked at similar irrigation rates under low salinity but showed divergent responses as salinity increased (fig. 6). While the irrigation threshold for maximum yield is comparable under non-saline conditions, crop-specific tolerance to salt stress led to downward shifts in yield plateaus with rising EC_{iw} levels. At low salinity (0.5–2 dS m^{-1}), irrigation rates of approximately 0.25–0.27 in day^{-1} were generally sufficient to meet water demands and sustain full yield potential. However, the effectiveness of irrigation in mitigating salinity impacts varied among crops due to differences in salt exclusion, osmotic adjustment, and root-zone interactions. Almond production requires high-quality water; therefore, salt-tolerant alternatives, such as pistachios, merit consideration in areas with saline conditions. Almond profitability peaks at low salinity levels, where yields are maximized and water costs are minimal. However, profitability declines as salinity-induced yield losses increase, while fixed production costs remain unchanged. Water pricing further amplifies these economic impacts, rendering salt-sensitive crops economically unviable at higher salinity levels, even with increased irrigation.

Economic implications, regional applications

Economic analysis reveals that water price influences vary by crop type. Sensitivity analysis indicates that for alfalfa, water price changes produced larger absolute shifts in profit than commodity price fluctuations, while profits from almond and tomato production were more sensitive to commodity price variations. Table grapes showed high sensitivity to both water price and commodity pricing, exhibiting the greatest profit potential but also the most dramatic losses under adverse conditions (Nicolas et al. 2023).

While irrigation water prices typically represent a relatively small fraction of total production expenses compared to labor and other operational costs, water quality constraints can fundamentally alter cropping system viability by reducing yields while fixed costs persist. High-EC zones, especially the west side of the San Joaquin Valley, were consistently unprofitable, whereas fresher eastern uplands remained viable (Nicolas et al. 2023). These patterns provide valuable insights for strategic crop placement and regional planning decisions, as demonstrated by the economic losses from salinity-related yield reductions estimated at US$3.7 billion annually in California's agricultural sector (Welle and Mauter 2017).

Policy applications, strategic planning

The Yield-Salinity Model offers significant potential for SGMA implementation and regional water management. GSAs can use spatial screening capabilities to identify areas where agricultural productivity is most vulnerable to water and salinity constraints under sustainable management scenarios. While salinity was the dominant constraint on crop performance, spatial variability in soil texture and hydraulic properties, as captured in the POLARIS dataset, also influenced yield and profitability patterns across the valley. This heterogeneity enhances the tool's relevance for localized irrigation decisions and regional land-use planning; the use of data, especially spatially variable data like soil properties, supports evidence-based planning while minimizing economic disruption to agricultural communities. Areas showing consistently low profitability across crops under projected salinity scenarios can be prioritized for transition to habitat restoration, groundwater recharge, or renewable energy (Quinn and Oster 2021). Furthermore, the tool enables the evaluation of agricultural implications from increased reliance on recycled water or brackish groundwater sources, supporting the development of water pricing strategies that reflect the economic value of different water qualities (Bell et al. 2018; Ohab-Yazdi and Ahmadi 2016).

Significance and limitations of the tool

This tool provides an innovative solution to the complex challenges of managing irrigation water salinity. It also enables growers and policymakers to make decisions regarding crop selection and irrigation practices by predicting yield and profitability as functions of irrigation water salinity and quantity. The spatial yield and profitability prediction across the Central Valley significantly advances precision water management, allowing for more targeted salinity management and land repurposing strategies (Quinn and Oster 2021). Shahrokhnia and Wu (2021) developed a web-based soil salinity leaching management model (SALEACH) that focuses on estimating leaching requirements and predicting soil salinity. However, the model does not address economic implications and relies on empirical validation using observed yield data rather than model-to-model comparisons.

While the tool can help to fill some gaps, notable limitations persist. A steady-state salinity assumption omits temporal variability in leaching and evapotranspiration (Shani et al. 2007; 2009). In addition to covering only a few Central Valley commodities, the tool relies on historical price averages and simplified production costs, thereby failing to capture market volatility. The 98-feet-by-98-feet spatial resolution is suitable for regional screening but may not accurately reflect fine-scale field variations or temporal changes in groundwater quality. Thus, the output of this tool should be used for decision support and not be considered as absolute.

Salt accumulation around drip emitters and salinity stress in almond trees irrigated with saline water are visible as white salt rings in the wetted zone and leaf curling. *Photo:* Mae Culumber.

Conclusion

This decision support tool enables California farmers and water managers to make informed crop selection and irrigation decisions under increasing salinity constraints. The findings reveal critical economic thresholds and identify western Central Valley areas as unsuitable for salt-sensitive crops, supporting strategic land repurposing under SGMA implementation. The tool's integration of agronomic and economic predictions at field and regional scales addresses a critical gap in agricultural decision-making as water quality constraints intensify. Future research should expand crop coverage and incorporate climate projections to enhance long-term planning capabilities. As California implements stricter water regulations, tools such as the Yield-Salinity Model are essential for maintaining agricultural productivity while achieving sustainability.

F. Nicolas is Assistant Professor, Biological and Ecological Engineering Department, Oregon State University, Corvallis, Oregon; M. Culumber is Advisor, UC Cooperative Extension Fresno County, Fresno; H. Shahrokhnia is Environmental Scientist, Santa Ana Regional Water Quality Control Board, Riverside; U. Al-Dughaishi is Assistant Professor, Department of Soil, Water and Agricultural Engineering, Sultan Qaboos University; J. Do is Visiting Scholar, Department of Land, Air and Water Resources, UC Davis; S. Benes is Professor, Department of Plant Sciences, California State University, Fresno; I. Kisekka is Professor, Department of Biological and Agricultural Engineering, and Department of Land, Air and Water Resources, UC Davis.

This study was supported by the USDA NRCS CEAP Award # NR193A750023C016 and USDA NIFA Award # 2021-68012-35914. We are grateful to Alon Ben-Gal and Tamir Kamai for their feedback during the development of this web tool.

The Yield-Salinity Model is available at https://doi.org/10.15140/D3J04K.

References

Aegerter B, Lazicki P, Miyao G, et al. 2023. Sample Costs to Establish an Orchard and Produce Processing Tomatoes, Sacramento Valley. https://coststudies.ucdavis.edu/current/commodities/tomatoes

Bell EM, Stokes-Draut JR, Horvath A. 2018. Environmental evaluation of high-value agricultural produce with diverse water sources: Case study from Southern California. Environ Res Lett 13(2):025007. https://doi.org/10.1088/1748-9326/aaa49a

California Department of Water Resources. n.d. Groundwater water quality results [dataset]. California Open Data Portal. https://data.ca.gov/dataset/ground-water-water-quality-results (accessed October 2024).

California Department of Water Resources. 2024. Sustainable Groundwater Management Act (SGMA). https://water.ca.gov/programs/groundwater-management/sgma-groundwater-management#

California Natural Resources Agency. n.d. Statewide crop mapping [dataset]. California Natural Resources Agency Open Data. https://data.cnra.ca.gov/dataset/statewide-crop-mapping (accessed October 2024).

Chaney NW, Minasny B, Herman JD, et al. 2019. POLARIS soil properties: 30-m Probabilistic maps of soil properties over the contiguous United States. Water Resour Res 55(4):2916–38. https://doi.org/10.1029/2018WR022797

CV-SALTS. 2023. Central Valley Salinity Alternatives for Long-Term Sustainability. www.cvsalinity.org/about/

Eldeiry A, Garcia L, Colorado State University. 2004. Spatial modeling using remote sensing, GIS, and field data to assess crop yield and soil salinity. https://hdl.handle.net/10217/200033

Faunt CC, Sneed M, Traum J, Brandt JT. 2016. Water availability and land subsidence in the Central Valley, California, USA. Hydrogeol J 24(3):675–84. https://doi.org/10.1007/s10040-015-1339-x

Fidelibus M, El-kereamy A, Haviland D, et al. 2018. Sample Costs to Establish and Produce Table Grapes. UC ANR and UC Davis.

Grieve CM, Grattan SR, Maas EV. 2012. Plant salt tolerance. ASCE Manual and Reports on Engineering Practice 71:405–59.

Kaner A, Tripler E, Hadas E, Ben-Gal A. 2019. Agronomic-economic coupled decision support application for irrigation with water containing salts. In *Bridging Among Disciplines by Synthesizing Soil and Plant Processes*. Wendroth O, Lascano RJ, Ma L (eds.). John Wiley & Sons, Ltd. p 223–35. https://doi.org/10.2134/advagricsystmodel8.2017.0013

Kisekka I, Grattan SR, Salcedo FP, et al. 2024. *Assessing the State of Knowledge and Impacts of Recycled Water Reuse for Irrigation on Agricultural Crops and Soils*. Denver, Colo.: The Water Research Foundation.

Nicolas F, Kamai T, Ben-Gal A, et al. 2023. Assessing salinity impacts on crop yield and economic returns in the Central Valley. Agric Water Manage 287:108463. https://doi.org/10.1016/j.agwat.2023.108463

Niederholzer F, Ott J, Jarvis-Shean KS, et al. 2024. Sample Costs to Establish an Orchard and Produce Almonds, Sacramento Valley. University of California Agriculture and Natural Resources Cooperative Extension. https://coststudies.ucdavis.edu/current/commodities/almonds

Ohab-Yazdi SA, Ahmadi A. 2016. Design and evaluation of irrigation water pricing policies for enhanced water use efficiency. J Water Resour Plann Manage 142(3):05015011. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000610

Prgomet I, Pascual-Seva N, Morais MC, et al. 2020. Physiological and biochemical performance of almond trees under deficit irrigation. Sci Hortic 261:108990. https://doi.org/10.1016/J.SCIENTA.2019.108990

Quandt A, Larsen AE, Bartel G, et al. 2023. Sustainable groundwater management and its implications for agricultural land repurposing. Reg Environ Change 23(4):120. https://doi.org/10.1007/s10113-023-02114-2

Quinn NWT. 2020. Policy innovation and governance for irrigation sustainability in the arid, saline San Joaquin River Basin. Sustainability 12(11):4733. https://doi.org/10.3390/su12114733

Quinn NWT, Oster JD. 2021. Innovations in sustainable groundwater and salinity management in California's San Joaquin Valley. Sustainability 13(12):6658. https://doi.org/10.3390/su13126658

Shahrokhnia H, Wu L. 2021. SALEACH: A new web-based soil salinity leaching model for improved irrigation management. Agric Water Manage 252:106905. https://doi.org/10.1016/j.agwat.2021.106905

Shani U, Ben-Gal A, Tripler E, Dudley LM. 2007. Plant response to the soil environment: An analytical model integrating yield, water, soil type, and salinity. Water Resour Res 43(8). https://doi.org/10.1029/2006WR005313

Shani U, Ben-Gal A, Tripler E, Dudley LM. 2009. Correction to "Plant response to the soil environment: An analytical model integrating yield, water, soil type, and salinity." Water Resour Res 45(5). https://doi.org/10.1029/2009WR008094

Skaggs TH, Anderson RG, Corwin DL, Suarez DL. 2014. Analytical steady-state solutions for water-limited cropping systems using saline irrigation water. Water Resour Res 50(12):9656–74. https://doi.org/10.1002/2014WR016058

[USDA NASS] US Department of Agriculture National Agricultural Statistics Service. 2024. Alfalfa, almonds, table grapes, and processing tomatoes price: California, 2018-2023 [dataset]. www.nass.usda.gov/Statistics_by_State/California/ (accessed October 2024).

Welle PD, Mauter MS. 2017. High-resolution model for estimating the economic and policy implications of agricultural soil salinization in California. Environ Res Lett 12(9):094010. https://doi.org/10.1088/1748-9326/aa848e

Wilson R, Galdi GC, Stewart D. 2020. Sample Costs to Establish and Produce Alfalfa Hay, Intermountain Region—Siskiyou County, Scott Valley—Mixed Irrigation. UC ANR. https://ucanr.edu/sites/default/files/2021-04/348687.pdf