Salinity and Water Reuse Research:
U.S. Salinity Laboratory
USDA-ARS

Donald L. Suarez
### Water Reuse & Remediation

- Plant adaptation/selection/genetic improvement
- Management systems
- Mapping
- Remediation of impacted soils
- Toxic elements associated with irrigation waters

### Contaminant Fate & Transport

- VOC (Air Quality)
- Pathogens
- Contaminant elements
- Other chemicals (Water Quality)
Water Reuse and Remediation Unit
Chemistry and Assessment

- Predict the impact of degraded and saline waters on infiltration
- Predict plant response to degraded waters (including saline waters) under different climatic conditions, water compositions, combined stresses and variable leaching and management regimes
• Develop a multi-sensor platform for salinity and irrigation management
• Improve models and develop management strategies for use of degraded waters
• Develop a combined mapping and model assessment, decision support tool for field application
Plant Research

• Identify variability in physiological and biochemical response mechanisms associated with the use of saline waters and develop strategies to mitigate negative effects of salts and toxic ions.

• Identify genetic markers for traits associated with physiological salt stress response that can be used to develop germplasm with improved salt tolerance.
Mobil Salinity Assessment Unit (developed by U.S. Salinity Laboratory)

Hoist

Dipole EM

Sled w/ Dual-dipole EM-38

D.L Corwin
Integrated System: Protocols, Mobile EC$_a$ Equipment, and ESAP Software

- Perform EC$_a$ survey
- Geostatistically interpolated map of hard data (e.g., salinity)
- Maps of Soil Salinity
- Map derived from hard and soft data
- EC$_e = b_0 + b_1(EM_v) + b_2(EM_H) + b_3(x) + b_4(y)$
- Conduct EC$_a$-directed soil sampling
- Lab analyses & GIS
  - Spatial stat analysis
  - Calibration models
  - Basic stats etc.
Cotton Yield Response Model

Final model adjusted for spatial autocorrelation:

Yield = 19.277 + 0.218(EC_e) - 0.015(EC_e)^2 - 4.420(LF)^2 - 1.991(pH) + 6.927(\theta_g) + \varepsilon
Measured vs. Predicted Yield

Cotton Yield Mg/ha

0 - 2.8
2.8 - 4.5
4.5 - 5.6
5.6 - 6.2
6.2 - 6.7
6.7 - 11.2
No Data

Management Recommendations for Site-Specific Management Units

- EC_a-directed soil sample locations
- Leaching fraction: reduce LF to < 0.4
- Salinity: reduce ECe to < 7.17 dS/m
- Coarse texture requires more frequent irrigation
- pH: reduce pH to < 7.9

Monitoring the Reclamation of a Saline-Sodic Site Using Drainage Water

1999

Westlake site - south end

California

USA

Kings County

Westlake site
Spatial Gain/ Loss in EC$_e$

1999-2002

0-0.3 m
0.3-0.6 m
0.6-0.9 m
0.9-1.2 m

EC$_e$ (dS/m) change
-19.5 to -11
-11 to -6
-6 to -3
-3 to 0
0 to 4
4 to 8
8 to 16

1999-2004

0-0.3 m
0.3-0.6 m
0.6-0.9 m
0.9-1.2 m

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Spatio-temporal Change in SAR

- EC$_e$ and SAR patterns are quite similar
- Leaching is decreasing SAR particularly in top 0.6 m and in the north, but SAR may be increasing at lower depths in the south
5-year results show the reuse of 3-5 dS/m drainage water improved soil quality on marginal saline-sodic soil.
Saline and Sodic Soil Management

Simulation models such as FAO-SWS (UNSATCHEM) are well suited to evaluate management options
SWS Model
D.L. Suarez, P. Taber, and P. Van

a) Water flow
b) Soil chemical processes
c) Climatic data
d) Plant response to water and salt stress
Measured 0.7 m water

Depth (m)

SAR

0.7 m water
0.8 m water

USDA
Developed by: Donald Suarez and Patrick Taber
of the United States Salinity Laboratory
Version: 2.0
Plant Water Suitability Model
D.L. Suarez and P. Taber

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Packed Columns Arlington Sandy Loam
Relationship of SAR with depth and quantity of rain infiltrated into Glendive loam and clay soil. The initial condition was based on earlier irrigation with water of EC = 1.0 dS m\(^{-1}\) and SAR = 10.
Infiltration (Irrigation Water), pH 7.0

Infiltration (Irrigation Water), pH 8.2
Salinity of applied water (EC_w) in dS/m

Sodium Adsorption Ratio (SAR)

Greater than 25 % reduction

Little or no reduction
Sodium Adsorption Ratio (SAR)

Salinity of applied water (EC$_w$) in dS/m

- >25% reduction
- 25% reduction
- No reduction
Adsorption-Desorption of Trace Elements in Irrigated Arid Land Soils

- Develop generalized predictive equations to represent B, Mo, and As adsorption
- Describe competitive ion effects on adsorption pertinent to natural systems such as field soils

S Goldberg, S. Lesch and D.L. Suarez
Boron Adsorption Modeling

Protonation and dissociation constants, log $K_-$ and log $K_+$, and B surface complexation constant, log $K_B$.

Prediction equations - Goldberg et al. (2000)

$log K_-$ = -4.83 - 0.375ln(SA) + 0.167ln(%OC) + 0.111ln(%IOC) + 0.466ln(%Al)

$log K_+$ = 5.73 - 0.102ln(%OC) - 0.198ln(%IOC) - 0.622ln(%Al)

$log K_B$ = -10.4 + 0.302ln(%OC) + 0.0584ln(%IOC) + 0.302ln(%Al)
Evaluation of B Soil Tests for Conditions of B Toxicity

- Prediction of B content of container-grown melons
- Prediction of B content of cotton, alfalfa, and melons under field conditions

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### B released by various soil tests and extracting solutions (mg B kg\(^{-1}\) soil)

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>NH(_4)-acetate</td>
<td>1.22 ± 0.02</td>
<td>0.744 ± 0.001</td>
<td>0.620 ± 0.01</td>
<td>0.815 ± 0.001</td>
</tr>
<tr>
<td>CaCl(_2)-mannitol</td>
<td>4.82 ± 0.12</td>
<td>2.82 ± 0.02</td>
<td>2.50 ± 0.02</td>
<td>3.00 ± 0.05</td>
</tr>
<tr>
<td>DTPA-sorbitol</td>
<td>6.52 ± 0.03</td>
<td>4.25 ± 0.05</td>
<td>3.71 ± 0.03</td>
<td>4.46 ± 0.07</td>
</tr>
<tr>
<td>Na(_2)CO(_3) 500 g L(^{-1})</td>
<td>2.95 ± 0.04</td>
<td>1.91 ± 0.04</td>
<td>1.61 ± 0.03</td>
<td>2.00 ± 0.05</td>
</tr>
<tr>
<td>Na(_2)CO(_3) 200 g L(^{-1})</td>
<td>5.46 ± 0.11</td>
<td>3.45 ± 0.07</td>
<td>2.94 ± 0.06</td>
<td>3.46 ± 0.08</td>
</tr>
<tr>
<td>0.1 M NaCl</td>
<td>4.64</td>
<td>2.93</td>
<td>2.62</td>
<td>2.99</td>
</tr>
<tr>
<td>0.05 M H(_3)PO(_4) +</td>
<td>8.36 ± 0.01</td>
<td>5.75 ± 0.09</td>
<td>4.42 ± 0.08</td>
<td>5.71 ± 0.06</td>
</tr>
<tr>
<td>0.05 M K(_2)HPO(_4)  pH 2.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1 M K(_2)HPO(_4)  pH 4.4</td>
<td>7.47 ± 0.17</td>
<td>5.01 ± 0.11</td>
<td>4.52 ± 0.05</td>
<td>5.12 ± 0.04</td>
</tr>
<tr>
<td>0.05 M K(_2)HPO(_4) +</td>
<td>6.82 ± 0.17</td>
<td>4.20 ± 0.16</td>
<td>3.75 ± 0.01</td>
<td>4.38 ± 0.06</td>
</tr>
<tr>
<td>0.05 M K(_2)HPO(_4)  pH 6.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1 M K(_2)HPO(_4)  pH 8.6</td>
<td>4.84 ± 0.31</td>
<td>2.81 ± 0.02</td>
<td>2.65 ± 0.03</td>
<td>3.24 ± 0.08</td>
</tr>
<tr>
<td>0.1 M K(_3)PO(_4)  pH 12.3</td>
<td>7.30 ± 0.03</td>
<td>4.61 ± 0.15</td>
<td>3.95 ± 0.04</td>
<td>4.72 ± 0.10</td>
</tr>
<tr>
<td>Native B desorbed</td>
<td>11.0</td>
<td>12.1</td>
<td>8.23</td>
<td>8.80</td>
</tr>
</tbody>
</table>

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Surface area estimated from clay content and mineralogy

IOC, Al, Fe content based on reported analysis

Initial pH and composition from a saturation extract
B Transport: Data and Model Predictions

Boron Adsorption
Bonsall pH 6.8

Boron Concentration (mmol/L)
0.10
0.05
0.00
0.10
0.05
0.00

Irrigation (cm)

Boron Prediction - General
Boron Prediction - Specific
Boron - Measured

Boron Adsorption
Bonsall pH 8.1

Boron Concentration (mmol/L)
0.10
0.05
0.00
0.10
0.05
0.00

Irrigation (cm)

Boron Prediction - pH 7.9
Boron Prediction - pH 8.2
Boron - Measured
Do we need “extra” irrigation water to manage salinity?

How do salinity and water stress interact?
Salt Stress (FAO 29)

Water applied = 210 cm
$ET_p = 200$ cm
EC irrigation water = 6.2 dS/m
Drainage = 9 cm
Average root zone salinity = 44.8 dS/m
L.F. = 0.043
Relative yield = 2%

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Salt Stress Calculation
(Using water uptake weighted salinity)

Water applied = 210 cm

EC irrigation water = 6.2 dS/m

ETₚ = 200 cm

Drainage = 9 cm

Water uptake weighted salinity = 23.3 dS/m

L.F. = 0.043

Relative yield = 13.4%

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SWS Model Prediction of Salt Stress

**Input**
- Water applied = 210 cm
- $ET_p = 200$ cm
- $EC_{iw} = 6.2$ dS/m

**Results**
- $ET_a = 122$ cm
- Drainage = 88 cm
- L.F. = 0.42
- Relative yield = 62%

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Comparison of SWS model and Ayers and Westcot (1985) predicted crop relative yield as related to irrigation water EC, for a crop with an \( h_{50} = -50 \text{ m (-0.5 MPa)} \), \( ET_p = 200 \text{ cm} \) and 209 cm applied water.
Mean rootzone solution B

Boron, mmol L$^{-1}$ vs. Day

LF = 0.5, SA = 0.1
LF = 0.5, SA = 1
LF = 0.1, SA = 0.1
LF = 0.1, SA = 1
Response of Leafy Vegetables to Irrigation with Saline-Sodic Waters

Methods

- Outdoor sand tanks
- Nine vegetable crops
- Six salinity treatments with ion compositions typical of San Joaquin Valley drainage effluents; $EC_{iw} = 3, 7, 11, 15, 19, 23$ dS m$^{-1}$
- Two salinization dates
  - Early - first true leaves on ~ 50% plants
  - Late - 3 weeks later
- Two replications

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Results/Conclusions

- Swiss chard - moderately tolerant. Yield was not significantly affected by timing of salt application.
- Yields of the other vegetables improved when salinization was delayed past early stage of establishment.
- Chard, salad greens, kale and pac choi have potential for use in drainage water reuse systems provided salinity is moderate and irrigation practices are appropriate.
- Irrigation with moderately saline water did not affect vegetable nutrient quality or consumer acceptability.
## Salt Tolerance Parameters

<table>
<thead>
<tr>
<th>Forage</th>
<th>Threshold $\text{EC}_e^*$ (dS/m)</th>
<th>Slope (%)</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa†</td>
<td>2.0</td>
<td>7.3</td>
<td>MS</td>
</tr>
<tr>
<td>Tall Wheatgrass‡</td>
<td>7.5</td>
<td>4.2</td>
<td>T</td>
</tr>
<tr>
<td>Kikuyugrass</td>
<td>NA</td>
<td></td>
<td>NA</td>
</tr>
</tbody>
</table>

* $\text{EC}_e = \sim 1.5 \text{EC}_{iw}$ (Ayers and Westcot 1985)
† Bernstein and Francois 1973
‡ Bernstein and Ford 1958
Effect of Saline Irrigation Waters on Cumulative Biomass Production

<table>
<thead>
<tr>
<th></th>
<th>Final Harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15 dS m⁻¹*</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>28a</td>
</tr>
<tr>
<td>Wheatgrass</td>
<td>20 b</td>
</tr>
<tr>
<td>Kikuyugrass</td>
<td>18 b</td>
</tr>
</tbody>
</table>

* In sand culture experiments: ECiw = ECsw. ECsw = ~ 2 ECe
† Within columns, means followed by a different letter are significantly different according to Tukey’s Studentized Range Test.
# Organic Quality Evaluation†

<table>
<thead>
<tr>
<th></th>
<th>FORAGE</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>ALFALFA</td>
</tr>
<tr>
<td>Crude Protein</td>
<td>★★★★*</td>
</tr>
<tr>
<td>Neutral Detergent Fiber</td>
<td>★★★</td>
</tr>
<tr>
<td>Digestible NDF</td>
<td>★★★</td>
</tr>
<tr>
<td>Organic Matter</td>
<td>★★★</td>
</tr>
<tr>
<td>Gas Evolution</td>
<td>★★★</td>
</tr>
<tr>
<td>Metabolizable Energy</td>
<td>★★★</td>
</tr>
</tbody>
</table>

†Evaluation based on harvest 5

* ★★★★ excellent; ★ poor

Robinson et al. Submitted to Animal Seed and Feed Technology
# Tomato Size Designations

<table>
<thead>
<tr>
<th>Boron Level (mg/l)</th>
<th>X-Small</th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
<th>X-Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>14</td>
<td>14</td>
<td>26</td>
<td>30</td>
<td>16</td>
</tr>
<tr>
<td>4.0</td>
<td>17</td>
<td>14</td>
<td>27</td>
<td>28</td>
<td>14</td>
</tr>
<tr>
<td>6.0</td>
<td>19</td>
<td>19</td>
<td>30</td>
<td>23</td>
<td>9</td>
</tr>
<tr>
<td>8.0</td>
<td>24</td>
<td>19</td>
<td>30</td>
<td>20</td>
<td>7</td>
</tr>
<tr>
<td>10.0</td>
<td>28</td>
<td>21</td>
<td>30</td>
<td>16</td>
<td>5</td>
</tr>
<tr>
<td>12.0</td>
<td>34</td>
<td>22</td>
<td>28</td>
<td>14</td>
<td>2</td>
</tr>
</tbody>
</table>
Ca-Mg-K
Cl
0.15 MPa

Ca-Mg-K
SO4
0.15 MPa

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Ventana

Relative Fruit Yield (g/plant)

Osmotic Potential (MPa)

Different symbols represent different salts: Mixed salt chloride, Mixed salt sulfate, NaCl, MgSO_4, CaCl_2.
Boron, pH, and Salt Effects on Cucumber Fruit Yield

**Graphs:**
- pH = 8
- pH = 6

- Cucumbers, kg/plants
- EC, dS/m

**Legend:**
- B, mg/L: 0.9, 5.0, 8.0
- EC, dS/m: 3, 6, 8

**Graph Details:**
- The graphs show the effect of different levels of boron (B), pH, and salt on cucumber yield.
- The x-axis represents the levels of boron (mg/L), with 0, 2, 4, 6, 8 B mg/L.
- The y-axis represents the cucumber yield, ranging from 0 to 12 kg/plants.
- Different colors represent different EC levels (3, 6, 8 dS/m).