Sustainable Soil Management Under Irrigation with Saline Waters

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Why do we need to leach?

Evapotranspiration - concentrates salts added in the irrigation water. Plants typically take up 60 to 95% of the water applied and only 2 to 8% of the salts present in the water.
Current Issues

- Current fresh water use by irrigated agriculture in arid and semi-arid regions is not sustainable.
- Irrigated agriculture cannot compete economically with the urban sector in a competitively priced water market.
Advantages of Water Reuse

• Tertiary water treatment, necessary for aquifer recharge is expensive
• Agricultural use of nutrients add value to irrigation water
• Agricultural use can reduce the drainage volume below that of an RO plant in one cycle and further reduce the volume with multiple uses (2% or less of initial volume)
Water Reuse

- Agriculture can utilize treated municipal waste waters, agricultural drainage waters and brackish ground waters.
- Water reuse by agriculture can reduce nutrient and contaminant discharge
Water Quality Concerns

• Recycled waters are elevated in salinity, SAR, and Mg/Ca. Many saline waters are also elevated in pH, alkalinity, and B.
Current Ocean Disposal

LA County Sanitation District 2004
363,500 acre ft/y (460 million m³) discharged
216,000 acre ft/year reclaimed

City of Los Angeles Hyperion Plant Discharge
average flow 500,000 acre ft/year
\[ \text{SAR} = \frac{[\text{Na}]}{[\text{Ca} + \text{Mg}]}^{0.5} \]

where concentrations are in mmol·L\(^{-1}\)
Cations ratio of soil structural stability (CROSS) 

\[ \text{ECR} = \frac{(\text{Na} + 0.56\text{K})}{(\text{Ca} + 0.6\text{Mg})/2} \times 100 \]
Existing Guidelines

USDA Handbook 60 (1954)
FAO Water Quality for Agriculture No. 29 rev. 1 (1985)
Agriculture Salinity Assessment and Management (1990)

All three consider ESP (or SAR) and salinity. Guidelines are simple and convenient, however they are not satisfactory for site specific recommendations.
Saline soil \( \text{EC}_e > 4 \text{ dSm}^{-1} \)
Sodic soil \( \text{ESP} > 15 \)
Saline-sodic soil \( \text{EC}_e > 4 \text{ dSm}^{-1} \) and \( \text{ESP} > 15 \)

These are soil classification criteria and are not useful for management purposes.
Water classification

- **Salinity hazard**
  - low: $\text{EC} < 0.25 \text{ dSm}^{-1}$
  - medium: $0.25 \text{ - } 0.75 \text{ dSm}^{-1}$
  - high: $0.75 \text{ - } 2.25 \text{ dSm}^{-1}$
  - very high: $\text{EC} > 2.25 \text{ dSm}^{-1}$

- **Sodium hazard**
  - low: $\text{SAR} < 10$
  - medium: $10 \text{ - } 18$
  - high: $18 \text{ - } 26$
  - very high: $\text{SAR} > 26$
# Flocculation of Clay Minerals

<table>
<thead>
<tr>
<th>Clay Type</th>
<th>Na$^+$ mmol$_c$·L$^{-1}$</th>
<th>Ca$^{2+}$ mmol$_c$·L$^{-1}$</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>montmorillonite</td>
<td>12</td>
<td>0.2</td>
<td>van Olphen (1977)</td>
</tr>
<tr>
<td>montmorillonite</td>
<td>12</td>
<td>1.7</td>
<td>Goldberg (1990)</td>
</tr>
<tr>
<td>illite</td>
<td>45</td>
<td>2.2</td>
<td>Goldberg (1990)</td>
</tr>
<tr>
<td>kaolinite</td>
<td>&lt;0.2</td>
<td>&lt;0.1</td>
<td>Goldberg (1990)</td>
</tr>
</tbody>
</table>
Factors Affecting Water Infiltration and Crop Production

1. SAR
2. EC
3. pH
4. Ca/Mg ratio
5. Crop selection
6. Extent, timing and intensity of rainfall
7. Evapotranspiration
8. Soil texture and soil hydraulic characteristics
9. Irrigation system
10. Soil organic matter
11. Tillage
12. Residue management
13. Drainage system
14. Uniformity of irrigation
15. Leaching fractions
16. Extent of canopy cover
17. Soil fertility
18. Acceptable relative yield - an economic consideration
19. Toxic elements (B, Mo, Se, As)
20. Fe and Al oxide content
21. Clay mineralogy
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.

Ayers & Westcot (1985)

Severe reduction in rate of infiltration

Slight to moderate reduction in rate of infiltration

No reduction in rate of infiltration

Sodium Adsorption Ratio - SAR

Salinity of applied water (ECw) in dS/m
## Experimental Design

<table>
<thead>
<tr>
<th>Irrigation Water</th>
<th>Replicates</th>
<th>Soils</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EC</strong></td>
<td><strong>SAR</strong></td>
<td></td>
</tr>
<tr>
<td>1 and 2 dS m(^{-1})</td>
<td>2, 4, 6, 8, 10</td>
<td>3</td>
</tr>
<tr>
<td>Control</td>
<td>Control</td>
<td>Kobase Silty Clay</td>
</tr>
<tr>
<td>EC = 0.5 dS m(^{-1})</td>
<td>SAR = 0.5</td>
<td>Glendive Sandy Loam</td>
</tr>
</tbody>
</table>

Alternating rain – irrigation events of 5 cm each. Rain applied in 0.25 cm intervals. Soils packed into 29 cm x 25 cm plastic containers. A vacuum of 50 kPa was applied to extractors at the bottom of the container.
Relationship between SAR and ln infiltration time; date is averaged across sampling periods

Pachappa Infiltration, Irrigation Water (with Rain)

Relative Infiltration (Final/Initial)

Infiltration rate as related to SAR of applied water.
Disturbed (laboratory packed) cores of untreated loam soil.

(Suarez and Gonzalez, unpublished data)

Part I - Conclusions

• There is no threshold to the SAR relationship – any increase in SAR reduces the infiltration rate
• Even a small increase in pH reduces the infiltration rate
• As expected rain infiltration was slower than irrigation water infiltration
• The adverse effect of SAR on irrigation water infiltration is enhanced in systems that also receive rain
• Short-term experiments do not simulate the extent of SAR effects on infiltration rate observed in season-long experiments
• The relative reduction in hydraulic conductivity and infiltration rate as affected by SAR is not dependent on soil texture.
• Reductions in infiltration rate are critical for clay soils and usually not important for sandy soils.
• Canopy cover did not protect the soil from reduction in infiltration.
• There is no “threshold” for reductions in infiltration as related to SAR, however reductions of less than 20% might not be noticed (except clay soils).
UNSATCHEM 3.0 Model

Includes:

- Variably saturated water flow
- $\text{CO}_2$ production and gas and liquid transport
- Root water uptake and plant growth
- Multicomponent solute transport
- Chemical effects on hydraulic properties
Salt Stress (FAO 29)

Water applied = 210 cm
\( ET_p = 200 \text{ cm} \)
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%

D.L. Suarez
Salt Stress Calculation
(Using water uptake weighted salinity)

Water applied = 210 cm
EC irrigation water = 6.2 dS/m
ET_p = 200 cm
Drainage = 9 cm
Water uptake weighted salinity = 23.3 dS/m
L.F. = 0.043
Relative yield = 13.4%

D.L. Suarez
SWS Model Prediction of Salt Stress

Input
Water applied = 210 cm
$\text{ET}_p = 200 \text{ cm}$
$\text{EC}_{iw} = 6.2 \text{ dS/m}$

Results
$\text{ET}_a = 122 \text{ cm}$
Drainage = 88 cm
L.F. = 0.42
Relative yield = 62%
Comparison of SWS model and Ayers and Westcot (1985) predicted crop relative yield as related to irrigation water EC, for a crop with an $h_{50} = -50$ m (-0.5 MPa), $ET_p=200$ cm and 209 cm applied water.

Comparison of SWS model and Ayers and Westcot (1985) predicted leaching fraction as related to irrigation water EC, for a crop with an $h_{50}= -50$ m (-0.5 MPa) salt tolerance value, $ET_p=200$ cm and 209 cm applied water.

Currently utilize the threshold slope response function for toxicity and a B leaching requirement approach is overly conservative in that it is steady state.

Waters deemed unsuitable may be used in certain scenarios.
threshold crop tolerances

\[ B_s \]

\[ B_{iw} \]

\{ asparagus \}
\{ celery \}
\{ sorghum \}
\{ tomato \}
\{ cowpeas \}
\{ lettuce \}

LF = 0.05
LF = 0.1
LF = 0.2
LF = 0.3
LF = 0.4
Simulations of Irrigation with High B Concentration Water

- 120 day simulations
- Leaching fractions = 0.05 and 0.4
- Two soils: Bonsall sandy loam and Ryepatch clay
- ET = 0.6 cm/d
- B concentration = 0.5 mmol/L
Bonsall LF = 0.4

Profile Information: H3BO3

*Concentrations determined using predicted volumetric theta.

Bonsall LF = 0.05

Profile Information: H3BO3

*Concentrations determined using predicted volumetric theta.
Ryepatch LF = 0.4

Profile Information: H3BO3

H3BO3 [meq/L] *

Print Time
0  10  30  50  70  120

z [cm]

*Concentrations determined using predicted volumetric theta.

Ryepatch LF = 0.05

Profile Information: H3BO3

H3BO3 [meq/L] *

Print Time
0  20  40  60  80  100

z [cm]

*Concentrations determined using predicted volumetric theta.
General Parameter Boron Desorption Curves at Varying pH