Salinity Management Strategies

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No magic solution for Salinity Problems!

Good Soil/Water… and Crop… Management is Key!

Recommended publication: UC-ANR Publ. #8550, Nov. 2015

***Managing Salts by Leaching*. Drought Tips series**

https://anrcatalog.ucanr.edu/Details.aspx?itemNo=8550

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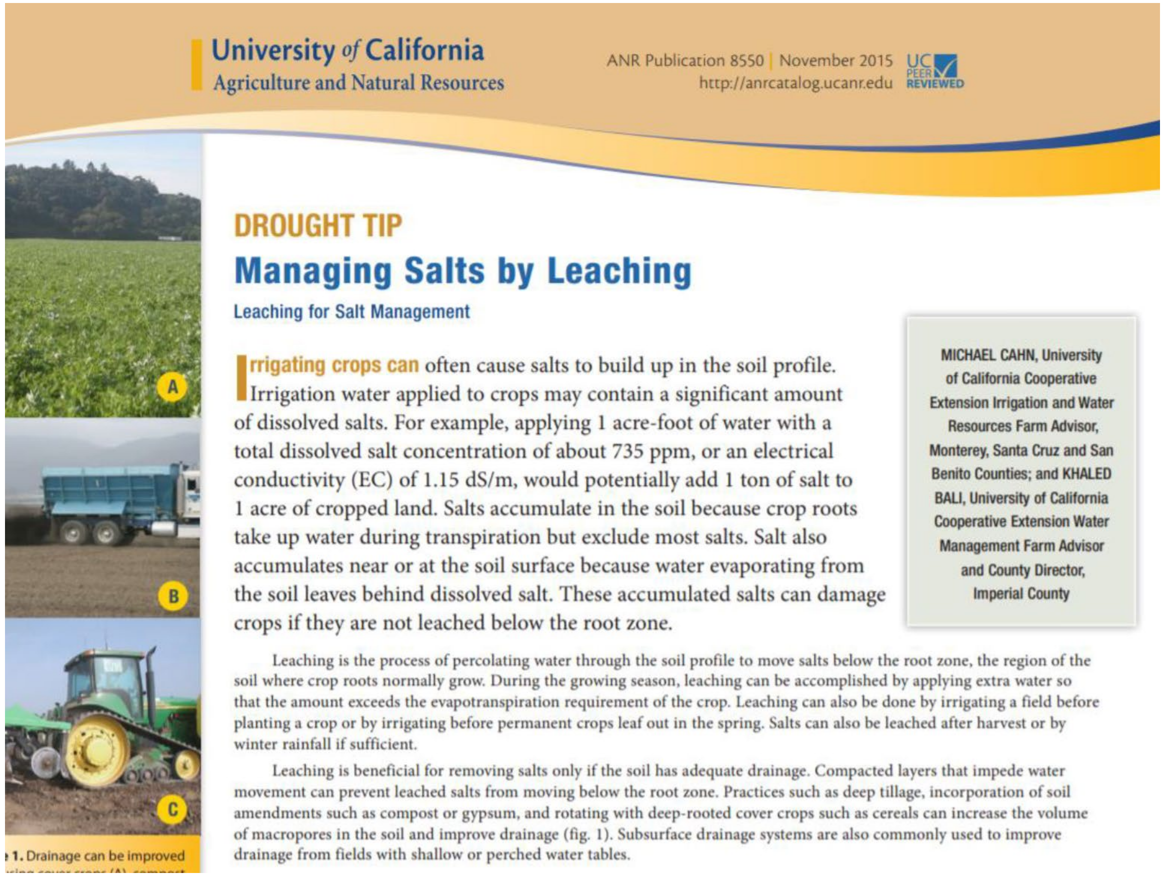
<u>Other contributors</u>

- **Robert Hutmacher, UCCE and UC Davis, Dept. Plant Sciences**
- **Blake Sanden, UCCE Kern Co., Farm Advisor (Emeritus)**
- **Laosheng Wu and Hossein Shahrokhnia, UC Riverside, Dept. of Environmental Science** ***(SALEACH decision support tool)***



University of California
Agriculture and Natural Resources

ANR Publication 8550 | November 2015
http://anrcatalog.ucanr.edu

UC PEER REVIEWED

DROUGHT TIP

Managing Salts by Leaching

Leaching for Salt Management

MICHAEL CAHN, University of California Cooperative Extension Irrigation and Water Resources Farm Advisor, Monterey, Santa Cruz and San Benito Counties; and KHALED BALI, University of California Cooperative Extension Water Management Farm Advisor and County Director, Imperial County

Irrigating crops can often cause salts to build up in the soil profile. Irrigation water applied to crops may contain a significant amount of dissolved salts. For example, applying 1 acre-foot of water with a total dissolved salt concentration of about 735 ppm, or an electrical conductivity (EC) of 1.15 dS/m, would potentially add 1 ton of salt to 1 acre of cropped land. Salts accumulate in the soil because crop roots take up water during transpiration but exclude most salts. Salt also accumulates near or at the soil surface because water evaporating from the soil leaves behind dissolved salt. These accumulated salts can damage crops if they are not leached below the root zone.

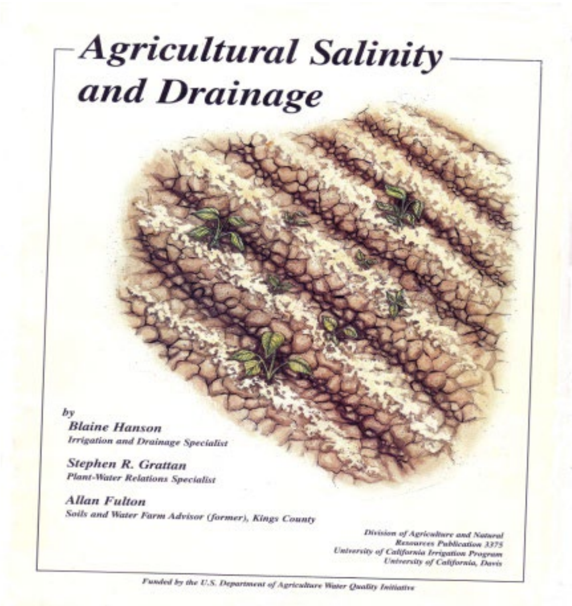
Leaching is the process of percolating water through the soil profile to move salts below the root zone, the region of the soil where crop roots normally grow. During the growing season, leaching can be accomplished by applying extra water so that the amount exceeds the evapotranspiration requirement of the crop. Leaching can also be done by irrigating a field before planting a crop or by irrigating before permanent crops leaf out in the spring. Salts can also be leached after harvest or by winter rainfall if sufficient.

Leaching is beneficial for removing salts only if the soil has adequate drainage. Compacted layers that impede water movement can prevent leached salts from moving below the root zone. Practices such as deep tillage, incorporation of soil amendments such as compost or gypsum, and rotating with deep-rooted cover crops such as cereals can increase the volume of macropores in the soil and improve drainage (fig. 1). Subsurface drainage systems are also commonly used to improve drainage from fields with shallow or perched water tables.

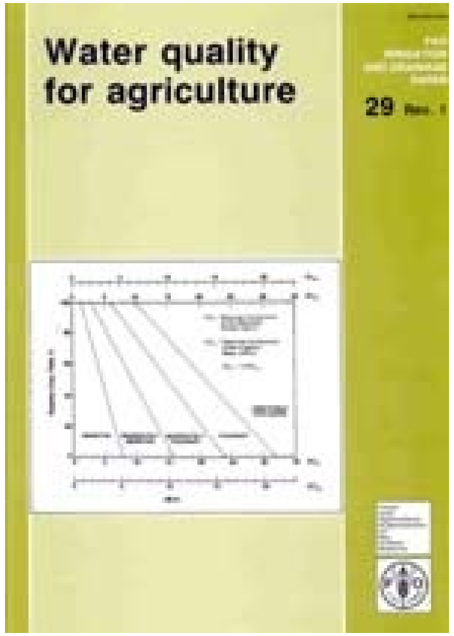
1. Drainage can be improved

Other Useful References/ articles

- **Hanson, Grattan, Fulton (2006)**
  "Agricultural Salinity & Drainage". Univ. California Agriculture & Natural Resources (UC-ANR) Publ. #3375
  anrcatalog.ucanr.edu/Items.aspx?hierId=17200



- **Ayars & Westcot (1985)**
  FAO #29 Irrig. & Drainage series.
  "Water Quality for Agriculture"
  www.fao.org/DOCREP/003/T0234E/T0234E00.HTM



- **Rhoades et al. (1992)**
  FAO #48 Irrigation & Drainage Series
  "Use of Saline Waters for Crop Production"
  www.fao.org/docrep/T0667E/T0667E00.htm

Outline

- **Salinity Basics**
- **Saline, saline-sodic or sodic conditions?**
- High boron? Alkalinity?
- **Salinity Stress**
  - **osmotic**
  - **toxic ion**
- **Amendments for sodicity management.**
  - if infiltration impaired, must address in order to leach
- **Variety selection (annuals & perennial forages) and rootstock selection (trees & vines)**
- **Planting position for annual crops**

- **Leaching**
  - **Maintenance**
  - **Reclamation*** **ideally when soil NO_3^- is low*

****consider potential for nitrate leaching***

- **Decision Support Tools for salinity management**
  - Excel Calculator (UCCE Kern, B. Sanden)
  - SALEACH (UC Riverside, Envi. Sciences; Laosheng Wu and Hossein Shahrokhnia)

Where do the salts come from?

- **Parent Material of soil**
  - San Joaquin Valley (SJV) of California: Westside (marine sediments) vs. Eastside (granitic, low in salts)

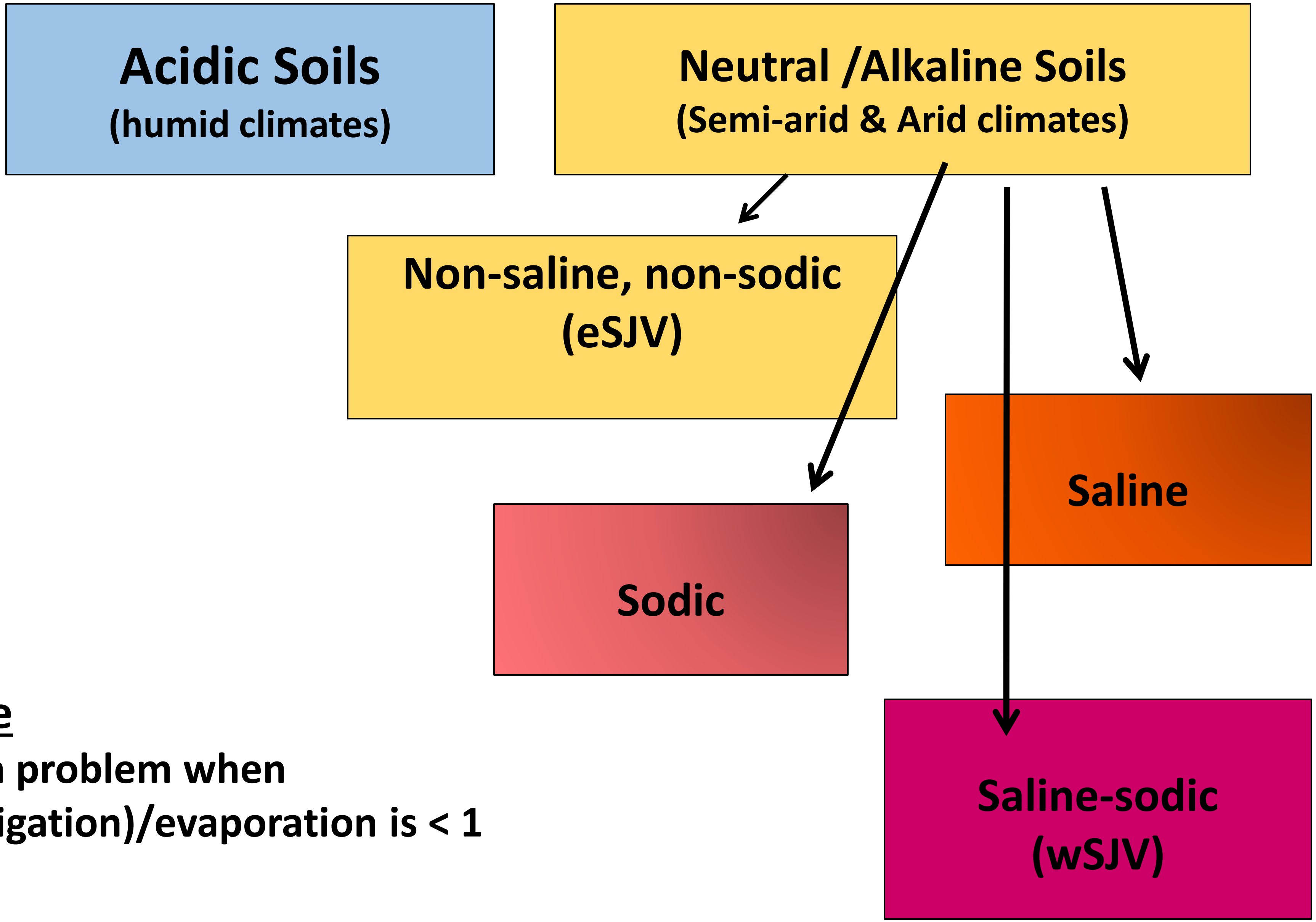
- **Irrigation water**
  - Imperial Valley, southern CA (Colorado River water), more saline
  - Westside SJV

    - canal water: low salt, but high volume applied = large salt load

    - groundwater: typically more saline, depending on depth of extraction

- **Fertilizers, manures, other amendments**
- **Perched water table (capillary flow of water & salt upward)**
- **Sea spray or seawater intrusion (coastal areas)**

⇒ Across all these situations, inadequate drainage and limited plans or ability to put in subsurface drains and export salt are common.



Role of climate

- soil salinity a problem when precip (or irrigation)/evaporation is < 1

Salinity Effects on Plants

<u>Osmotic (immediate)</u>: salinity reduces the soil water potential

- more difficult for plants to extract water.
- Reduced height, leaf size/canopy

<u>Toxic/ Specific Ion (over time)</u>:

- leaf injury (chlorosis/necrosis)
- decreases photosynthetic area

Sodicity Effects on Soil (and secondarily on plants)

Na disperses clays → loss of aggregation: crusting, ↓ infiltration

High pH (sodic soil) → some nutrients (P, Fe, Zn, Mn, Cu) less available. Na may depress K uptake

Soils affected by sodicity have reduced infiltration due to sodium dispersion of clays (breaks down soil structure)

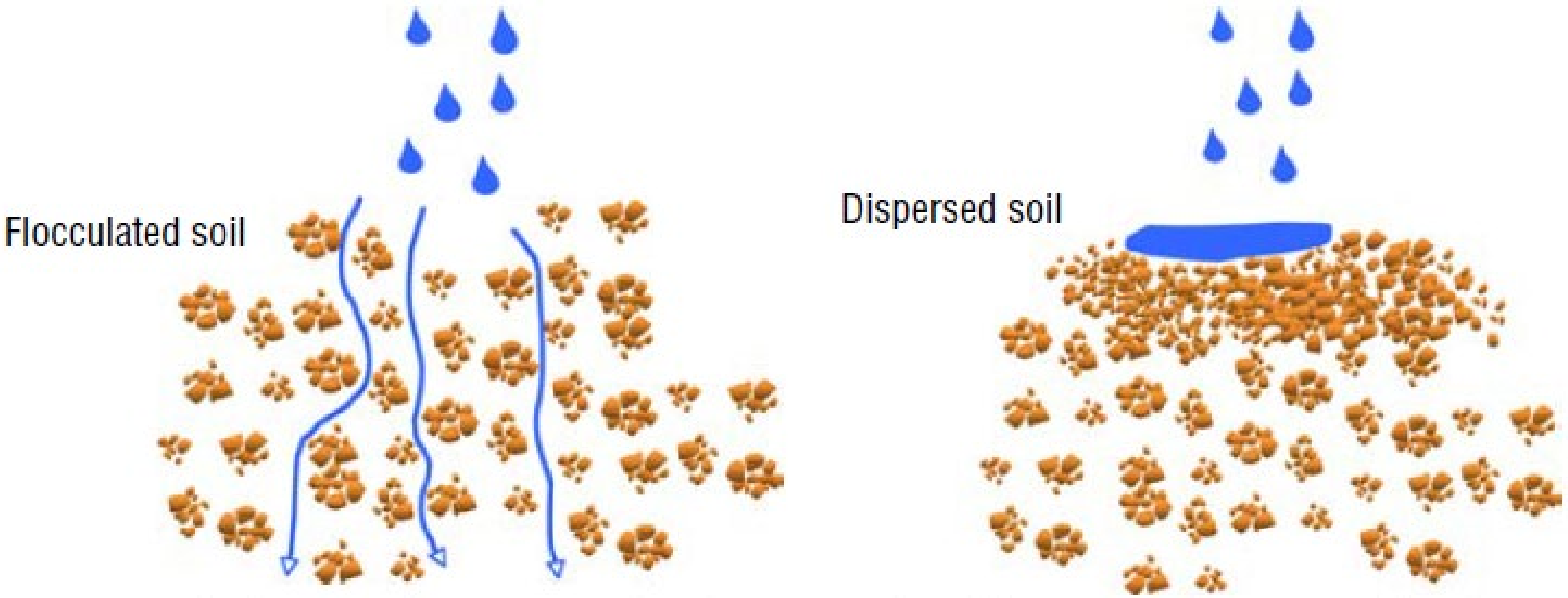


Figure 1.—The difference between flocculated (aggregated) and dispersed soil structure. Flocculation (left) is important because water moves through large pores and plant roots grow mainly in pore space. Dispersed clays (right) plug soil pores and impede water movement and soil drainage in all but the sandiest soil.

Classification of Soils

$$SAR^* = \frac{[Na+]^*}{\sqrt{\frac{[Ca^{2+} + Mg^{2+}]^*}{2}}}$$

**concs. in meq/L*

Need to know soil salinity ***(EC_e)***, amount of sodium ***(SAR)***, and ***soil pH***

- *have* ***critical values*** for each:

	Salinity (ECe) (dS/m)	Sodicity (SAR)	pH	Physical/Structural Condition of Soil
Not salt-affected	<4	<13	<8.5	Normal
"Saline"	>4	<13	<8.5	Normal
"Saline-sodic"	>4	>13	<8.5	Fair to poor
"Sodic"	<4	>13	>8.5	Poor

Can "assign" soils a certain classification, but salinity issues can change over time, so there can be changes or a progression from "not salt-affected" to some level of salinity impact

PRACTICES NEEDED: to manage salt-affected soils

1) **Irrigation water analysis**- *how much total salt and specific ions (Na, Cl, B) are contributed by each source. If necessary to use a more saline water source, when in season is best?*

2) **Soil samples/analysis** (representative of field or zones) - *is it saline, saline-sodic or sodic?*

3) **Soil mapping** (EM-38, drone or satellite imagery)- *should the field be treated uniformly or are there areas of the field more saline or sodic?*

4) **Leaching Salinity Management**: *reclamation or maintenance?*

5) **Amendments** (gypsum, or sulfur/acid if free lime is present)- **if sodicity a problem, or poor infiltration for other reasons*

6) **Appropriate irrigation management** to *avoid water-logging, esp. if infiltration problem*

7) **Suitable crop/variety/rootstock** for salinity level existing in field (MH salinity tolerance tables). *How much yield loss is acceptable? Are there known differences in salinity tolerance at different growth stages (i.e. seedling germination/emergence vs. established plants)?*

Maas Hoffman Salinity Tolerance Tables– a starting point. Improved varieties ma have higher tolerance

Crop	*Threshold Salinity (A)*	*Slope (B)*	*Rating**
Alfalfa	2.0	7.3	MS
Alkali grass, nuttall			T
Alkali sacaton			T
Barley (forage)	6.0	7.1	MT
Bentgrass			MS
Bermuda grass	6.9	6.4	T
Bluestem, Angleton			MS
Brome, mountain			MT
Brome, smooth			MS
Buffelgrass			MS
Burnet			MS
Canary grass, reed			MT
Clover alsike	1.5	12.0	MS
Clover, Berseem	1.5	5.7	MS
Clover, Hubam			MT
Clover, ladino	1.5	12.0	MS
Clover, red	1.5	12.0	MS
Clover, strawberry	1.5	12.0	MS
Clover, sweet			MT
Clover, white Dutch			MS
Corn, forage	1.8	7.4	MS
Cowpea (forage)	2.5	11.0	MS

**S = sensitive; MS = moderately sensitive; MT = moderately tolerant, T = tolerant*

***Grattan, S. R., L. Zeng, M. C. Shannon and S. R. Roberts. 2002. "Rice is more sensitive to salinity than previously thought." California Agriculture 56:189–195.*

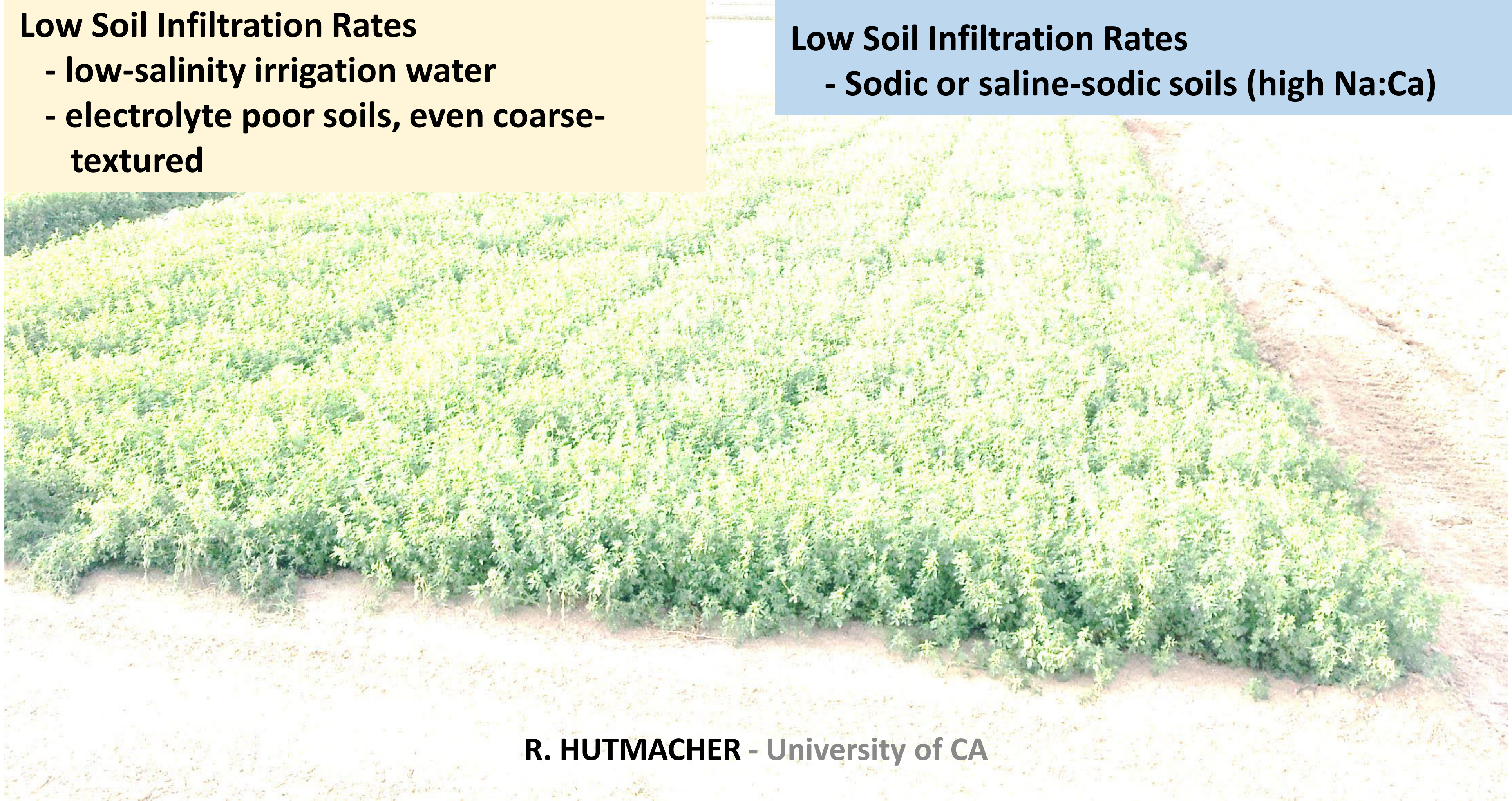
Review some Situations where Gypsum or Acid Amendments have Potential Uses:

<u>SOILS WITH:</u>

Low Soil Infiltration Rates
- **low-salinity irrigation water**
- **electrolyte poor soils, even coarse-textured**

<u>SOILS WITH:</u>

Low Soil Infiltration Rates
- **Sodic or saline-sodic soils (high Na:Ca)**



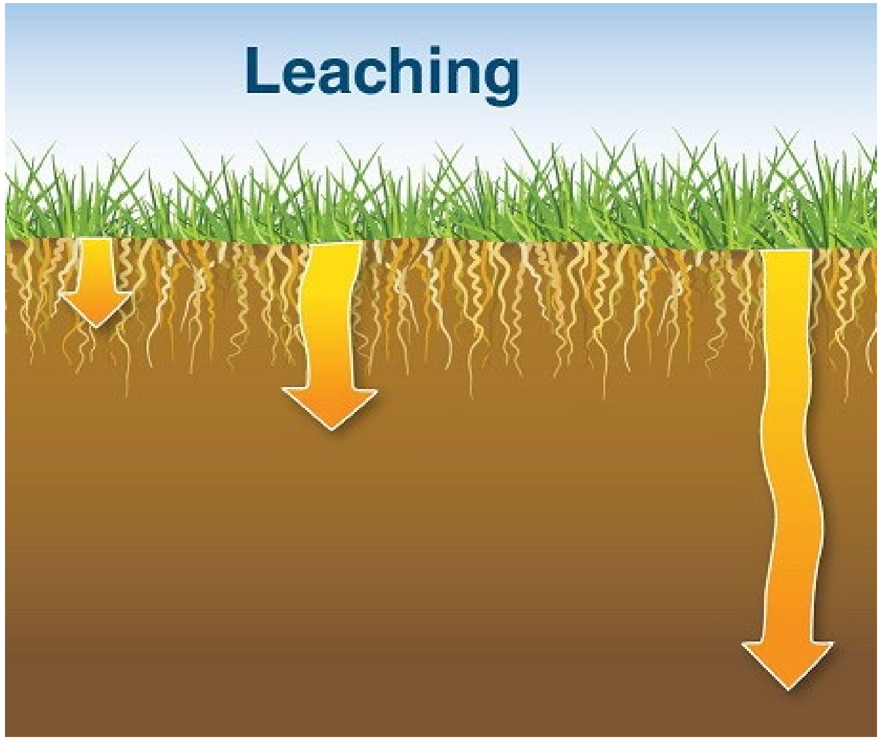
R. HUTMACHER - University of CA

Leaching

- process of applying more water to the soil than the soil can hold allowing for excess drainage below the root zone

"Leaching is the key factor in controlling soluble salts brought in by the irrigation water (or other sources)"

Ayers and Westcot, 1985



But what about nitrogen (nitrate form) and pesticides… don't those move downward in profile with leaching?…. Yes!

Types of Leaching

Maintenance Leaching

- Assumes that the level of soil salinity is not excessive and only small changes occur over time
- **Proactive approach: apply sufficient water so that salts do not accumulate**
- *Leaching requirement (LR) calculations refer to maintenance leaching– the extra water you need to apply across the season (~each irrigation)*

? *- given the current focus on reducing NO_3 leaching to groundwater), do we really want to do maintenance leaching?*

? *- are we overestimating the amount of water required for leaching with the traditional LR calculation?*

Reclamation Leaching

- Salinity has accumulated in the root zone.
- Periodic, heavier applications of water, to reclaim soil
- *Leaching Calculator (UCCE Kern Co.)*
- *More feasible if irrigation water supplies are scarce*

Estimating a Leaching Requirement (LR)

Irrigation water salinity = 1.4 dS/m EC_w

Yield loss threshold (tomatoes) = 2.5 dS/m ECe

1) $$LR = \frac{EC_w}{(5 \times EC_e) - EC_w}$$

$$= \frac{1.4}{(5 \times 2.5) - 1.4} = 0.126 \quad (12.6\%)$$

2) Total water needed (Applied Water- AW)

$$AW = \frac{ET}{1 - LR}$$

LR = 0.126 (above)

$$= \frac{28 \text{ in.}}{1 - 0.126} = 32 \text{ in.} \quad (81.4 \text{ cm})$$

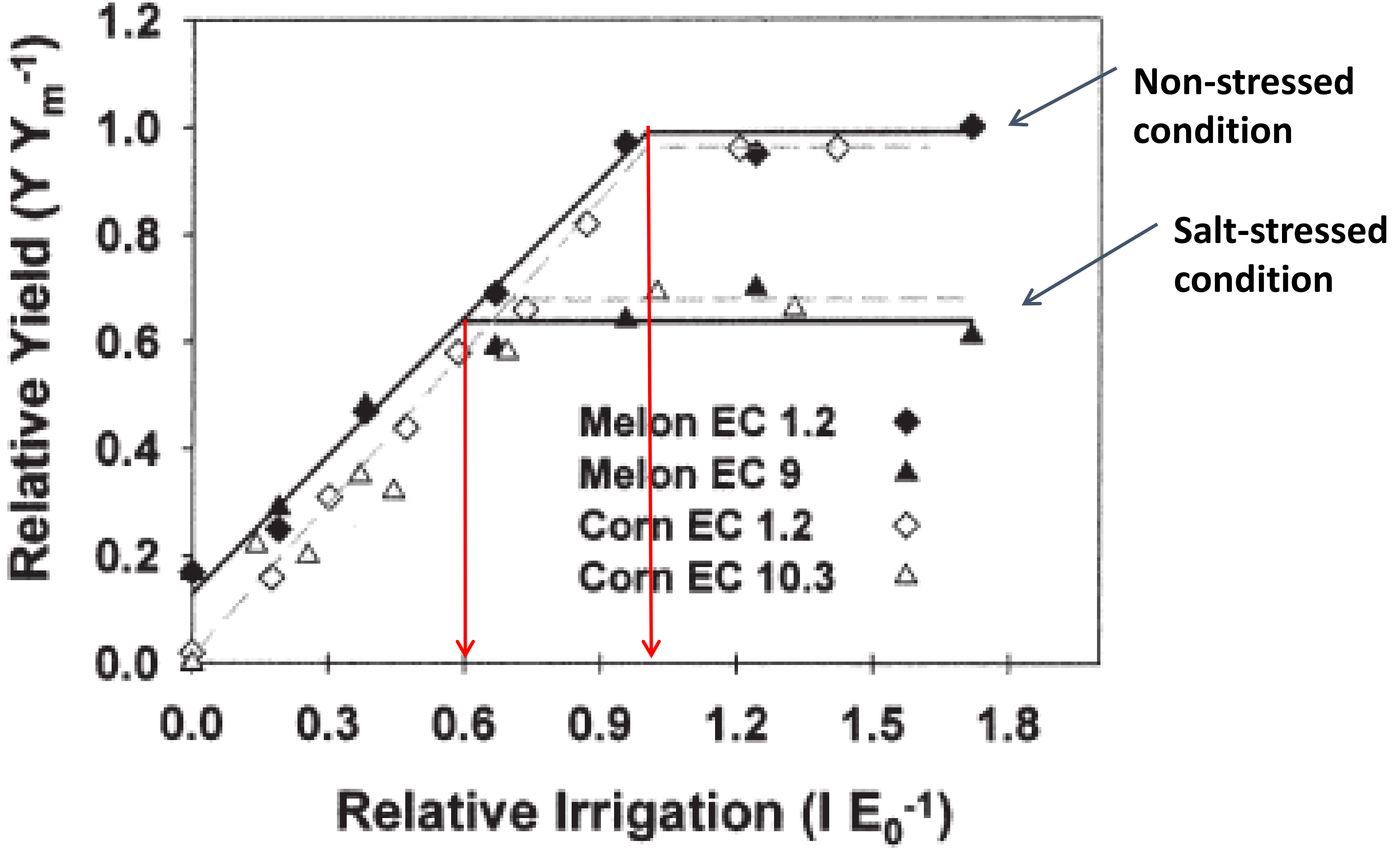
Dominant Factor approach* & implications for amount of water required for leaching

***if salinity affects the crop to the extent that ET is reduced, then applying just the normal crop water requirement may result in some leaching of the profile.**

And we may be able to apply less N… if reducing water application means less leaching of N.

*Shani et al. (2005). Environmental Implications of Adopting a Dominant Factor Approach to Salinity Management. J. Envi. Quality 34:1455-1460.
doi.10.2134/jeq2004.036

Yield Response– combined salinity & water stress (Shani et al.,2005. JEQ)

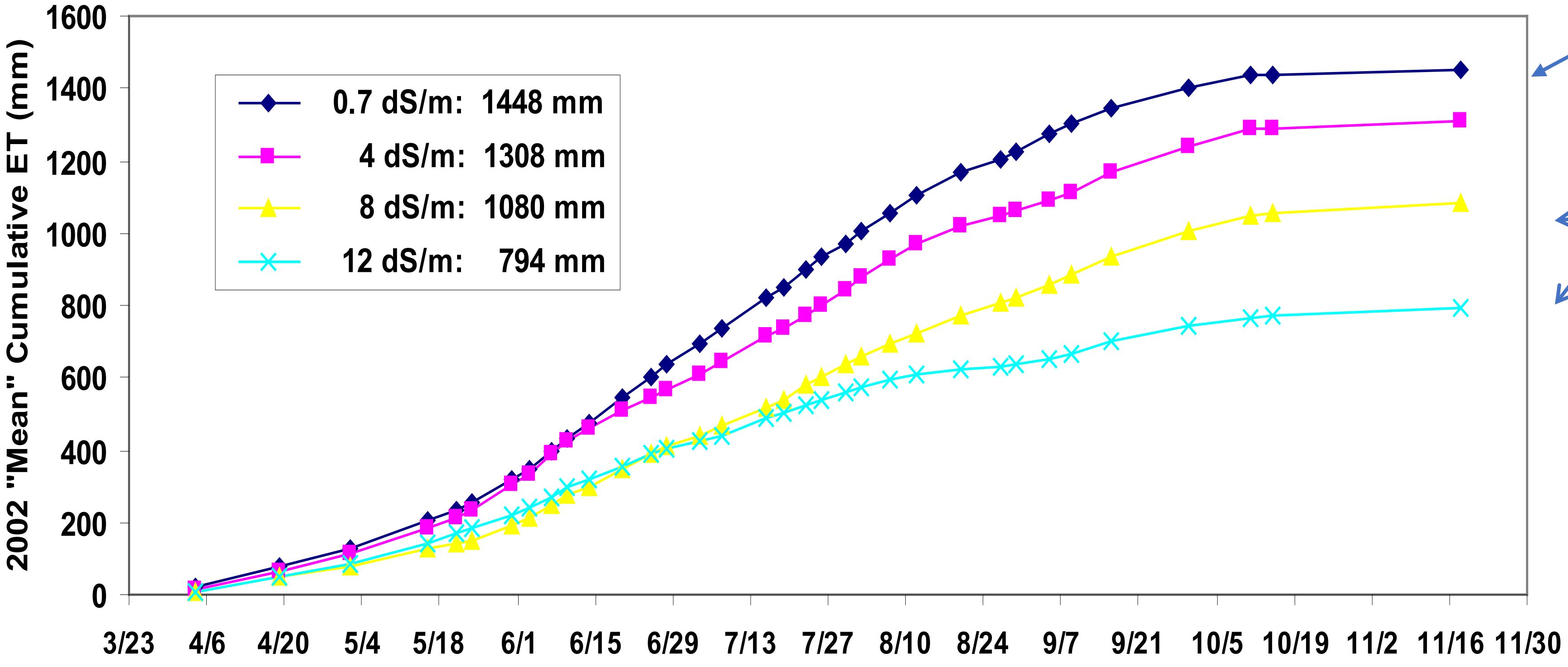


Water requirement of melons & corn under "non-saline" irrigation was ~1.0 potential evaporation (E_o, Class A Pan) vs. 0.6 E_o under saline irrigation

SOIL SALINITY & EVAPOTRANSPIRATION

Pistachio Salinity trial ET for 2002 season

(From: Sanden, Ferguson, Reyes, Grattan. 2004. Effect of salinity on evapotranspiration and yield of San Joaquin Valley pistachios. Acta Horticulturae 664:583-589. Also: Ferguson, Poss, Grattan, Grieve, Wang, Wilson, Donovan, Chao. JASHS 127(2): 194-199.



ET meeting or exceeding applied irrigation, low soil moisture, salts accum. in profile

ET reduced. Volumetric water content 80-100% of field capacity throughout season.

Pistachios showed significant decreases in relative cumulative evapotranspiration, but average yields did not decline until irrigation salinity was 8 dS/m.

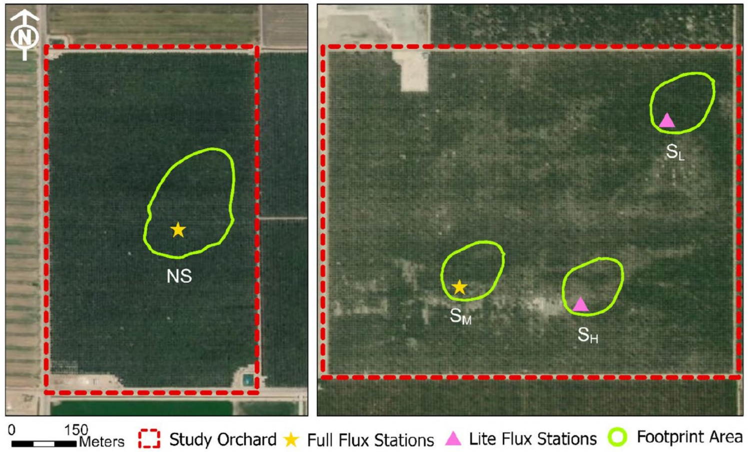
If ET is significantly lowered by salinity, some of the applied water fulfills the leaching requirement

→ Evidence: volumetric water content in the high salinity plots remained at 80 – 100% of field capacity for most of the season

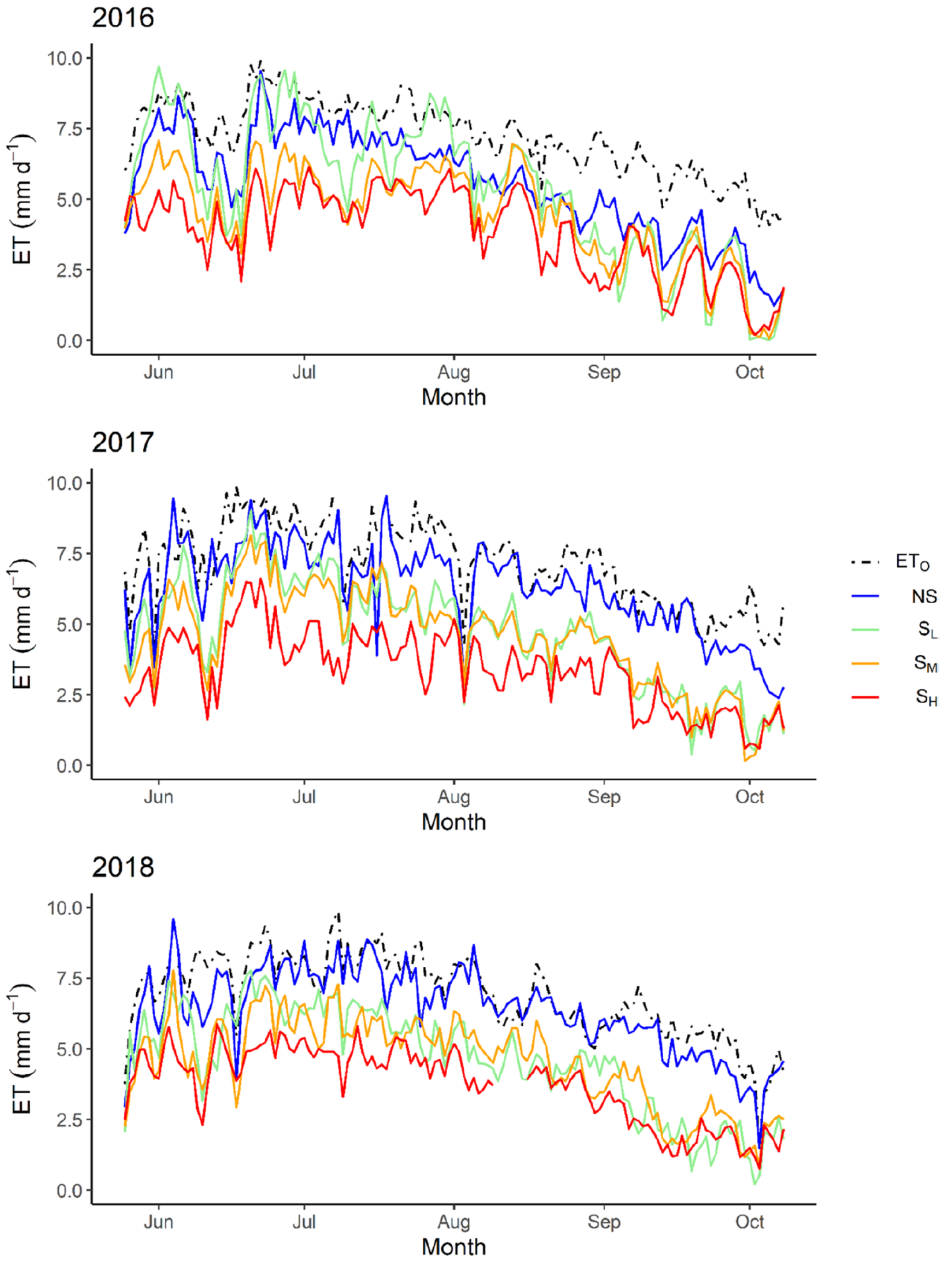
Another example: reduced ET under saline conditions

Effects of salinity and sodicity on the seasonal dynamics of actual evapotranspiration and surface energy balance components in mature micro-irrigated pistachio orchards

Giulia Marino[1] · Daniele Zaccaria[2] · Luis O. Lagos[3] · Camilo Souto[3] · Eric R. Kent[1] · Stephen R. Grattan[2] · Kristen Shapiro[2] · Blake L. Sanden[4] · Richard L. Snyder[2]



A non-saline orchard (NS) and a saline orchard (S) with selected areas of low, medium and high salinity (S_L, S_M, S_H),



But how do you know if crop ET is substantially reduced such that less water can be applied for leaching?

- **Monitoring soil moisture may be one way of detecting**

Decision Support Tools

1) SALEACH. Web-based program. UC Riverside, Dept. of Envi. Sciences. (Laosheng Wu)

https://salinity.ucr.edu/Sindex.html

Calculates Leaching fraction based on the following factors

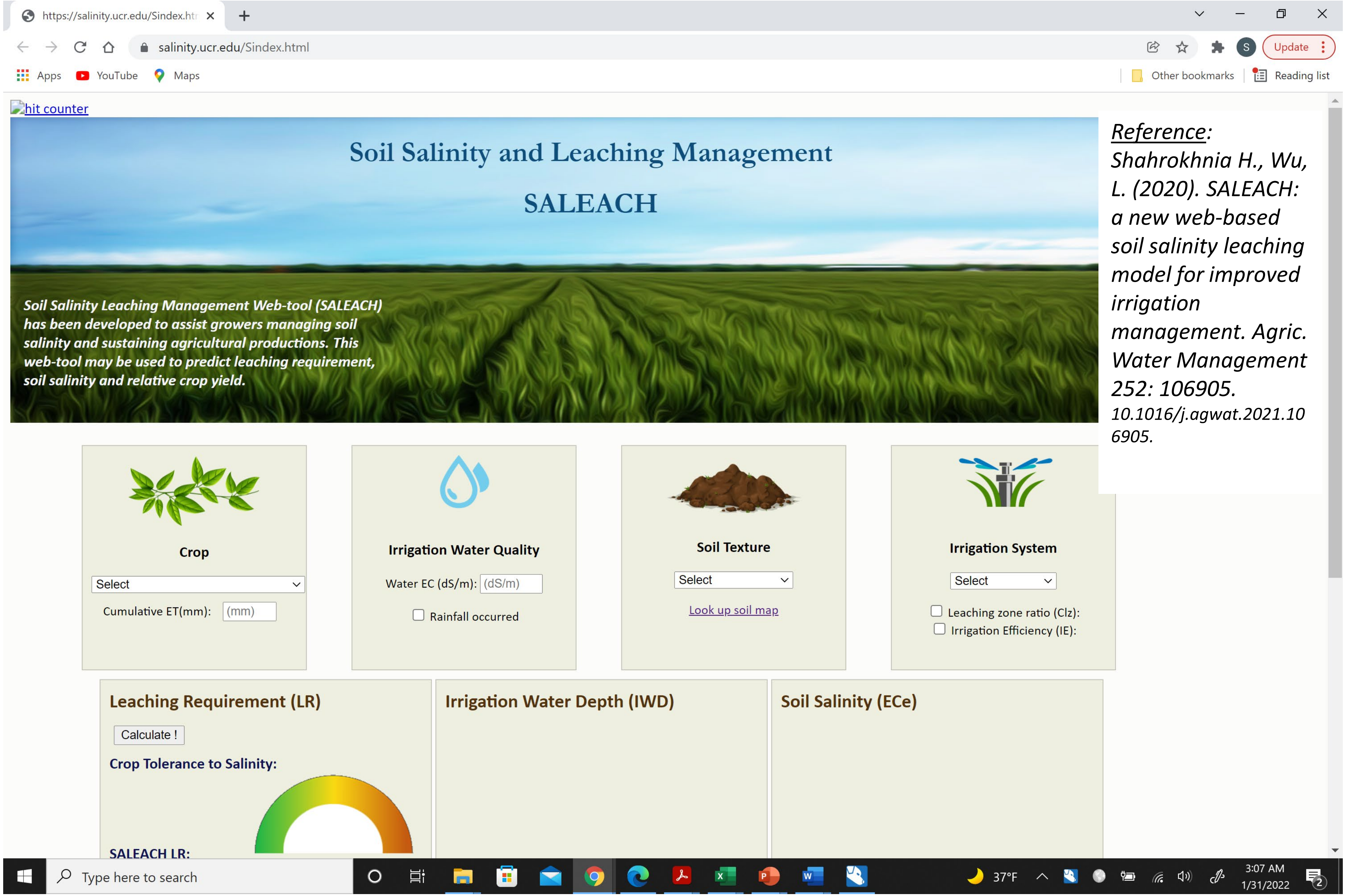
- crop
- Irrigation water salinity,
- *soil texture
- irrigation system (sprinkler, drip, flood) and its efficiency
- Output: traditional LR (Rhoades) vs. SALEACH LR and/or your Preferred LR

Reference: Shahrokhnia H., Wu, L. (2020). SALEACH: a new web-based soil salinity leaching model for improved irrigation management. Agric. Water Management 252: 106905. 10.1016/j.agwat.2021.106905.

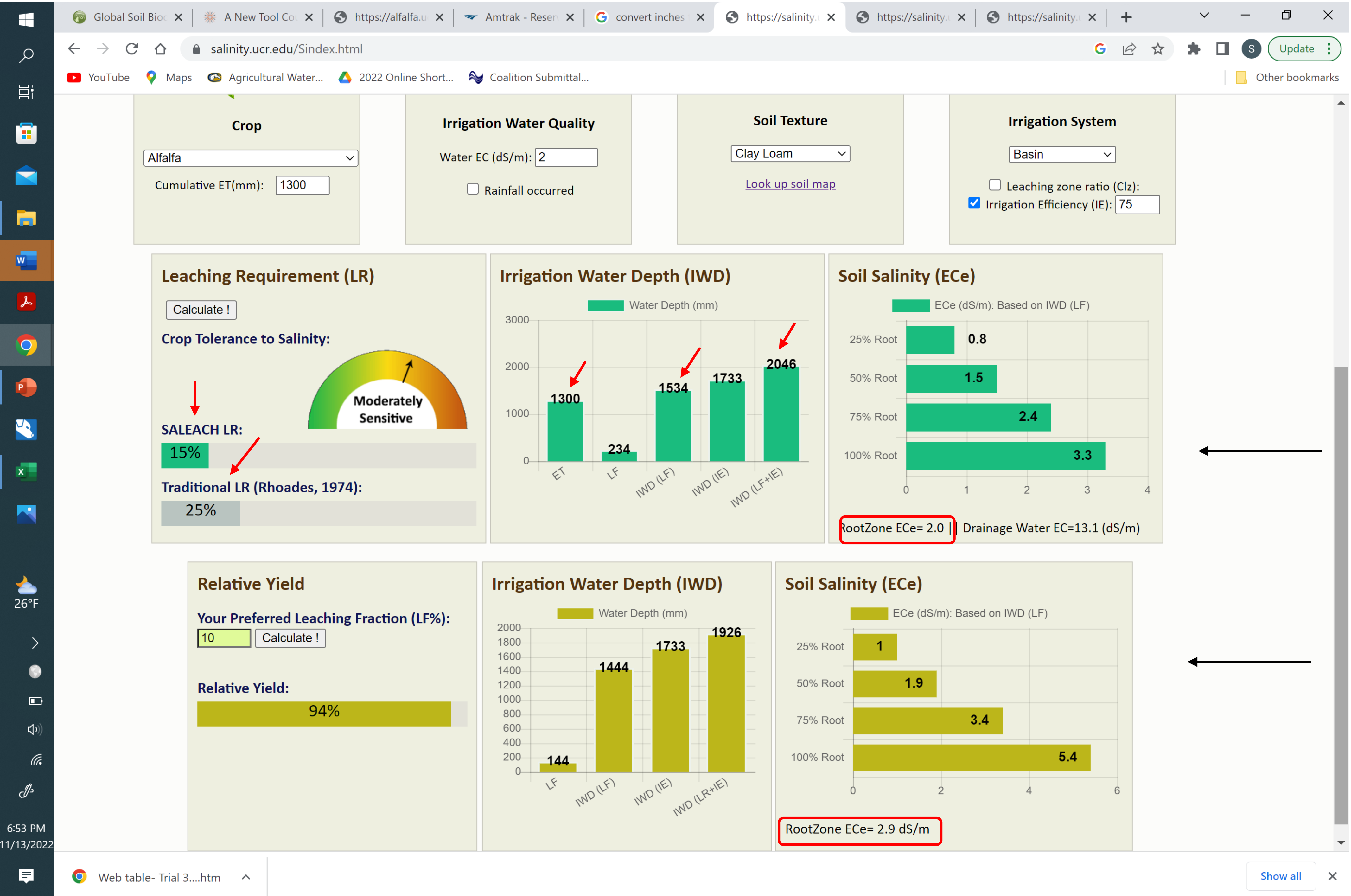
2) Leaching Calculator (Excel-based). UCCE Kern Co. (Blake Sanden)

https://cekern.ucanr.edu/Irrigation_Management/ANALYTICAL_CONVERSIONS_AND_LEACHING_CALCULATIONS/

- Output: Reclamation leaching (sprinklers or drip): in. water/ft. rootzone to leach from current to desired ECe



<u>Reference</u>: Shahrokhnia H., Wu, L. (2020). SALEACH: a new web-based soil salinity leaching model for improved irrigation management. Agric. Water Management 252: 106905. 10.1016/j.agwat.2021.106905.



Alfalfa

EC_w = 2 dS/m

Clay loam

Basin Irrig. (75%)

ET = 1300 mm

(51 in.)

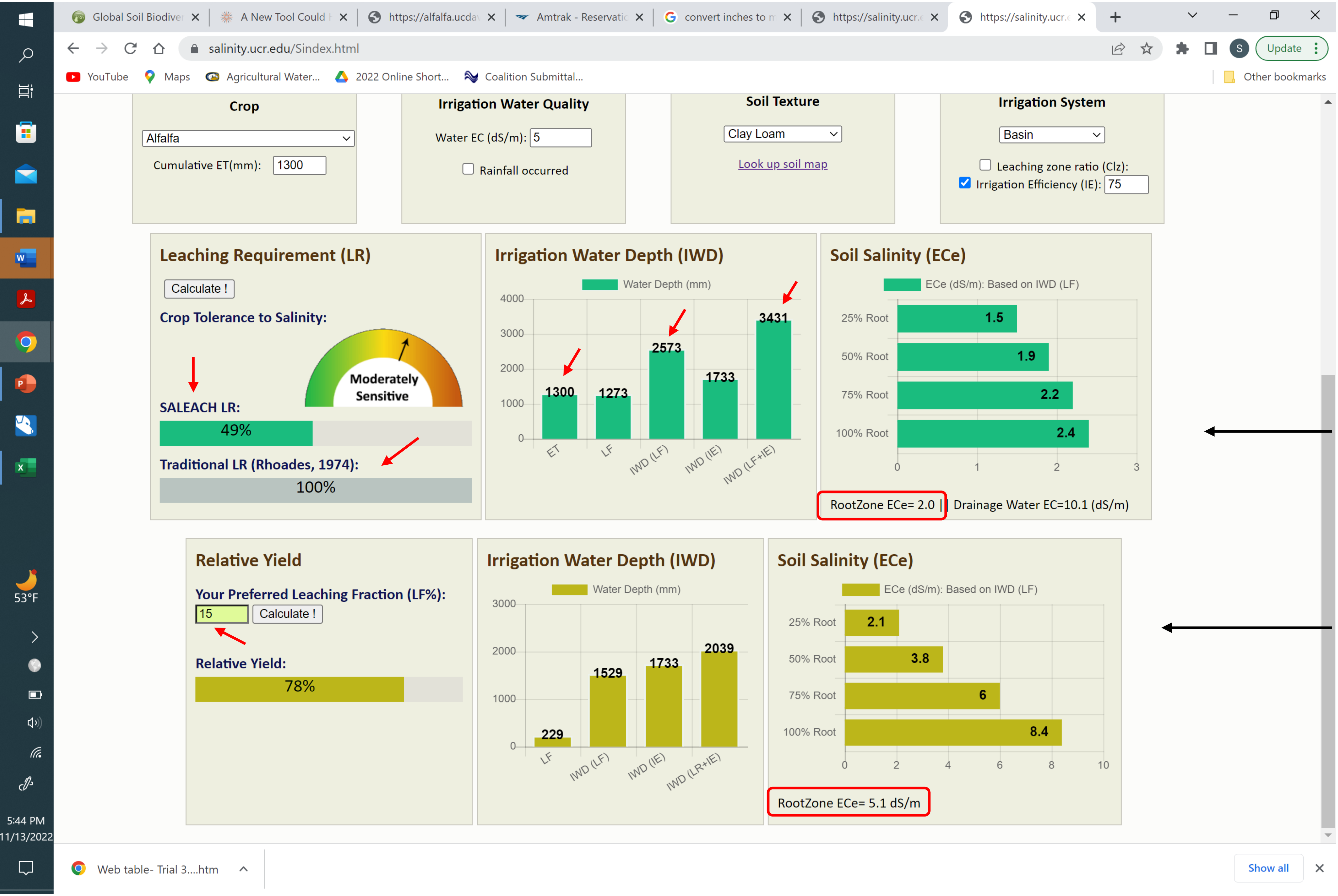
Traditional LR =25% (0.25)

SALEACH LR = 15%

$IWD_{leaching}$ (additional) = 1534 mm **(60.4 in.)**

Preferred LR = 10%

$IWD_{leaching}$ (additional) = 1444 mm **(56.9 in.)**



Alfalfa

EC_w = 5 dS/m

Clay loam

Basin Irrig. (75%)

ET = 1300 mm

(51 in.)

Traditional LR = 100%

SALEACH LR = 49%

$IWD_{leaching}$ (additional)

= 2573 mm!

(101 in.!)

Preferred LR = 15%

$IWD_{leaching}$ (additional)

= 1529 mm

(60.2 in.)

Reclamation leaching calculations

Leaching Calculator UCCE Kern Co: (Excel spreadsheet)
https://cekern.ucanr.edu/Irrigation_Management/ANALYTICAL_CONVERSIONS_AND_LEACHING_CALCULATIONS/.

Required Leaching (ft water/ft depth soil) = K / (Desired EC/Original EC)

(K factor of 0.3 for continuous ponding.)

(K factor of 0.15 for sprinkling or drip.)

(K can be as small as 0.1)

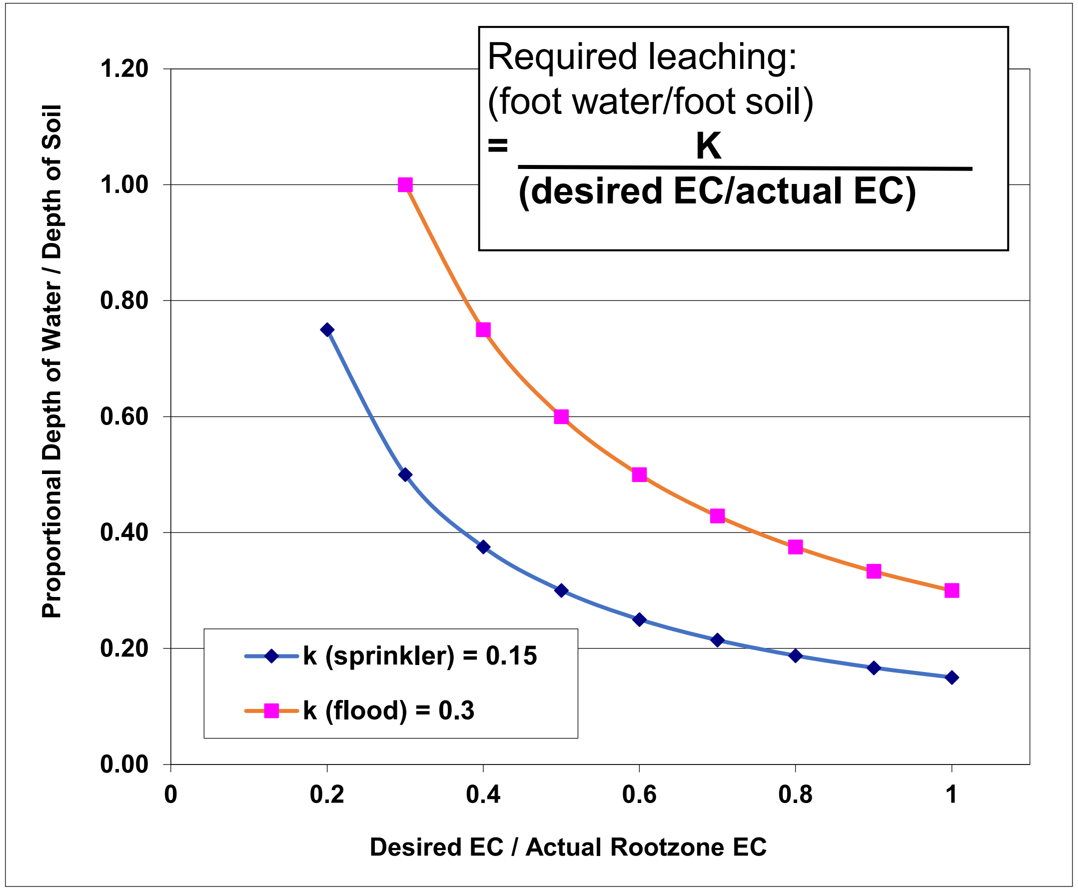
SPRINKLING RECLAMATION

Desired Rootzone Salinity dS/m	*Inches of water/foot of rootzone Required to leach initial salinity of:			
	4	**8**	**12**	**16**
2	3.6	7.2	10.8	14.4
4	--	3.6	5.4	7.2
6	--	2.4	3.6	4.8

ECe = 6 dS/m, 5.4 in. water per ft. depth soil

**if boron is high, increase LR*

(K factor of 0.3 for continuous ponding)
(K factor of 0.15 for sprinkling or drip.)

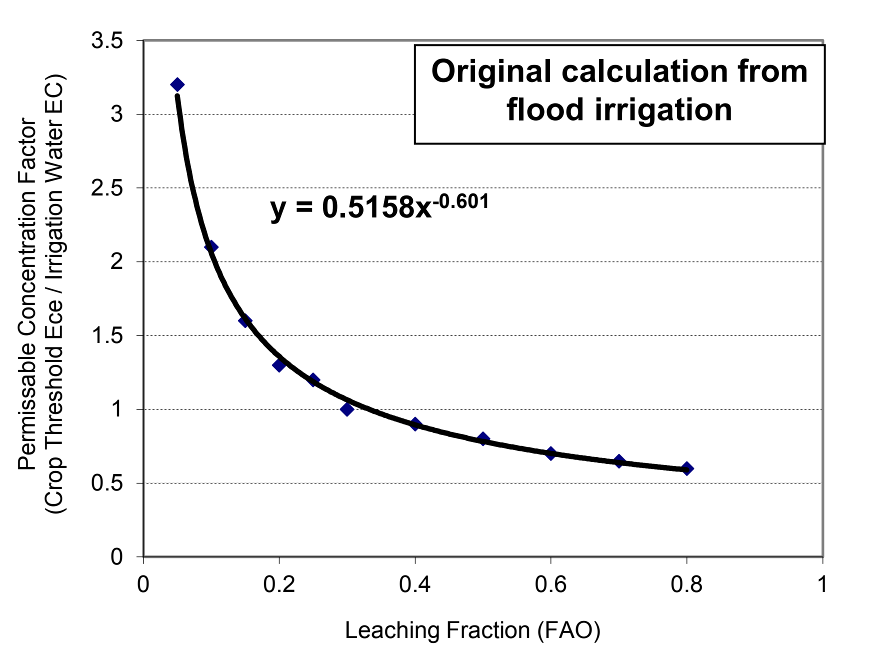


Leaching Calculator UCCE Kern Co: ("Final root zone ECe by LF Worksheet")

https://cekern.ucanr.edu/Irrigation_Management/ANALYTICAL_CONVERSIONS_AND_LEACHING_CALCULATIONS/.

Table 3 CONCENTRATION FACTORS (X) FOR PREDICTING SOIL SALINITY (ECe)1 FROM IRRIGATION WATER SALINITY (ECw) AND THE LEACHING FRACTION (LF)

Leaching Fraction (LF)	Applied Water Needed (Percent of ET)	Avg ECe Ro Concentration Factor X
0.05	105%	3.2
0.1	111%	2.1
0.15	118%	1.6
0.2	125%	1.3
0.25	133%	1.2
0.3	143%	1
0.4	167%	0.9
0.5	200%	0.8
0.6	250%	0.7
0.7	333%	0.65
0.8	500%	0.6



Average RZ saturation extract EC (dS/m) after long-term irrigation with a given salinity water (ignoring precipitation/dissolution reactions in the soil) and Leaching Fraction

Irrigation Water EC (dS/m)	Leaching Fraction (LF) above crop ET requirement				
	0.05	**0.1**	**0.15**	**0.2**	**0.3**
0.2	0.62	0.41	0.32	0.27	0.21
0.6	1.87	1.24	0.97	0.81	0.64
1.0	3.12	2.06	1.61	1.36	1.06
1.5	4.69	3.09	2.42	2.04	1.60
2.0	6.25	4.12	3.23	2.72	2.13
2.5	7.81	5.15	4.03	3.39	2.66
3.0	9.37	6.18	4.84	4.07	3.19
3.5	10.94	7.21	5.65	4.75	3.72
4.0	12.50	8.24	6.46	5.43	4.26
4.5	14.06	9.27	7.26	6.11	4.79
5.0	15.62	10.30	8.07	6.79	5.32
5.5	17.19	11.33	8.88	7.47	5.85

SOLVING FOR DESIRED LEACHING FRACTION DIRECTLY:

LF = 0.3086(Desired ECe/ECirr)^ -1.66

In-Season vs Dormant-Season Leaching – *pros & cons*

(maintenance) *(reclamation)*

In-Season Leaching

Pros:

- ✓ leaching tied to weekly ETc
- ✓ If effective, lower salt & trace element exposure during peak growth periods

Cons:

- ✓ Some soils can't infiltrate full amounts to meet ETc + leaching requirements
- ✓ localized soil volumes can be under conditions of anoxia – plant damage, disease?
- ✓ Increase potential for fertilizer nutrient leaching

Dormant Season Leaching

Pros:

- ✓ low water use time of year, may be more effective leaching
- ✓ **Potentially more effective for Boron, Chloride leaching**
- ✓ Avoids anaerobic conditions during more active growth
- ✓ Better separation from timing of soluble nutrient applications

Cons:

- ✓ soil water content must be brought back to field capacity for leaching to occur (can be an issue low rainfall year)

Summary

- **Leaching is required** to prevent/reduce salt accumulation in the root zone
- **Soil testing should be done to assess the need for leaching.** Compare to established threshold values for yield loss due to salinity… but keep in mind that varieties improved for salt tolerance may tolerate soil salinities higher than the threshold values.
- **Address sodicity if also a problem**
- **Know your water quality** and whether boron might be present at toxic levels
- **Choose a more salt tolerant crop / variety /rootstock, if available.**
- Monitor soil moisture to get an idea if ET being reduced under salinity
- ---
- **Under water scarcity, maintenance leaching may not be feasible** and it increases the risk for leaching of nitrate (or other nutrients) below the root zone… or water-logging of soils if infiltration is not good.

  - ***properly-timed reclamation leaching may be better in terms of salt and N management***

  - ***reclamation leaching should be conducted at the time of year when soil N is low***
- Decision Support tools are available to predict yield loss at a given soil salinity and/or to estimate the amount of water to apply for reclamation leaching (UCCE Kern Co Leaching)

Insights from others

- **Utilize crop residues to avoid run-off**. More water infiltrated in the dormant season may provide leaching.
- **Pre-irrigation: often excessive (Salinas Valley)**. Conserve this water, use later and strategically for leaching
- **Do you need the same LF with frequent, drip irrigation** where salts are moving outward, not just downward. Maybe less water during the season to allow for post-season leaching (as guided by soil testing). Sprinkling may be best.

- **Monitor soil moisture in-season** to get an idea if ET being reduced under salinity
- **Be cognizant of type of water using**. If pulling from deeper depths, may be picking up more boron, or water much more alkaline (high pH).

More severe water shortage

- Don’t leach all fields. Consider where best to put your limited water, considering economic return
- Cannot protect all ground and budget may not allow for the amount needed for chemical amendments in some fields…. where sodicity is also a problem

Almond

EC_w = 2 dS/m

Clay loam

Drip Irrig. (85%)

ET = 1220

Traditional LR

= 36% (0.36)

SALEACH LR

= 14%

$IWD_{leaching}$
(additional)
= 1415 mm (55.7 in.)

$IWD_{leaching + IE}$
(additional)
= 1665 mm (65.6 in.)

Tomato

EC_w = 2 dS/m

Clay loam

Drip Irrig. (85%)

ET = 610 mm

(24 in.)

Traditional LR

= 19% (0.19)

SALEACH LR

= 7%

$IWD_{leaching}$ (additional)

= 658 mm (25.9 in.)

$IWD_{leaching + IE}$ (additional)

= 774 mm (30.5 in.)

How much salt added with irrigated agriculture?

EC (dS/m) x 640 = TDS (mg/L)** **applies if EC of water <5 dS/m*

**milligram (mg) /10^6 = kilogram (kg)* *1 kg = 2.20 lbs.*

1 gallon= 3.785 liters *1 acre-ft = 325,850 gal.*

Example: irrigating with 1.5 dS/m water (about double average for the CA Aqueduct), how much salt would be added?

For one acre foot:

$$1.5\ \text{dS/m} \times 640\frac{\text{mg}}{\text{L}} \times \frac{3.785\ \text{L}}{\text{gal}} \times \frac{\text{kg}}{10^6\ \text{mg}} \times \frac{2.2\ \text{lbs.}}{\text{kg}} \times \frac{325{,}850\ \text{gal.}}{\text{acre-ft.}}$$

= 2,605 lbs salt per acre-foot of water applied

…. or ~10,420 lbs per acre if applied 4 feet of this irrigation water

Steady-state equations (for maintenance leaching) may over-estimate the water required for leaching

$$LR = \frac{EC_w}{5\ EC_{e(100\%)}^{*} - EC_w} \times 100$$

**ECe= crop's estimated yield loss threshold (100% yield). Threshold value may be higher for improved varieties / rootstocks*

Use $EC_{e90\%}$ instead? Growers may accept a 10% yield loss when water supplies are tight.

⇒ Transient state models: estimate root zone salinity real-time and calculate appropriate leaching requirements within season

- but still a challenge for growers or consultants to use these models

Review

Evaluation of soil salinity leaching requirement guidelines

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SALT-AFFECTED SOIL CLASSIFICATIONS *(NRCS & USDA-ARS Salinity Lab)*

Soil classification	Electrical conductivity (ECe, dS/m)	Sodium Absorption Ratio (SAR)	Exchang. Sodium Percentage (ESP)	Soil pH	Resulting Soil Physical / Structural Conditions
Not salt-affected	< 4	Below 13	Below 15	< 8.5	Flocculated
Saline	> 4	Below 13	Below 15	< 8.5	Flocculated
Sodic	< 4 typically	Above 13	Above 15	> 8.5	Poor - Dispersed
Saline-sodic	Greater than 4	Above 13	Above 15	< 8.5	Impacted but Flocculated

Can "assign" soils a certain classification, but salinity issues can change over time, so there can be changes or a progression from "not salt-affected" to some level of salinity impact