Gypsum and Acid Amendments to Soils and Irrigation Water:

Infiltration Problems / Issues with Use

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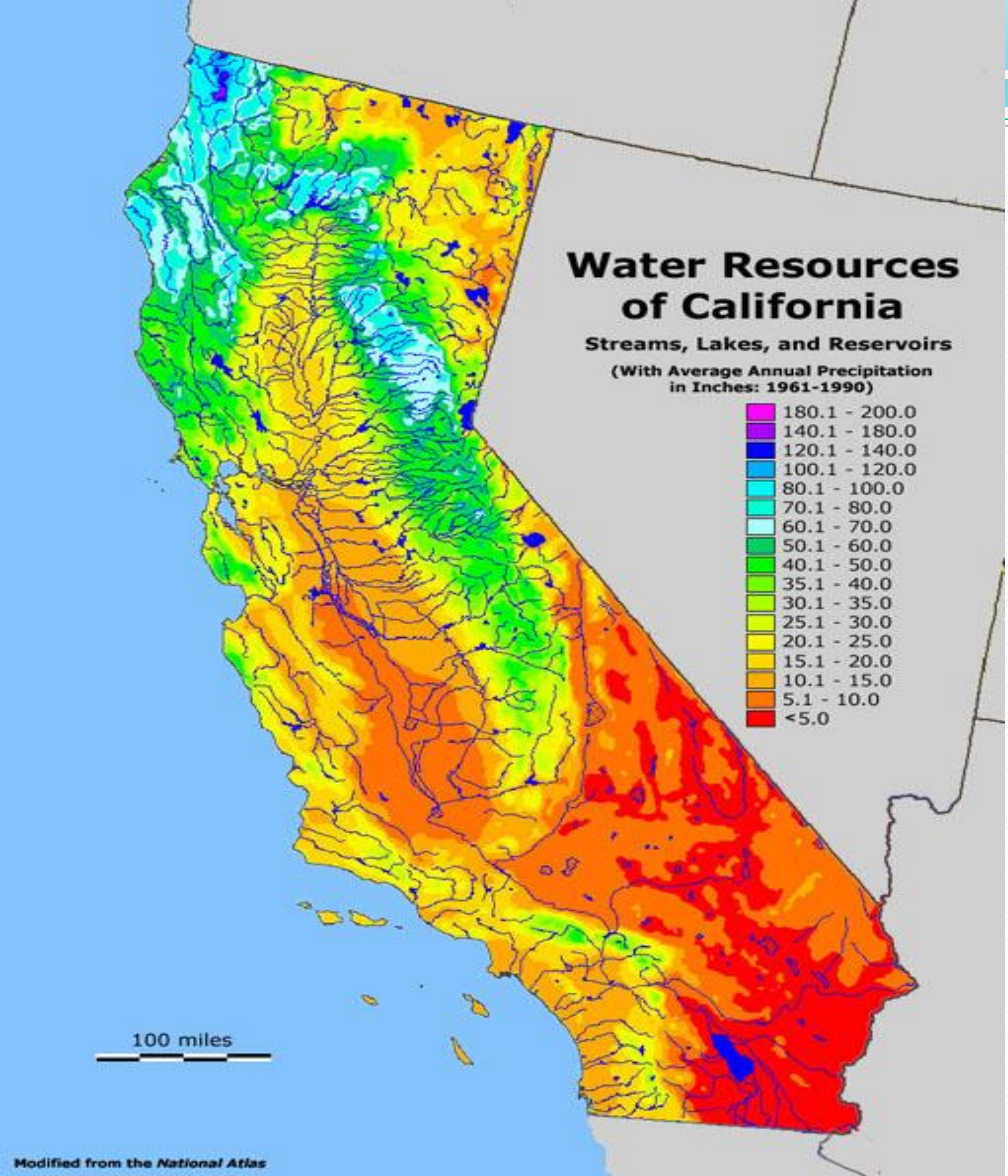
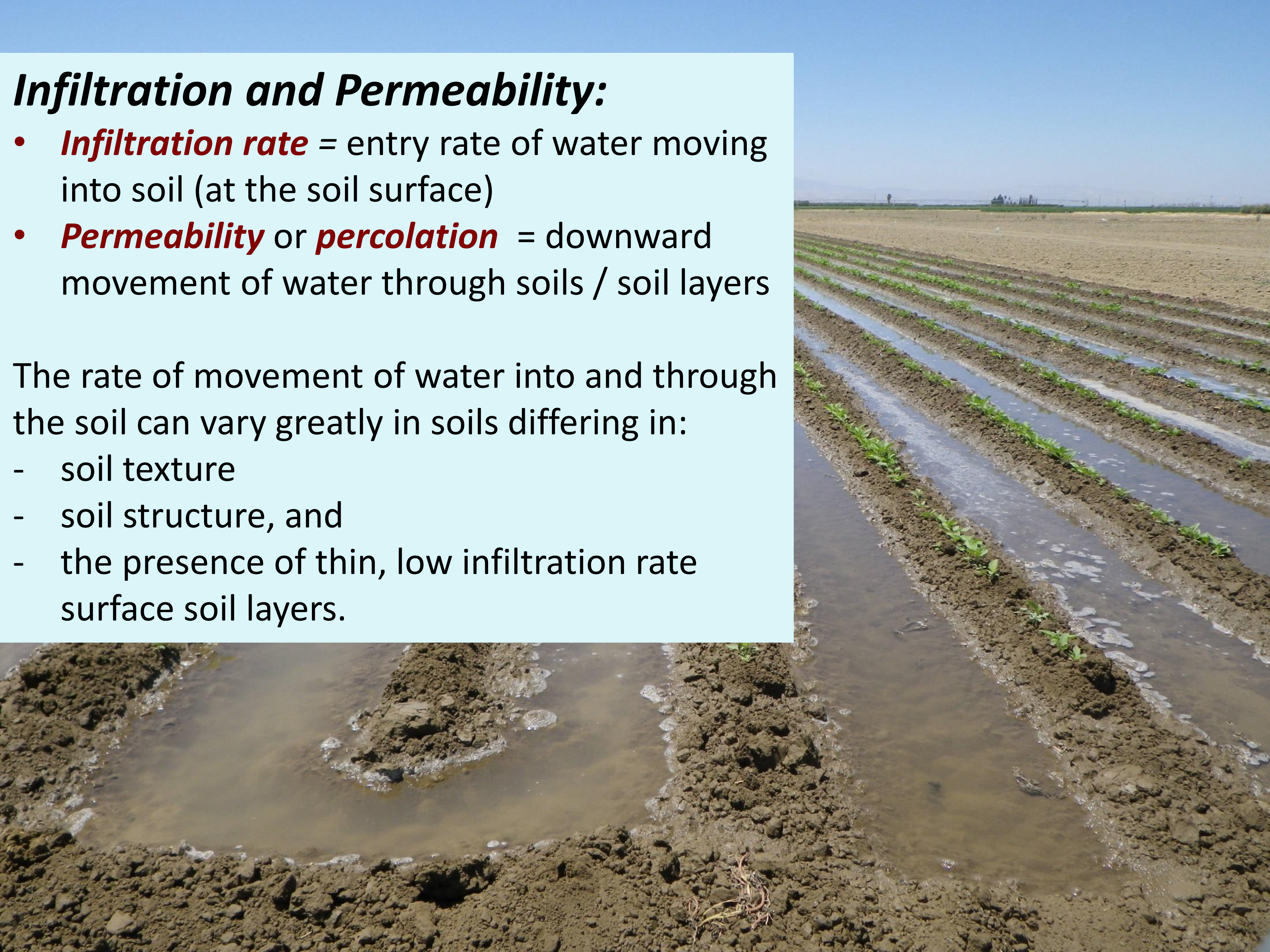


Irrigation capabilities and rainfall are highly variable across the state.

Soil characteristics can be highly variable too, on a much smaller scale that also impacts issues in irrigation & salinity management



Infiltration and Permeability:

- ***Infiltration rate*** = entry rate of water moving into soil (at the soil surface)
- ***Permeability*** or ***percolation*** = downward movement of water through soils / soil layers

The rate of movement of water into and through the soil can vary greatly in soils differing in:

- soil texture
- soil structure, and
- the presence of thin, low infiltration rate surface soil layers.

Soil Water Infiltration Issues

Influenced by a collection of factors, including:

- ✓ biological activity / including cropping
- ✓ Soil physical characteristics (structure, mineralogy, damage to structure, etc.)
- ✓ Soil and water chemistry

Chemical parameters influencing irrigation water infiltration to large degree include:

- ✓ ECw (electrical conductivity, irrig water)
- ✓ SAR (sodium absorption ratio, a relative indicator of predominance of Na ions)

Factors that can influence soil aggregate dispersal and irrigation water infiltration

Although these may seem like extremes … the following conditions both can result in reduced infiltration:

LOW ECw (very low irrigation water EC – salinity)

or

HIGH IRRIGATION WATER SAR (sodium absorption ratio)

- ✓ *These conditions can separately or together cause aggregate dispersal, reducing the # of large pores in the soil, and increase formation of soil crusts and layers that cause soil sealing.*

Assessing Infiltration Issues/ relationship to salts

Irrigation water analysis- *how much total salt and specific ions (Na, Cl, B) are contributed by each water source utilized during season?*

Soil samples/analysis (representative of field or zones) – details important in determining if: *it is saline, saline-sodic or sodic?*

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?*

Leaching Salinity Mgmt: *reclamation or maintenance? Drainage options?*

Amendments *(gypsum, or sulfur/acid if free lime is present)*- *sodicity issues*

Appropriate irrigation management to *avoid water-logging, infiltration issues*

Suitable crop/variety for salinity level existing in field (Maas-Hoffman salinity tolerance tables). *How much yield loss is acceptable? Are there known differences in salinity tolerance at different growth stages (ie. Seedling germination/emergence versus established plants?*

Example: Irrigation water analysis

		EC	Ca	Mg	Na	SAR	Adj SAR	Cl	HCO_3 + CO_3	SO_4	B	NO_3-N	pH	TDS
		dS/m	meq/L	meq/L	meq/L			meq/L	meq/L	meq/L	mg/L	mg/L	unit	mg/L
001	0.5 ds/m	0.47	1.38	0.67	1.2	1.1	1.8	0.3	2.5	0.1	0.03	19.1	8.3	
002	5 ds/m	6.51	7.16	7.48	53.2	19.7	43.1	30.0	3.6	37.6	10.9	23.3	9.1	

General Ag Levels	Total				Sodium Abs. Ratio		Carbonates &					
	Salts	Calcium	Magnesium	Sodium	SAR	Adjusted	Chloride	Bicarbonate	Sulfate	Boron	Nitrate	pH
Low	<0.50	<4.00	-	-	-	-	-	-	-	-	-	<6.5
Normal	0.60-1.50	5.0-10.0	1.1-5.0	<4.0	0.1-4.0	0.1-4.0	0.1-1.5	0.1-2.5	0.1-5.0	0.01-0.40	0.1-5.0	6.8-7.9
High for Sensitive Crops	1.51-2.20	> 10.00	> 5.0	4.1-7.0	4.1-9.0	4.1-9.0	1.6-3.5	2.5-3.5	-	0.41-0.59	5.1-7.0	8.0-8.4
High for Tolerant Crops	> 2.20	-	-	> 7.0	> 9.0	> 9.0	> 3.5	> 3.5	-	> 0.60	> 7.0	> 8.4

Many of the above parameters need specific adjustment for crops, uses, irrigation procedures, etc. Check report for specifics.

When sodium is greater than calcium (or high SAR), the water is considered sodic or "alkali".

Black = Normal	
Red = High	Green = Sl. Low
Orange = Sl. High	Blue = Low

WHAT TO MEASURE?

Test	Information Provided	How use for Management?
Electrical conductivity (EC)	Measures soil solution electrical conductance, related to quantity of salts that impact conductance	Relative indicator of the quantity of salts, dissolved ions in the soil. Higher EC levels (>3-4 dS/m) often associated with reduced seedling germination and survival, growth reductions.
pH	Relative indicator or soil acidity, alkalinity	Can be an indicator of sodic soil (if pH>8.5), impacts solubility of some nutrients, minerals. When pH exceeds 8.2-8.5, attention is needed to monitoring Na, Ca, Mg to identify problematic ESP and SAR levels
Calcium Carbonate Equivalent	Amount of undissolved calcium carbonate in soil	When calcium carbonate relatively high, may use acid (sulfuric or others) or elemental S instead of gypsum

Test	**Information Provided**	**How use for Management?**
Cation levels (Na, Ca, Mg, K) & CEC (cation exch. capacity)	Relative ion conc. impacts adsorption & soil properties. With higher CEC, typically harder to remove salts.	Determines dominant cations. CEC is total quantity of cations that can be exchanged (Ca, Mg, K, Na, H, Al). When both known, ESP values can be determined as well as gypsum requirement.
Sodium Absorption Ratio (SAR)	Relative indicator of Na ion conc. relative to Ca, Mg (in soil or irrigation water)	Measure of relative sodium hazard (**SAR>13**) in water or soil saturated paste extract (soil solution). Higher Na & SAR damage soil structure
Exchangeable Sodium Percentage (ESP)	Na as percentage of cation exchange sites in soil	**ESP** used in determining gypsum application amounts for sodic soils. ESP = (Na / CEC)*100 (in meq/100g) ** Can also be estimated using SAR*

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

<u>SOILS WITH:</u>

Low Soil Infiltration Rates under conditions of low-salinity irrigation water

<u>SOILS WITH:</u>

Low Soil Infiltration Rates in Sodic soils (high Na:Ca+Mg ratios)

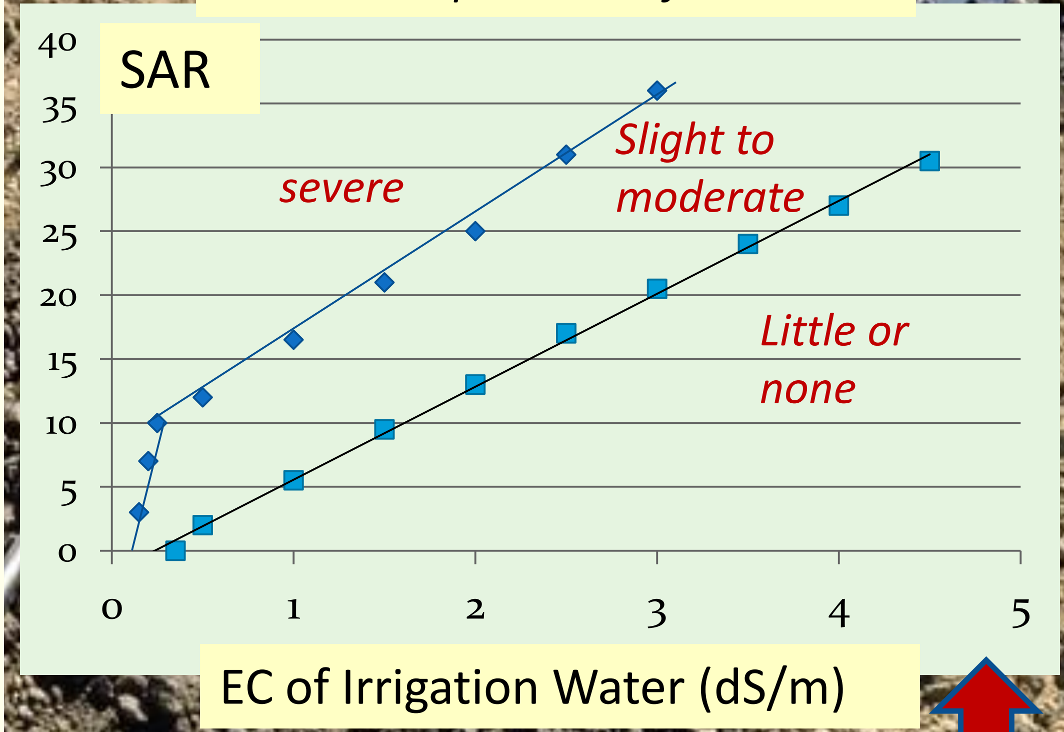
Water Quality Impacts on Infiltration – *adding* *gypsum to irrigation water*

Ayers and Westcot developed well-known chart of irrigation water EC (elect. cond.) & SAR (Na absorption ratio) impacts on infiltration.

In situations where you deal with **low EC water** (ex: some eastern SJV areas) and soil structure damage, adding enough gypsum to water can shift location in SAR:ECw chart out of "severe" zone

***General approach can be to aim for SAR < 5 times ECw**

EC & SAR Impacts on Infiltration



SAR (sodium absorption ratio) is a ratio of cations with "bad" (Na) vs "good" (Ca, Mg) effects on soil flocculation. With >SAR, Na is more dominant & soil aggregates disperse & infiltration decreases

Irrigation Water Gypsum Injections - How Much to Apply When Goal is to Alter EC:SAR ?

- Obtain irrigation water sample and have analysis run to determine Ca, Mg, Na, SAR (Sodium Absorption Ratio) and EC
- Assume gypsum added is essentially 100% or adjust as needed
- Determine "approximate adjusted EC" after gypsum addition as total cation concentration (meq/l) / 10

Example: Ca (meq/l) = 0.7; Mg (meq/l) = 0.5; Na (meq/l) = 8 and EC = 0.3 dS/m; calculate SAR = 8 / sq rt (0.7+0.5/2) = 10.3 *which from Westcot and Ayers chart would indicate reduced infiltration issues.*

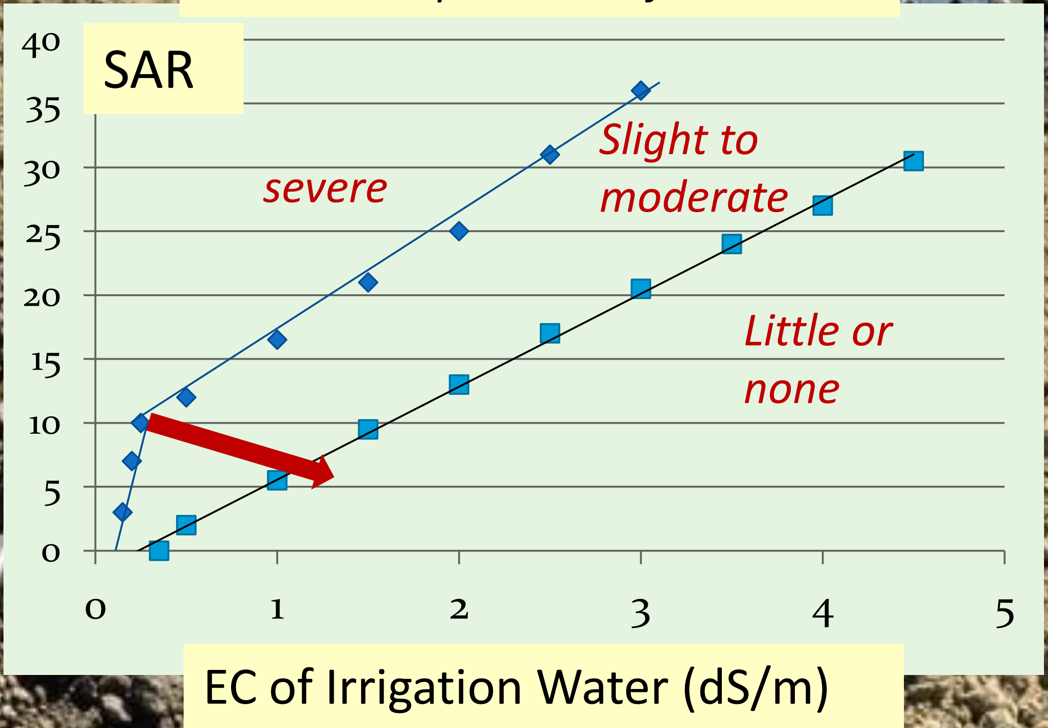
To make adjustments, do calculations to determine impacts of adding a source of calcium (such as from gypsum) to the irrigation water:

- *If added 3.0 meq/L to water in example above, new Ca+Mg+Na=1.2 + 3.0 + 8 meq/L = 12.2, so new SAR = 5.5 and EC = 12.2/10 = 1.22*

If added gypsum amount equivalent to 3.0 meq/l Ca to irrig. **water** in example given:

new Ca+Mg+Na=1.2 + 3.0 + 8 meq/L = 12.2, calc. SAR = 5.5 and EC = 12.2/10 = 1.22 …. Should produce situation with < infiltration issues

EC & SAR Impacts on Infiltration



How much needed?

Meq Ca/l To add	Lbs of Gypsum Needed per ac-ft (assume 100% gypsum)
1	235
2	470
3	705
4	940

Comparison of amounts of different materials needed for IRRIGATION WATER TREATMENTS:

- ✓ Water treatments good to consider when trying to deal with surface soil crusts or localized infiltration issues
- ✓ Low injection rates about 1-2 meq/L Ca; moderate 3-4 meq/L and relatively high about 5-6 meq/L Ca

Amounts to add to achieve 1 meq/L free Ca+ (lbs/ac-ft water)	
Gypsum (100%)	235
Sulfuric acid (100%)*	133
Calcium Chloride (13% Ca)	418
N-Phuric (different types)*	148 - 240
** Only use in calcareous soils (may range few % to 10+% $CaCO_3$)*	

- ✓ sulfur burners also used (solid S heated in chamber to release SO_2, introduced into water to form sulfurous acid (H_2SO_3)

Other Acid-Based, Acid-Forming Amendments –

Irrigation Water - injectable:

- ✓ **Nitro-Sul** – ammonium polysulfide (NH_4=20%, S=40%), increases acidity after microbial oxidation
- ✓ **Thio-Sul** (and variations) – ammonium thiosulfate (12% NH_4, 26% S), increases acidity, but mostly a fertilizer
- ✓ **N-phuric** – urea and sulfuric acid (10-28% Nm 9-18% S depending on formulation), increases acidity and helps with drip system anti-clogging efforts
- ✓ Most of these are more expensive than other sources discussed, and some might be suitable also for fertilization, anti-clogging for microirrigation systems, and irrigation system maintenance treatments

Does this approach work for all (most) situations?

No - The approach just described is best for use where **excess sodium (Na)** and it's impacts on plant responses and soil structure and flocculation / dispersal is the primary problems

(1) **Some situations warrant different approaches**, including:

- ✓ when waters **high in carbonates (CO3-) and bicarbonates (HCO3-)** are used or present in soil solution, Ca and Mg carbonates tend to form and concentrate in soil, reducing soil solution Ca & Mg relative to Na. <u>This is important since even less Ca & Mg will be available to counter soil aggregate dispersion associated with Na.</u> ** often an issue in western soils where pH > 7.5; more problems if bicarb >2 meq/L (about 90-100 ppm)*
- ✓ The USDA-ARS Salinity Lab in Riverside and others have adjusted SAR calculation methods that can be used under situations with these high bicarbonate/carbonate waters.

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(2) Some situations warrant different approaches, including:

- ✓ Serpentine soils derived from igneous rocks, found in scattered locations in CA. These soils have much higher Mg:Ca ratios than most agricultural soils, and when Mg:Ca ratios are high the Mg can act somewhat like Na in other situations, causing infiltration problems.
- ✓ Some other soils with very high exchangeable K content or high Mg content (relative to Ca) associated with different mineralogy can influence soil particle / aggregate dispersal and don't necessarily match expectations using the Ayers and Westcot approach

SALT-AFFECTED SOIL CLASSIFICATIONS (NRCS & USDA-ARS

Salt–affected soil classification	Electrical conductivity (EC)	Sodium Absorption Ratio (SAR)	Exchang. Sodium % (ESP)	Soil pH	Resulting Soil Physical / Soil Structure Conditions
Not salt-affected	Less than 4	Below 13	Below 15	<8.5	Flocculated
Saline	Greater than 4	Below 13	Below 15	<8.5	Flocculated
Sodic	Less than 4 typically	Above 13	Above 15	>8.5	Poor - Dispersed
Saline-sodic	Greater than 4	Above 13	Above 15	<8.5	Impacted

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

- *It is important to know details of soil and irrigation water chemistry, since a focus with sodic soils will be on sodium (Na), not just Ca and Mg salts.*

- ***SALINE – SODIC SOIL MANAGEMENT** (some differences from sodic soils):*
  - *For reclamation, treat these soils first for sodicity problems (1st focus on addition of amendments that impact Na displacement; followed by leaching to degree possible)*
  - *<u>If try to leach with good quality water first</u>, while Na still high (relative to Ca + Mg) and not very soluble, will likely :*
    - *Reduce salinity to limited degree (if water can infiltrate)*
    - *Increase sodicity problems since haven't removed Na*
    - *Make soil structure and infiltration problems worse*

SOIL TREATMENTS: When soil is sodic (high in Na), available chemical amendment options include:

(1) If significant quantities of free lime (calcium carbonate) are present in soil, you can **add acids or acid-forming amendments** .

What happens when you add them to the soil?

- ✓ Acids such as **sulfuric acid** and variants such as N-phuric acid and other acids react rapidly with soil calcium carbonate and release soluble Ca which can exchange with CA
- ✓ **Acid-forming materials** such as elemental S or calcium carbonate-sulfur have to 1^{st} be oxidized by soil bacteria in the presence of water to form sulfuric acid. This can be a slow process occurring over weeks or even months, and the rate can be influenced by form and texture of added S, and soil and environmental conditions.

SOIL TREATMENTS: When soil is sodic (high in Na), Ca-containing amendments are useful, available chemical amendment options:

Ca-containing amendments can be added also to soil (typically gypsum, could also use calcium chloride, usually more costly)

What happens when you add these materials to the soil?

- ✓ Multiple forms of gypsum available, adds Ca and S (refined gypsum anhydrite is 29% Ca, 23% S)
- ✓ It is moderately water soluble, a neutral salt, and not acid soluble so it won't change soil pH
- ✓ In the soil, the Ca ions interact with soil exchange sites and the S is dissolved into an available form in the soil solution
- ✓ How quickly the gypsum acts in soil can also be affected by texture/fineness of material, application method (mixed into the soil vs. placed on surface) and exposure to soil moisture or irrigation water.

Sodic Soil Management – *amendments as part of process*

GYPSUM:

- ✓ *Common choice to supply Ca for sodic soil reclamation, also high in S*
- ✓ *Dissolves well at high pH; quantity needed can be high, so often recommend split applications or only treat worst –affected areas*

ELEMENTAL S: *can also add sulfuric acid directly for similar affect*

- ✓ *Adding S doesn't add Ca – it oxidizes to form sulfuric acid, which dissolves free lime (CaCO3) present in many arid-zone soils (same process w/ acid)*

Amount to **treat one ft of soil** (Tons/acre)	Exchangeable Sodium you want to replace with Calcium (meq Na / 100 g soil) – from soil test			
	1	**2**	**4**	**6**
Gypsum	1.75**	3.5	7	10.5
Elem. Sulfur*	0.325	0.65	1.3	1.95
Sulfuric acid*	0.99	1.98	3.96	5.95
N-Phuric 10/55	0.5			
**assumes soil contains adequate free lime (CaCO3) ** split amounts > 2T/ac separate applications*				

Gypsum Application Decisions

- ✓ Can be simple decisions based on "<u>general guidelines</u>" with calculations based on treatments of a foot of soil depth …. OR
- ✓ A more detailed approach considers:
  - ✓ Soil mineral and morphological issues
  - ✓ Na adsorption potential related to clays
  - ✓ Amount of Ca needed to replace adsorbed Na
  - ✓ Depth of soil you want to treat

Sodic Soil Management – amendments as part of process

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***GYPSUM**: Amounts shown in prior table (above) are general "rules"*

Calculation approach *(Oster (1999) adapted for app (DeSutter, ND State Univ.)*

$GR = 0.86 * F * D * d_b * CEC * (ESPi – ESPt)/p$

Where: GR (gypsum requirement(Mg/ha), F = Ca:Na exchange efficiency (1.1 for ESP=15; 1.3 for ESP=5); D = soil depth treated (m); d_b = soil bulk density (Mg/m3); CEC is cation exchange capacity (mmol/kg); ESPi = initial exch. Na %; ESPt = target exch. Na %; p = purity of gypsum source

** could use alternate calculations if basic treatment results in question*

TIMING & AMOUNTS – *considerations for soil or irrigation water treatments:*

- **Broadcast, larger amounts of amendments, tilled in:**
  - These types of applications probably best-suited for trts to reclaim upper root zone / large volumes of soil
- **If concerned about use of problematic water supplies:**
  - can treat irrigation water multiple times/year (ie. Gypsum applied at 250-750 lbs/ac to address use of higher Na water)
- **Time soil and/or irrigation water-based applications before usual timing of infiltration problems:**
  - If infiltration & water-logging concerns usually associated with warmer, higher ET periods, start treatments weeks or even 1+ months earlier
  - Consider how finely ground you want materials, ie. finer ground matl's for quicker "action"

TIMING & AMOUNTS – *considerations for soil & IW treatments:*

- **If using elemental S:**
  - Consider reaction rate of S with moist soil, even in warm, moist soils conversion to H2SO3 may take 4-6+ weeks. Use coarser materials for more delayed timing of effects.
- **For any applications, for reduced costs and treatments targeted to zones where you apply most water, banded or zone treatments:**
  - With treatments applied in water with micro-irrigation, you are essentially already banding treatments if the drip lines are far apart and there are “dry” zones (such as with drip-irrigated orchards, widely-spaced annual crop beds)
  - Banded or targeted zone surface gypsum applications are not unusual, not as sure about incorporated Sulfur or other mat’ls to avoid physical or chemical root damage.

Leaching = *a necessary follow-up in salt-affected soils*

In-season versus dormant season leaching: ***pros & cons***

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)*

SOIL TREATMENTS: Efforts at reclamation/restoration in sodic soils can be a long (and sometimes costly) process – Why?

- ✓ Quantities of amendments can be large. May make more economic sense to: (a) treat worst-affected parts of fields, or (b) the likely most-responsive parts of the fields
- ✓ Once soil structure has been badly damaged, difficult/slow to improve
- ✓ At first, some tillage may help break up Na-dominated surface crusts that recur due to soil aggregate damage & particle size "sorting". May help mix amendments into treated soil volume.
- ✓ Changes in soil chemistry can affect large soil volumes, so it may be beneficial to repeatedly grow cover crops, add residues, manures, composts to help stabilize soil aggregates and prevent surface soil crusts. Including some coarse, slower decomposition mat'ls better. **Keep in mind any salt load issues.*

Management Questions – *degree of control you have*

Keep in mind that salt buildup problems developed over time, and will also take time to reduce. **QUESTIONS include:**

Where did salt come from, and do you have any control over sources?

- ✓ *Originated with salt-containing irrigation water*
  - ✓ *occur over long time with use of low/moderate salinity waters?*
  - ✓ *result from short-term use of high salinity waters?*
  - ✓ *Is there a lower salinity water available for reclamation?*
- ✓ *Originated from shallow water table*
  - ✓ *Can you exert control over water table depth at specific times of year through drainage, or with crops able to use shallow GW?*
  - ✓ *Or … is shallow GW control/depth mostly out of your local control*
- ✓ *Consider basic limits of salt & trace element tolerance issues for crops you grow* (*ie. what can you get away with & for how long?)*

Thank you

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Summary – *Suggested Management Approaches*

- ✓ <u>Sample irrigation waters</u> & have basic chemical suitability analyses done for all water sources used for irrigation
- ✓ Depending on salinity, sodicity, trace element issues at your site(s), <u>sample soils and analyze chemistry</u> to assess developing problems & impacts of your leaching or amendment treatments
- ✓ Consider basic <u>limits of salt & trace element tolerance issues for crops</u> grown (ie. what can you get away with & for how long?)
- ✓ When soil type & chemistry result in low capacities to infiltrate water, consider pros and cons of growing season vs. dormant-season (winter +) periods for amendments & leaching.