Soil Salinity in Agricultural Systems: The Basics

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What is salt?

What is Salt?

- Salts are more than just sodium chloride (NaCl)
- Salts consist of anions and cations
- In terms of soil and irrigation water these generally include:

Cations		**Anions**	
Sodium	Na^{+}	Chlorides	Cl^{-}
Magnesium	Mg^{2+}	Sulfates	SO_4^{2-}
Calcium	Ca^{2+}	Carbonates	CO_3^{2-}
		Bicarbonates	HCO_3^{-}

What is Salt?

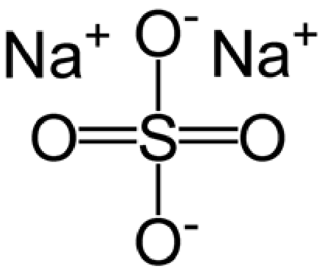
- Other salts in agriculture
  - Potassium (K^+)
  - Nitrate (NO_3^-)
  - Boron (B)
    - Often as boric acid (H_3BO_3, often written as $B(OH)_3$)
    - Can form salts such as sodium borate (borax; $Na_2B_4O_7$)

Photo: Georgia Agriculture

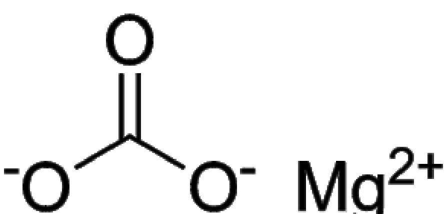
What is Salt?

$$NaCl(s) \xrightarrow{H_2O(l)} Na^{+}(aq) + Cl^{-}(aq)$$

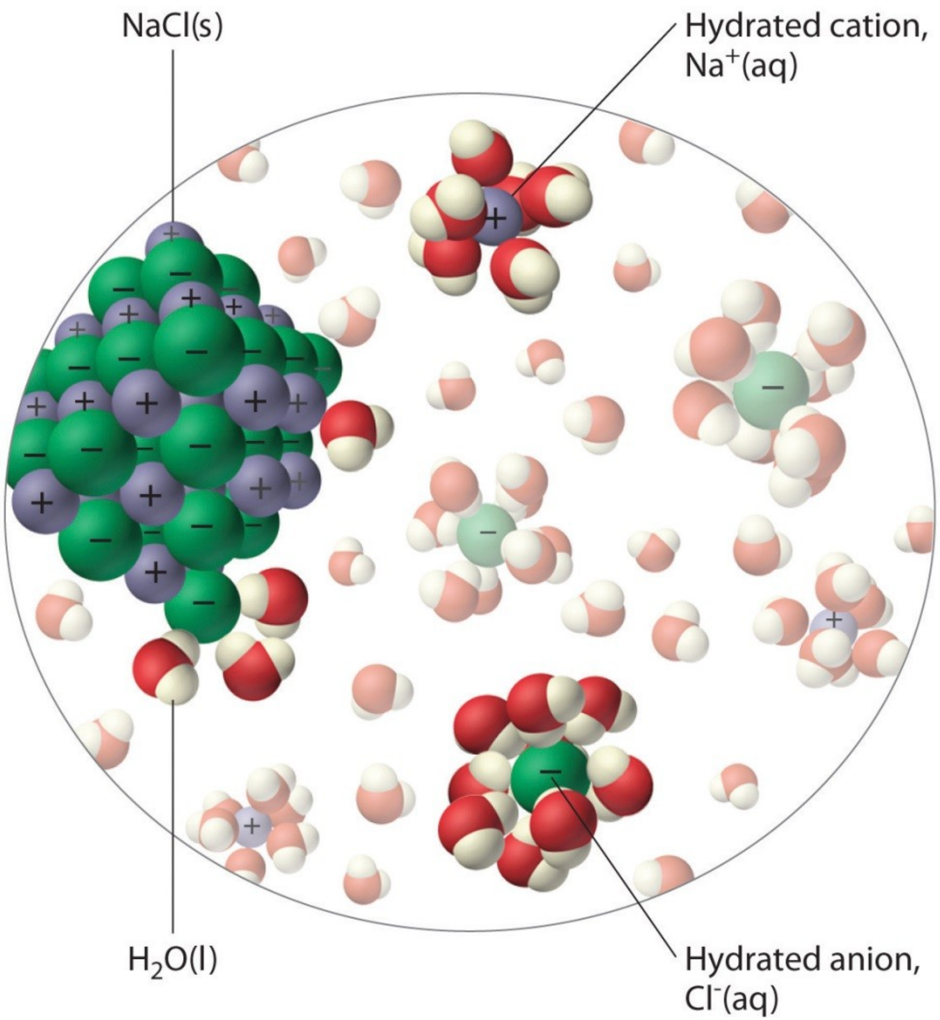
(aq) indicates that Na^{+} and Cl^{-} are hydrated ions



Sodium sulfate



Magnesium carbonate



Source: Averill and Eldredge (2007)

Types of Salts

CO_3^{2-}

Na^+

SO_4^{2-}

Cl^-

K^+

Ca^{2+}

Mg^{2+}

HCO_3^-

Some common salts

$NaCl$	Sodium chloride	Table salt (halite)
KCl	Potassium chloride	Muriate of potash
$NaHCO_3$	Sodium bicarbonate	Baking soda (nahcolite)
$CaSO_4$	Calcium sulfate	Gypsum
$CaCO_3$	Calcium carbonate	Calcite
$MgSO_4$	Magnesium sulfate	Epsom salt (epsomite)
K_2SO_4	Potassium sulfate	Sulfate of potash (arcanite)
Na_2SO_4	Sodium sulfate	Glauber's salt (thenardite and mirabilite)


Thenardite


Gypsum


Calcite

Sources of Salt

- Dissolution of parent rock material
- Irrigation water
- Saline groundwater
- Fertilizers
- Manure
- Seawater intrusion

Photo: J. Ullman

Saline Soils

- Accumulation of salts known as salination
- Can occur in diverse types of soil with different physical, chemical and hydrologic properties

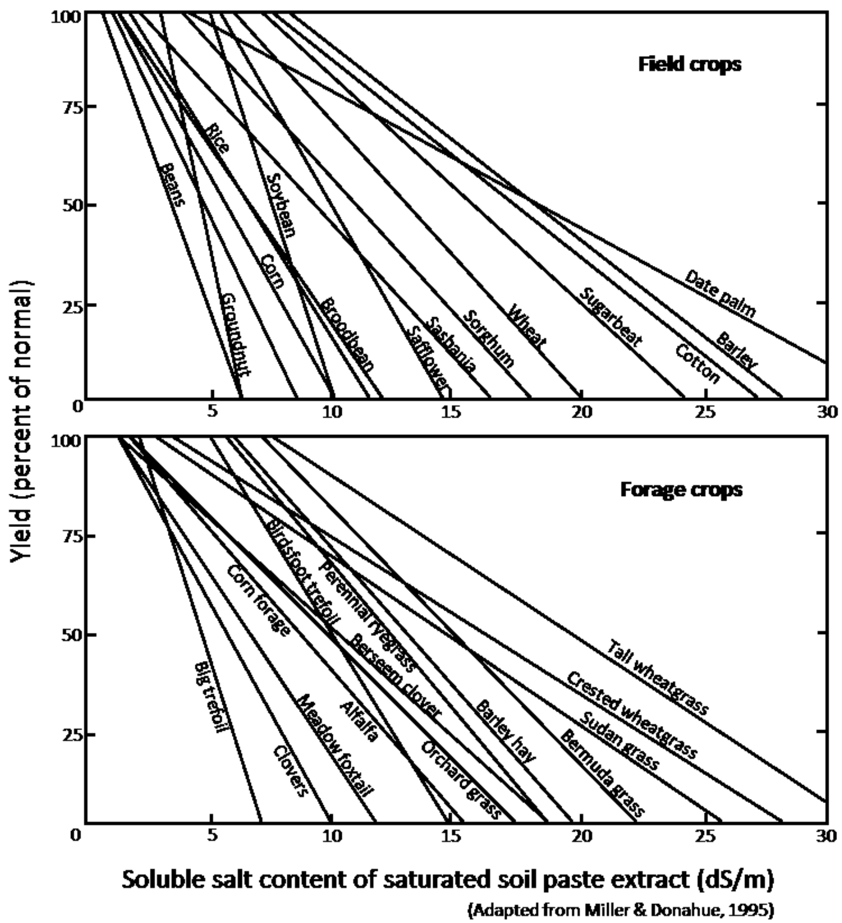
Photo: USDA-NRCS

Saline Soils

- Salt-affected soils are those where salt levels reduce yield

Traditional classifications for saline soils

Soil salinity class	EC (dS/m)	Effects on crop plants
Non-saline	0 – 2	Salinity effects negligible
Slightly saline	2 – 4	Yields of sensitive crops may be restricted
Moderately saline	4 – 8	Yields of many crops are restricted
Strongly saline	8 – 16	Only tolerant crops yield satisfactorily
Very strongly saline	> 16	Only very tolerant crops yield satisfactorily

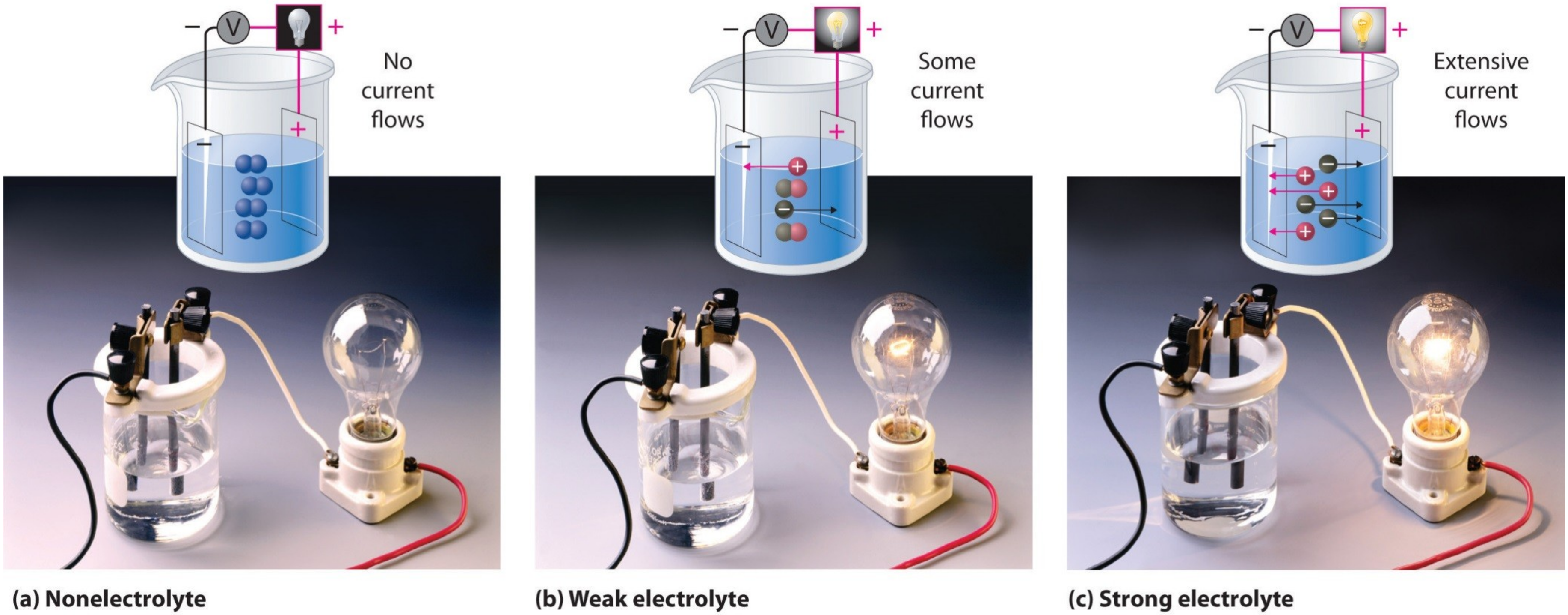


Saline Soils

- Saline soil traditionally defined as having an electrical conductivity (EC) of the saturated soil extract of more than 4 dS/m
  - Some consider a boundary of 2 dS/m
  - Crop loss may occur at lower EC for sensitive crops (more on this later…)
- Electrical conductivity (EC) measures a material's ability to conduct electrical current
- Can be used to measure salinity since ions in solution carry a current
- Conductivity of water depends on concentration of dissolved salts that ionize the solution

Electrical Conductivity

- The various ions in solution (e.g., Cl^-, SO_4^{2-}, NO_3^{2-}, PO_4^{3-}, Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, etc.) contribute to EC



Source: Averill and Eldredge (2007)

Salinity Units & Conversions

- Units include:
  - Siemen (S) is SI unit of electric conductance
  - Equal to inverse ohm, called mho
  - Measured per distance:

    millisiemens per cm (mS/cm) or millimhos per cm (mmhos/cm)
- Common unit - Decisiemens per meter (dS/m)
- Easy conversion between units:

  dS/m = mS/cm (since 1 m = 100 cm)

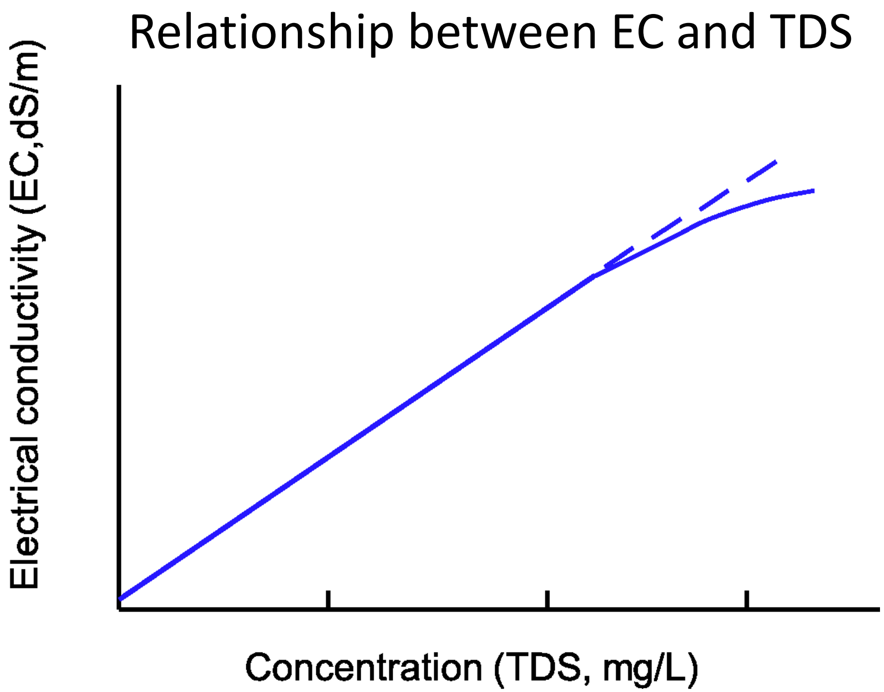
  dS/m = 1,000 µS/cm

  mS/cm = mmho/cm

dS/m = mS/cm = 1,000 µS/cm = mmho/cm = 1,000 µmhos/cm

Salinity Units & Conversions

- Total dissolved solids (TDS) describes all solids (including mineral salts) dissolved in water
- Close connection between EC and TDS



Salinity Units & Conversions

- TDS expressed in units of ppm (parts per million) or as a concentration

  1 ppm = 1 mg/L = 1000 ppb = 1,000 µg/L

  1 ppm = mg/kg

  1% = 10,000 ppm = 10,000 mg/L = 10,000 mg/kg

- Salinity often expressed as parts per thousand parts (‰)

  Salt concentration in seawater:

  3.5% = 35‰ = 35 g/L = 35,000 mg/L = 35,000 ppm

Salinity Units & Conversions

- May also see salts expressed as milliequivalents
  - An equivalent (eq) is the amount of a substance that will exchange one mole of electrons
  - Divide by 1,000 to get milliequivalent (meq)

Na	1 meq/L = 23 mg/L
Ca	1 meq/L = 20 mg/L
Mg	1 meq/L = 12 mg/L
Cl	1 meq/L = 35 mg/L
SO_4	1 meq/L = 48 mg/L
HCO_3	1 meq/L = 61 mg/L

Salinity Units & Conversions

- Converting between EC and TDS
  - EC <5 dS/m (mmhos/cm)

    TDS (mg/L) = 640 x EC (dS/m)
  - EC >5 dS/m

    TDS (mg/L) = 840 x EC (dS/m)

- Waters with high sulfate concentrations
  - EC <5 dS/m (mmhos/cm)

    TDS (mg/L) = 740 x EC (dS/m)
  - EC 5 to 10 dS/m

    TDS (mg/L) = 840 x EC (dS/m)
  - EC >10 dS/m

    TDS (mg/L) = 920 x EC (dS/m)

From Hanson et al., 1999

Types of Electrical Conductivity

- Different types of EC to consider
  - EC_{iw} - electrical conductivity of the irrigation water
  - EC_{sw} - electrical conductivity of the soil water
  - EC_s - electrical conductivity of ions absorbed to soil surface
  - EC_e - electrical conductivity of the saturated soil paste
  - EC_a - apparent electrical conductivity of bulk soil
  - EC_b - directly measured conductivity of bulk soil

May also see EC_b in the literature in reference to bulk liquid electrical conductivity

Measuring Electrical Conductivity

- Saturated soil paste extract
  - Standard procedure for determining soil electrical conductivity (EC_e)
  - Bring soil sample just to point of saturation
  - Allow to equilibrate for at least 2 hours
  - Extract soil solution by vacuum through filter paper
- Other extracts

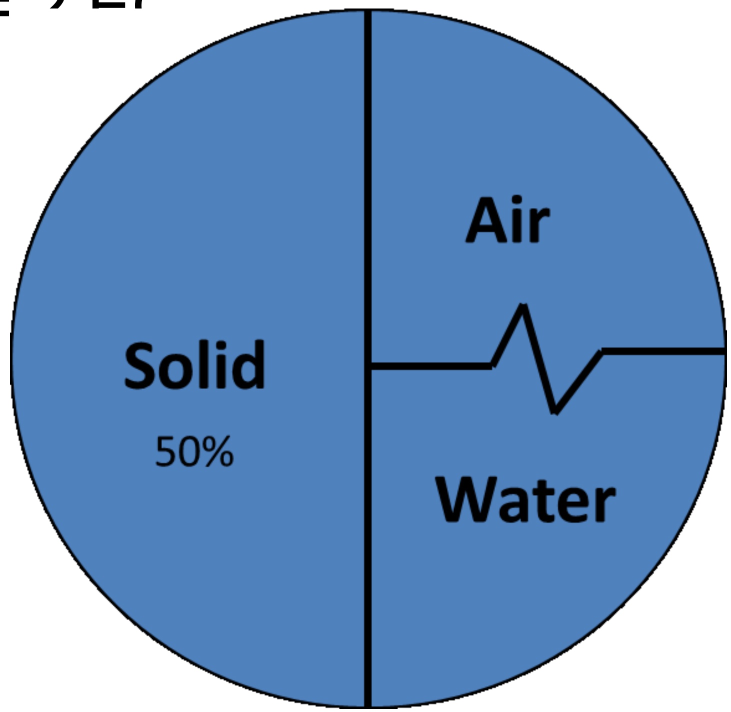
  (e.g., 1:5 soil water extract)

Photo: S Grattan

Measuring Electrical Conductivity

- Rule of thumb for mineral soils

$EC_{sw} = 2\ EC$



% Bulk soil volume

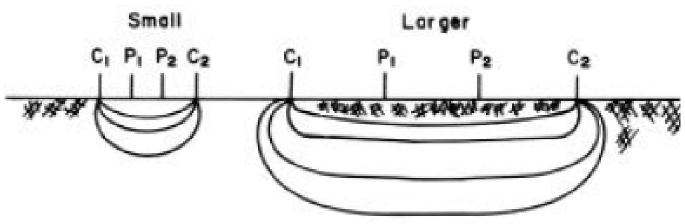
$EC_s < EC_e < EC_{sw}$

Measuring Electrical Conductivity

- Field measurements of EC_a
  - Electrode probes

    (four-electrode sensors)
  - Electromagnetic induction (EM 31 and EM38)
  - Time domain reflection (TDR)

Schematic showing increased depth and volume of EC_a measurement with increased C_1-C_2 electrode spacing. Effective depth of measurement is approximately equal to one-third of (C_1 - C_2). C stands for current-electrode and P stands for potential-measuring electrode (after Rhoades, 1976)



Electromagnetic (EM) sensor

Photo: S Grattan

Saline Soil

- Historically EC_e > 4 dS/m considered saline
- Depends on type of plant
  - EC_e >2 dS/m denotes saline soil for sensitive crops
  - EC_e >8dS/m may denote saline soil for tolerant plants
- More recently classifications define as:

Updated thresholds for saline soils based on crop type (Maas, 1990)

EC_e (dS/m)	Crop class
1.5	Sensitive crops
3.0	Moderately sensitive crops
6	Moderately tolerant crops
10	Tolerant crops

Saline Water

- Need to also consider quality of irrigation water

Irrigation water quality criteria for salinity (Essington, 2004)

Class	EC_{iw} (dS/m)	Effects on crop plants
Low salinity (no problem)	<0.75	No detrimental effects usually observed
Medium salinity (increasing problem)	0.75-3.0	Detrimental effects on sensitive crops may occur and require management
High salinity (severe problem)	>3.0	Only use for salt-tolerant crops on permeable soil with careful management

Photo: J. Ullman

Saline Water

Table 2. Estimated yield of vegetable and row crops with long-term use of irrigation water of different qualities (potential yields are based on a 15 to 20 percent leaching fraction and do not account for the effects of specific elements)

	ECw (mmhos/cm)					
	Yield potential[1]				Rating[2]	
Vegetable and row crops	**100%**	**90%**	**75%**	**50%**	**Salt**	**Boron**
Asparagus	2.7	6.1	11.1	19.4	T	VT
Bean	0.7	1.0	1.5	2.4	S	S
Beet, red	2.7	3.4	4.5	6.4	MT	T
Broccoli	1.9	2.6	3.7	5.5	MS	MS
Cabbage	1.2	1.9	2.9	4.6	M	MT
Carrot	0.7	1.1	1.9	3.0	S	MS
Cauliflower	1.9	2.6	3.7	5.5	MS	MT
Celery	1.2	2.3	3.9	6.6	MS	VT
Corn, sweet	1.1	1.7	2.5	3.9	MS	VT
Cucumber	1.7	2.2	2.9	4.2	MS	MS
Eggplant	0.7	1.7	3.1	5.6	MS	—
Lettuce	0.9	1.4	2.1	3.4	MS	MS
Onion	0.8	1.2	1.8	2.9	S	S
Pepper	1.0	1.5	2.2	3.4	MS	MS
Potato	1.1	1.7	2.5	3.9	MS	MS
Radish	0.8	1.3	2.1	3.4	MS	—
Spinach	1.3	2.2	3.5	5.7	MS	—
Squash, scallop	2.1	2.6	3.2	4.2	MS	MT
Squash, zucchini	3.1	3.8	4.9	6.7	MT	MT
Strawberry	0.7	0.9	1.2	1.7	S	S
Sweet potato	1.0	1.6	2.5	4.0	MS	—
Tomato	1.7	2.3	3.4	5.0	MS	T
Turnip	0.6	1.3	2.5	4.3	MS	MT

— Data not available.
[1] Based on data from Maas and Grattan 1999.
[2] Sensitive (S), moderately sensitive (MS), moderately tolerant (MT), tolerant (T), and very tolerant (VT).

Source: Grattan (2002)

Salt Balance

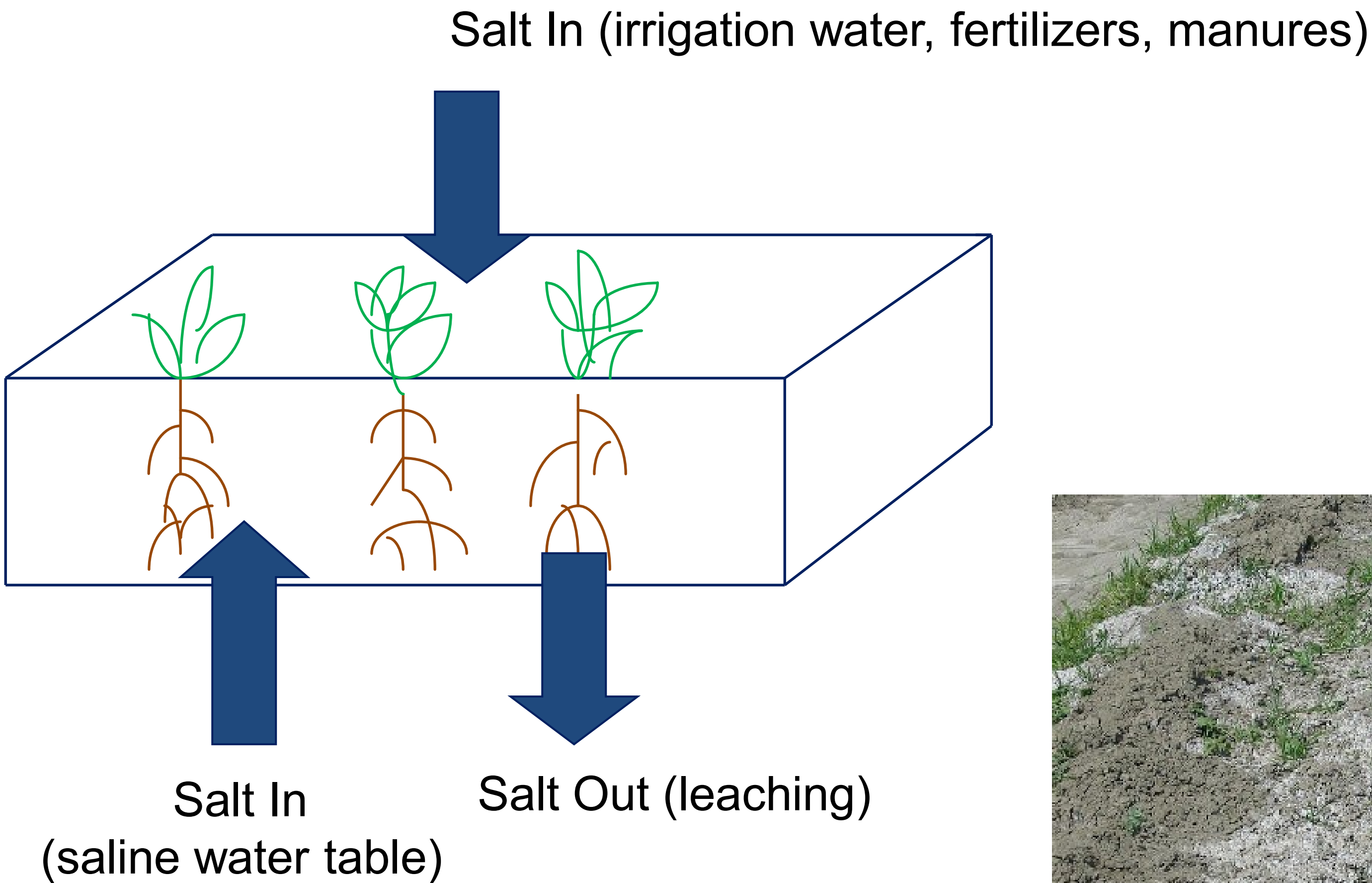


Photo: G. Varvel et al.

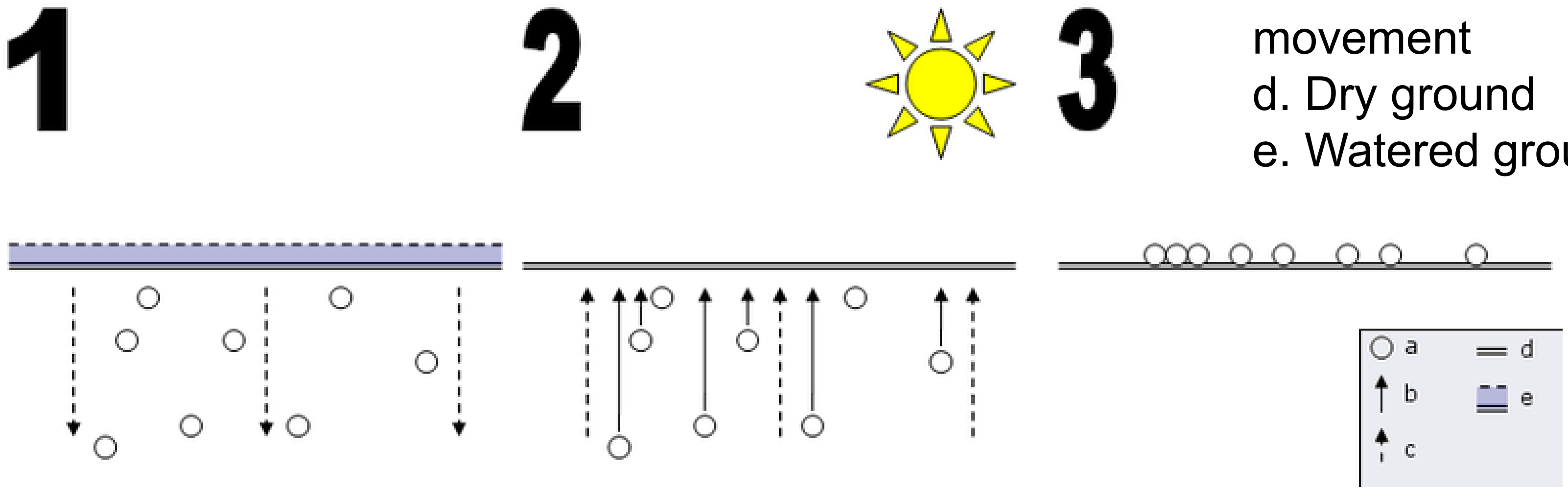
Formation of Salinity Issues

- Problems formed by:
  - Saline irrigation water
  - Salts present in moderate to high amounts in soil or with a shallow saline water table
  - Inadequate leaching (drainage) occurs
  - Evaporation greatly exceeds precipitation
  - Application of manure and fertilizer

Photo: J. Ullman

Salinity from Irrigation

a. Salt
b. Salt movement
c. Water movement
d. Dry ground
e. Watered ground



Salinity from irrigation

1. After irrigation, water seeps into the soil and loosens salt
2. Sunshine lets the water evaporate on the ground and capillary action brings water and salt to the surface.
3. Salt deposits on the surface and accumulates

Salt Effects on Plants

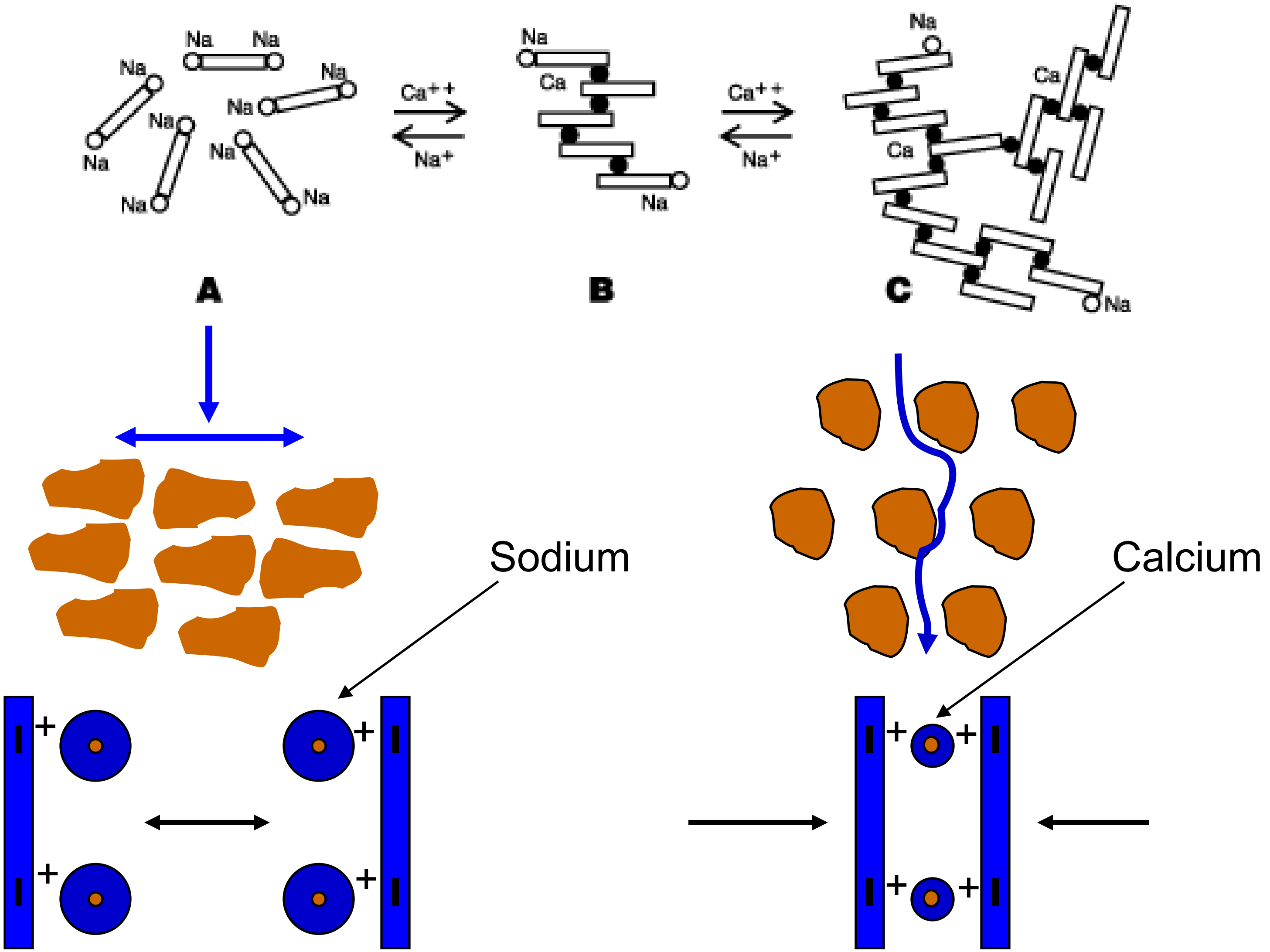
- Reduces available water ("Chemical drought")
  - Water held tighter by soil and less available to plant due to osmotic forces
- Interferes with nutrient uptake
  - Nutrients proportionally less available
  - Osmotic forces impede uptake and transport in plant
- Specific ion toxicities
  - e.g., Sodium, chloride, boron
- Plants need salt but in specific ranges

Salt Effects on Plants

Salinity Effects on Soil Properties

- Flocculation
  - Salinity can cause flocculation
  - Fine particles bind together in aggregates
  - Voids become larger – soils remain more permeable
- Dispersion
  - Sodium causes aggregates to disperse
  - Degrade soil structure
  - Low infiltration rates and poor aeration
- Soil type determines what happens

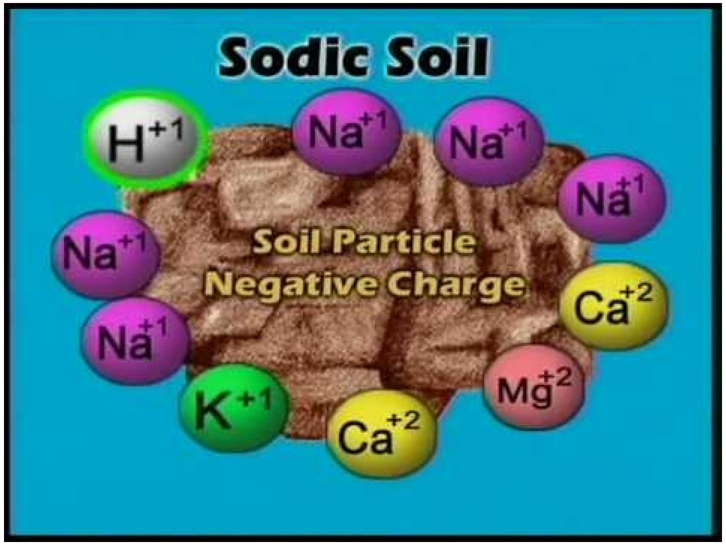
Salinity Effects on Soil Properties



Sodic Soil

- Sodic soils contain high sodium (Na^{+}) levels relative to calcium (Ca^{2+}) and magnesium (Mg^{2+}) that impede plant growth
- Usually not saline, since the total amount of soluble salts is not excessive
- Can also find saline-sodic soils

Not a significant problem in Florida



Sodic Soil

- Parameters used to measure sodic hazard
  - Sodium adsorption ratio (SAR)
  - Exchangeable sodium percentage (ESP)

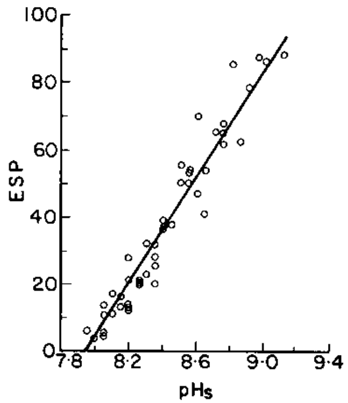
$$\mathrm{SAR} = \frac{[\mathrm{Na}^+]}{([\mathrm{Ca}^{2+}] + [\mathrm{Mg}^{2+}])^{1/2}}$$

$$\mathrm{ESP} = \frac{\text{exchangeable sodium } (\mathrm{cmol_c/kg})}{\text{cation exchangeable capacity } (\mathrm{cmol_c/kg})} \times 100$$

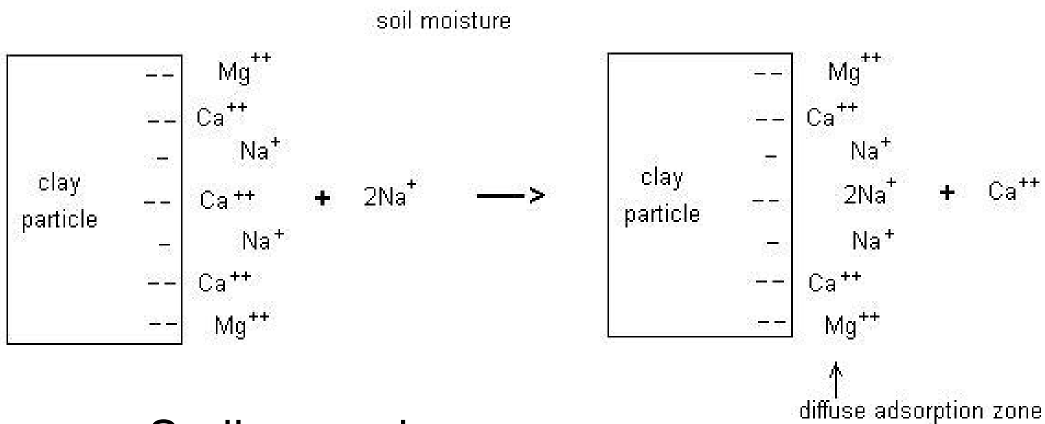
- SAR >13 and ESP >15 are generally used to designate sodic conditions (these parameters are different and not precisely equal numerically)

Sodic Soil

- Generally have high pH (>8.5)
  - Referred to as alkaline soils
- More pronounced in clay soils
- Associated with sodium carbonates (Na_2CO_3)

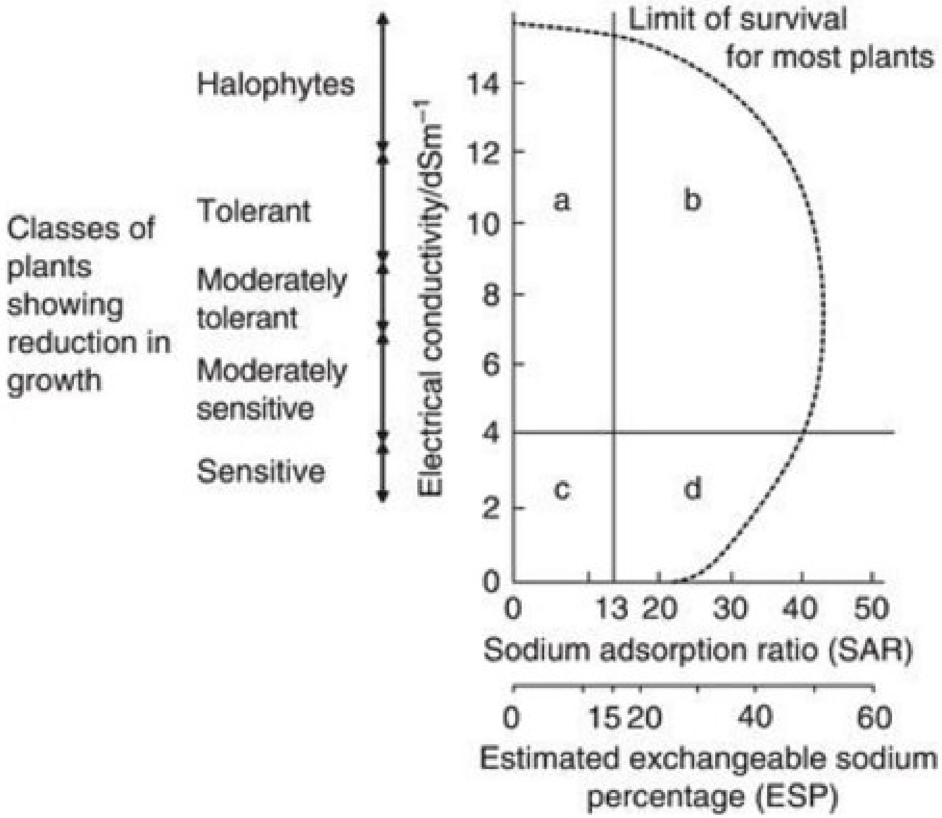


Relationship of soil pH with exchangeable sodium percentage (Abrol et al., 1980)



Sodium exchange process

Saline, Sodic and Saline-Sodic Soils



a) Saline soils pH <8.5
b) Saline-sodic soils (soil pH generally <8.5
c) Normal soils pH <8.5
d) Sodic soils (soil pH >8.5)

Classification of normal, saline, saline-sodic and sodic soils in relation to soil pH, electrical conductivity, sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP). (From Brady & Weil, 2010)

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Salinity Management

- Need careful irrigation, fertilization and cropping management to deal with salinity issues

Photo: USGS

Photo: G. Hutchinson


Photo: J. Ullman
Thank You