# Managing Soil Salinity and Sodicity: A Biological Perspective

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# We Do Not Have Salinity and Sodicity Problems in Kentucky

Human Error
Human Activity - Oil Drilling
Wastewater
Natural Events - Saline Seeps



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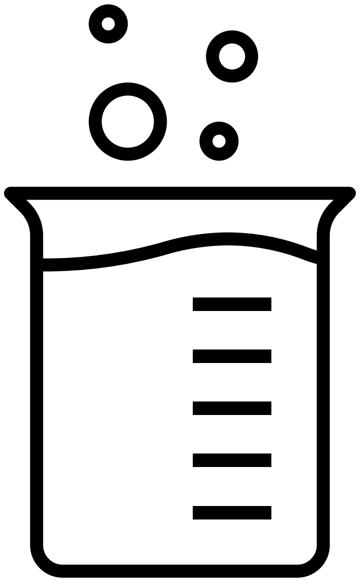
# Outline of Presentation

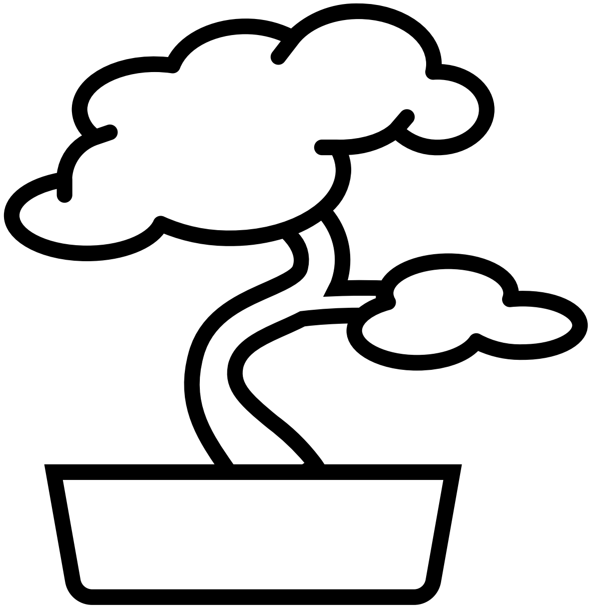
- Review (things you already know)
  A. What are saline soils?
  B. What are sodic soils?
  C. Where and why do they occur?
  D. Why are they bad for plants and soil biology?
  E. What are the mitigation strategies?
- How do you manage the biological environment?
  A. Structure
  B. Microbes

# Chemical Degradation

- Salinization
- Sodification
- Alkalinization
- Acidification
- Nutrient Depletion
- Nutrient Excess
- Agrichemicals
- Industrial Contamination



# Directly Affects Plant Growth



Indirectly Affects Growth by Influencing Soil Biological and Physical Properties

# Acidity/Alkalinity

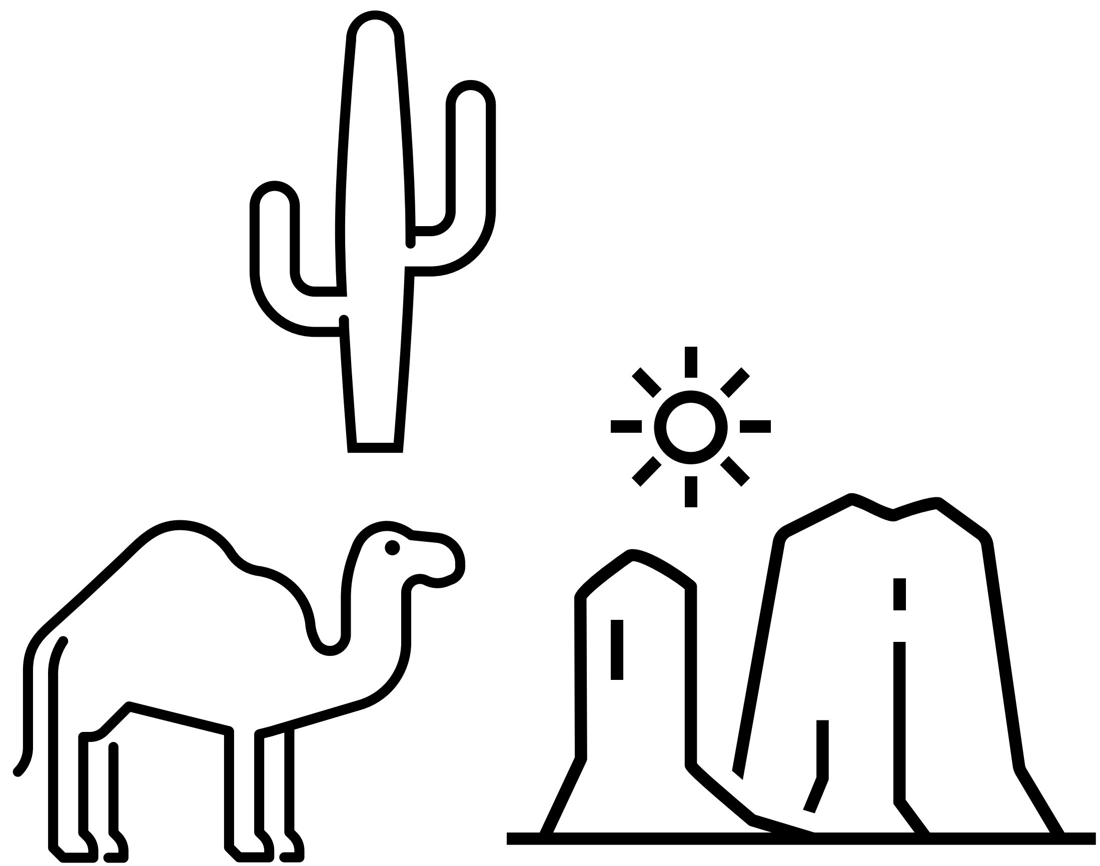
| | |
|---|---|
| ultra acid | < 3.5 |
| extremely acid | 3.5 to 4.4 |
| very strongly acid | 4.5 to 5.0 |
| strongly acid | 5.1 to 5.5 |
| moderately acid | 5.6 to 6.0 |
| slightly acid | 6.1 to 6.5 |
| Neutral | 6.6 to 7.3 |
| slightly alkaline | 7.4 to 7.8 |
| moderately alkaline | 7.9 to 8.4 |
| strongly alkaline | 8.5 to 9.0 |
| very strongly alkaline | > 9.1 |

Affects Nutrient Availability (P/Fe), Nutrient Toxicity (Al/Mn/Mo), Plant Growth

Individual Microbes Have pH Minimum and Maximum

# Salt- and Sodium-Affected Soils Are in:

- Arid regions
- Irrigated regions with high water tables
- Irrigated regions with poor water quality
- Saline seeps after fallow





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## Table 2. Salt classifications in soils (NRCS).

| Characterization | EC† | ESP‡ | $SAR_e$§ | pH# |
|---|---|---|---|---|
| Normal | <4 | <15 | <12 | <8.5 |
| Saline | >4 | <15 | <12 | <8.5 |
| Sodic | <4 | >15 | >12 | >8.5 |
| Saline-Sodic | >4 | >15 | >12 | >8.5 |

† EC, electrical conductivity, $dS\ m^{-1}$.

‡ ESP, exchangeable sodium percentage.

§ $SAR_e$, sodium adsorption ratio determined from a saturated paste extract.

# pH, term describing the concentration of hydrogen.

# General Characteristics

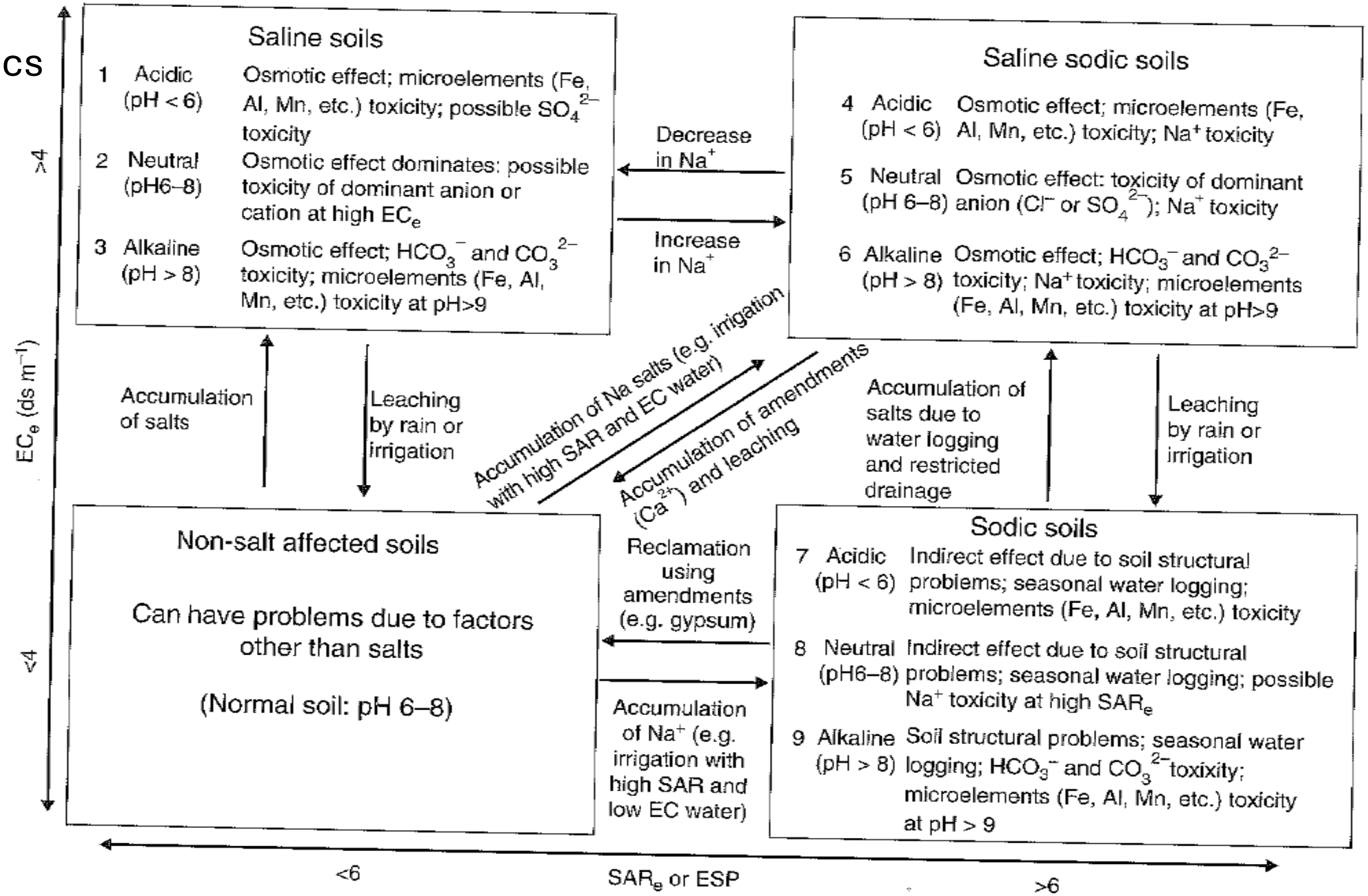


**Figure 7.7** Key properties of the major types of salt-affected soils and possible mechanisms of impact on plant growth. Soils are categorised absorption ration ($SAR_e$) and electrical conductivity (ECe) measured in soil saturation extracts and pH1:5 measured in soil:water suspension. The (SARe ≈ ESP) of 6 and above to classify a soil as sodic is based on the Australian soil classification criteria (Isbell, 1996); however, the general are of relevance worldwide. Toxicity, deficiency or ion-imbalance due to other elements (e.g. B, K, N, P) will depend on the ionic composition o and the particular species of plant.

# Salinity – Too Much Salt!



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# Salinity – EC

## Measured by Electrical Conductivity (EC, dS $m^{-1}$)

EC = electrical conductance of a saturated paste solution

Salts with solubility greater than that of gypsum (a less soluble salt)

Salic (saline) soil: EC > 30 dS $m^{-1}$

The upper EC limit for drinking water is 1.6 dS $m^{-1}$ (1 dS $m^{-1}$ = 1 mmho $cm^{-1}$)

Table 1. Common soluble salts found in soils (FAO, 1973).

| Compound | Common name | Molecular formula | Solubility (20°C) |
|---|---|---|---|
| | | | g $L^{-1}$ |
| Calcium carbonate | lime | $CaCO_3$ | 0.06† |
| Magnesium carbonate | | $MgCO_3$ | 2.51‡ |
| Sodium carbonate | soda | $Na_2CO_3$ | 179 |
| Sodium bicarbonate | baking soda | $NaHCO_3$ | 87 |
| Calcium sulfate | gypsum | $CaSO_4$ | 1.9 |
| Magnesium sulfate | epsom | $MgSO_4$ | 252 |
| Sodium sulfate | glauber's salt | $Na_2SO_4$ | 161 |
| Magnesium chloride | | $MgCl_2$ | 410 |
| Sodium chloride | table salt | NaCl | 264 |
| Calcium chloride | | $CaCl_2$ | 427 |

† Solubility of $CaCO_3$ in 0.00032 atm of $CO_2$.

‡ Solubility of $MgCO_3$ in 0.005 atm of $CO_2$ at 18°C.

Table 3. Salinity classes of soils (NRCS).

| Classes | Electrical conductivity |
|---|---|
| | $dS\ m^{-1}$ |
| Nonsaline | 0-2 |
| Very slightly saline | ≥2-4 |
| Slightly saline | ≥4-8 |
| Moderately saline | ≥8-16 |
| Strongly saline | ≥16 |

# Salinity and Plant Damage

- Due to the lower osmotic potential in saline soils, plants commonly exhibit **water stress symptoms**: wilting, stunting with cupped leaves, browning and brittle leaf tips and margins, and potentially become deep blue-green from excessive wax accumulation.
- Reduced P, K, or essential ions due to high Ca concentrations.
- Reduced K and Ca uptake because of high Na concentrations.
- Reduced  nitrate-nitrogen uptake due to excess sulfate and chloride.
- The toxic effects of excess levels of Na and Cl on plants include leaf-tip burn, scorching of the leaf margin, chlorosis, and premature leaf drop.

# Wilting Occurs Sooner With Higher Salt (EC) Content in Soil Water – Salt Decreases Water Potential (ψ)

**214** Soil Conditions and Plant Growth

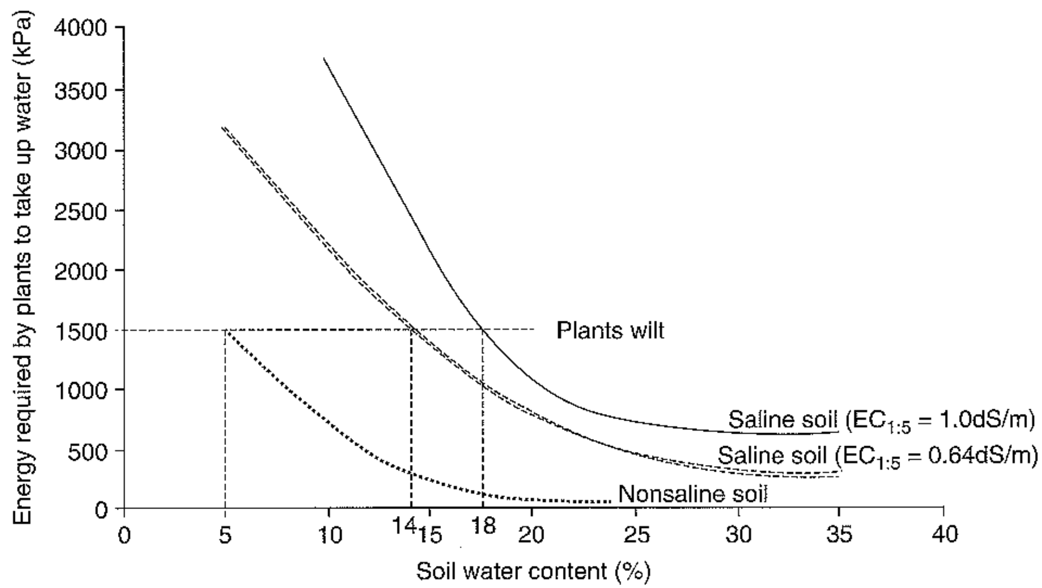


**Figure 7.8** Energy (equivalent to soil matric plus osmotic potential) required by plants to take up water from a loamy soil as influenced by EC1:5 and % soil-water content.

Note: 1500 kPa = 1.5 Mpa = 15 Atm

*Soil Conditions and Plant Growth.* Edited by Peter J. Gregory and Stephen Nortcliff.




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# Soil Microbes and Salinity

- Microbes vary from being very sensitive to low osmotic potential to very resistant
- Gram negative bacteria are sensitive
- Fungi and Gram positive bacteria are more resistant
- Halophiles grow in environments that are incredibly salty
- Increasing salinity decreases the diversity of microbes in the soil and selects for resistant organisms

# Solutions to Salinity

IMPROVE DRAINAGE

IRRIGATE WITH GOOD WATER

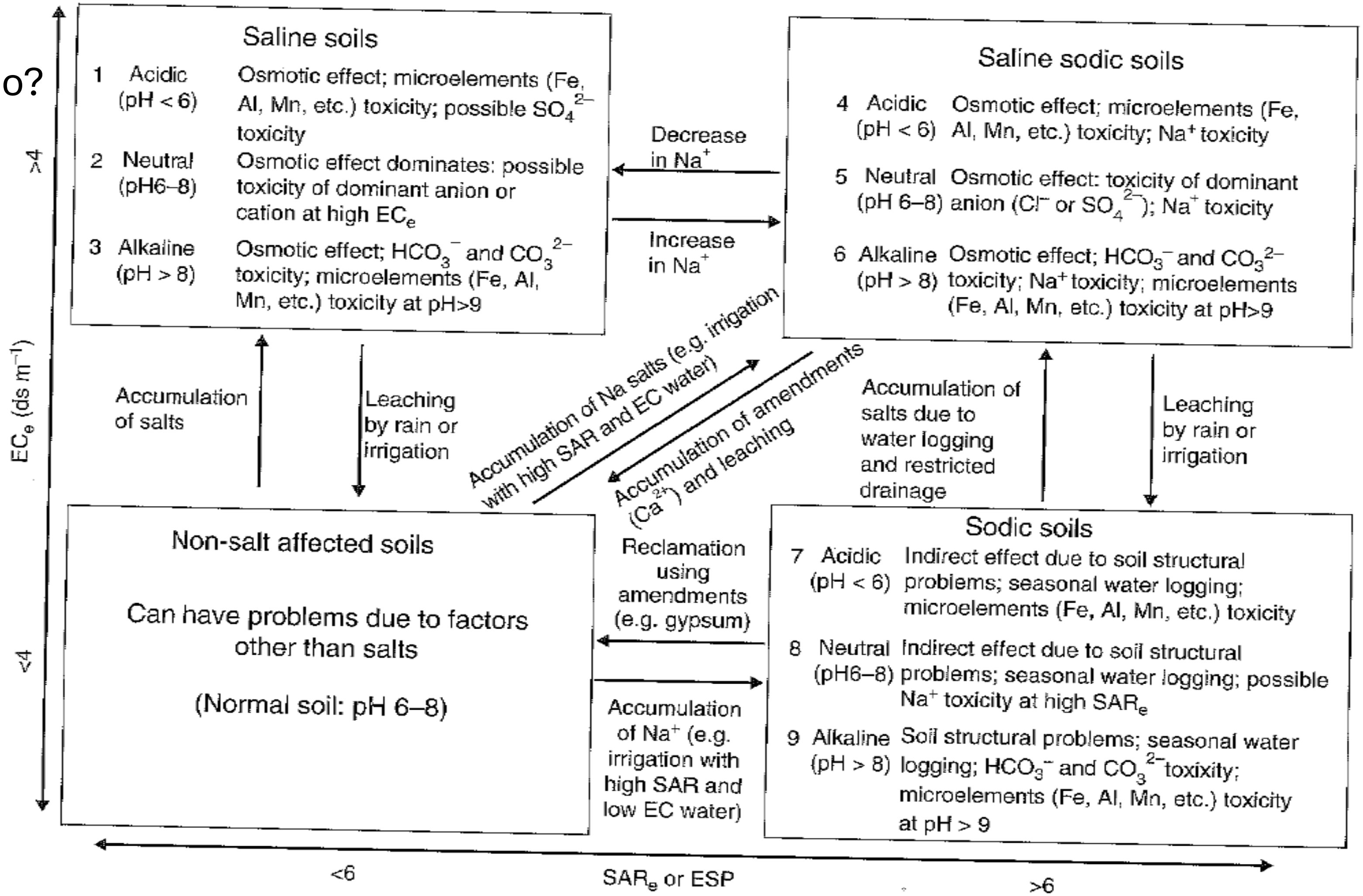
PLANT PLACEMENT

PLANT SELECTION
- SALT TOLERANT
- SALT RESISTANT

SALT TOLERANT SYMBIONTS
- MYCORRHIZAE
- PGPR

ORGANIC MATTER TO REPLACE SOURCES OF SALT AS FERTILIZER

## What to Do?

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# What is a Sodic Soil and Why Does it Matter?

- Sodic soils have excess Na on the soil's exchange sites. The dominant cations on the soil exchange sites are typically $Ca^{+2}$, $Mg^{+2}$, and $K^{+}$. As the concentration of $Na^{+}$ increases in soil, $Na^{+}$ replaces other cations on the soil exchange sites by mass action.

- The result can be slaking, swelling, and clay dispersion of soil particles upon wetting.

- **Slaking** is the breakdown of soil aggregates into particles >20 um in size.

- **Dispersion** is the breakdown of fine soil particles to <2 um in size.

- The NRCS classifies soils as sodic if the SARe is >12, the ESP is >15, the EC is <4.0 dS $m^{-1}$, and the pH is >8.5



# Sodicity – SAR & ESP

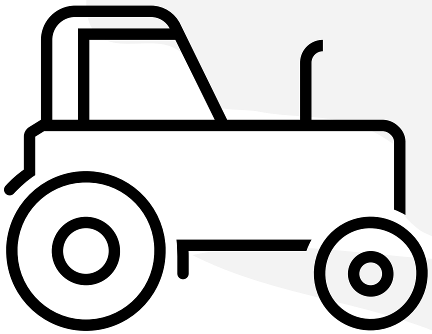
- SAR = sodium adsorption ratio = $Na/\sqrt{(1/2[Ca+Mg])}$

  all expressed in meq/L, in a saturated paste extract

- ESP = exchangeable sodium percentage = $100(Na_{ex}/CEC)$
  all in meq/100 g soil.

| | SAR |
|---|---|
| slight | < 13 |
| moderate | 13-30 |
| strong | > 30 |

# Sodicity Damage



- Plants experience nutrient imbalance and water stress similar to that with salinity
- Plants suffer from soil physical changes
- When soils with excess Na are drained or washed with high quality irrigation water they can get dispersion, loss of structure, pore plugging with dispersed clay, low percolation and infiltration; crusting; hard-setting



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# Dispersion

- Clay particles become repulsive to one another.
- Structure breaks down - large pores collapse
- Clay particles move downward, plug small pores
- The opposite of dispersion is flocculation.
- What is behind the dispersion problem with sodic soils?
  - Large sphere of hydration for Na



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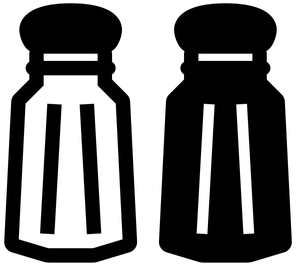
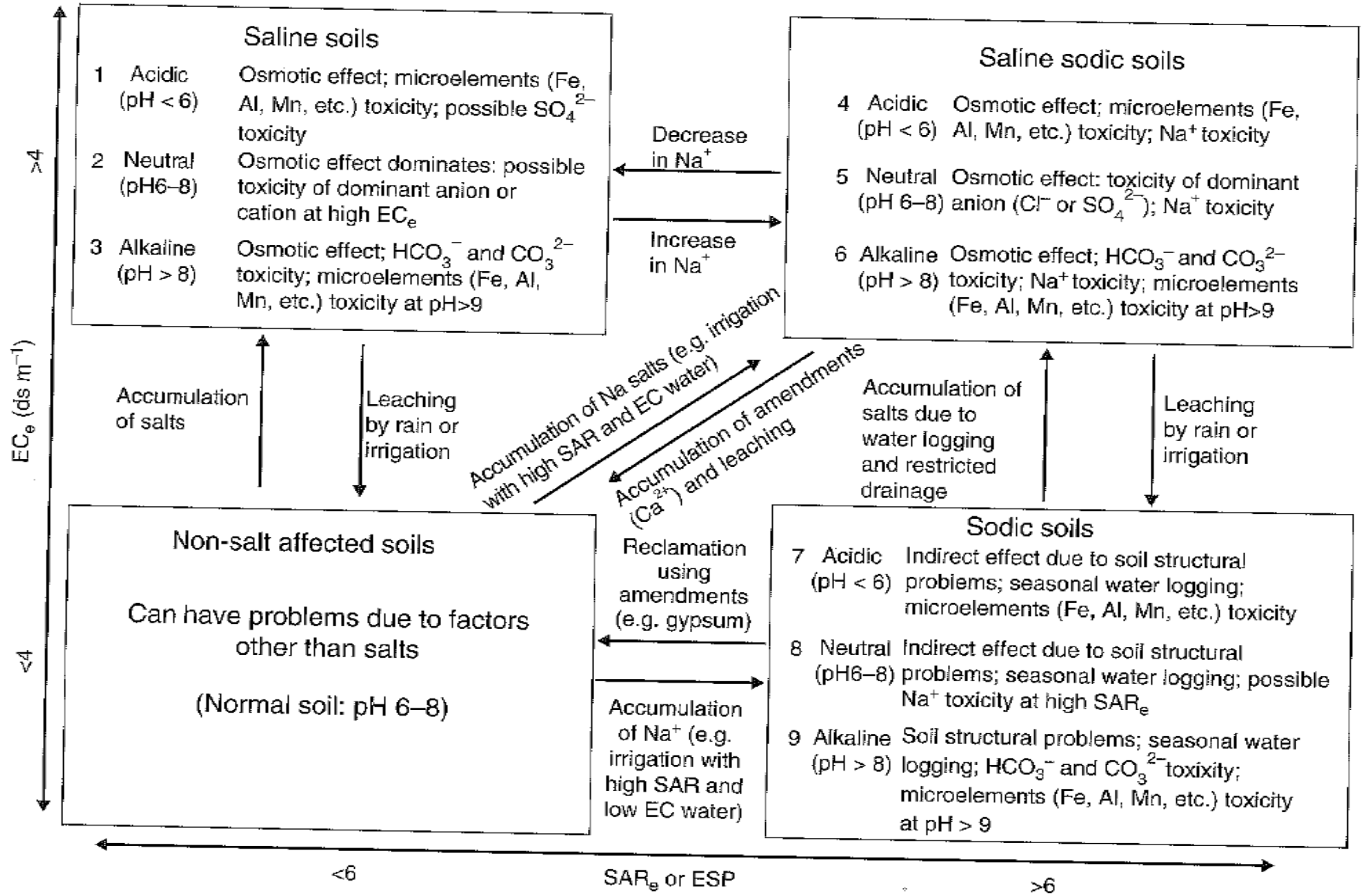
# Salinity and Sodicity

- Salinity and sodicity exasperate water stress
- Drought strategies
  - Controlled irrigation: furrow, drip, sprinkler
  - Resistant resources: phenotypes and breeding
  - Agronomic: residue, rotation, and position
  - Bioresources: PGPR



# What to Do?

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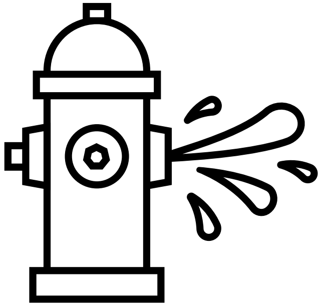
# Removing Excess Salinity

- You need water, water above and beyond what is needed to grow the crop
- The salt "Leaching Requirement"
- $LR = EC_w/[5(EC_e) - EC_w]$ where $EC_w$ is the electrical conductance of the irrigation water and $EC_e$ is the electrical conductance of the soil at which no yield loss occurs. The $EC_e$ value differs with the chosen crop.
- The fraction of additional water needed.



# Managing Sodicity

- You need to remove Na, without causing dispersion – you need both water AND Ca
- Why can't you use Ca carbonate?
- Gypsum ($CaSO_4 \cdot 2H_2O$) is a cheap and more soluble Ca source
- The gypsum requirement, GR:

$$GR = 0.0086 F D_s \rho_d CEC(ESP_i - ESP_f).$$

# The Biological Perspective for Chemically Degraded Soils

# Acidity and Alkalinity

Raise pH if it is acid
- Lime with $CaCO_3$ or a Mg/Ca oxide

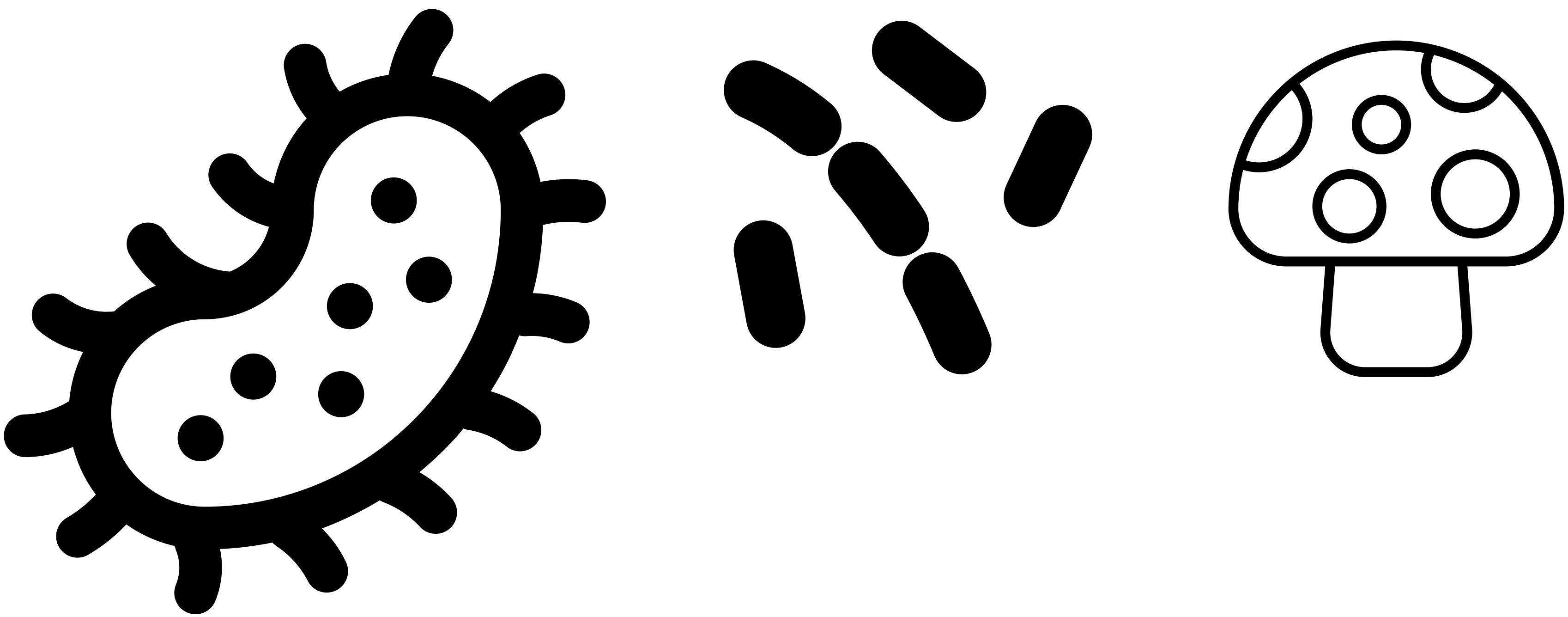
Lower if the pH is alkaline
- Everyone mineralizes, few solubilize when alkalinity is an issue

# Agronomic Solutions

- Ridge planting avoids the most salt-affected soil - a desperate solution.
- Increasing soil residue will decrease evapotranspiration and keep soil cooler
  - Maintains more water in soil and reduces plant stress
- Increasing soil organic matter improves soil structure and release soil nutrients
  - Reduces dispersion and increases infiltration
  - Helps to minimize soil acidity effects by increasing CEC
  - Mineralization releases nutrients that replace chemical salts
    - Unless the organic matter is high in salts (e.g. poultry litter)
- Legumes replace chemical N as the N source and preserve available P

# Microbial Solutions

Find Microbes That Persist in Saline or Sodic Environments and Improve Plant Growth in Water Stressed Environments



# Pathways for Drought Tolerance Through Rhizosphere Bacteria

- Create phytohormones
- Produce the  enzyme ACC-deaminase, which lowers the amount of ethylene
- Cause induced systemic resistance
- Develop biofilms
- Produce extracellular polysaccharides

# Stress Tolerant Microbes That Enhance Growth

- Auxins, cytokinins, and gibberellins are among the phytohormones produced by rhizobacteria that help plants grow.
- Crop plants exposed to beneficial bacteria develop extensive roots, and root hairs, all of which may enhance the plant’s capacity to endure various stressful environments
- P solubilizing bacteria reduce the need for chemical P fertilization

# Microbes That Reduce Stress Hormones

- Ethylene is a plant stress hormone.
- The metabolic pathway leading from from methionine to ethylene is:

  Methionine → S-adenosylmethionine → 1-aminocyclopropane-1-carboxylic acid (ACC) → ethylene ($C_2H_4$)
- Microbes with ACC deaminase reduce ethylene production and promote plant growth during water stress.

# Common Genera Bacteria That Can be PGPR

- *Acetobacter*
- *Azospirillum*
- *Bacillus (e.g. B. subtilis)*
- *Burkholderia*
- *Pseudomonas*
- *Rhizobium*

PGPR = Plant Growth Promoting Rhizobacteria

# Selection Strategies

- Pick isolates that are inherently resistant to high salt and Na and water stress
- Increase mass in environments that mimic the stressed conditions
- Inoculate in high numbers early
- One interesting approach is to use rhizobia with PGPR properties and rotate with legumes
  - this maintains the population of the PGPR in the soil environment with time.
  - Rotation is good anyway

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# How Do Mycorrhizae (AMF) Improve Salt Tolerance?

- Enhance nutrient acquisition (P, N, Mg and Ca)
- Maintain the $K^+ : Na^+$ ratio
- Accumulate non salt osmolytes: proline, betaines, polyamines, carbohydrates and antioxidants
- Promote physiological changes (photosynthetic efficiency, relative permeability, water status, abscissic acid accumulation, nodulation and nitrogen fixation)
- Induce molecular changes (the expression of genes: *PIP*, $Na^+/H^+$ antiporters, *Lsnced*, *Lslea* and *LsP5CS*)
- Stimulate ultra-structural changes.

# Mycorrhizae

| Increase | Have | Develop | Extend |
|---|---|---|---|
| Increase the volume of soil exploited for nutrients and water | Have the capacity to take up water at lower potential than plant roots | Develop improved aggregation in the soil surrounding roots, which increases percolation | Extend the lifespan of roots for water sorption |

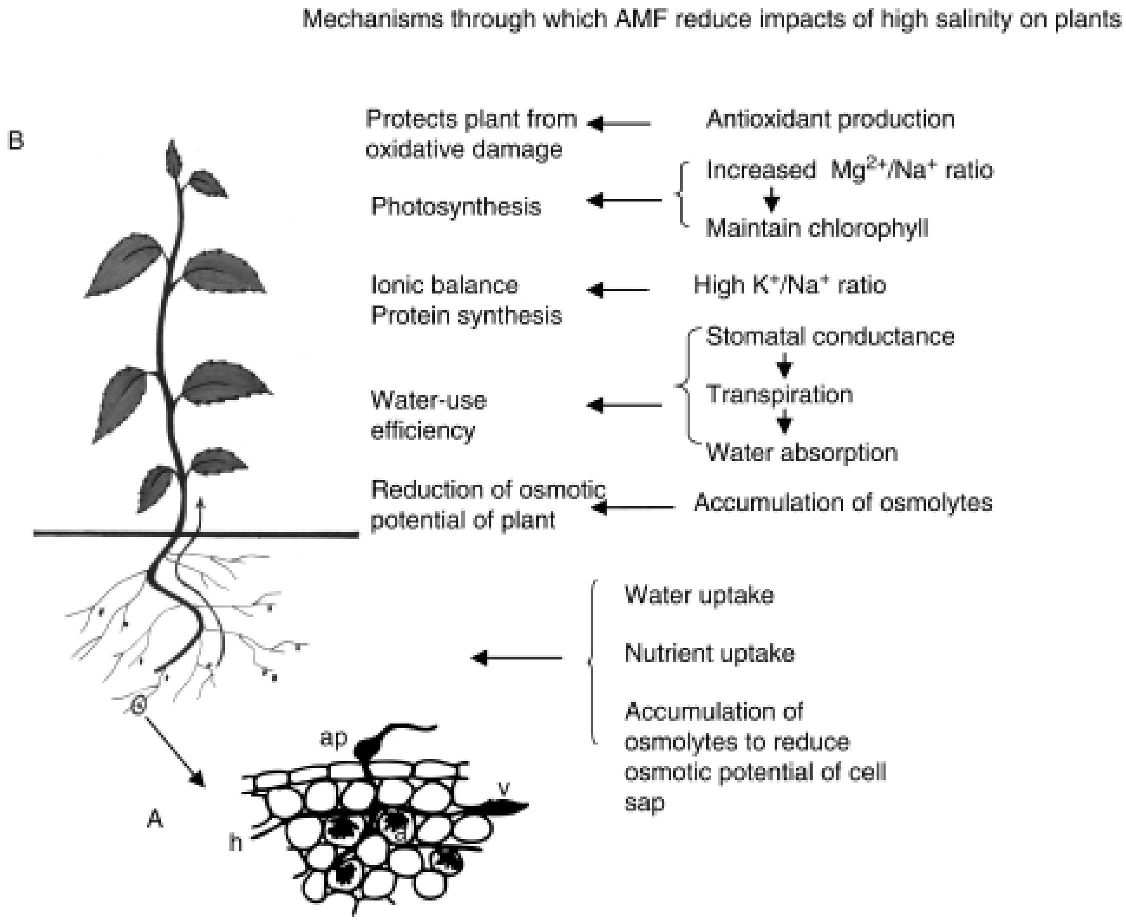


Fig. 2

The intricate functioning of arbuscular mycorrhizal (AM) fungi in ameliorating salt stress in plants. In AM symbiosis, the fungus forms an appressorium (ap) on the root surface and enters the root cortex by extending its hyphae (h). The hyphae form arbuscules (a) and vesicles (v) in the cortex. Salinity deprives plants of the basic requirements of water and nutrients, causing physiological drought and a decrease in osmotic potential accompanied by nutrient deficiency, rendering plants weak and unproductive. Arbuscular mycorrhiza help plants in salt stress by improving water and nutrient uptake: a decrease in osmotic potential is countered by increasing accumulation of osmolytes, and water-use efficiency, photosynthesis and antioxidant production (to scavenge ROS) is more efficient in salt-stressed plants in the presence of AMF (see text).

From Evelin et al. (2009)

# Salinity Reduces Spore Formation

Reduces Overall Mycorrhizal Population and Diversity

Mycorrhizae still colonize roots at very high salinity

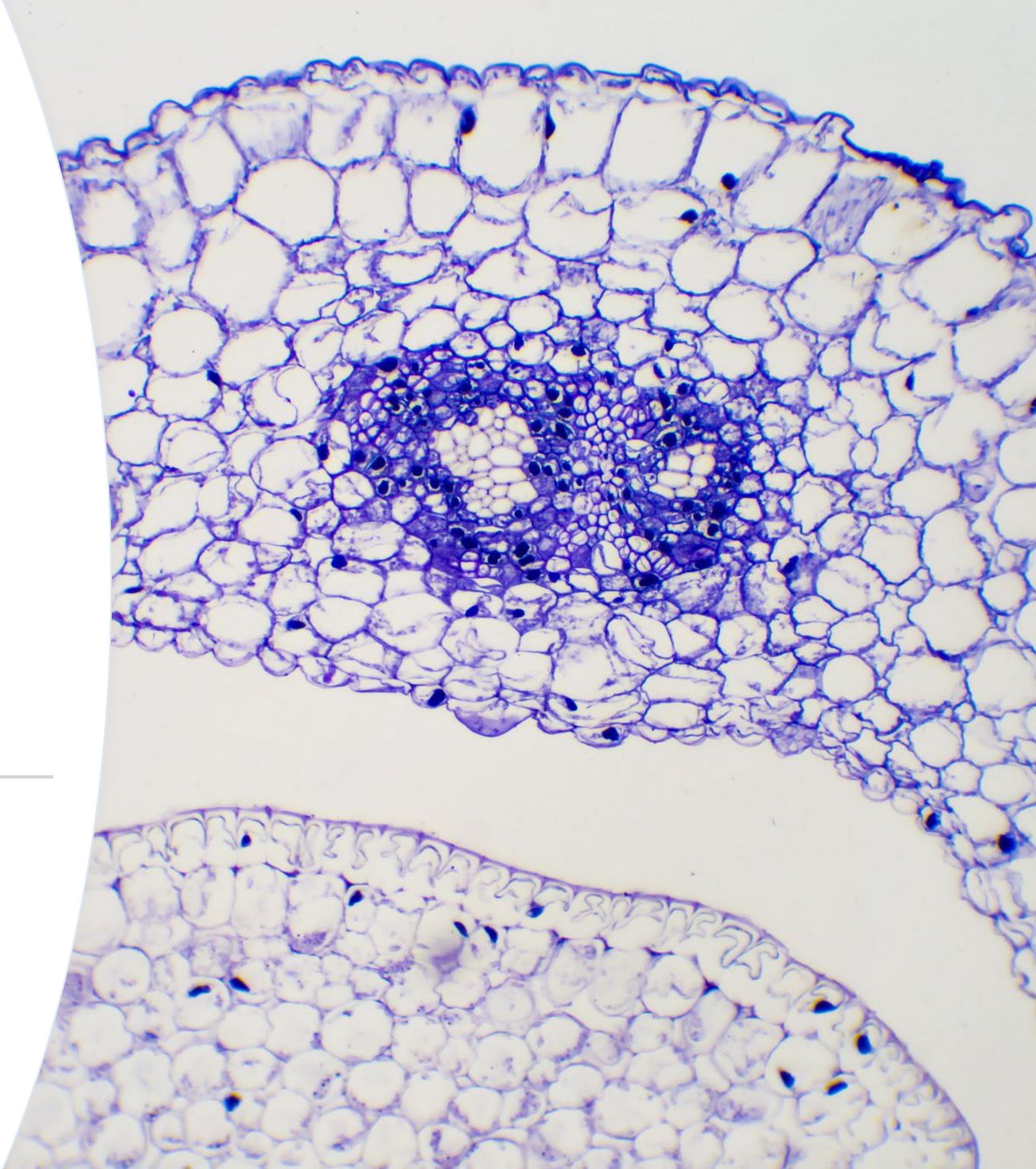

Table 1. Studies on percentage of AMF colonization in root under salinity stress
* The range of salinity within brackets is the actual salt concentrations used by the authors.

| Range of salinity* | Plant | Fungus | % root colonization in AM plants | References |
|---|---|---|---|---|
| 1·4–7·4 dS $m^{-1}$ | *Lycopersicon esculentum* | *Glomus mosseae* | **49·6–36** | Al-Karaki (2000) |
| 2 –12 dS $m^{-1}$ | *Lactuca sativa* | Mixture of *Glomus*, *Acaulospora* and *Entrosphora* spp. procured from (*a*) saline playa or (*b*) non-saline vegetable farm | **(*a*) 43·0–26·2**<br>(*b*) 34·8–29·9 | Cantrell and Linderman (2001) |
| 2–12 dS $m^{-1}$ | *Allium cepa* | Mixture of *Glomus*, *Acaulospora* and *Entrosphora* spp. procured from (*a*) saline playa or (*b*) non-saline vegetable farm | (*a*) 61·7–38·8<br>**(*b*) 28·8–18·0** | Cantrell and Linderman (2001) |
| 0–13·19 dS $m^{-1}$ (0–100 mM) | *Zea mays* | *Glomus mosseae* | **70–80** | Feng *et al.* (2002) |
| 0–6·10 dS $m^{-1}$ (0–3 g $kg^{-1}$) | *Gossypium arboreum* | *Glomus mosseae*: (*a*) GM1 from non-saline soils; (*b*) GM2 from saline soils | (*a*) 38 ± 3 to 15 ± 2<br>**(*b*) 46 ± 5 to 21 ± 3** | Tian *et al.* (2004) |
| 40·2 dS $m^{-1}$ | *Tamarix chinensis*, *Phragmites communis*, *Suaeda glauca*, *Aeluropus littoralis* var. *sinensis* and *Cirsium setosum* (in Yellow River Delta, China) | Mixture of *Archaeospora*, *Acaulospora* a nd *Glomus* | **0·2–9·5** | F. Y. Wang *et al.* (2004) |

# Sources


- Evelin, H., R. Kapoor, and B, Giri. 2009. Arbuscular mycorrhizal fungi in alleviation of salt stress: a review. Ann Bot. 2009. 104(7): 1263–1280.
- Tahir, M.N. 2024. Evaluating the effect of microbial consortium for improving growth and quality of sorghum and residual effect of inoculation on berseem under water deficit conditions. PhD dissertation. University of Faisalabad, Pakistan.

Questions?