Saline - Sodic Soils

Chapter 10

Concepts to Master

- Sources of alkalinity
- Carbonate equilibria
- Classes of salt-affected soils
  - Saline, Saline-sodic, Sodic
- Plant tolerance
- Reclamation of salt-affected soils

Introduction

- Found on more than 1/2 the Earth's arable land
- Rangelands, dryland farming, and irrigated agriculture
- Precipitation insufficient to leach base cations and soluble salts (e.g. Ca^{+2}, K^{+}, NaCl, and $MgCl_2$)

Introduction

- Irrigation can make soils into extremely productive
- Conversely irrigation can cause salt problems
  - Waters carry high quantity of dissolved solutes
  - Insufficient drainage
- 1/3 irrigated lands have salt problems

Introduction

- Acidity generated by Al^{+3} and H^{+}
- Alkalinity generated by base cations
  - Ca^{+2}, Mg^{+2}, K^{+}, Na^{+}
- Humid regions (high rainfall) base cations are leached
  - Colloids have low base saturation

Introduction

- Arid regions (low rainfall) base cations are conserved
  - Cations generated by primary mineral weathering
  - Soluble salts and cations also generated by low quality irrigation water

Role of Carbonates and Bicarbonates

- $CO_2 + H_2O = H_2CO_3$
- $H_2CO_3 + OH^- = \mathbf{HCO_3^-} + H_2O \quad pK_a = 6.35$
- $\mathbf{HCO_3^-} + OH^- = \mathbf{CO_3^{2-}} + H_2O \quad pK_a = 10.33$
- Based on the above equations as pH increases HCO_3^- and CO_3^{2-} will be the dominate species
- CO_2 concentration in soils much higher than atmosphere

Carbonate, Cations, and pH

- Bicarbonate dominated system will have a pH of about 8.3
- The ubiquity of CO_2 in soils ensures that alkalinity accumulates in the form of carbonate and bicarbonate salts
- Base cations associated with carbonate anions determines severity of alkalinity in soils

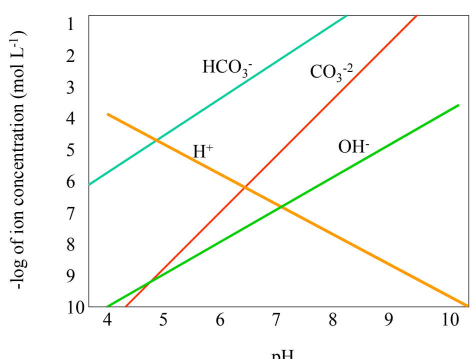


Figure 10.1

Carbonate, Cations, and pH

Carbonate	Solubility (g/liter)
$CaCO_3$	0.014
$MgCO_3$	1.76
Na_2CO_3	71
K_2CO_3	1120

Carbonate, Cations, and pH

- Bicarbonate forms of all cations are quite soluble ensuring high levels of HCO_3^-
  - $HCO_3^- + H_2O = H_2CO_3 + OH^-$
- High concentration of carbonate (CO_3^-) anions in Na system can produce very high pH values

Carbonate, Cations, and pH

- $Na_2CO_3 = 2Na^+ + CO_3^{2-}$
- $CO_3^{2-} + H_2O = HCO_3^- + \boldsymbol{OH^-}$
- $CaCO_3 = Ca^{+2} + CO_3^{2-}$ (insoluble)
- Hence soils derived from primary minerals rich in Ca and Mg will experience lower pH values than Na
- Ca dominant cation in most alkaline soils

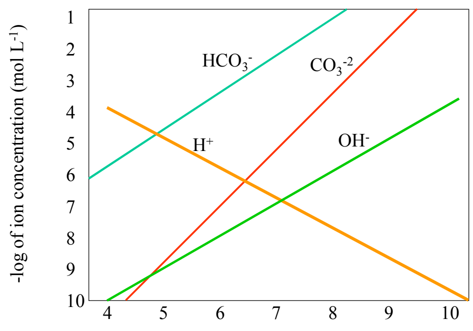
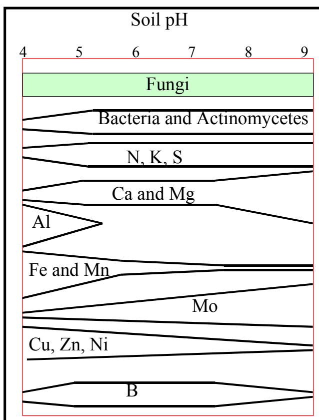


Figure 10.1

Nonsaline Arid Soils

- Nutrient deficiencies
  - P deficiencies (insoluble Ca and Mg phosphates)
  - Micronutrient deficiencies (Cations and Boron)
    - Chelates
  - Molybdenum toxicity
- CEC higher than humid soils
  - Dominated by 2:1 minerals
  - pH dependent CEC



Influence of pH
On nutrient availability

Development of Salt-Affected Soils

- Insufficient precipitation to leach salts
  - Formed during primary mineral weathering or brought to soil through rainfall or irrigation
- Primarily chlorides and sulfates of calcium, magnesium, sodium, potassium
- Fossil deposits of extinct lakes, oceans, or underground saline water pools

Development of Salt-Affected Soils

- Irrigation induced
  - Irrigation waters may contain significant quantities of soluble salts
  - Salts may accumulate
    - Not well drained
    - Insignificant quantity of water
  - Disaster to ancient cultures

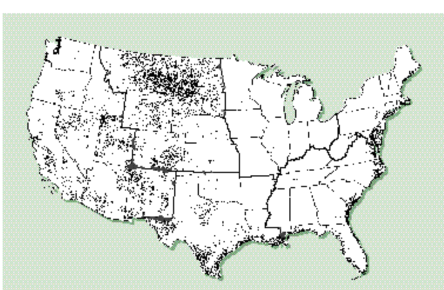


Figure 10.4

Measuring Salinity and Alkalinity

- Salinity
  - Measured via electrical conductivity (decisiemens per meter dS/m)
  - Saturated paste extract
  - Apparent EC in field
  - Electromagnetic induction in field
  - Should be measured when soil is at field capacity

Measuring Salinity and Alkalinity

- Sodium status - soil structure problems
  - Exchangeable sodium percentage - (ESP) degree to which the exchange complex is saturated with sodium

$$ESP = \frac{\text{Exchangeable sodium, cmol}_c\text{/kg}}{\text{CEC, cmol}_c\text{/kg}} \times 100$$

  - ESP levels of 15 or greater are associated with pH values of 8.5 or higher

Measuring Salinity and Alkalinity

- Sodium adsorption ratio (SAR) - gives measurement of the comparative conc. of Na^{+}, Mg^{+2}, and Ca^{+2} in solution

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

- Takes into consideration that the adverse affect of Na is moderated by Ca and Mg

Measuring Salinity and Alkalinity

- SAR is related to the ESP through the process of cation exchange
- Empirical relationship between SAR and ESP

$$\frac{ESP}{100 - ESP} = 0.015\ SAR$$

Classes of Salt-Affected Soils

- Saline Soils - accumulation of neutral soluble salts (salinization)
- EC > 4 dS/m
- White alkali soils
- ESP < 15
- SAR < 13
- pH < 8.5
- Crop growth affected by excess salts

Classes of Salt-Affected Soils

- Saline-Sodic soils
- EC > 4 dS/m
- ESP > 15 and SAR at least 13
- Crop growth adversely affected by excess salts and excess sodium
- Subject to rapid change

Classes of Salt-Affected Soils

- Sodic soils
- EC < 4 dS/M
- ESP > 15 and SAR > 13
- pH > 8.5 hydrolysis of sodium carbonate

$2Na^{+} + CO_3^{2+} + H_2O = 2Na^{+} + HCO_3^{-} + OH^{-}$

Classes of Salt-Affected Soils

- Plant growth constrained by high levels of Na^{+}, OH^{-}, and HCO_3^{-} and poor soil structure
  - Na^{+} causes soil to be in a dispersed condition due to the large hydrated radius of Na^{+}
- Black alkali soils - dispersed humus

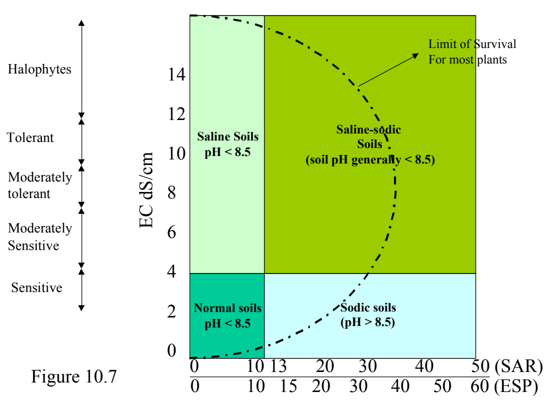


Figure 10.7

Plant Growth

- Saline and Saline-Sodic soils - High salts move water out of roots collapsing cells
- Sodic soils
  - High pH
  - Toxicity of bicarbonate
  - Adverse affects of sodium
  - Low micronutrient availability
  - O_2 deficiency due to poor soil structure

Plant Growth

- Salt tolerance of plants
  - Four general groups
    - Sensitive
    - Moderately sensitive
    - Moderately tolerant
    - Tolerant

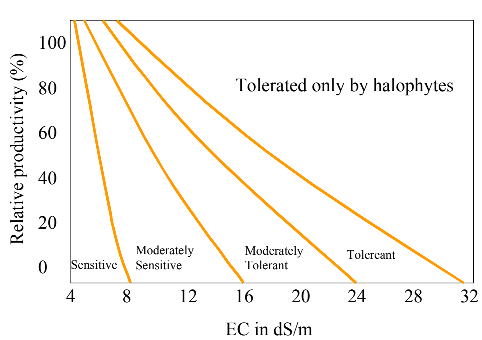


Figure 10.11

Management of Saline and Sodic Soils

- Water quality
  - High SAR levels increase formation of sodic soils
  - Bicarbonates reduce levels of Ca^{+2} and Mg^{+2}
  - Concentrate elements to toxic levels (e.g. Se and Mo)

Reclamation of Saline Soils

- Ample irrigation water with low SARS and good soil drainage
- Leaching requirement or LR (crop specific)
  - $LR = EC_w/EC_{dw}$
  - LR is water added in excess of the moisture needed to wet soil and meet ET
  - Dependent on quality of irrigation water and crop to be grown, and placement of irrigation water

Reclamation of Saline-Sodic Soils

- Adverse properties of both saline and sodic soils
- Leaching of soluble salts may increase ESP and pH
  - Reduce the level of exchangeable sodium
    - $CaSO_4$ (gypsum)
  - Remove excess salts

Reclamation of Saline-Sodic Soils

- Gypsum ($CaSO_4 \cdot H_2O$)
- $2NaHCO_3 + CaSO_4 = CaCO_3 + Na_2SO_4 + CO_2 + H_2O$
- Clay-$2Na^+ + CaSO_4 =$ Clay-$Ca^{+2} + Na_2SO_4$
- Soluble salt (Na_2SO_4) is easily leached from soil
- Sulfuric acid produces similar effect

Summary

- If properly managed dryland soils can be extremely productive
- Water quality issues
- More research is needed to more thoroughly understand physical and chemical processes in salt effected soils