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 Al³⁺ and H⁺
• Alkalinity generated by base cations
  – Ca²⁺, Mg²⁺, 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

- $\text{CO}_2 + \text{H}_2\text{O} = \text{H}_2\text{CO}_3$
- $\text{H}_2\text{CO}_3 + \text{OH}^- = \text{HCO}_3^- + \text{H}_2\text{O}$  $\text{pK}_a = 6.35$
- $\text{HCO}_3^- + \text{OH}^- = \text{CO}_3^{2-} + \text{H}_2\text{O}$  $\text{pK}_a = 10.33$

- Based on the above equations as pH increases $\text{HCO}_3^-$ and $\text{CO}_3^{2-}$ will be the dominate species
- $\text{CO}_2$ 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 $\text{CO}_2$ 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

- A graph showing the concentration of $\text{HCO}_3^-$, $\text{CO}_3^{2-}$, $\text{H}^+$, and $\text{OH}^-$ ions vs. pH.
Carbonate, Cations, and pH

<table>
<thead>
<tr>
<th>Carbonate</th>
<th>Solubility (g/liter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaCO₃</td>
<td>0.014</td>
</tr>
<tr>
<td>MgCO₃</td>
<td>1.76</td>
</tr>
<tr>
<td>Na₂CO₃</td>
<td>71</td>
</tr>
<tr>
<td>K₂CO₃</td>
<td>1120</td>
</tr>
</tbody>
</table>

- Bicarbonate forms of all cations are quite soluble ensuring high levels of HCO₃⁻:
  \[ \text{HCO}_3^- + \text{H}_2\text{O} = \text{H}_2\text{CO}_3 + \text{OH}^- \]
- High concentration of carbonate (CO₃²⁻) anions in Na system can produce very high pH values

- \( \text{Na}_2\text{CO}_3 = 2\text{Na}^+ + \text{CO}_3^{2-} \)
- \( \text{CO}_3^{2-} + \text{H}_2\text{O} = \text{HCO}_3^- + \text{OH}^- \)
- \( \text{CaCO}_3 = \text{Ca}^{2+} + \text{CO}_3^{2-} \) (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
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
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
  \[ \text{ESP} = \frac{\text{Exchangeable sodium, cmol/kg}}{\text{CEC, cmol/kg}} \times 100 \]
  – 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⁺, Mg²⁺, and Ca²⁺ in solution
  \[ \text{SAR} = \frac{[\text{Na}^+]}{\sqrt{1/2 ([\text{Ca}^{2+} + [\text{Mg}^{2+}])}} \]
  – 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

\[
\frac{\text{ESP}}{100 - \text{ESP}} = 0.015 \text{ SAR}
\]

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
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
  - O₂ 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\(_d_w\)
  - 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$_4$·H$_2$O)
- 2NaHCO$_3$ + CaSO$_4$ = CaCO$_3$ + Na$_2$SO$_4$ + CO$_2$ + H$_2$O
- Clay-2Na$^+$ + CaSO$_4$ = Clay-Ca$^{2+}$ + Na$_2$SO$_4$
- Soluble salt (Na$_2$SO$_4$) 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