Chemistry of Tiling and Crusting

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Soil and Soil/Water Training
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What is Dispersion?

• Soil particles are repelled away from each other and the particles act independently.

• The three main problems caused by sodium-induced dispersion are reduced infiltration, reduced hydraulic conductivity, and surface crusting.

• Opposite of flocculation.
Clay particles

http://www.okstate.edu/artsci/botany/bisc3034/lnotes/micelle.jpg
Where do the cations come from?

- $\text{Na}^+ , \text{K}^+, \text{Ca}^{2+}, \text{Mg}^{2+}$
- Dissolution of secondary minerals
- Concentration in soil depends on the secondary minerals and their solubility
Salt is initially put into the water and begins dissolving.

Salt continues to dissolve; however, dissolved ions will also precipitate. Because the salt dissolves faster than its ions precipitate, the net movement is towards dissolving.

Eventually, the rate of dissolution will equal the rate of precipitation. The solution will be in equilibrium, but the ions will continue to dissolve and precipitate.

http://www.chem.ubc.ca/courseware/pH/section17/index.html
Parts of double layer

"Single layer"  Stern layer  Guoy diffuse layer Or "double layer"

M. Hubbe

http://www4.ncsu.edu/~hubbe/Defnitns/DefnitnGIFs/Slide15.GIF
\[
SAR_e = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}
\]

where concentrations of the respective cations are reported as mmol\(_{(c)}\) L\(^{-1}\)

Conversion from mg L\(^{-1}\) to mmol\(_{(c)}\) L\(^{-1}\) for Ca, Mg, and Na can be accomplished by dividing mg L\(^{-1}\) by 20, 12.2, and 23, respectively.
Guoy-Chapman Theory

\[ k^{-1} = \frac{3.042 \left(10^{-10}\right)}{Z \sqrt{I}} \]

\( k^{-1} \) = thickness of the diffuse double layer
\( Z \) = valence of the counter ion
\( I \) = Ionic strength of the soil solution (electrical conductivity)
Parts of double layer

“Single layer”  Guoy diffuse layer Or “double layer”  Stern layer

M. Hubbe

http://www4.ncsu.edu/~hubbe/Defnitns/DefnitnGIFs/Slide15.GIF
In general...
Effect of EC

Effect of counter ion charge
If the double layer is small (i.e. 2+ or high EC)...

no repulsion = no dispersion
If the double layer is large (i.e. 1+ and low EC)...  

Double layers of adjacent particles will overlap, setting up electrostatic repulsion
Figure 2.18

A) No overlap = no repulsion

B) Overlap = repulsion
What happens during drainage?

• Move water out of the soil
• Move nutrients out of the system
• Move salts out of the system
• What are salts made up of?
  – Anions and cations
• Why do we care about anions and cations?
  – Help control the diffuse double layer
  – Dispersion vs flocculation
    • Flocculation is good!
    • Dispersion is bad!
Tiles move water out of the soil

• Only drainable water leaves via drains
  – *Total soil porosity minus soil moisture at field capacity*
• This is generally thought of as “gravitational water”
• Drainable water depends on texture

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>Field Capacity (% by vol.)</th>
<th>Wilting Point (% by vol.)</th>
<th>Drainable Porosity (% by vol.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>clays, clay loams, silty clays</td>
<td>30-50%</td>
<td>15-24%</td>
<td>3-11%</td>
</tr>
<tr>
<td>well structured loams</td>
<td>20-30%</td>
<td>8-17%</td>
<td>10-15%</td>
</tr>
<tr>
<td>sandy</td>
<td>10-30%</td>
<td>3-10%</td>
<td>18-35%</td>
</tr>
</tbody>
</table>

http://www.extension.umn.edu/distribution/cropsystems/DC7644.html
Tiles move salts out of the soil

• Anions: \( \text{SO}_4^{2-}, \text{Cl}^-, \text{NO}_3^- \),

• Cations: \( \text{Na}^+, \text{Mg}^{2+}, \text{Ca}^{2+}, \text{K}^+, \text{Al}^{3+}, \text{H}^+ \)

• Not all ions contribute to EC in the same way.

• Depends on their “activity” and their involvement in ion-pairing.

• In general:

<table>
<thead>
<tr>
<th>Ion</th>
<th>dS/m per mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca(^{2+})</td>
<td>2.60</td>
</tr>
<tr>
<td>Mg(^{2+})</td>
<td>3.82</td>
</tr>
<tr>
<td>K(^+)</td>
<td>1.84</td>
</tr>
<tr>
<td>Na(^+)</td>
<td>2.13</td>
</tr>
<tr>
<td>Cl(^-)</td>
<td>2.14</td>
</tr>
<tr>
<td>NO(_3^-)</td>
<td>1.15</td>
</tr>
<tr>
<td>SO(_4^{2-})</td>
<td>1.54</td>
</tr>
</tbody>
</table>
Why do we care about anions and cations?

– Help control the thickness of the diffuse double layer

– Dispersion vs flocculation
  • Flocculation is good!
  • Dispersion is bad!
Impacts on soil

• Subsurface dispersion has not been widely studied
• Some cases reported to us but not confirmed
• What does one need to be concerned about?
  – Concentration of Na in your soil
  – May not take much to induce dispersion once the EC has been lowered

Need to soil sample and have Na\(^+\), Ca\(^{2+}\), and Mg\(^{2+}\) (SAR) and soil EC determined by saturated paste extracts.
EXLINE SERIES

The Exline series consists of very deep, somewhat poorly drained or moderately well drained soils formed in lacustrine and alluvial deposits on lake plains and terraces. These soils have very slow permeability. Slopes are 0 to 3 percent. Mean annual precipitation is about 21 inches and mean annual air temperature is about 42 degrees F.

**TAXONOMIC CLASS:** Fine, smectitic, frigid Leptic Natrudolls

**TYPICAL PEDON:** Exline silt loam - in a slightly depressed shallow basin on a west-facing slope of less than 1 percent in native vegetation. When described the soil was moist throughout. (Colors are for dry soil unless otherwise stated.)

A--0 to 2 inches; dark gray (10YR 4/1) silt loam, black (10YR 2/1) moist; weak fine and very fine granular structure; soft, friable, slightly sticky; slightly acid; clear smooth boundary. (0 to 3 inches thick)

E--2 to 3 inches; gray (10YR 5/1) silt loam, very dark gray (10YR 3/1) moist; weak very thin platy structure; soft, friable, slightly sticky; slightly acid; abrupt smooth boundary. (0 to 3 inches thick)

Btu--3 to 7 inches; dark gray (10YR 4/1) clay, black (10YR 2/1) moist; strong medium columnar structure parting to strong fine and medium blocky; very hard, very firm, very sticky and very plastic; gray (10YR 5/1) coatings on tops of columns and faces of peds; continuous shiny films on vertical faces of peds; neutral; clear wavy boundary.

Btuz--7 to 11 inches; dark gray (10YR 4/1) clay, black (10YR 2/1) crushing to very dark brown (10YR 2/2) moist; moderate medium prismatic structure parting to strong very fine and fine blocky; very hard, very firm, very sticky and very plastic; continuous shiny films on vertical faces of peds; common fine and medium accumulations of salts; moderately alkaline; clear wavy boundary. (Combined thickness of Bt horizon is 5 to 26 inches thick)

Btkuz--11 to 19 inches; gray (10YR 5/1) clay, very dark gray (10YR 3/1) moist; weak very coarse prismatic structure parting to moderate very fine and fine blocky; very hard, very firm, very sticky and very plastic; continuous shiny films on vertical faces of peds; many fine and medium accumulations of salts; common fine accumulations of carbonate; strong effervescence; moderately alkaline; gradual wavy boundary. (0 to 20 inches thick)
RYAN SERIES

The Ryan series consists of very deep, poorly drained, very slowly permeable soils that formed in alkaline clayey sediments. These soils are on stream terraces and glacial lake plains and have slopes of 0 to 1 percent. Mean annual air temperature is 42 degrees F, and mean annual precipitation is 18 inches.

TAXONOMIC CLASS: Fine, smectitic, frigid Typic Natraquerts

TYPICAL PEDON: Ryan silty clay on a plane level slope of less than 1 percent under grass. When described the soil was moist throughout. (Colors are for moist soil unless otherwise stated)

E--0 to 2 inches; black (10YR 2/1) silty clay, dark gray (10YR 4/1) dry; weak thin platy and angular blocky structure; very hard, firm, sticky and plastic; many fine roots; moderately alkaline; abrupt smooth boundary. (0 to 3 inches thick)

Btn1--2 to 4 inches; black (10YR 2/1) silty clay, dark gray (5Y 4/1) dry; strong medium and coarse columnar structure parting to strong fine angular blocky; top of columns coated with gray (5Y 5/1) silt coatings; very hard, firm, very sticky and very plastic; common fine roots; many faint clay films on faces of peds; strongly alkaline; clear smooth boundary.

Btn2--4 to 8 inches; black (10YR 2/1) silty clay, dark gray (5Y 4/1) dry; moderate medium and coarse prismatic structure parting to strong fine angular blocky; very hard, firm, very sticky and very plastic; many fine roots; many faint clay films on faces of peds; slight effervescence; strongly alkaline; clear wavy boundary. (Combined Btn horizons 5 to 25 inches thick)
STIRUM SERIES

The Stirum series consists of very deep, poorly drained and very poorly drained soils on outwash plains, deltas, lake plains, floodplains and adjacent to current lakes. Permeability is moderately slow in the Btn horizon and moderate to rapid below the Btn horizon. These soils formed in glaciofluvial deposits, glaciolacustrine deposits or alluvium. They have slope ranging from 0 to 3 percent. Mean annual air temperature is 42 degrees F, and mean annual precipitation is 19 inches.

TAXONOMIC CLASS: Coarse-loamy, mixed, superactive, frigid Typic Natraquolls

TYPICAL PEDON: Stirum fine sandy loam - cultivated. (Colors are for moist soil unless otherwise stated)

Ap--0 to 7 inches; black (10YR 2/1) fine sandy loam, dark gray (10YR 4/1) dry; weak fine and medium subangular blocky structure; very friable; slight effervescence; moderately alkaline; abrupt smooth boundary. (Combined A horizons 3 to 13 inches thick)

Btn--7 to 15 inches; dark grayish brown (10YR 4/2) fine sandy loam, gray (10YR 5/1) dry; strong coarse columnar structure parting to moderate fine and medium angular blocky; very hard, firm, slightly sticky and plastic; very dark grayish brown (10YR 3/2) clay films on faces of peds; slight effervescence; strongly alkaline; gradual wavy boundary. (4 to 15 inches thick)

Bk--15 to 26 inches; light brownish gray (2.5Y 6/2) loam, light gray (2.5Y 7/2) dry; common fine prominent yellowish brown (10YR 5/4) redoximorphic concentrations; strong very coarse prismatic structure parting to weak fine and medium angular blocky; very hard, firm, plastic; strong effervescence; very strongly alkaline; gradual wavy boundary. (0 to 20 inches thick)

Bg--26 to 34 inches; olive gray (5Y 5/2) very fine sandy loam, light gray (5Y 7/2) dry; common medium prominent yellowish brown (10YR 5/4) and many medium very dark grayish brown (10YR 3/2) redoximorphic concentrations; weak subangular blocky structure; very friable, slightly sticky; slight effervescence; strongly alkaline; clear wavy boundary. (0 to 20 inches thick)
Previous thoughts...

- That only Na⁺ could cause dispersion
- However, this may not be true
- Many soil clays are dispersible at low levels of Na⁺ or even zero Na⁺
- How do ‘our’ soils react?
- NDSU research.
NDSU Research

• Effects of SAR, Na\(^+\), Mg\(^{2+}\), EC, and clay mineralogy on saturated hydraulic conductivity.

• Where are the “danger zones” with respect to cations and soil EC?

• Are the values from Handbook 60 (1954) applicable for ‘our’ soils?

<table>
<thead>
<tr>
<th>Characterization</th>
<th>EC</th>
<th>ESP</th>
<th>SAR(_e)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>&lt;4</td>
<td>&lt;15</td>
<td>&lt;12</td>
<td>&lt;8.5</td>
</tr>
<tr>
<td>Saline</td>
<td>&gt;4</td>
<td>&lt;15</td>
<td>&lt;12</td>
<td>&lt;8.5</td>
</tr>
<tr>
<td>Sodic</td>
<td>&lt;4</td>
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<td>&gt;12</td>
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<td>&gt;4</td>
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</tbody>
</table>
Subsurface Drainage Suitability Rating (SDSR)

Dr. Larry Cihacek
Soil and Range Science Department
NDSU School of Natural Resource Sciences
Fargo, ND
• While most soils are suitable for drainage, some are not.
• Some soils have subsurface properties that may prohibit economical drainage practices.
• Some soils may have subsurface properties that may result in drainage failure.
Steps to Evaluating Soils for Tile Drainage Suitability

1. Identifying Soil Series – Knowledge of Soil Series.
2. Evaluating Soil Chemical Characteristics or Drainage Properties
3. Verification of Soil Properties
Subsurface Drainage Suitability Rating (SDSR)

- Soil Drainage Suitability Rating *will not provide is a comprehensive site evaluation, determination of wetlands and flooding issues, address social or environmental issues, or soil productivity or design information.*
Crusting
Crusting

- Occurs in similar ways across many soil types
- Causes reduced pore space
- Decreases infiltration
- Decreases gas exchange
- Increases runoff and erosion
- Has been a cause of agricultural disasters
- Can greatly inhibit emergence of seedlings
Crusting process, in general...

- Aggregate breakdown after impact from rainfall
- Clay dispersion (soil surface)
  - Thin, impermeable layer at surface
- Crust formation
  - Strength increases as drying occurs
- Crust management
Aggregate breakdown

• Aggregates breakdown if the energy influencing the aggregate is greater than the energy holding soil particles together
  – Similar to erosive forces
Clay dispersion

• Discussed above...
Crust formation

• Thin, hard layer at soil surface

• Creation of “washed-in” and “washed-out” layers
  – Act like a mini “B” and “E” horizons, respectively
    • The mini “B” restricts infiltration, choked pores
    • The mini “E” has cleaned sand grains

• Density of the crust increases due to
  – 1) clay plates settling in horizontal direction, 2) attraction among adjoining particles, and 3) retreat of water held between particles

• Cementation occurs due to reorientation of particles and precipitation of calcium carbonate
Types of crusts

• **Structural Crusts:**
  – 1. water-drop impact
  – 2. runoff starts and sands are left behind
  – 3. as runoff continues these sands are washed away leaving a thin (0.1 mm) “skin” composed mainly of fine particles

• **Depositional Crusts:**
  – Created by the translocation and deposition of fine soil particles (E and B mini-horizons)
  – Thickness equals the “peeling” layer as soil dries
  – “skin” is also present here
  – No sand, texture is different than bulk soil
Crust strength

• Strength is a function of moisture content, thickness, rate of drying, texture, energy of rainfall impact, type of clay, organic matter content, and bulk density

• Measured by
  – Modulus of rupture, mechanical probes (penetrometer)

• Crust strengths are related to energy needed by seedlings to emerge
Crust management

• Tillage
  – Creation of aggregates by tillage has resulted in less crusting and increased seedling emergence
  – Excessive tillage, however, can destroy aggregates and increase crusting
  – Minimum- and no-tillage are best options

• Surface mulches
  – Dissipation of raindrops is key to reducing crusts
  – Not always very convenient, however.

• Amendments and conditioners
  – Gypsum, calcium carbonate, organics (manure), polymers, polyvalent salts
Sources not previously identified


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