An Overview of Soil Trace Metal Chemistry

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What are Trace Metals?

- Found in low concentrations in the environment (<0.1 %).
- May be beneficial or detrimental at very low concentrations in man and animals (<1 mg/kg)
- Micronutrients (Fe, Zn, Mn, Cu)
- Heavy metals (>7 g/cm³) (Cd, Pb, Hg, Cr, Ni)
Sources of Trace Elements

- Rocks and ores
- Primary and secondary minerals
- Atmospheric fallout
- Anthropogenic wastes
- Fertilizers.
Reactions in Soils

- Dissolution/solubilization
- Precipitation
- Hydrolysis/pH
- Exchange/adsorption
- Oxidation-reduction (redox)
- Chelation
Solubility Reactions

- Reaction with the universal solvent - $\text{H}_2\text{O}$.
- Substance dissociates into original (ionic) components.
- Formation of ions in solution
- Ex:

\[ \text{ZnCl}_2 \overset{\text{in } \text{H}_2\text{O}}{\rightleftharpoons} \text{Zn}^{2+} + 2\text{Cl}^- \]

\[ \log K^\circ = 7.07 \]
Solubility Reactions

ZnCl₂ → Zn²⁺ + 2Cl⁻
Precipitation Reactions

- Occurs when solubility exceeded.
- Drying and concentrating solutes.
Precipitation Reactions

\[ \text{Zn}^{2+} + \text{Cl}^- \rightarrow \text{ZnCl}_2 \]
Solubility/Precipitation

Miranda – fine-loamy, mixed Leptic Natriborolls
Hydrolysis/pH Reactions

- Ionic reaction/interaction with $\text{H}_2\text{O}$ molecules in soil solution.
- May influence soil/solution pH.
- May be influenced by soil/solution pH.
- Classic examples - Al, Fe
Hydrolysis/pH Reactions

Example: $\text{Al}^{3+}$
Hydrolysis/pH Reactions

Reactions:

\[ \text{Al(H}_2\text{O)}_6^{3+} \leftrightarrow \text{Al(H}_2\text{O)}_5(\text{OH})^{2+} + \text{H}^+ \]
\[ \leftrightarrow \text{Al(H}_2\text{O)}_4(\text{OH})^{2+} + \text{H}^+ \]
\[ \leftrightarrow \text{Al(H}_2\text{O)}_3(\text{OH})_3^\circ + \text{H}^+ \]
\[ \leftrightarrow \text{Al(H}_2\text{O)}_2(\text{OH})_{4}^- + \text{H}^+ \]
\[ \leftrightarrow \text{Al(H}_2\text{O})(\text{OH})_5^{2-} + \text{H}^+ \]

Note: \( \text{Al(H}_2\text{O)}_3\text{(OH)}_3^\circ = \text{Gibbsite (Al(OH)}_3 \)
Hydrolysis/pH Reactions

Gibbsite
Hydrolysis/pH Reactions

Oxisol - East-central Brazil
Exchange/Adsorption Reactions

- Soil minerals tend to be negatively charged.
- Trace metals and positively charged.
- “Magnet effect”.
- Polarity.
Exchange/Adsorption Reactions

Cl\(^-\)  
Zn\(^{2+}\)  
K\(^+\)  
H\(^+\)  
Cl\(^-\)  

Clay

Ca\(^{2+}\)  
Na\(^+\)  
H\(^+\)  
K\(^+\)  

Zn\(^{2+}\)  

d

Cl\(^-\)  
Zn\(^{2+}\)  
H\(^+\)  
K\(^+\)  
Cl\(^-\)  

Mg\(^{2+}\)
Exchange/Adsorption Reactions

\[
\begin{align*}
\text{Fe} - \text{OH} & \quad + \quad \text{Zn}^{2+} \\
\text{H} & \quad \text{O} \\
\text{O} & \quad \text{H} \\
\text{H} & \quad \text{H} \\
\text{Fe} - \text{OH} & \quad \text{Zn} + 2\text{H}^+
\end{align*}
\]
Oxidation-Reduction (Redox) Reactions

- Involves exchange of electrons by a metal.
- Oxidation – loss of electron(s).
- Reduction – gain of electron(s)
- Related to presence/availability of oxygen \((O_2)\).
- Usually expressed as half-cell reaction.

\[
Fe^{3+} + e^- \rightleftharpoons Fe^{2+}
\]
Redox Reactions

Completely Oxidized

Normal range of soils

Completely reduced
Redox Reactions

Mottling
Chelation

- Chele - Greek word for “claw”
- Reaction with organic compounds in the soil.
- Organic compounds hold the metal and protect it from other reactions.
Chelation
Chelation

Organic Matter
– Fe Complex

Spodosol
Metals in Soils

Binford soil - Sandy, mixed Udic Haploborolls
Trace Metals in Landscapes

Well-drained
(Oxidized)

Poorly-drained
(Reduced)

Waterlogged
(Anoxic)

Dissolution

Precipitation
Trace metals in soils are affected by many factors:

- Soil mineralogy
- Mineral solubility
- Other cations/anions
- pH
- Redox
- Organic matter
Other Factors:

- Drainage
- Aeration
- Local hydrology
- Local biota
Summary

- Soil characteristics and formation factors that influence soil classification also may influence status of trace metals.
- Knowledge of soil mineralogy and chemistry aids soil survey.
References