Herbicide Behavior in Soil

Section 4
Why is it important to understand herbicide behavior in soil?

That behavior can affect:

• success or failure of weed control
• presence or absence of crop injury
• persistence of the herbicide (length of control; potential for carryover)
• environmental impact
Environmental Fate of Herbicides

Herbicide

- Adsorbed by clay and organic matter
- Leaching
- Runoff and erosion
- Chemical decomposition
- Microbial decomposition
- Plant uptake
- Photochemical decomposition
- Volatilization
- Adsorbed by clay and organic matter
- Leaching
Environmental Fate of Herbicides in Soil

- Transport processes
  - Adsorption
  - Leaching
  - Volatilization
  - Plant uptake
  - Runoff

- Degradation processes
  - Microbial degradation
  - Chemical degradation
  - Photodegradation
Environmental Fate (Degradation Processes)

Herbicide

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Environmental Fate (Transport processes)

- Herbicide
  - Adsorbed by clay and organic matter
  - Leaching
  - Chemical decomposition
  - Microbial decomposition
  - Plant uptake
  - Photochemical decomposition
  - Volatilization
  - Runoff and erosion
  - Adsorbed by clay and organic matter
Environmental Fate of Herbicides

- Adsorbed by clay and organic matter
- Leaching
- Runoff and erosion
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- Photochemical decomposition
- Chemical decomposition
- Microbial decomposition
- Plant uptake
Adsorption vs Absorption
What is Herbicide Adsorption?

- Binding of herbicide to soil colloids (clay and organic matter fraction of soil)
- Determines herbicide availability to plants
- Also impacts leaching, volatilization, and microbial degradation
Factors Affecting Herbicide Adsorption

1. Organic (humic) matter content
2. Clay content
3. Soil moisture
4. Chemical properties of herbicide
5. Soil pH (affects some herbicides, not others)
Factors Affecting Herbicide Adsorption

1. Organic (humic) matter content

- High capacity to adsorb herbicides
  Greater OM = greater adsorption

- Negative surfaces (ionic binding) and organophillic surfaces (non-ionic binding)
Figure 1. Structure for humic acid. From Stevenson, J. Environ. Qual. 1:333-344.
Humic Matter vs Organic Matter

- Herbicide labels base application rates on organic matter content
- NCDA soil analyses include humic matter content
- Humic matter is the highly degraded organic fraction of soil; humic matter fraction is what binds most of the herbicide
- Humic matter and organic matter contents highly correlated; absolute values differ
<table>
<thead>
<tr>
<th>Soil series</th>
<th>Humic matter</th>
<th>Organic matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rion</td>
<td>0.1</td>
<td>1.0</td>
</tr>
<tr>
<td>Norfolk</td>
<td>0.3</td>
<td>1.2</td>
</tr>
<tr>
<td>Rains</td>
<td>0.6</td>
<td>1.9</td>
</tr>
<tr>
<td>Roanoke</td>
<td>2.8</td>
<td>3.2</td>
</tr>
<tr>
<td>Cape Fear</td>
<td>3.1</td>
<td>3.4</td>
</tr>
<tr>
<td>Portsmouth</td>
<td>3.2</td>
<td>3.8</td>
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From: Blumhorst et al., Weed Technol. 4:279-283.
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Factors Affecting Herbicide Adsorption

2. Clay content and type

Clay is negatively charged; ionic binding with positively charged herbicides

More clay = more adsorption

2:1 clays adsorb more than 1:1 clays
Herbicide labels break soil texture into three major categories:

<table>
<thead>
<tr>
<th>Categories</th>
<th>Textural classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>sand, loamy sand, sandy loam</td>
</tr>
<tr>
<td>Medium</td>
<td>loam, silt loam, silt, sandy clay loam, sandy clay</td>
</tr>
<tr>
<td>Fine</td>
<td>silty clay loam, silty clay, clay loam, clay</td>
</tr>
</tbody>
</table>
Herbicides and Soil Adsorption

A. Clay and organic matter adsorb herbicides

B. Clay and organic matter content of soil affects application rate of soil-applied herbicides

C. Clay and organic matter content also put limitations on use of some herbicides
Application rate recommendations for Axiom herbicide applied PRE to corn.

<table>
<thead>
<tr>
<th>Soil texture</th>
<th>Organic matter content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>Coarse</td>
<td>4-6 oz</td>
</tr>
<tr>
<td>Medium</td>
<td>8-11 oz</td>
</tr>
<tr>
<td>Fine</td>
<td>15 oz</td>
</tr>
</tbody>
</table>

Note the rate increase
Application rate recommendations for Sencor DF herbicide applied PRE to soybeans.

<table>
<thead>
<tr>
<th>Soil texture</th>
<th>Organic matter content</th>
<th>lb product/acre</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 2%</td>
<td>2 to 4%</td>
</tr>
<tr>
<td>Coarse</td>
<td>Do not use</td>
<td>0.50</td>
</tr>
<tr>
<td>Medium</td>
<td>0.50 - 0.67</td>
<td>0.67 - 0.83</td>
</tr>
<tr>
<td>Fine</td>
<td>0.67 - 0.83</td>
<td>0.83 - 1.00</td>
</tr>
</tbody>
</table>

Note the rate increase.
Lexar Preemergence Rate Recommendations
For Corn

<table>
<thead>
<tr>
<th>Soil OM content</th>
<th>Lexar use rate (qt/A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 3%</td>
<td>3.0 qt</td>
</tr>
<tr>
<td>3% to 10%</td>
<td>3.5 qt</td>
</tr>
<tr>
<td>Greater than 10%</td>
<td>Not recommended</td>
</tr>
</tbody>
</table>

1 Taken from Lexar label.
Factors Affecting Herbicide Adsorption

3. Soil moisture

Herbicides are more tightly bound to drier soil. Due to less competition with water for binding sites under dry conditions.
Soil water

Moist soil

Dry soil

Soil colloid
Factors Affecting Herbicide Adsorption

4. Herbicide chemistry and soil pH
Sorption Coefficient, $K_{OC}$

Measures the tendency for pesticide adsorption by soil. Adjusted for organic carbon content of soil.
**K\textsubscript{OC} Values**

**Low K\textsubscript{OC}**
Not tightly bound to soil.
Most of the herbicide in soil solution and available for uptake, leaching, volatilization, microbial degradation.

**High K\textsubscript{OC}**
Tightly bound to soil.
Most of the herbicide not available for plant uptake, leaching, volatilization, microbial degradation.
<table>
<thead>
<tr>
<th>Herbicide</th>
<th>$K_{OC}$ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paraquat (Gramoxone)</td>
<td>1,000,000 mL/g</td>
</tr>
<tr>
<td>Glyphosate (Roundup)</td>
<td>24,000 mL/g</td>
</tr>
<tr>
<td>Trifluralin (Treflan)</td>
<td>7,000 mL/g</td>
</tr>
<tr>
<td>Alachlor (Micro-Tech)</td>
<td>124 mL/g</td>
</tr>
<tr>
<td>Imazaquin (Scepter)</td>
<td>20 mL/g</td>
</tr>
</tbody>
</table>
pH has no effect on adsorption of some herbicides, but major effects on others
Soil pH and Herbicide Adsorption

A. Non-ionizable herbicides

- Have no charge regardless of soil pH
- No effect of soil pH on adsorption

![Chemical structure of trifluralin](image)

*trifluralin*
Soil pH and Herbicide Adsorption

B. Cationic herbicides

- Always positively charged
- Very tightly bound to colloids
- Soil pH has no effect

\[
\text{paraquat}
\]

\[\text{H}_3\text{C}^+\text{N} - \text{N}^\text{+}\text{CH}_3\]
Soil pH and Herbicide Adsorption

C. Basic herbicides

- Charge on molecule is pH dependent
- Neutral or positively charged, depending upon pH
- Positively charged at lower pH; neutral at higher pH
- Greater adsorption under low soil pH
Atrazine

Higher pH

Lower pH
Soil pH and Herbicide Adsorption

C. Basic herbicides

- Charge on molecule is pH dependent
- Neutral or positively charged, depending upon pH
- Positively charged at lower pH; greater adsorption under low soil pH
- At low pH, less available for plant uptake; also less available for microbial degradation and leaching
Effect of Soil pH of Adsorption of Basic Herbicides

\[ \text{HB} \xleftrightarrow{\text{Lower pH}} \text{HB}^+ \xleftrightarrow{\text{Higher pH}} \]
Effect of Soil pH of Adsorption of Basic Herbicides

\[ pK_a = \text{the pH at which half of the herbicide molecules are neutral and half are charged} \]

\[
\begin{align*}
\text{HB} & \overset{\text{pH at pK}_a}{\leftrightarrow} \text{HB}^+ \\
\text{HB} & \overset{\text{pH below pK}_a}{\leftarrow} \rightarrow \text{HB}^+ \\
\text{HB} & \overset{\text{pH above pK}_a}{\leftarrow} \rightarrow \text{HB}^+ 
\end{align*}
\]
Soil pH above pKa

Soil pH below pKa
Soil pH and Herbicide Adsorption

D. Acidic herbicides

- Charge on molecule is pH dependent
- Neutral at low pH, negatively charged at high pH
- Soil pH has little to no effect on adsorption

\[ \text{O-CH}_2\text{-C-OH} \]

\[ \text{O-CH}_2\text{-C-O}^- \]

Low pH          High pH
Soil pH effect on water solubility

For some herbicides, soil pH can affect the water solubility of the herbicide.

An example is sulfentrazone, which behaves as an acidic herbicide.

Soil pH has little to no effect on sulfentrazone adsorption, but pH affects solubility (greater solubility at lower pH). This in turn can affect leaching and also affect the amount absorbed by plants.
Environmental Fate of Herbicides

- Hericides adsorbed by clay and organic matter
- Leaching
- Runoff and erosion
- Chemical decomposition
- Microbial decomposition
- Photochemical decomposition
- Volatilization
- Plant uptake
- Adsorbed by clay and organic matter
Herbicide Leaching

Downward movement of herbicide through soil profile by water
Importance of Leaching

1. Provides for activation of PRE herbicides (leaching into weed seed germination zone)
Preemergence herbicide

Weed seed
Germination zone

Rain

Weed seed
Germination zone
Importance of Leaching

1. Provides for activation of PRE herbicides

2. Excessive leaching may reduce weed control (concentration in weed seed germination zone less than lethal)
Importance of Leaching

1. Provides for activation of PRE herbicides

2. Excessive leaching may reduce weed control

3. Can explain crop selectivity, or lack of selectivity
= Root-absorbed herbicide
Importance of Leaching

1. Provides for activation of PRE herbicides
2. Excessive leaching may reduce weed control
3. Can explain crop selectivity, or lack of
4. Can contribute to ground water contamination
Factors Affecting Herbicide Leaching

1. Chemical characteristics of the herbicide
   a. Water solubility: higher water solubility, more prone to leaching
   b. Degree of adsorption: tighter adsorption, less leaching
   c. Determines PLP (pesticide leaching potential)
Pesticide Leaching Potential (PLP) of Commonly Used Herbicides

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>PLP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pendimethalin (Prowl)</td>
<td>very low</td>
</tr>
<tr>
<td>Imazethapyr (Pursuit)</td>
<td>low</td>
</tr>
<tr>
<td>Atrazine</td>
<td>medium</td>
</tr>
<tr>
<td>Prometone (Pramitol)</td>
<td>very high</td>
</tr>
</tbody>
</table>

Factors Affecting Herbicide Leaching

1. Chemical characteristics of the herbicide
   a. Water solubility
   b. Degree of adsorption
   c. Determines PLP (pesticide leaching potential)

2. Soil characteristics
   a. Texture and organic matter
      i. Affect adsorption
      ii. Affect water infiltration
   b. Determines SLP (soil leaching potential)
### Soil Leaching Potential (SLP) of Selected NC Soils

<table>
<thead>
<tr>
<th>Soil Series</th>
<th>SLP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cape Fear</td>
<td>very low</td>
</tr>
<tr>
<td>Alamance</td>
<td>medium</td>
</tr>
<tr>
<td>Tarboro</td>
<td>very high</td>
</tr>
</tbody>
</table>

**Ground Water Contamination Potential (GWCP)**

<table>
<thead>
<tr>
<th>PLP</th>
<th>V. Low</th>
<th>Low</th>
<th>Mod</th>
<th>High</th>
<th>V. High</th>
</tr>
</thead>
<tbody>
<tr>
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<td>V. Low</td>
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<td>Low</td>
<td>Mod</td>
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<tr>
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*From: N. C. Agricultural Chemicals Manual, Chapter 1.*
Ground Water Contamination Potential (GWCP) for Selected Herbicide-Soil Combinations

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<td><strong>Low</strong></td>
<td>Mod</td>
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<td>High</td>
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From: N. C. Agricultural Chemicals Manual, Chapter 1.
Factors Affecting Herbicide Leaching

1. Herbicide chemical properties
   a. Water solubility
   b. Degree of adsorption
   c. Determines PLP (pesticide leaching potential)

2. Soil characteristics
   a. Texture and organic matter
      i. Affect adsorption
      ii. Affect water infiltration
   b. Determines SLP (soil leaching potential)

3. Volume of water flow
Environmental Fate of Herbicides

- Adsorbed by clay and organic matter
- Leaching
- Runoff and erosion
- Chemical decomposition
- Microbial decomposition
- Plant uptake
- Photochemical decomposition
- Volatilization
- Adsorbed by clay and organic matter
Herbicide Runoff

a. Movement in surface water leaving site; herbicide dissolved or suspended in water

b. Herbicide attached to soil carried by runoff water

c. Herbicide can enter rivers and reservoirs
Factors Affecting Amount of Herbicide Transported by Runoff

1. Herbicide application rate
2. Time of first rainfall, intensity, amount
3. Soil texture (infiltration rate) and slope
4. Chemical properties of herbicide
   a. Water solubility
   b. Extent of adsorption
Reducing Herbicide Runoff

Best Management Practices (BMP’s)

a. No-till (reduced soil erosion)
b. Soil tilth, residue cover (water infiltration)
c. Vegetative buffer strips (trap runoff soil)
d. Containment ponds around nurseries
e. Timing of application in relation to anticipated rainfall event
Environmental Fate of Herbicides

- Herbicide adsorbed by clay and organic matter
- Leaching
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- Chemical decomposition
- Microbial decomposition
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- Photochemical decomposition
- Volatilization
- Adsorbed by clay and organic matter
Herbicide Volatilization

Change from a solid or liquid phase to a gaseous phase, with subsequent dissipation into the atmosphere
Factors Affecting Extent of Loss by Volatilization

1. Vapor pressure of herbicide

   The primary factor affecting volatilization losses;
   
greater VP = greater volatilization losses
Factors Affecting Extent of Loss by Volatilization

1. Vapor pressure of herbicide

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>VP (mm Hg @ 25C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>butylate (Sutan)</td>
<td>(1.3 \times 10^{-2} = 130,000 \times 10^{-7})</td>
</tr>
<tr>
<td>trifluralin (Treflan)</td>
<td>(1.1 \times 10^{-4} = 1,100 \times 10^{-7})</td>
</tr>
<tr>
<td>pendimethalin (Prowl)</td>
<td>(9.4 \times 10^{-6} = 94 \times 10^{-7})</td>
</tr>
<tr>
<td>atrazine (AAtrex)</td>
<td>(2.9 \times 10^{-7} = 2.9 \times 10^{-7})</td>
</tr>
</tbody>
</table>
Factors Affecting Extent of Loss by Volatilization

1. Vapor pressure of herbicide
2. Soil moisture content
3. Soil temperature
4. Adsorption
5. Application method (PPI vs PRE)

Mechanical incorporation decreases volatilization losses of soil-applied herbicides
Importance of Volatilization

1. Excessive volatilization losses can adversely affect weed control

2. Volatilization can cause injury to off-target vegetation
Environmental Fate of Herbicides

- Herbicide
  - Adsorbed by clay and organic matter
  - Leaching
  - Runoff and erosion
  - Chemical decomposition
  - Microbial decomposition
  - Photochemical decomposition
  - Volatilization
  - Plant uptake

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- Adsorbed by clay and organic matter
Microbial Degradation of 2,4-D

2,4-D: Herbicidally active

α-chloromuconic acid: No herbicide activity
Herbicide Fate -- Degradation Processes

1. Microbial degradation
   a. Aerobic microorganisms (require oxygen)
      i. Rate of herbicide degradation related to population of microorganisms in soil
      ii. Populations and activity affected by:
          - Soil temp: 80 to 90F best; cool soil retards microbial degradation
          - Soil moisture: 50 to 100% field capacity is best; dry soil retards degradation
          - Soil aeration: poor aeration (and flooding) retards aerobic degradation
Environmental Fate of Herbicides

- Adsorbed by clay and organic matter
- Leaching
- Runoff and erosion
- Chemical decomposition
- Microbial decomposition
- Photochemical decomposition
- Volatilization
- Plant uptake
- Adsorbed by clay and organic matter
- Leaching
Chemical Degradation of Herbicides

a. Non-biological, chemical reactions

b. Affected by temperature; more rapid at higher temperatures

c. May be affected by soil pH
Example of Chemical Degradation

Herbicidally active

Less active

Herbicidally inactive
Environmental Fate of Herbicides

- Herbicide
  - Adsorbed by clay and organic matter
  - Leaching
  - Runoff and erosion
  - Chemical decomposition
  - Microbial decomposition
  - Plant uptake
  - Photochemical decomposition
  - Volatilization
  - Adsorbed by clay and organic matter
Herbicide Persistence

• Length of time a herbicide remains phytotoxic in soil
Importance of Persistence

- Length of weed control
- Toxicity to following crop (carryover)
Herbicide Dissipation Over Time
Hypothetical Case

Minimum concentration necessary for weed control

Maximum concentration for safe recropping
Herbicide Persistence

• Typically expressed as half-life \((t_{1/2})\), or the time it takes for 50% of the herbicide to breakdown to an inactive form.

• Half-lives can vary considerably, depending upon soil and environmental conditions.
Herbicide Dissipation Over Time
Hypothetical Example

$\text{t}_{1/2} = 6 \text{ weeks}$
Factors Affecting Herbicide Persistence

A. Soil properties
B. Climatic conditions
C. Herbicide properties
Herbicide Dissipation Over Time
Hypothetical Example

Favorable Environmental conditions \( t_{1/2} = 2 \) weeks

Less favorable environmental conditions \( t_{1/2} = 6 \) weeks
Importance of Persistence

- Length of weed control
- Toxicity to following crop (carryover)
- Possibly illegal residues in next crop
- Impacts environmental fate