SOIL ACIDIFICATION

Chouteau County
January 11, 2016

Clain Jones
crainj@montana.edu  994-6076

MSU Soil Fertility Extension
Objectives

• Illustrate consequences of acidic soils to crop production
• Present soil and agronomic conditions that lead to acidic soils
• Explain how to recognize and test acidic soil
• Present management options to slow further acidification and increase productivity of acidic soil
Questions for you

• How many think you have seen yield losses from acidic soils?
• How many of you have soil pH levels below 5.5?
Acidic soil samples (pH<6.5) are increasing in MT

Unpub data Agvise
% of 2015 soil samples pH < 6.4 by zip code region (# samples)

Zip code map courtesy of www.zipmap.net
Soil data courtesy Agvise

Some may represent adviser’s business location rather than farm location
pH affects soil nutrient availability

**Low pH, acidic soils** – may limit N, Ca, Mg, Mo because they don’t stick tight and can leach away (Fe) or form minerals (P)

**High pH, alkaline calcareous soils** – may limit P, Fe, Mn, B, Cu, Zn because they stick tight to the soil, plant can’t get them
pH affects soil nutrient availability

What happens when large + ions are in a lower pH?

They let go!

Then what?

They can be leached from the soil and therefore no longer available!
Soil pH and nutrient availability

At low soil pH:
• Plants go hungry for some nutrients
• Nutrients can be lost to environment
• Al and Mn reach toxic levels
Low pH increases Al to toxic levels

Carter et al., 2015. Columbia County, WA
Plant symptoms of Al toxicity

- Roots: witch’s broom roots, thickened, twisted, club ends, stubby, no fine branching
- Leaves: yellowing, purple upper leaves, stunted growth
- Reduced yields
- Higher impact on forage than grain yield (Johnson et al., 1997)
Acid soils have many additional negative impacts

- Herbicide persistence (Raeder et al., 2015)
- Damaging to rhizobia (N-fixing by legumes)
- Increase in fungal diseases
- Increase Mn to toxic levels
Conditions for low soil pH

- Soils with low buffering capacity, granitic > calcareous
- Sandy soils > clay
- Historical forest/long term cropland > historical grassland (still have buffering capacity)
- Crop residue removal – removes Ca, Mg, K, all “+” ions
- No-till (concentrates acidity in 3-5” zone)
- Leaching loss of nitrate (NO$_3^-$)
- Nitrification: $\text{NH}_4^+$(fertilizer) + 2$\text{O}_2$ $\rightarrow$ $\text{NO}_3^-$ + $\text{H}_2\text{O}$ + 2$\text{H}^+$

Leaching loss

Soil solution
Fertilizers differ in potential to acidify the soil

Ammonium sulfate (21-0-0-24) 
= MAP (11-52-0) 
> urea (46-0-0) 
> calcium ammonium nitrate (CAN; 27-0-0) 

≈ 3 x urea 
≈ 3 x CAN 
Little acidification
Excess N over time decreases soil pH, regardless of source.

Schroder et al., 2011, OK, Grant silt loam, 32” rainfall, treatments started 1971, recommended N = 80 lb N/acre
Excess N over time decreases wheat yield likely due to lowered pH and aluminum toxicity

Schroder et al., 2011, OK, Grant silt loam, 32” rainfall, treatments started 1971, recommended N = 80 lb N/acre
Questions?
Al testing

Soil sample

- Al (KCl or CaCl₂ extraction) 2-5 ppm (mg Al/kg) toxic to some species, > 5 ppm toxic to most. Highwood Bench where pH close to 4.5: Al = 20 to 169 ppm (Wichman, unpub data)
- Percent saturation of Al, 10-30% of CEC = plant toxic (McFarland et al, 2015; Kariuki et al, 2007)

Mature plant tissue total Al >200 ppm = toxic (Koenig et al, 2011)
pH soil testing

- Sample top foot of soil, divide into 0-3, 3-6, 6-9 and 9-12” increments
- Get exchangeable acidity as % of CEC
  >60% exchangeable acidity indicates potential toxicity (Koenig et al, 2011)
- Compare between ‘good’ and ‘bad’ areas – use color kits to select ‘bad’ soils to send to lab
- pH varies seasonally, compare samples taken the same time of year

Washington State University data

Soil pH

Pre-cropping use

Prairie

Forest
Managing low pH

- Plant Al-tolerant crops or varieties
- Leave crop residue in field – retains base cations and SOM buffers pH changes and Al toxicity
- Use legumes in rotation – they don’t need N fertilizer
- Inversion till to mix acid zone throughout plow layer – one-time summer tillage doesn’t negate long term benefits of no-till (Norton et al., 2014)
Managing low pH (cont.)

- Use practices to optimize N use efficiency – no left-over N
- Amend with lime, or seed-place lime to compensate for annual N application
- Band P with seed (binds some Al)
- Select N source with lower acidifying potential, e.g. Ca-nitrate
Crop species vary in tolerance to low soil pH. Legumes are least tolerant. 

McFarland et al., 2015. Wheat high vs. low Al tolerant varieties.
Wheat varieties have different tolerance to pH and Al

<table>
<thead>
<tr>
<th>Variety</th>
<th>Threshold pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Custer</td>
<td>6.6</td>
</tr>
<tr>
<td>Ok101</td>
<td>5.5</td>
</tr>
<tr>
<td>Jagalene</td>
<td>6.0</td>
</tr>
<tr>
<td>Jagger 2174</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td>5.9</td>
</tr>
<tr>
<td>AP502CL</td>
<td>6.2</td>
</tr>
<tr>
<td>Ok102</td>
<td>6.4</td>
</tr>
<tr>
<td>2137</td>
<td>5.3</td>
</tr>
</tbody>
</table>

(Kariuki et al, 2007)
Winter wheat varieties with higher pH and Al tolerance

• Judee based on variety screening in Oklahoma
• Warhorse and Bearpaw have gene for Al tolerance (P Bruckner pers comm)

http://plant sciences.montana.edu/crops
## Benefits of liming on acid soils

<table>
<thead>
<tr>
<th>Soil pH</th>
<th>Direct effect on crop</th>
<th>Indirect effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1-6.5</td>
<td>None</td>
<td>Soil structure, crusting; small seed crops; reduced power need for tillage</td>
</tr>
<tr>
<td>5.6-6.0</td>
<td>Rhizobia health for N-fixation; legumes and barley</td>
<td>As above; microbial activity; release of plant nutrients</td>
</tr>
<tr>
<td>5.1-5.5</td>
<td>As above; reduce Al and Mn toxicity; availability of P and other nutrients; most crops</td>
<td>As above</td>
</tr>
<tr>
<td>&lt;5.1</td>
<td>As above; all crops; few can produce if not limed</td>
<td>As above</td>
</tr>
</tbody>
</table>

Source: Albert Agriculture & Forestry
Lime need to raise soil to pH 6.5 decreases as soil texture becomes more coarse and initial pH increases.

Figure 4. Approximate amount of limestone required to increase pH of upper 7 inches of soil to 6.5 for 4 soils with differing CECs. Adapted from Halvin et al., 1999.
Liming rate

Know:
- Calcium carbonate equivalent (CCE; how the source compares to pure CaCO₃)
- Lime score (LS; adds factors for moisture and fineness to CCE)
- Desired pH
  - >5 to reduce Al toxicity
  - >5.5 to have some buffer
  - >6 to be good for 10+ years
- Desired crop

Rate: from soil test lab or calculate (WSU equation)
Lime rate (ton/acre) = 1.86*(final desired pH – 4.6)
Calculate cost/acre

- Soil test lab provides recommended rate based on soil test and desired crop
- Recommended rates given in units CaCO$_3$ – adjust for “lime score” (LS):
  \[(Rate/LS) \times 100 = \text{rate of given source}\]
  \[\text{Rate} \times \$/\text{ton} = \$/\text{acre}\]

  e.g. soil test recommends 6,000 lb CaCO$_3$/acre

<table>
<thead>
<tr>
<th></th>
<th>Product 1</th>
<th>Product 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>LS</td>
<td>89</td>
<td>67</td>
</tr>
<tr>
<td>$/\text{ton}</td>
<td>$75</td>
<td>$62</td>
</tr>
<tr>
<td>Ton product</td>
<td>$253</td>
<td>$278</td>
</tr>
<tr>
<td>6000/89x100 = 6,741 = 3.37 ton</td>
<td>4.48 ton</td>
<td></td>
</tr>
</tbody>
</table>
## Lime characteristics vary among sources

<table>
<thead>
<tr>
<th>Material</th>
<th>CCE (%)</th>
<th>LS</th>
<th>Ca (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common mined products</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limestone (CaCO$_3$)</td>
<td>90-100</td>
<td>90-100</td>
<td>32-39</td>
</tr>
<tr>
<td>Dolomite (CaCO$_3$+MgCO$_3$)</td>
<td>95-110</td>
<td>95-110</td>
<td>18-23</td>
</tr>
<tr>
<td>Specialty oxides and hydroxides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrated lime (Ca[OH]$_2$)</td>
<td>120-135</td>
<td>120-135</td>
<td>54</td>
</tr>
<tr>
<td>Burnt lime or calcium oxide (CaO)</td>
<td>150-175</td>
<td>150-175</td>
<td>71</td>
</tr>
<tr>
<td>By-products</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugar beet lime</td>
<td>76</td>
<td>40-50</td>
<td>25</td>
</tr>
</tbody>
</table>

Source: Oregon State University; Dry weight basis

CCE calcium carbonate equivalent; LS lime score
How much does lime cost in Choteau (delivered)?
Limestone vs Sugarbeet lime
Treatments

- Lime
  - Broadcast – 2-8 yrs. to reach 4” depth (Brown et al, 2008)
  - Surface spray – 6 mo. to reach 2-3” depth (McFarland 2015)
  - Incorporated – better but more $
  - Seedplaced lime pellets – works in no-till, reduces Al toxicity in root zone with less lime/acre (Huggins et al, 2004)

- P with seed
Only high rates of surface applied lime change pH at seed depth within 6 months after application.
Surface applied lime does reduce Al concentration at seed depth within 6 months after application as shown in the graph. The Al toxic level is approximately 5 ppm. The graph indicates that lime application can reduce the Al concentration, but it does not necessarily increase yield. According to McFarland et al., 2015.
Seed placed lime reduces acidity caused by seed-placed fertilizer

Gypsum generally for sodic soils but with the seed helps with Al toxicity

Huggins et al., 2004, Palouse Prairie, WA
P fertilizer is quick acting ‘band-aid’ to increase wheat yield even when P soil test is sufficient.
Summary

- Cropland soils are becoming more acidic, at least on Highwood Bench, in part due to N fertilization.
- This reduces yields for several reasons.
- Management options exist to cope with, slow down or reverse the trend of soil acidification.
- My colleague, Rick Engel, is writing a Fertilizer Check-Off proposal to study this issue.
Increase in alfalfa yield with lime application, Lane County, OR, 1926.
Image from Oregon State University

For more information on soil fertility see MSU Extension’s:
http://landresources.montana.edu/soilfertility

For more information on acidic soils in PNW see WSU’s site:
http://smallgrains.wsu.edu/soil-and-water-resources/soil-acidification-in-the-inland-northwest/