Soil Acidification
ID, prevent, and restore

4-County Crop School, Three Forks
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Image courtesy Rick Engel

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Objectives

1. Show prevalence of acidification in Montana (similar issue in WA, OR, ID, ND, SD, and CO)
2. Review acidification’s cause and contributing factors
3. Depict low-pH soil affected crops
4. Present ways to identify low soil pH
5. Discuss steps to prevent or reverse acidification
6. Suggest crop management options in low pH soil

The Montana Fertilizer Check-Off and the Western Sustainable Agriculture Research and Education Program help fund our studies.
Prevalence: MT counties with at least one field with pH < 5.5

Dec. 2018
Symbol is not on location of field(s)

40% of 20 random locations in Chouteau County have pH < 5.5 in top 2”
What were historical surface horizon pH values in this region?

Many arable soils in our region are high pH because of a calcium layer.

Is that changing?

pH 4.1 in top 3”, 40% sand 40% gravel

Map courtesy of NRCS

Photo by C. Jones
Natural reasons for low soil pH

- Soils with low buffering capacity (low soil organic matter, coarse texture, granitic rather than calcareous), e.g. edge of hills
- Historical forest vegetation soils have lower pH than historical grassland
- Regions with high precipitation, leading to nitrate leaching (and higher yields, therefore generally receiving more N fertilizer)
Agronomic reasons for low soil pH

- Ammonium-based N fertilizer above plant needs due to nitrification:
  \[ \text{ammonium or urea fertilizer} + \text{air} + H_2O \rightarrow \text{nitrate (NO}_3^-) + \text{acid (H}^+) \]
- Leaching loss of nitrate: less nitrate to take up = less root release of basic anions (OH\(^-\) and HCO\(_3^-\))
- Crop residue removal: removes Ca, Mg, K (‘base’ cations).
- Lack of deep tillage concentrates acidity where N fertilizer applied
- Legumes acidify their rooting zone through N-fixation. Perennial legumes (e.g., alfalfa) more so than annuals (e.g., pea). Yet apparently much less than fertilization of wheat.
Low soil pH in MT’s historically calcareous soils is generally only in upper 6 inches, 0.3 pH unit difference has huge impact on barley yields.

Long farm, Highwood Bench, unpub Nov 2016 data
14-yr of N fertilization reduce top 4” pH on dryland cropping west of Bozeman up to 1 pH

What rotations lower pH the least? The most?

Silt loam, 2% OM

Engel, Ewing, Miller, unpub data
6-yr N fertilization reduce soil pH (0-3”) west of Big Sandy

- Sandy clay loam, 1.1% OM
- Alternate year was always winter wheat; Jones and Miller unpub data

100 lb N/acre
~0.15 pH units

why faster rate?
Have any of you seen decreases in soil pH?

Questions?

On to impact on crop
pH affects soil nutrient and aluminum availability

**Low pH, acidic soils** may limit N, and eventually Ca, Mg, K, Mo because they don’t stick tight and can leach away. P can be low because minerals form, Al toxicity

**High pH, alkaline calcareous soils** may limit P, Fe, Mn, B, Cu, Zn, plant can’t get them

Troeh and Wegner, 2013
Low pH increases soil Al to toxic levels

Engel unpub. data, 2016, 5 farms near Highwood, MT

Soil pH

Extractable Al, ppm

pH where yield declines can occur

toxicity

5 ppm

0-3"

3-6"

6-12"
What to look for

- Unexplained poor health in low or mid-slope areas
- **AI** toxicity
  - stubby club roots, no fine branching (similar to nematode damage)

photo sources: Engel

A. Robson, 
https://agric.wa.gov.au/n/4487
Above ground symptoms of Al toxicity

- small leaves, short thick internodes
- yellow along margin near tip on older leaves
- purple or brown lesions in chlorotic regions, indentations
- leaf withering and collapse in center
Acid soils change efficacy and persistence of chems

Have you see unexplained damage?
May be first indicator of pH change.

• Small changes in pH across a field = difference between high crop safety with low efficacy, and high crop damage with weed control.

• Chemical treatments and rotation intervals may need modification. Read and follow label directions.
Poor N fixation may be indicator of low pH

Have any of you seen ‘unexplained’ low N fixation?

Pea rhizobia (#/g soil)

Soil pH

Drew et al. 2014
Acid soils have additional negative impacts

- Increase in some fungal diseases (e.g., Cephalosporium stripe) and root rot
- Mn toxicity – has not yet been found an issue in MT

Image from *Wheat Disease ID*. MT Wht & Barley Co.
Questions?

On to diagnosis and prevention
Diagnose: scout, soil test

Look at pH on prior soil tests from composited samples

- pH < 6 likely have spots with pH ≤ 5
- 6 < pH < 7.5 don’t assume no areas have low pH
- pH > 7.5, likely don’t have problem (yet).

Symptoms are not uniform across field landscapes
Soil test

1. Scout or use aerial maps to locate healthy and unhealthy areas

2. Field pH test, use soil/water slurry of top 3”. Why not the standard 6”?

3. Avoid compositing samples from different slope areas.

4. Send 0-3” depth sample to lab for pH (<5?). Test 3-6” if might till.

5. pH varies seasonally and annually, test from same area and time of year by same lab using same procedure to see trend

6. Veris can also sample for pH
Management to prevent acidification: Increase N fertilizer use efficiency

- Soil test close to application time. Make sure enough PKS
- Use conservative pre-plant rate, top-dress if adequate moisture
- Apply N close to peak crop uptake
- Use variable, site specific rates: Less N in low production areas limited by factors other than N (e.g., low pH, shallow soils)
- Reduce N rates especially when protein discounts low
- Large overlap with management to reduce N leaching (see our N Leaching Extension bulletin and MTGuide)
Management to prevent acidification: Change N source?

- Use calcium ammonium nitrate (27-0-0; $$) instead of urea or UAN (CAN shouldn’t volatilize so can likely also lower rate)
- Include legume rotations, manure if available

Most acidifying
MAP = AS ≈ 2x urea
DAP (18-46-0)
Urea (46-0-0), UAN (28-0-0)
CAN ≈ 1/3x urea

Least acidifying
Potassium nitrate (13-0-46)
More preventive options

- Leave crop residue in field – retains base cations and SOM buffers pH changes and Al toxicity. 6x base cations removed by oat straw harvest than just oat grain harvest (Pierre and Banwart 1973)

- Legumes in rotation – no N fertilizer and residue increases soil surface pH more than non-legumes (Paul et al., 2003)

Which of these (or previous) might you try?
Perennial forage can maintain or increase soil pH

pH differs between crops with * > 90%, ** > 95%, *** > 99% confidence, Mandan, ND, Liebig et al., 2018
What else are people trying?

Questions?

On to adaptation and restoration options
Adaptation: Select tolerant crop species. Legumes are least tolerant.

“Wheat high” are Al and acid tolerant varieties

MT variety trial results are available at
http://landresources.montana.edu/soilfertility/acidif/index.html

Mahler and McDole 1987
Long pers comm
Seed-placed $P_2O_5$: increased durum grain yield in one farm, no response another farm

- Olsen P = 48 ppm
- Olsen P = 53 ppm

*Economics?*

Engel unpub data using Ag lime
Seed-placed $\text{P}_2\text{O}_5$ may or may not pay off

TSP $0.50/\text{lb} \; \text{P}_2\text{O}_5$

What to do?

Field strip trials
**Restoration: Liming**

- **Know:**
  - Calcium carbonate equivalent (CCE; how the source compares to pure CaCO$_3$)
  - Lime score (LS; adds factors for moisture and fineness to CCE)
  - Current soil pH (from a lab) and desired pH
    - $> 5$ to reduce Al toxicity
    - $> 5.5$ to have some buffer, rhizobia health for N fixation
    - $> 6$ to be good for 10+ years
  - Buffer pH – a lab measurement of soil’s ability to buffer (resist) pH change with lime addition. Regionally specific test.
  - Desired crop
Lime sources

- **Sugarbeet lime**
  - Good – it doesn’t cost anything
  - Bad – shipping costs (up to $35/ton); challenging material to work with (moisture and clumping), need a wet lime spreader, contains chunks and some trash, and incorporation w/ tillage needed for best results
  - Rates of 3-6 tons/acre may be necessary to bring pH to acceptable level (pH > 6)

- **Aglime** – more expensive and further away

- **Pelletized lime?** Expensive and need about 400 lb/acre per year just to offset typical N rate.
The lower the soil pH, the more lime it takes to get to pH 6

- 10 acidic MT cropland soils tested, 6 shown here
- Incubated in lab with lime for 90 days
- pH 4 soil = 3-4 ton CaCO$_3$ → pH 6
- pH 4.7-5.4 soil = 1.75 ton CaCO$_3$ → pH 6

Engel unpub data

This is using very fine grade lime
Restoration needs a lot of lime

- Rate:
  - Find from online tables (or your lab) with buffer pH and target pH
  - Or use MSU preliminary results

- Only lime field areas with low soil pH

<table>
<thead>
<tr>
<th>Initial pH</th>
<th>Ton SBeet lime to pH 6.0</th>
<th>Ton SBeet lime to pH 6.5</th>
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</thead>
<tbody>
<tr>
<td>4.0</td>
<td>4.7</td>
<td>7.2</td>
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<tr>
<td>4.5</td>
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</tr>
<tr>
<td>5.5</td>
<td>1.6</td>
<td>4.0</td>
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</table>
Yield declines as lime ‘wears off’ and soil again becomes acidic (assumes linear pH decline)

Modeled. Assumes 100 lb N/ac per year causes 0.1 pH drop/year

Mahler and McDole 1987, ID
Liming is a capital investment

Lime needed
pH 5.2 → 6.0, 2.3 ton/ac = $90/ac
pH 4.8 → 6.0, 3.2 ton/ac = $122/ac

Mahler and McDole 1987 yield decline curves
50 bu/ac yield potential, $6/bu grain, $35/ton lime + $10/ac to spread
low-pH tolerant wheat/low-pH sensitive durum rotation; 100 lb N/ac/yr
Tillage?

- Inversion till to mix acid zone with higher pH zone below – one-time summer tillage doesn’t negate long term benefits of no-till (Norton et al., 2014)
- Problem: eventually make low pH zone deeper, when need to lime, requires more lime and deeper tillage. Will negate some no till benefits.

Photo by W.H. Lathrop, 1945. Rice Soil And Water Cons. Dist
Good news

- MT has less acidic soil issues than other regions; catch and prevent now.
- MT’s issue generally in upper 3”, Palouse Prairie and SK have low pH at 3-6”. Why important?
- Many MT cropland soils have large pH range with calcareous parent material
- P and metal micronutrient availability better at low to neutral pH

### Soil survey northern Idaho

<table>
<thead>
<tr>
<th>Soil pH</th>
<th>% of fields in each category</th>
</tr>
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<tbody>
<tr>
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<td>1982-’84</td>
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<tr>
<td>&gt;6.4</td>
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<tr>
<td>6.0-6.4</td>
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<tr>
<td>5.8-5.9</td>
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<tr>
<td>5.2-5.3</td>
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<tr>
<td>5.0-5.1</td>
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<tr>
<td>&lt;5.0</td>
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</table>

Schroeder, Univ of Idaho, unpub data
Summary

• Cropland soils are becoming more acidic, largely due to N fertilization
• This reduces yields for several reasons
• Identify whether fields have a problem now to slow or prevent acidification with sound management
• Selecting crop rotations with lower N needs is likely best way to prevent further acidification
• Crop and variety selection or seed placed P fertilizer can help adapt to acid soils
• Liming or planting perennials can reverse acidification
Thank you!

Questions?

For more information and links to additional resources on soil acidification see MSU’s cropland soil acidification website http://landresources.montana.edu/soilfertility/acidif/index.html

If you have questions about soil and buffer pH tests go to https://www.youtube.com/watch?v=w9PWZSaFfb4