Soil Acidification in Montana - An Emerging Problem

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MFAC supported

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Sustainable Agriculture Research & Education
Acidic soil samples (pH<6.5) are increasing in MT

Unpub data AgVise
Objectives

- Discuss causes
- Illustrate consequences of acidic soils to crop production
- Soil acidity patterns in the field
- Present soil acidity management options – adaptation, prevention or remediation
Causes

• soil acidification can occur naturally as basic salts are leached from surface; carbonic acid in rainwater
  – slow process

• pH of cultivated soils < adjacent rangeland because of greater water transport through profile & also bases are removed by crops

• fertilizer N inputs
Montana Fertilizer N Consumption

- consumption of fertilizer N is up 3x since 1985; 86% urea
Fertilizer N reactions

- Urea hydrolysis (soil enzymes – urease)
  \[ \text{CO(NH}_2\text{)}_2 + \text{H}_2\text{O} + 2\text{H}^+ \rightarrow 2\text{NH}_4^+ + \text{CO}_2 \]
  1 N atom consumes 1 H⁺

- Nitrification (soil bacteria) - oxidation of ammonium to nitrate
  \[ \text{NH}_4^+ + 2\text{O}_2 \rightarrow \text{NO}_3^- + 2\text{H}^+ + \text{H}_2\text{O} \]
  1 N atom produces 2H⁺

Net effect urea addition → N atom produces 1 H⁺
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What about other N fertilizers? ammonium sulfate
Fertilizers differ in potential to acidify soil

Most acidifying

- ammon. sulfate (21-0-0-24) = MAP (11-52-0) ≈ 2x urea
- DAP (18-46-0)
- urea (46-0-0)
- calcium ammonium nitrate (CAN; 27-0-0) ≈ 1/3 x urea
- sodium nitrate (16-0-0) - does not acidify

Least acidifying
Counties with cultivated soils pH< 5.5

- Sampled by MSU
- Reported by CCA or County Ext
Why soil acidity problems are appearing in Chouteau Co.? possible explanations

- saline seeps
- annual cropping to remediate – more fertilizer N inputs
- no-till – pH stratification
- annual precipitation in many areas (e.g. Highwood Bench) is somewhat greater than many other Montana dryland areas → promotes nitrate transport out of surface layers
Nitrate leaching

How does it accelerate acidification process?

- plants uptake $\text{NO}_3^-$ release $\text{OH}^-$ or $\text{HCO}_3^-$ to maintain neutral charge

$$2\text{NH}_4^+ + 2\text{O}_2 \rightarrow \text{NO}_3^- + 2\text{H}^+ + 2\text{H}_2\text{O}$$
Legacy effects – Telstad loam – Big Sandy
Legacy effects of N fertilizer – e.g. Big Sandy

farmer acquired property with prior low N input

Low pH and Al toxicity

<table>
<thead>
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<td>pH74</td>
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• Illustrate consequences of acidic soils to crop production - e.g. Chouteau Co.

• Soil acidity patterns in the field

• Present soil acidity management options – adaptation, prevention or remediation
Aluminum toxicity in durum
Plant Symptoms of Al toxicity

- Tops – stunted growth, yellowing or purple upper leaves
- Roots: witch’s broom roots, thickened, twisted, club ends, stubby, no fine branching
Low pH increases extractable soil Al to toxic levels

Engel unpub. data, 2016, 5 farms near Highwood, MT
Where is the aluminum coming from?

Soil composition – 3rd most abundant element in earth crust

- Oxygen: 47%
- Silicon: 28%
- Aluminum: 8%
- Iron
- Calcium
- Sodium
- Potassium
- Magnesium
- Other
Where is the aluminum coming from?

Soil composition – 3rd most abundant element in earth crust

- clay minerals (Al-silicates layers)
- Al oxides and hydroxides
- solution = (0.5 ppm) x 0.25 water
Soil pH and Al toxicity – two issues

- **solubility** of Al increases as pH falls (more Al coming off minerals, and oxides and hydroxides)

- **Al** hydroxide ions in soil solution; Al ions can exist in soil solution as different charged ions \( \text{Al}^{+3} \), \( \text{Al(OH)}^{+2} \), \( \text{Al(OH)}_2^{+1} \), \( \text{Al(OH)}_3^- \),

most toxic ion and it is found in < abundance in acidic solutions
Acid soils - additional negative impacts

- Herbicide persistence (Raeder et al., 2015) – Metribuzin
- Damaging to rhizobia (N-fixing by legumes)
- Increase in fungal diseases
- Increase Mn to toxic levels
Manganese toxicity has been associated with acidic soils - pH < 5.8 threshold – do we have a problem?
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Dryland fields can exhibit large spatial gradients in pH e.g. north Geraldine

toe slope, bottom positions – low pH

summit positions – higher pH
Winter wheat – Al toxicity & spatial gradients

pH 3.8

pH 5.1
Soil pH stratification in Montana

Summary

• lowest pH likely to be found in shallowest depth because...

1. N applied near surface & no-till
2. subsoils have a lot of natural lime (Ca, Mg, Na carbonates).
Questions for you

• Observed stand issues in low lying areas?

• Soil pH levels < 5.0 or 5.5?

• How many of you are aware of pH stratification?
Soil sampling approaches

• Compare between ‘good’ and ‘bad’ areas – use color kits to select ‘bad’ soils to send to lab

• Avoid compositing from different slope positions
  • mixing a soil sample pH 8 + soil sample pH 4 → ?

• Sample top foot of soil, divide into 0-3, 3-6, 6-9 and 9-12” increments
Soil Al analysis by soil testing labs

- KCl, NH$_4$Cl or CaCl$_2$ extraction protocols
- 2-5 ppm (mg Al/kg) toxic to some crop species; > 5 ppm toxic to most.
- Highwood Bench where pH close to 4.5: Al = 20 to 169 ppm (Wichman, unpub data)
- % saturation of Al, 10-30% of CEC = plant toxic (McFarland et al, 2015; Kariuki et al, 2007)
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Cultivar selection

Aluminum tolerance – single gene (Alt1)

Wheat cultivars with Alt1 release malate (○ = organic acid) from root tips in response to high conc. of solution Al\(^{3+}\); malate in turn chelates with Al\(^{3+}\) in the soil to form a non-toxic complex.
Montana breeding program

- field trials & screening on the Highwood Bench (in coop. with CARC) and Palouse of eastern Washington
- marker for Alt1 gene
Wheat varieties with have higher acid tolerance (Bruckner & Talbert personnel comm)

Winter wheat
• Judee based on variety screening in Oklahoma
• Warhorse and Bearpaw have gene for Al tolerance

Spring wheat (50% cultivars with Alt1 gene)
• Egan, Alum, Egan, McNeal, Duclair, Reeder
Crop species vary in tolerance to low soil pH

McFarland et al., 2015

Wheat high and low are Al tolerant varieties
Management strategies - prevention

- leave crop residue in field – retains base cations and SOM buffers pH changes and Al toxicity
- minimize N inputs - 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)
- band P with seed (binds some Al)
P fertilizer is quick acting ‘band-aid’ to increase wheat yield even when P soil test is sufficient

Kaitibie et al., 2002, OK
Remediation – lime applications

- Lime or limestone products – neutralize the soil acidity

\[
\text{Soil with exchangeable acidity (H}^+\text{)} \quad \text{+} \quad \text{CaCO}_3 \quad \text{↔} \quad \text{Soil with exchangeable calcium (Ca}^{2+}\text{)}
\]

- lime effectiveness will be defined by particle size also composition of product
<table>
<thead>
<tr>
<th>Material</th>
<th>CCE (%)</th>
<th>LS</th>
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</thead>
<tbody>
<tr>
<td>Common mined products</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limestone $(\text{CaCO}_3)$</td>
<td>90-100</td>
<td>90-100</td>
</tr>
<tr>
<td>Dolomite $(\text{CaCO}_3+\text{MgCO}_3)$</td>
<td>95-110</td>
<td>95-110</td>
</tr>
<tr>
<td>Specialty oxides and hydroxides</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrated lime $(\text{Ca[OH]}_2)$</td>
<td>120-135</td>
<td>120-135</td>
</tr>
<tr>
<td>Burnt lime or calcium oxide $(\text{CaO})$</td>
<td>150-175</td>
<td>150-175</td>
</tr>
<tr>
<td>Sugar beet lime</td>
<td>70-75</td>
<td>40-50</td>
</tr>
</tbody>
</table>

Source: Oregon State University
CCE = calcium carbonate equivalent, LS = lime score
Sugar beet lime – Western Sugar Co.

35$/ton to ship to Chouteau County
Stoltzfus wet-lime applicator
Sugar beet lime strip trials – Chouteau Co
Sugar beet lime strip trials (example)

Data to be collected:
- biomass & grain yield
- soil cores (0-5, 5-10, 10-15, & 15-20 cm) at GPS referenced points
- time – 0, 6, 12, and 24 months
- record pH, extractable Al conc. exchangeable bases

Lime app rates (each strip is 60’ wide)
Soil pH/Al toxicity mapping to reduce costs

- Symptoms are not uniform across field landscapes
- Mapping symptoms may be a way to reduce lime remediation costs.
- How to map efficiently?
NDVI Aerial Images (June 7)

Soil pH analysis

- soil cores this spring at random locations in field or
- soil mapping with Veris
Summary

• Cropland soils in many dryland areas of Montana are becoming more acidic (e.g. Chouteau Co.)

• We are still trying to understand the extent of this problem (soil samples anyone?).

• N fertilizer inputs are a big reason
  ▪ no-till has accelerated acidification process near the soil surface
  ▪ problem is not unique to Montana

• Yield impacted – Al toxicity pH < 5

• Management options exist to cope with, slow down or reverse the trend of soil acidification
Thank you