Goals Today

• Introduce basics of soil fertility
• Describe function and deficiency symptoms of nutrients
• Introduce soil sampling
• Show how to use Fertilizer Guidelines and soil lab results to estimate fertilizer need
• HELP your bottom line!
There are 14 mineral nutrients that have been found to be essential for growth of most plants:

<table>
<thead>
<tr>
<th>Macronutrients</th>
<th>Micronutrients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (N)</td>
<td>Boron (B)</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>Chloride (Cl)</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>Copper (Cu)</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>Iron (Fe)</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>Manganese (Mn)</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>Molybdenum (Mo)</td>
</tr>
</tbody>
</table>

The macronutrients are simply needed in larger amounts by the plant than the micronutrients.

Nutrient deficiencies of the bolded nutrients have been observed in Montana.
# Mobility in soil of selected nutrients

<table>
<thead>
<tr>
<th>Mobile (and soluble)</th>
<th>Relatively immobile</th>
<th>Very immobile (and insoluble)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (as nitrate)</td>
<td>Potassium</td>
<td>Phosphorus Copper Iron Manganese Zinc</td>
</tr>
<tr>
<td>Sulfur</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boron</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloride</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Why important?** Affects fertilizer placement
Fertilizer guidelines

• Guidelines for N, P, K and 5 micro-nutrients for winter wheat and spring wheat production are provided in Fertilizer Guidelines for Montana Crops (EB 161).

• They are based on soil analysis.
Advantages of soil testing (even if only occasionally)

- To identify nutrient deficiency or imbalance
- To help calculate optimal fertilizer rates
- Especially important in case where soil nutrient availability has been depleted or is in excess
- Can increase yield and/or save on fertilizer costs, and decrease environmental risks
N function and deficiency symptoms

N is important for high photosynthetic activity, vegetative growth and protein.

1. Pale green to yellow lower (older) leaves. Why lower leaves?
   - N is MOBILE in plant

2. Stunted, slow growth
What makes yield?

Heads/area $\times$ Kernels/heads $\times$ Weight/kernel
N application timing effects on yield and protein

*Nitrogen* early
Number of tillers and kernels/head

Grain protein from remobilized N

*Nitrogen* late
Weight/kernel

Higher grain protein

**Growth Stages in Cereals**

**Stage 1** one shoot

**Stage 2** tillering begins

**Stage 3** leaf sheaths lengthen

**Stage 4** leaf sheaths strongly erected

**Stage 5** first node of stem visible

**Stage 6** second node visible

**Stage 7** last leaf just visible

**Stage 8** ligule of last leaf just visible

**Stage 9** boot

**Stage 10** flowering

**Stage 10.5** (wheat)

**Stage 11** ripening
N uptake by irrigated spring wheat

Cumulative N uptake (% maximum)

- Early leaf
- Tillering
- Stem elong.
- Heading
- Ripening

a. NITROGEN

Grain
Heads
Stems
Leaves

Miller et al. 1994/EB0191
Table 17. Spring and winter wheat N guidelines based on soil analysis.

<table>
<thead>
<tr>
<th>Yield Potential (bu/a)*</th>
<th>Available N (lbs/a) **</th>
<th>Yield Potential (bu/a)*</th>
<th>Available N (lbs/a) **</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>99</td>
<td>30</td>
<td>78</td>
</tr>
<tr>
<td>40</td>
<td>132</td>
<td>40</td>
<td>104</td>
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<tr>
<td>50</td>
<td>165</td>
<td>50</td>
<td>130</td>
</tr>
<tr>
<td>60</td>
<td>198</td>
<td>60</td>
<td>156</td>
</tr>
<tr>
<td>70</td>
<td>231</td>
<td>70</td>
<td>182</td>
</tr>
<tr>
<td>80</td>
<td>264</td>
<td>80</td>
<td>208</td>
</tr>
<tr>
<td>90</td>
<td>297</td>
<td>90</td>
<td>234</td>
</tr>
<tr>
<td>100</td>
<td>330</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Attainable yield with all growth factors optimized.
** Fertilizer N = Available N - soil analysis NO₃-N.
***Includes durum and hard red and hard white spring wheat at 13% and 14% protein, respectively.
Example

- Winter wheat
- Yield potential = 40 bu/ac
- Soil test N = 54 lbs/ac (top 2 ft.)

<table>
<thead>
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<th>Yield Potential (bu/a)*</th>
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<td>208</td>
</tr>
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<td>90</td>
<td>234</td>
</tr>
</tbody>
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Fertilizer N = Available N – soil test N

Fertilizer N = 104 lbs/ac – 54 lbs/ac = **50 units**
Legumes for N

Consider replacing fallow with legume

N credit following legume for grain is ≈ 10 lb/ac, more if grown for ‘green manure’
Economic Analysis of Fertilizer Application Rates for Spring Wheat After Fallow in Montana.

Funding for the development of this program was provided by the Montana Fertilizer Advisory Committee.

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This program was developed to aid the agriculture industry in optimizing nitrogen fertilizer application on Spring Wheat after fallow. The model used to estimate the economic optimal allocation of nitrogen fertilizer requires the user specify a minimal set of input values for their location. The model was developed as a statewide application, but the user must keep in mind that many variables will affect their final results and this model can not incorporate all of those individual variables. Because the model allows the user to set their expected yield goal, it allows the individual user to determine a cap on the estimated yield response from the application of nitrogen fertilizer, considering ALL of the user specific knowledge and conditions for an individual producer's site. The yield and protein models are based on a best fit regression analysis of plot research performed in Montana from 1993 to 2006 on 24 research plots, (24 site years) for spring wheat. Actual N needed to optimize yield on your farm/site may vary from that predicted due to differences in soil depth, texture, and climate.

This model is not valid for recrop spring wheat.

The F11 key will toggle (switch on and off) the screen viewable area between normal and maximum viewable area.
Economic Model spring wheat fertilizer, yield & protein

http://www.montana.edu/software/downloads/software/SWFertilizerEconomics.swf

Soil samples should be from early spring samples rather than fall sampling.

The horizontal axis is Lbs Per Acre applied N, NOT total N. However, total N (soil N + applied N) is used to calculate the values shown in the graphs.
Economic Model spring wheat fertilizer, net revenue

Prices 2/14/12 s-west MT
QUESTIONS?
The N cycle

- NH₃ (g)
- Organic Nitrogen
  - Volatilization
  - Immobilization
  - Mineralization
- NH₄⁺
  - Plant Uptake
  - Nitrification
    - NO₂⁻
  - Urea
    - UAN
  - N₂ and N₂O
- NO₃⁻
  - Plant Uptake
  - Denitrification
  - Leaching
‘Mineralization’

Release of minerals as organic matter (O.M.) is decomposed, releasing soluble N

Organic-N → Plant-Available N

If have higher than normal O.M. (>3%), can back off on N fertilizer by 20 units of N

‘Immobilization’

Uptake of available N into microbial cells or plant tissue

Plant-Available N → Organic-N

If leave more than ½ ton stubble, increase N fertilizer by 10 units of N

How know how much stubble (straw residue)?

Ex: Spring wheat straw (lb/ac) = 1.33 x grain yield (lb/ac)
Soluble ‘Ammonium’  ➔ Ammonia Gas

- Not an issue if fertilizer is incorporated at least 1.5 inches into soil—not an option with no-till
Factors affecting volatilization

- Soil pH and Temperature
- Wind
- Cation Exchange Capacity (CEC). WHY?
- Buffering capacity (resistance to pH change)
- Soil moisture/humidity
- Rainfall/Irrigation following fertilization (depth in soil)
- Ground cover/vegetation/residue. WHY?
- Soluble and Exchangeable Calcium

Bottom line: Large number of factors make volatilization amounts VARIABLE and difficult to predict.
In 13 trials over 3 years in Montana, urea applied during cold weather averaged 20% loss of applied N, with wide range (3 – 44%). Engel et al 2011.

Significant ammonia losses (30-40% of applied N) from surface-applied urea can occur even though soil temperatures are near freezing!

Soil moisture conditions at surface that dissolve urea granules (i.e. prolonged damp) without rain promote high ammonia losses (more common to find these conditions in MT during late fall or early spring)

NBPT (Agrotain®) reduced losses 62% over untreated urea
N source

“A pound of N is a pound of N”- cost per unit of N, available equipment to apply N, and potential losses should be most important factors in selecting N. Beware of those who say differently.
If you want more information on N cycling, see Nutrient Management Module 3:

http://landresources.montana.edu/nm

More information on urea volatilization, see:

http://landresources.montana.edu/soilfertility/ammonvolat.html
QUESTIONS?
P function and deficiency symptoms

P is critical in the first 5-6 weeks for rooting and tillering

1. Dark green, often purple
2. Lower leaves sometimes yellow
3. Often seen on ridges of fields
Impact of starter P in a cool spring on spring wheat emergence

Both sides received fall-banded 70-30-10-10

10 lb of starter \( P_2O_5 \) with seed

No starter P
Contribution of tillers to yield

Goos and Johnson, 1996

Spring Wheat
Embden, ND – 46 bu/A

Percent of final yield

Main stem  T1 + T2  Other

Main stem  Second tiller T2  First tiller T1

Goos and Johnson, 1996
Phosphorus increases tiller initiation

Hettinger, ND
Olsen P = 10 ppm

Goos and Johnson, 1996

Percent initiation

Tillers

Lb P₂O₅/A placed with the seed

0

30
Factors decreasing P availability

- Soil pH below 6.0 or above 7.5
- Cold, wet weather
- Calcareous soils
- Leveled soils
- Highly weathered, sandy soils
### P fertilizer guidelines

Table 18. P fertilizer guidelines based on soil analysis (EB 161)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Olsen P soil test level (ppm)</th>
<th></th>
<th>4</th>
<th>8</th>
<th>12</th>
<th>16*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P fertilizer rate (lbs P₂O₅ /acre)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring wheat</td>
<td></td>
<td>0</td>
<td>50</td>
<td>45</td>
<td>35</td>
<td>30</td>
</tr>
<tr>
<td>Winter wheat</td>
<td></td>
<td>55</td>
<td>50</td>
<td>45</td>
<td>40</td>
<td>35</td>
</tr>
</tbody>
</table>

* With P>16 ppm consider using crop removal rates as P fertilization guideline

**Example**

Winter wheat, Olsen P = 10 ppm

P₂O₅ needed = **42.5 lb/ac**
Banding P is much more effective than banding N, because P is much more immobile in the soil.

Figure 7. The advantages of P banding are greatest when STP levels are very low (VL) to low (L). From Randall and Hoeft (1988).
P fertilization

- P is immobile so needs to be close to root-zone
- With low amounts of P (< 20-30 lb P$_2$O$_5$/ac), can place fertilizer directly with seed
QUESTIONS?
K functions and factors decreasing availability

K is used in photosynthesis, protein formation, sugar transport and activation of enzymes

Factors decreasing K availability

- Cold, dry soils
- Poorly aerated soils
- High calcium and magnesium levels
- Sandy, low clay soils
- Low soil organic matter, or high amounts of available N
1. Corn and grasses – chlorosis and necrosis on lower leaves first. WHY?

   **K is mobile in plant**

2. Weakening of straw-lodging in small grains.

3. Wilting, stunted, shortened internodes.
Crop response to added K in high K soils in Montana (264 sites)

Yield response to KCl fertilizer in high K soils may be a Cl response

Each crop represents 2 to 8 cropping years
Soils testing > 600 ppm (1967-1979)

Winter Wheat
- 97 Experiments
- 5.5 bu/A

Spring Wheat
- 33 Expts
- 4.8 bu/A
S functions and factors decreasing availability

S is important for protein and chlorophyll synthesis

Factors decreasing S availability

- Irrigated with low S in irrigation water
- Sandy, acidic, or low organic matter soils
- Cold soils
- Soils formed from minerals low in S or far from industrial sources
S deficiency symptoms

1. Upper leaves light green to yellow. WHY?
   S is immobile in plant

2. Small, thin stems

3. Low protein

4. Delayed maturity

5. No characteristic spots or stripes
S fertilization

- Tissue sampling is more reliable than soil testing. If < 0.20 to 0.25% S in uppermost leaves before heading then may limit yield and protein.
- In-season applications of ammonium thiosulfate and ammonium sulfate, can rapidly correct sulfur deficiency.
- Sulfate fertilizers are not suggested for fall application. They can leach overwinter.
- Elemental sulfur is slow to supply plant available sulfur. Apply in fall or before seeding to become available before peak demands. It will supply crop needs for over 2 to 3 years.
S can increase yield at higher N

Grain Yield (bu/ac) vs N (lb/acre)

- 27 lb S/ac
- 0 lb S/ac

rainfed 'short season' wheat silty loam, 1.3% OM, pH 5.8 ammon-nitrate & ammon-sulfate broadcast after planting
Salvagiotti et al. 2009
Micronutrients

• Use visual tissue assessment for potential deficiency

• Conduct a ramp calibration strip trial

http://landresources.montana.edu/soilfertility
then go to “Press Releases”
Visual tissue assessment

MOBILE NUTRIENTS

Older or lower leaves affected

YES

Effects mostly generalized; plants dark or light green

YES

Plants dark green, often developing purple or red color

NO

Effects mostly localized; chlorosis with or without spotting

YES

Chlorosis with interveinal chlorosis; leaves sometimes red or with dead spots

NO

Plants light green with leaves light green or yellow; no necrotic spotting

NO

PHOSPHORUS (P)

NO

MAGNESIUM (Mg)

YES

No interveinal chlorosis; chlorotic areas with a burning of leaf margins; spotting sometimes along leaf margins

NO

NITROGEN (N)

NO

KITCHEN POTASSIUM (K)

YES

No interveinal chlorosis; distinct chlorotic and necrotic lesions (spotting) with abrupt boundary between dead and live tissue

NO

MOLYBDENUM (Mo)

YES

* CHLORIDE (Cl)


IMMOBILE NUTRIENTS

Newer or younger leaves affected; symptoms localized

YES

Growing point (terminal bud) dies

NO

Growing point typically remains alive

YES

Chlorosis without interveinal chlorosis

NO

Young leaves with interveinal chlorosis

YES

Sharp distinction between veins and chlorotic areas

NO

** IRON (Fe)

NO

SULFUR (S)

YES

Young leaves of terminal bud typically hooked at first, finally turning brown and dying back

NO

** MANGANESE (Mn)

YES

Chlorosis of young leaves; tips appear withered and will eventually die

NO

Middle leaves with interveinal chlorosis, stunted growth

YES

** COPPER (Cu)

NO

** ZINC (Zn)

YES

Note: Since nickel (Ni) was only recently added as an essential nutrient, specific Ni deficiency symptoms are not well defined. Common symptoms include chlorosis and interveinal chlorosis in younger leaves.

* If symptoms don’t meet any of the key descriptions, either go back through the key another time or refer to text for more specific symptom descriptions.
Pseudo-deficiencies

What else can cause symptoms that look like nutrient deficiency symptoms?

- Insects
- Salinity
- Moisture stress
- Disease
- Herbicides

Photo: Ontario Ministry of Ag., Food & Rural Affairs
Table 20. Micronutrient fertilizer guidelines based on soil analysis.

<table>
<thead>
<tr>
<th>Micronutrient Soil Test* ppm</th>
<th>Micronutrient Fertilizer Rate lbs/a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Boron</td>
<td></td>
</tr>
<tr>
<td>0 - 0.5</td>
<td>2</td>
</tr>
<tr>
<td>0.5 - 1.0</td>
<td>1</td>
</tr>
<tr>
<td>&gt;1.0</td>
<td>0</td>
</tr>
<tr>
<td>Copper</td>
<td></td>
</tr>
<tr>
<td>0 - 0.5</td>
<td>2</td>
</tr>
<tr>
<td>&gt;0.5</td>
<td>0</td>
</tr>
<tr>
<td>Iron</td>
<td></td>
</tr>
<tr>
<td>0 - 2.5</td>
<td>4</td>
</tr>
<tr>
<td>2.5 - 5.0</td>
<td>2</td>
</tr>
<tr>
<td>&gt;5.0</td>
<td>0</td>
</tr>
<tr>
<td>Manganese</td>
<td></td>
</tr>
<tr>
<td>0 - 0.50</td>
<td>20</td>
</tr>
<tr>
<td>0.50 - 1.0</td>
<td>10</td>
</tr>
<tr>
<td>&gt;1.0</td>
<td>0</td>
</tr>
<tr>
<td>Zinc</td>
<td></td>
</tr>
<tr>
<td>0 - 0.25</td>
<td>10</td>
</tr>
<tr>
<td>0.25 - 0.50</td>
<td>5</td>
</tr>
<tr>
<td>&gt;0.50</td>
<td>0</td>
</tr>
</tbody>
</table>
Conclusions

- Efficient use of fertilizers helps production, the environment and your bottom line.
- Time applications and place fertilizer correctly for optimal plant use and minimal loss.
- Deficiency symptoms can ID trouble, but if apparent then have already lost yield.
- Soil testing is necessary to apply the correct amount of nutrients.
Additional soil fertility information is available at
http://landresources.montana.edu/soilfertility

• On plant nutrient functions and deficiency symptoms, refer to Nutrient Management Module 9.
• On soil fertility and plant nutrition, look at Module 2.
• On fertilizer placement, look at Module 11.

http://landresources.montana.edu/nm
Questions?

Watrous, SK, 1920s