Nitrogen management for grain yield and protein in the Northern Great Plains

The single most important thing a grower can do to get record wheat yields is improve nitrogen (N) management. Optimum N management for increased grain yield and protein includes: basing N rates on realistic yield potential, knowing the soil residual N, determining application rate and timing, and using appropriate placement and N sources. The steps are the same for all regions, but decisions should be based on guidelines specific to a grower’s area. Earn 1 CEU in Nutrient Management by reading this article and taking the quiz at www.certifiedcropadviser.org/certifications/self-study/724

Realistic yield goal

Crop advisers can use variety selection tools (see “Resources” below) to help pick a variety based on the traits their clients need, location, and cropping system. Past yields are a good indication of future performance. Given advances in equipment and technology that have made mid-season N applications more commonplace and less damaging to the crop, CCAs can use a conservative yield goal to determine pre-plant N rates.

Residual soil nitrate

Fall soil sampling is far more common than spring sampling in the winter wheat regions of the Northern Great Plains, yet spring soil samples better reflect available soil nitrate-N, especially on shallow soils with greater than 60 lb N/ac. In a three-year study at eight sites in Montana, 35% of soils sampled lost nitrate from November to April. Up to 60 lb N/ac was lost overwinter from the top 2 ft on some sites (Jones et al., 2011a), meaning fall sampling would result in significant under-fertilization. Other sites gained substantial soil N over winter due to N mineralization. Fall sampling is still needed to determine crop P and K needs. To avoid always sampling twice a year, a comparison of fall with spring samples over a few years would identify whether a given field and rotation generally gains or loses N over winter. Patterns of loss or gain can guide adjustments to spring N rates based on fall samples or the decision to spring sample.

Rate

In Montana, dryland winter wheat requires an average of 2.6 lb N/bu to produce 40 bu/ac with 12.5% protein, and spring wheat requires an aver-
age of 3.3 lb N/bu to produce 40 bu/ac with 14% protein when soil organic matter is 2% (Jones and Olson-Rutz, 2012). Exact amounts will vary with variety and growing conditions. These rates were based on avoiding grain protein discounts but do not take into account fertilizer costs, grain prices, and protein discounts. Nitrogen rate calculation tools designed to optimize net revenue are listed under “Resources” below.

Variable rate- or site-specific rate technology adjusts N rates for within-field growing conditions. At this time, the economic benefit of variable-rate technology is inconsistent in our region. In a simplified version, fields can be divided into zones with historically low, medium, and high productivity with N rates adjusted by those zones. North Dakota State University Extension has a series of bulletins on zone farming (SF1176 series at www.ag.ndsu.edu/publications).

The effectiveness of N fertilization practices can be evaluated by compiling several years of grain protein levels. In Montana, if winter wheat protein is under 12.5%, then yield and protein have likely been N limited. To gain 1 protein point (percent) in winter wheat would require approximately an additional 22 lb N/ac with less than 6 inches of growing season precipitation or 33 lb N/ac with more than 12 inches of growing season precipitation. For spring wheat, grain protein under 13.2% indicates that yield and protein have been compromised by under-fertilization (Jones and Olson-Rutz, 2012). This post-harvest protein evaluation should prove more useful than using a strict lb N/bu guideline because the protein–yield relationship incorporates all of the factors affecting N losses and yield such as specific management practices, soil characteristics, and weather.

Once N for yield is met, protein increases proportionately with increasing N, at least up to 14% in spring wheat. Increasing protein above 14% may be more difficult, and higher yields require more N to increase protein by one point. There may be a limit to how much late-season N can be applied, as high late-season N on irrigated wheat can increase lodging.

In dry regions, where residue decomposition rates are slow, reduced or no-till management requires more broadcast N than conventional till due to N tie-up by residue. Small grain stubble in no-till systems can increase N required by 10 lb N/1,000 lb stubble up to 40 lb N/ac. In wheat–fallow systems, it can be assumed that half of the stubble has decomposed so only 5 lb N/1,000 lb stubble may be necessary (Dinkins et al., 2014). To attain stubble weight in pounds per acre, multiply grain weight in pounds per acre by 1.67 for winter wheat and by 1.33 for spring wheat.

There is no single suggestion on how much longer no-till in dry regions may need more fertilizer-N than conventional till. In semi-arid regions of Saskatchewan with medium and fine-textured soils, an additional 20 lb N/ac was required under no-till than conventional till to produce acceptable grain protein in the first six years after conversion. No-till systems on medium- to fine-textured soils may require additional fertilizer N for at least 15 years after conversion. Coarse soils may require less additional N for fewer years (Dinkins et al., 2014).

However, in moist regions with more rapid decomposition and higher residue production, such as eastern North Dakota, mature soils in no-till for more than five years can get up to a 50 lb N/ac N credit (the amount of fertilizer N to back off from a standard recommended rate; Franzen, 2014).

Credit for soil organic matter also varies with growing conditions. North Dakota State University suggests a 50 lb N/ac credit in soils with 6% soil organic matter and for each additional full percent soil organic matter (Franzen, 2014). In contrast, in more arid regions, soils with >3% organic matter receive a 15 to 20 lb N/ac credit (Jacobson et al., 2005). Soils with organic matter less than 1% should receive an additional 15 to 20 lb N/ac.
Timing

Nitrogen available to wheat plants up through stem elongation generally benefits yield, while N available after stem elongation contributes directly to grain protein. However, fertilizer-N must convert to plant available N (ammonium or nitrate) and reach the plant roots. This can take several weeks to months after application, depending on the N source and soil moisture and temperature.

Sources that slowly provide N, such as polymer-coated urea (e.g., ESN), manure, or legume residue, are generally best incorporated in the fall in order to provide N for early growth. Fertilizers with readily available N [e.g., urea (46–0–0) and urea ammonium nitrate (28–0–0)] are best applied shortly before seeding up to mid-tillering to benefit yield. Nitrogen for protein can be applied later.

Applying high rates of N before or at seeding is risky. High N can produce more tillers than are able to produce grain, even in irrigated production. Excessive vegetative growth in dryland farming may deplete soil moisture before flowering and grain fill, reducing yield.

Split applications allow for in-season N adjustment based on precipitation to date. Pre-plant and at-seeding N should be high enough to meet the crop’s early needs and for longer if there is a risk that high rainfall amounts would interfere with in-season field access. If yield potential is lower than expected, extra N will go towards protein. Topdressing can then boost yield and/or protein. Topdress application timing and rate depends on the amount of N available in the soil at seeding and whether the crop will reach its estimated yield potential. See Table 1 for an example calculation of in-season N rate and timing. Chlorophyll meters (e.g., SPAD, GreenSeeker, and Crop Circle) and remote-sensing technologies are increasingly available to guide in-season N adjustments.

Applications after stem elongation have less chance of causing lodging and will go towards grain protein. Ideally, N for protein is applied at flowering. However, in dryland production, the ability to incorporate fertilizer applied anytime between boot to shortly after flowering with rainfall is more important than timing the application exactly at flowering. Late-season N produces a more consistent protein response under irrigation than dryland production because the N is usually incorporated with irrigation (Fig. 2).

Grain protein is likely to increase with late-season N if the flag-leaf (uppermost leaf of the stem sampled at heading) N concentration is less than 4.2%. Flag-leaf analysis alone cannot indicate how much N to add or the final protein level (Jones and Olson-Rutz, 2012).

Chlorophyll readings of irrigated spring wheat at heading that are less than about 93 to 95% of a well-fertilized reference plot indicate grain protein will likely respond to late-season N. However, chlorophyll readings are not a

Table 1. Example in-season topdress rate and timing calculation for a semi-arid region.

<table>
<thead>
<tr>
<th>Step</th>
<th>N need</th>
<th>N credit</th>
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<tbody>
<tr>
<td>1. Select realistic yield goal, e.g., 60 bu/ac winter wheat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Look up local recommended lb N/bu, e.g., 2.6 lb N/bu × 60 = 156 lb N/ac (or use economic N rate calculator)</td>
<td>+156</td>
<td></td>
</tr>
<tr>
<td>3. Adjust for:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Residual soil N (spring soil test), e.g., 61 lb N/ac</td>
<td>-61</td>
<td></td>
</tr>
<tr>
<td>b. Cropping system, e.g., grain pulse crop grown once</td>
<td>-10</td>
<td></td>
</tr>
<tr>
<td>c. Soil organic matter, e.g., 3.1%</td>
<td>-15</td>
<td></td>
</tr>
<tr>
<td>4. Total fertilizer N need</td>
<td>+70</td>
<td></td>
</tr>
<tr>
<td>5. Reduce by amount placed at seeding, e.g., 10 lb N/ac</td>
<td>-10</td>
<td></td>
</tr>
<tr>
<td>6. The amount to topdress = 156–61–10–15–10 = 60 lb N/ac</td>
<td>+60</td>
<td></td>
</tr>
<tr>
<td>7. By when topdress?</td>
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$(61 + 10 + 15 + 10)/156 = 61\%$ of total need. According to Fig. 1, this is used up by the end of tillering, but since fertilizer takes time to become available and enter the plant, the 60 lb N/ac should be applied by mid tillering to prevent N deficiency.
reliable tool to predict protein response in dryland winter wheat in our region (Jones and Olson-Rutz, 2012).

Source

Nitrogen fertilizers have different potentials for N loss to leaching and volatilization (loss as ammonia gas to the air) depending on how quickly they convert to ammonium and nitrate and how long those are in the soil before crop uptake. Ammonium nitrate, ammonium sulfate, and urea ammonium nitrate (UAN; 28–0–0; 32–0–0) have lower volatilization potential than urea but equal leaching potential. Dry urea is still the best choice if it can be incorporated by tillage or more than ½-inch of water in a single event.

Specialized products such as polymer-coated urea (e.g., ESN), or urea treated with N-butyl-thiophosphoric triamide (NBPT, e.g., Agrotain) or other enzyme inhibitors (NBPT + NPPT, e.g., Limus), have lower volatilization losses than regular urea. NBPT delays urea conversion to ammonia, thus buying time for incorporation by precipitation. This can increase wheat grain protein by up to 0.75 percentage points but may not significantly increase grain yield (Engel, unpublished, 2014).

In the Northern Great Plains, slow- and controlled-release N sources to reduce leaching loss have shown inconsistent benefit to grain yield and protein. In semiarid dryland conditions, broadcast polymer-coated urea may get stranded on the soil surface and not release N for a long time. Fall seed-placed polymer-coated urea may increase yield over fall broadcast urea, especially in wet conditions when urea may leach over winter. If fall seed-placed application is used to avoid a spring broadcast application, then the extra cost might be worth it. Nitrogen release from polymer-coated urea can be too slow with late winter and early-spring broadcast applications to benefit yield, but may increase protein. An option is to use a blend of urea and a slow- or controlled-release N fertilizer.

Legumes in rotation are an economical N source. The benefits of legumes depend on the species, when they are terminated, whether they are harvested for seed, forage or grown for green manure cover crops, and the number of times planted in rotation.

Termination of cover crops by approximately first bloom is key to preventing yield and protein losses in the subsequent wheat crop because of high water use after bloom (Miller et al., 2006). Legumes should make

For protein boost, consider applying additional N:

- If you have a way to apply without substantial damage to the crop with on-field traffic or leaf burn
- If indicated by flag leaf N concentration < 4.2%
- Ideally during flowering on irrigated fields, unless high risk of scab, in which case avoid within five days of flower
- On dryland, it is more important to get incorporation with > ½-inch rain event than “correct” timing

Fig. 2. Change in grain protein points in response to N per bushel of yield applied pre/during flowering or after flowering in (a) dryland and (b) irrigated production (Jones and Olson-Rutz, 2012).
Estimated N credit from pulse/legume crops in areas with less than 15 inches rainfall

- Grain pulse
  - grown once: 10 lb N/ac
  - grown three or more times on same field in 10-year period: 20-30 lb N/ac

- Legume cover crop
  - grown once: 20-30 lb N/ac (higher if moist)
  - grown three or more times on same field: 30-50 lb N/ac

- Fall soil test (rather than spring), increase all of above by 10 lb N/ac

up more than 50% of a cover crop biomass in order to contribute substantial available N to the following crop (Sullivan and Andrews, 2012).

Based on Montana studies, legumes can provide a N credit after just one year (see above), but the wheat yield goal needs to be adjusted lower than after fallow. After three cycles with dryland lentil green manure in northeast Montana, wheat yields were the same following green manure without additional N and fallow with 30 lb N/ac fertilizer. Fewer legume rotations were needed to match wheat grain protein after fallow than match grain yield (Fig. 3). Legume N credit is greater in more productive systems. Over the long term (at least four cycles), wheat grain yield and protein can be greater after cover crops than fallow with less or no fertilizer N. This provides higher economic returns with greater stability, by reducing the reliance on fertilizer N (Fig. 4).

**Placement**

Ammonia and ammonium-based fertilizers should be subsurface placed or incorporated by tillage or a single rain/irrigation event greater than ½ inch to reduce N volatilization loss. Safe rates of seed-placed fertilizer increase as soil texture goes from light (sandy loam) to heavy (clay), with wider openers, and as row spacing decreases. Enhanced-efficiency fertilizers such as polymer-coated urea or the addition of NBPT effectively reduce seedling damage. Safe rates of seed-placed N can be increased up to 50% when using NBPT-treated urea as compared with untreated urea or UAN and 2- to 4-fold for polymer-coated urea. Resources to calculate safe rates are listed at the end of this article.
Foliar applications risk leaf burn. No more than 30 lb N/ac of UAN and 45 lb N/ac of liquid urea should be applied to minimize burn and yield loss, and far less can be applied if tank-mixed with herbicide or fungicide. Only 8 to 11% of foliar N is taken up by the leaf compared with 37 to 67% of soil-applied N (Rawluk et al., 2000). However, under dry conditions, the small amount of foliar N taken up by the plant might help more than surface-applied N stranded on the soil surface. Foliar N needs about ½ inch of rain or irrigation to be washed into the soil to be very effective. The ease of application of liquids can be outweighed by foliar damage, even with streamer bars, so consider granular urea prior to jointing as an alternative.

Nitrogen management begins with setting realistic yield goals, determining residual soil N values, and adjusting N rates for soil organic matter and prior rotations. The right N source and placement increases the amount of N going to the crop rather than being lost to leaching or the air. Sufficient N must be available to meet the crop’s early growth requirements. In-season N rate and timing can be adjusted to meet the needs of the current growing season. Close attention to N management is very important for optimal grain yields, protein, and economic returns and for protecting groundwater.

References

Resources
Small-grain variety selection tools
Alberta: www.agric.gov.ab.ca/app119/compare
Montana: www.sarc.montana.edu/php/varieties/
North Dakota and Minnesota: www.ag.ndsu.edu/smallgrains/newsvariety-selection-tool

N rate calculation tools
Alberta Ag and Rural Development Grains, Forage and Straw Nutrient Use Calculator: www.agric.gov.ab.ca/app19/calc/crop/nutrientuse.jsp
Alberta Ag and Rural Development Farm Fertilizer Information and Recommendation Manager: http://bit.ly/1MubSTT
North Dakota State University Wheat N Calculator: www.ndsu.edu/pubweb/soils/wheat/

Safe seed-placed rates
Manitoba Agriculture and Rural Development: http://bit.ly/1Jw4EHW
South Dakota State University Fertilizer Seed Decision Aid: www.sdstate.edu/ps/extension/soil-fert/fertapp.cfm