NITROGEN FERTILIZER RATES AND APPLICATION TIMING FOR WINTER WHEAT IN WISCONSIN – WHAT ARE THE ECONOMIC OPTIMUMS?[1]

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Introduction

While somewhat of a minor crop in Wisconsin, many farmers look to wheat for achieving the economic and pest management benefits associated with more diversified grain crop rotations. For winter wheat to be an economic competitor in Wisconsin crop rotations, farmers must be able to raise high yielding, high quality wheat year after year. Progress has been made toward this goal with improved varieties that are more winter hardy, have better stand-ability and are more disease resistant. In addition, wheat growers have become more knowledgeable with respect to optimal planting dates, seeding rates, depth of planting and use of fungicides. Farmers applying top management in south-central Wisconsin often achieve soft red winter wheat yields of from 75 to 100 bushels per-acre.

One of the bigger, seemingly un-resolved questions is with respect to nitrogen fertilization. Nitrogen (N) tends to be the most limiting soil nutrient for wheat. However, research and recommendations on economic optimum rates and application times at Midwest universities is often old, is based on limited research and tends to vary significantly from one university to another. Observations from the field suggest that many high-yield wheat growers in Wisconsin tend toward higher rates of nitrogen than suggested by University of Wisconsin recommendations. Many wheat growers in south-central Wisconsin report applying from 75 to 120 lb N/acre, which is 25 to 100% more than the base recommendation of 60 lb/acre offered by the University of Wisconsin.

As a first-step toward helping wheat grower decisions on nitrogen rates and application times this paper provides a review of:

1. Current nitrogen management recommendations for winter wheat from the University of Wisconsin;
2. Current nitrogen management recommendations for winter wheat from other Midwest universities including Minnesota, Iowa State, Illinois, Purdue and Michigan.
3. A sampling of recent studies pertaining to N rate, time of application and use of the preplant soil nitrate test for winter wheat.

University of Wisconsin Recommendations

Nitrogen Rates

Nitrogen fertilizer rate recommendations offered by the University of Wisconsin Cooperative Extension Service (UWEX) for crops produced in Wisconsin are based on rate-response trials

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conducted under various soil and climatic conditions at University of Wisconsin (UW) research stations (Kelling et al., 1998). For corn and potatoes, these rate-response trials have led to specific recommendations according to the estimated yield potential of the 300 named soils throughout the state. Nitrogen rate recommendations for corn and potatoes are further specified according to soil organic matter content as determined by a soil test and whether there is irrigation. Guidelines are also offered by UW as to time of application for these crops.

For all other crops, including winter wheat, there is insufficient data for soil-specific nitrogen rate recommendations. **For wheat, recommendations are based on soil organic matter (OM) content for a rather wide yield range of 40 to 90 bu/acre. The N rate recommendations range from 80 lb N/acre for soils below 2% OM to 40 lb N/acre for soils above 10% OM. Probably the most common N recommendation in Wisconsin is 60 lb N/acre for soils testing between 2 and 9.9% OM content**. However, no N rate response trials have actually been conducted in Wisconsin on sandy soils or soils significantly below 2% OM content (Bundy, 2003).

Adapted from UWEX A2809, Kelling et al. (1998).

	University of Wisconsin Extension N Recommendations for winter wheat – lbs/acre			
Yield Goal	**Soil organic matter content**			
bu/acre	<2	2 - 9.9	10 - 20	> 20
40-90	80	60	40	0

Credit Nitrogen from On-Farm Sources

Nitrogen credits from manure or legume crops should be accounted for and subtracted from the base N recommendation (Kelling et al., 1998). Alfalfa N credits published by UWEX soil scientists range from 40 to 190 lbs N per-acre available for a following crop, depending on soil type and the alfalfa's final stand density and re-growth. This would often exceed the N recommendation for wheat in most cases. **However, research conducted at Arlington, Lancaster and Ashland from 1999-2001 (Kelling et al., 2002) suggest that when alfalfa is killed after a typical 3rd cutting, N credits to winter wheat are actually much lower, closer to the recommendation of 60 lbs N per-acre, than for spring-planted crops such as corn.** This is because most of the N released from alfalfa will occur later than most of the N uptake by winter wheat. In the trials, wheat yields were often decreased and lodging was increased when N fertilizer was added, especially when the alfalfa stand was killed earlier. Small nitrogen fertilizer additions sometimes improved yield only when the wheat was planted no-till.

Updated manure credit values for N, P_2O_5 and K_2O can be found in the Nutrient Management Fast Facts (Nutrient and Pest Management Program) or in the Technical Note accompanying the USDA-NRCS standard 590 (Natural Resource Conservation Service, 2002). While no specific evaluations have been done, first-year N credits could be somewhat lower for wheat due to the time required for conversion of manure's organic N to mineral forms useable by plants.

For wheat following soybeans, the suggested N credit is 40 lb/acre. This would make the N recommendation for wheat following soybeans only 20 lb/acre for most Wisconsin soils where wheat is likely to be grown. However, few N rate response trials have been conducted at UW for wheat following soybeans.

Time of N Application

There are no specific guidelines recently offered by UW researchers as to time of application of N for winter wheat.

Preplant Nitrate Test-Based Recommendations

One difficulty in predicting the economic optimum N rate arises from the fact that wheat appears to be very sensitive to both under-fertilization and over-fertilization with N. Unlike with corn, most N rate/yield response studies with wheat indicate yield reductions when fertilizer N is applied above some level. This is often attributed to increased lodging, disease and lower grain test weight associated with excessive N availability. Availability of N from soil organic matter or residual fertilizer N left un-used by previous crops can provide a significant portion of the wheat crops' needed N. Since these sources vary from year to year, it is more difficult to predict the optimum rate of N fertilizer to apply. Research at several universities in the 1990's has focused on the utility of in-season tests of N availability such as plant tissue analysis and soil nitrate tests for predicting optimal N rates for wheat.

Wisconsin research shows good promise for the preplant soil nitrate test (PPNT) for guiding season-specific and site-specific N rate decisions (Bundy and Andraski, 2001). Specific recommendations for use of the PPNT are currently in "proposed" status and are similar to recommendations for using the test for corn. The PPNT can be taken in the fall just prior to or during wheat planting time. The PPNT requires three soil cores, each in 1-foot increments, taken to a depth of three feet. Optionally, two one-foot increment cores can be taken to a depth of two feet, with the third foot value predicted by the soil testing lab based on the first 2 feet. Fifty pounds per-acre of nitrate-N are considered background level. Any amount over and above 50 lb/acre measured by the PPNT can be credited against the base N recommendation.

PPNT N Rate Recommendation = Base N Recommendation - (PPNT NO_3^--N – 50)

For example, if the PPNT value is 90 lb/acre and the base N rate recommendation is 60 lb/acre, the PPNT N rate recommendation would be 20 lb/per-acre.

Michigan State University Recommendations

According to Michigan State Extension Bulletin E-2526 (Vitosh, 1998), "information on soil texture, organic matter level and yield goal is used to determine the optimum amount of N fertilizer to apply." However, the publication's Table 1: Nitrogen recommendations for wheat, expresses pounds N/acre only in terms of wheat yield goal. For yield goals above 60 bu/acre, Michigan's recommendations exceed those from Wisconsin by 15 to 50 lb/acre. The publication provides no guidelines for adjusting N rates according to legume, manure or other on-farm credits.

The publication recommends "to apply no more than 25 lb of N in the fall" (to avoid excessive fall growth and potential conversion to leachable nitrate) with the balance applied "early in the spring before the ground thaws or stems elongate." It is also pointed-out that splitting N applications may be desirable in a year with excessive spring rainfall, but since this is not predictable, most

farmers don't use this practice. Further, dry conditions after the last application may render the N unavailable for plant use.

Nitrogen recommendations for wheat from Michigan State Extension (Extension Bulletin E-2526)				
Wheat yield goal (bu/acre)				
50	60	70	80	90+
Pounds N/acre				
40	60	75	90	110

Indianna – Purdue University Recommendations

Nitrogen recommendations for wheat offered by Purdue emphasize both rate and time of application. "Regardless of soil type, 15 to 30 lb N should be applied at seeding, with the balance topdressed as close as possible to the time regrowth begins in the spring" (Mansfield and Hawkins, 1992). Topdress recommendations are presented in the following table and are based on "yield goal and soil texture." However, soil texture is expressed as cation exchange capacity (CEC) in milliequivalents of cations per 100 grams of soil (meq/100g).

Recommended Topdress Nitrogen Fertilizer Rates for Wheat at Various Yield Levels and Soil Textures From Purdue University (Co-op Extension AY-244)				
Cation Exchange Capacity	Nitrogen rate when bu. per a. yield goal is...			
	55-64	**65-74**	**75-85**	**85+**
meq/100g	lb./a.			
<6	70	80	90	100
6-10	60	70	80	100
11-30	50	60	70	90
>30	40	50	60	60

Generalized relationship between soil texture and cation exchange capacity*	
Soil Texture	Cation Exchange Capacity (milliequivalents per 100g of soil) (normal range)
Sands	1-5
Fine Sandy Loams	5-10
Loams and Silt Loams	5-15
Clay Loams	15-30
Clays	Over 30

*Donahue, et. al., 1983

Thus, Purdues' recommendations are slightly more broken-down according to specific soil and yield goal criteria compared with Wisconsin. However, for south-central Wisconsin yield goals of 75 to 85 bu/acre, Purdue's recommendations will be higher by 25 to 50 lb N/acre, including both at-plant and topdress applications. For yield goals above 85 bu/acre, they will be 45 to 70 lb N/

acre higher. For the clay loams of eastern Wisconsin, the Purdue recommendations may only be slightly higher.

The Purdue University Cooperative Extension Service publication reviewed for this report provides base N recommendations only and makes no mention of adjusting the nitrogen rate according to previous legume crops or manure applications.

Iowa State University

Iowa State University (ISU) has no up-to-date recommendations for nitrogen and wheat. Agronomists from ISU report that very little wheat is produced beyond the southeastern portion of the state; and that wheat growers there rely on wheat research and extension from Illinois and Missouri.

"The "old" N recommendations for wheat are only provided in the *ISU Extension Pocket Notebook*. That recommendation is Lbs N/acre = bu/acre yield potential X 1.3 lb N/bu. "This recommendation has been around for a long time" (Sawyer, 2003).

For a yield goal of 90 bu/acre, therefore, the ISU recommendation would be 117 lb N/acre nearly double the UW recommendation.

University of Minnesota Recommendations

There are two strategies for determining N application rates in Minnesota, depending on where in the state you are (Rehm et al., 2002). In the western-most counties, the University of Minnesota Extension Service recommends use of the soil nitrate test, taken to a depth of 2 feet. The optimal N rate is then estimated according to the following formula:

$$Nrec = 2.5(YG) - STN - Npc$$

where YG = yield goal, STN = soil tests nitrate value, and Npc = N available from the previous crop.

In the eastern two-thirds of the state, N rate recommendations are based on yield goal, soil organic matter content and the previous crop, similar to Wisconsin. However, University of Minnesota's (UM) recommendations break-out the yield goal variable in more detail and the soil organic matter content variable in slightly less detail than UW. Previous crops are placed into five legume groups and one non-legume group. Therefore, recommendations for wheat when the previous crop is in the non-legume category could be considered the base recommendations.

There are sizeable differences between Minnesota's and Wisconsin's recommendations, particularly at high but achievable yield goals. The base recommendations for yield goals of 70 to 80+ bu/acre, when soil organic matter content is 3% or more, range from135 to 150 lb N/acre. If soil OM is less than 3%, rates are boost to between 155 and 170 lb N/acre. These rates would be from 125 to 180% higher than the Wisconsin recommendations. If wheat follows soybeans, N applications are reduced by 20 lb/acre. Even when wheat follows alfalfa, recommended rates range from 60 to 120 lb N/acre depending on soil organic matter content and alfalfa stand density when it is killed.

Adapted from *Fertilizing Wheat in Minnesota*, Rehm, Schmitt and Eliason, 1998.
Nitrogen recommendations for wheat where the soil nitrate test is not used.

Crop Grown Last Year	Organic* Matter Level	Yield Goal (lb/acre)					
		Less than 40	40-49	50-59	60-69	70-79	80+
		N to apply (lb.acre)					
alfalfa, (4+ plants/ft^2) non-harvested sweet clover	low	0	0	30	55	80	95
	medium and high	0	0	0	35	60	75
soybeans	low	35	60	85	110	135	150
	medium and high	0	40	65	90	115	130
edible beans, field peas, harvested sweet clover	low	45	70	95	120	145	160
	medium and high	25	50	75	100	125	140
alfalfa (2-3 plants/ft^2) alsike clover birdsfoot trefoil grass/legume hay grass/legume pasture fallow red clover	low	0	30	55	80	105	120
	medium and high	0	0	35	60	85	100
alfalfa (0-1 plants/ft^2) and non-legumes	low	55	80	105	130	155	170
	medium and high	35	60	85	110	135	150
organic soil	—	0	0	0	0	30	35

* *Low = less than 3.0%; medium and high = 3.0% or more < /EM > < /EM >*

University of Illinois at Urbana-Champaign

Wheat represents a small but significant crop in Illinois. Most of Illinois' wheat is grown in the southern half of the state where it is double-cropped with soybeans. Some wheat is planted in northern Illinois where yields tend to be higher, but where corn is believed to have a comparative economic advantage.

Fertilizer recommendations provided by the University of Illinois - Urbana-Champaign Department of Crop Sciences for Illinois' major agronomic crops are provided in the *Illinois Agronomy Handbook*. Illinois' N recommendations for soft red and hard red winter wheat are more similar to Wisconsin's than those of the other universities examined in this report. Agronomists from the University of Illinois report that their N recommendations for wheat have

been around for a long time, but that recent un-published data confirms them for current public and private varieties (Nafziger, 2003).

Fertility recommendations for Illinois crops are given in Chapter 11 of the handbook (Hoeft and Peck, 2003). As with Wisconsin, N recommendations for wheat are based primarily on soil organic matter content and not yield goal. The ISU Extension small grains agronomist suggests that basing N rates on yield goals does not make sense. He reports that N rates required for optimal yields in southern Illinois tend to be slightly higher than those in the northern areas even though wheat yields are lower in the south (Nafziger, 2003).

Nitrogen rates recommended are similar to Wisconsin's. One difference, however: Illinois differentiates between wheat grown by itself and wheat grown as a companion to a seeding of alfalfa or clover. When planted with alfalfa or clover, the N recommendation is reduced 20 lbs per-acre. This appears to be based on the premise that slightly less vegetative growth of the small grain is desirable for establishment of the legume seeding.

The following table shows Illinois' N recommendations for small grains. With respect to wheat, the midpoint of the suggested range for N application when planted with a legume under-seeding for each organic matter category closely matches the Wisconsin recommendation. However, the range of suggested N when wheat is planted without a legume (usually the case in Wisconsin) averages 20 lb N/acre higher than Wisconsin for each organic matter category.

	Fields with alfalfa or clover seeding		Fields with no alfalfa or clover seeding	
Organic Matter	Wheat	Oats and Barley	Wheat	Oats and Barley
- - - - - - - - - - - - - - - nitrogen (lb/A) -				
< 2 %	70-90	60-80	90-110	70-90
2-3 %	50-70	40-60	70-90	50-70
> 3 %	30-50	20-40	50-70	30-50

The University of Illinois also provides specific guidelines for adjustments to nitrogen applications when the preceding crop is a legume (soybeans or alfalfa) and if manure is applied (nutrient credits). The N credits from legumes are lower than those offered by Wisconsin. For example, only 10 lbs of N per-acre is credited from soybeans by Illinois compared with the 40 lb of N credit from soybeans suggested by Wisconsin. The N credits from alfalfa are also conservative compared to Wisconsin, with only 30 lb N/acre credited to an alfalfa stand of 5 or more plants/ft^2 and 10 lb N/acre for 2-4 plants /ft^2.

These credits are lower when applied to wheat than when used for corn. The *Illinois Agronomy Handbook* states: "the contribution of legumes, either soybeans or alfalfa, to wheat will be less than the contribution to corn because the oxidation of the organic nitrogen from these legumes will not be as rapid in early spring, when nitrogen needs of small grain are greatest, as it is in the summer, when nitrogen needs of corn are greatest." The handbook suggests no specific difference between wheat and corn in the N credit from manure.

Chapter 4 of the handbook emphasizes that boosting N rates beyond the recommendations has generally not increased yields, and that excessive N applications can reduce yields through

delayed maturity and lodging. Chapter 4 also suggests applying "some N and necessary phosphorous (P) before planting and applying the remainder of the N in late winter or early spring when dormancy breaks and the crop begins to green-up.

Recent Investigations

Nitrogen Rates

A recent study at the UW Arlington Agricultural Research Station (Boerboom and Gaska, 2002) compared 60 lb N/acre with 120 lb N/acre for wheat after soybeans across three winter wheat varieties. Average yields associated with 60 lb added N were 95.4 bu/acre, and were 92.6 bu/acre for 120 lb N/acre. Thus, a slight reduction in terms of both yield and economic return, associated with the higher rate. The difference was relatively consistent across varieties. In 2001, the same rates were compared with a single hard red winter wheat variety following a barley crop (Boerboom and Gaska, 2001). In this comparison, the 120 lb rate out-yielded the 60 lb rate by 5.2 bu/acre (67.4 vs. 62.2). This was reported as a break-even proposition in-terms of the added cost of N.

Time of N Application

Winter wheat normally takes-up 20 to 40 lb N/acre through tillering in the fall and very early spring (Sullivan et al., 1999). Wheat root development is extensive during this period (Daigger and Sander, 1976). Shortly after spring green-up, as tillering concludes and stem elongation (jointing) begins, nitrogen is taken-up rapidly, potentially accumulating 100 to 150 lb N/acre by the boot stage. Ample N availability is critical during this time. Later, as heads form and fill, N is mobilized from the plants' leaves and stems. Theoretically, then, N fertilizer additions, if needed, should be made in fall and/or very early spring. Split applications where one-half or more of the N is delayed until jointing (late spring) are probably only warranted on soils where early season losses are likely (Sullivan et al., 1999). Split applications are often recommended for wheat grown in southern states due to milder winters increasing the potential for leaching (Murdock, undated). Split applications and delaying some of the N application until after spring green-up, or even as late as boot stage, may be advantageous where high protein is the goal – especially in years of high rainfall (Alberta AFRD, 2000).

There are few good recent field studies comparing different N application times for high-yield winter wheat in the upper Midwest. Those that have been conducted provide varied results.

Research conducted at three UW experimental farms in 1986-87 (Kelling et al., 1997) compared various combinations of **fall** (preplant), **early spring** (GS 25, late tillering or spring green-up) and **late spring** (GS 30, stem elongation or jointing) N applications. Total N rates ranged from 0 to 140 lb N/acre. One outcome, consistent across the trials, was that yields were highest with the lowest N rates of 35 to 70 lb N/acre. However, yields in the trials ranged only from 51 to 67 bu/acre. Wheat variety was not reported. The previous crop was corn. Preplant nitrate levels were not reported.

With respect to application time, however, results were mixed between locations and years. Yields were highest most often when some N was applied in the fall with the balance applied at late spring. Yields were slightly lower when all or most of the N was applied at early spring. This differs slightly from "the theoretical" described above. However, average yields across the

different application time treatments did not appear to differ significantly and yields were all somewhat low in these trials (51 to 67 bu/acre).

Research conducted in western Minnesota with hard red spring wheat gave results more consistent with the guidelines presented above (Wiersma et al., 2002). Three levels of preplant N were established by a combination of soil test-measured residual nitrate plus fertilizer: 50, 100 and 150 lb N/acre. Then, topdress N was applied at 0, 15, 30, 45 and 60 lb N/acre. "Applying N fertilizer as a top dress increased grain yields and protein only when there was not sufficient preplant N available. Top dressing 45 lb N/acre increased grain yields by 6 bushels when the preplant N was 50 lb/acre." There were only small grain yield and protein responses to top dress fertilizer when preplant N was 100 lb/acre and no response when preplant N was 150 lb/acre. Yields were always lower when preplant N was limited to 50 lb/acre, regardless of subsequent topdress amounts, compared to the higher preplant N levels. Spring wheat yields were in the 39 to 47 bu/acre range. These results bolster the argument, at least with spring wheat, that earlier is better.

Preplant Soil Nitrate Test

As mentioned above, the economic optimum rate of N to apply for winter wheat production is difficult to anticipate from year to year due to the variability of soil residual nitrate-N. Research was conducted at four UW research sites from 1996 to 1999 to evaluate different in-season diagnostic tests for determining field and season-specific N needs for wheat (Bundy and Andraski, 2001). The study provides evidence that wheat yield response to fertilizer N is strongly effected by residual soil nitrate-N and found the preplant soil nitrate test to be the most accurate predictor of N need.

From 21 "site-years" of data, the study found that "as soil nitrate-N plus fertilizer N increased beyond 150 lb/acre, relative (wheat) yields declined from 100 to about 60%." These wheat yield reductions were determined to be the "result of excessive N availability due to N fertilizer additions on soils containing high residual nitrate-N content." Two major reasons were cited as contributing to the yield reductions in these cases: increased lodging and reduced grain test weight.

In nine of the 21 sites, the economic optimum N fertilizer application rate turned-out to be higher than the current, standard UW recommendation of 60 or 80 lb N/acre. The other 12 sites showed economic optimum rates at or below the standard recommendation. Economic N rates for wheat showed a strong negative correlation with N rates applied to the previous crop. Preplant soil nitrate test values showed a strong positive relationship with previous crop N rates. The previous crop in 15 of the 21 sites was corn silage. Only one site hosted wheat following soybeans (Racine, 1998). In this case, the economic optimum N rate was found to be about 77 lb N/acre, 17 lb above the base recommendation, not even considering the soybean N credit.

Summary and Conclusions

Research behind current N management recommendations for winter wheat given by the University of Wisconsin Extension is limited and has mostly used older, lower-yielding public varieties. Nitrogen recommendations for wheat production offered by neighboring state's universities tend to be significantly higher than Wisconsin's, particularly those from Minnesota, Iowa State, Purdue and Michigan. Many wheat growers in south-central Wisconsin report application rates 25 to 80% higher than the UW recommendation of 60 lb N/acre, along with

yields significantly higher than those observed in many UW trials. All of this suggests that current UW recommendations for N on winter wheat may be inadequate and/or out of date.

However, more recent studies at UW and elsewhere suggest that the very high rates recommended by other universities for high yield goals, sometimes in excess of 120 lb N/acre, are likely too high and could result in economic yield loss, at least for Wisconsin conditions.

Research trials are particularly needed to determine the economic optimum rate of N for wheat following soybeans. This is a popular place in Wisconsin grain crop rotations for wheat to be planted and there have been no complete evaluations for this practice. Soybean N credit recommendations from neighboring state's universities tend to be lower than Wisconsin's and N released from soybean residue may be available later than needed for wheat, such as is the case with alfalfa. The one trial in Wisconsin where wheat followed soybeans showed and economic optimum N rate of 75 lb/acre.

Although indications are mixed, most research and recommendations suggest that earlier applications of N for wheat are better than later applications. In Wisconsin, in fields where the risk of N loss is relatively low, some or all of the N could be probably be applied in the late fall after soil temperatures are below 50° F. Fall-applied N should be in the ammonium form. Any remainder should be applied in early spring just as the wheat breaks dormancy. Large fall applications should probably not be made on soils with high potential for leaching or runoff losses. More field trials to measure the relationships between time of N application, N losses and wheat yield under contemporary production systems are necessary.

Use of the preplant soil nitrate test for wheat appears to have good potential for assisting in determining rates. Additional evaluation in the field would be useful.

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