EVALUATION OF NITROGEN TESTS FOR SITE-SPECIFIC N RECOMMENDATIONS FOR WINTER WHEAT [1/]

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Soil nitrate tests are an effective method for identifying optimum nitrogen (N) rates for corn in several cropping systems commonly used in Wisconsin (Bundy and Andraski, 1995). Use of these tests often allows a reduction in the N rate applied for corn and thereby provides economic benefits to producers as well as reduced potential for loss of nitrate to groundwater. The success of this approach has stimulated producer’s interest in using similar methods for other nitrogen-demanding cereal crops such as wheat. Diagnostic tests for predicting wheat N requirements have been evaluated in the eastern U.S. and in the Great Plains wheat producing areas. The substantial soil and climatic differences between these regions and Wisconsin prevent direct transfer of N test methods for use in humid northern climates where little or no evaluation of N tests for predicting wheat N needs has been done.

The N test approaches that have been found most successful in previous work are: i) soil inorganic N measured at various times and soil depths early in the wheat growing season; ii) N concentrations in wheat plants at specific growth stages; and iii) chlorophyll meter readings on wheat plants at specific growth stages. Wheat stem nitrate concentrations have also been used to determine N needs in some areas (Papastylianou, et al., 1982; 1984; Roth et al., 1989; Knowles, et al., 1991). However, Vaughan et al. (1990a) found that stem and whole plant nitrate-N concentrations were too variable for reliable use in wheat N recommendations. Goos et al. (1982) reported that grain protein concentration was an effective post-harvest indicator of N sufficiency in wheat.

Numerous studies have evaluated the use of residual soil profile nitrate tests in the Great Plains region as a guide for N fertilization of wheat and other small grains. Early work (Soper et al., 1971; Olson et al., 1976) showed that yield response to applied N and crop N uptake were strongly affected by soil residual nitrate. Olson et al. (1976) reported that grain yield response to added N was unlikely if soil profile inorganic N exceeded 107 lb N/acre. Gelderman et al. (1988) found that soil nitrate (0-1 ft) was the best predictor of N uptake by wheat in South Dakota, and consideration of several other N availability indices (soil organic matter, UV absorbance of $NaHCO_3$ soil extracts, and ammonia released by autoclaving soil with $CaCl_2$) improved the prediction of wheat N uptake. A more recent study in humid regions (Scharf and Alley, 1994) showed that winter wheat yield response to added N was strongly influenced by the amount of inorganic N in the top 4 ft of several soils in Virginia. Vaughan et al. (1990) found that soil ammonium-N levels in spring explained more wheat yield variation than did nitrate-N,

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and sampling to depths greater than 2 ft did not improve the test. However, the procedure providing the best prediction of wheat yield response in this eastern Colorado study included soil nitrate plus ammonium-N to a 2-ft depth.

Relationships between plant N concentrations at various growth stages and wheat yields or response to added N has been extensively studied. Most of these studies have found good predictive value from plant N concentrations or plant N uptake measured at or near GS 30 (Baethgen and Alley, 1989a; 1989b; Donohue and Brann, 1984; Roth et al., 1989; Scharf et al., 1993; Scharf and Alley, 1993; Vaughan et al., 1990a). This time of plant sampling represents a compromise between good test predictive value and time availability after sampling and analysis to apply additional N if needed. For example, samples taken at GS 25 would allow more time for analysis and subsequent N application, but the predictive value of samples taken at GS 25 are not as good as that from samples taken at GS 30 (Vaughan et al., 1990a). Vaughan et al. (1990b) found that a combination of spring soil inorganic N and plant N concentrations provided a better prediction of wheat N response than either soil or plant N measurements alone. Similarly, Scharf and Alley (1993) developed an N testing strategy involving both a soil nitrate test (3 ft) and plant N uptake at GS 30, depending on the availability of tiller density counts at GS 25 and grower interest in making split N applications.

Chlorophyll meter readings at GS 30 have been studied as a method of predicting wheat response to N fertilization (Follett et al., 1992; Fox et al., 1994). This work indicates that chlorophyll meter readings are well related to yield, leaf N concentration, and soil inorganic N content (Follett et al., 1992). Fox et al. (1994) found that chlorophyll meter readings were more accurate than plant N concentration for predicting wheat response to N fertilization, but too few N responsive treatments were included in their study to determine if chlorophyll meter readings can be used to predict optimum N rates for wheat. Schepers et al. (1992) suggested normalization of chlorophyll meter readings on corn ear leaves by comparison with readings from adequately fertilized treatments. This approach was used by Fox et al. (1994) and recommended by Follett et al. (1992).

The sites selected in our study represent a range of production conditions including variables such as soil characteristics, tillage system, previous crop and N management, and annual climatic differences. The objective of this study was to evaluate several N tests (soil nitrate in the root zone at two sampling times, UV absorbance of $NaHCO_3$ soil extracts in the top 1 ft at preplant, plant N concentration and uptake, and chlorophyll measurements) for site-specific prediction of optimum N rates for winter wheat on a site-specific basis.

MATERIALS AND METHODS

Experiments to evaluate N tests for site-specific prediction of optimum N rates for winter wheat were established at the University of Wisconsin Research Stations at Lancaster (Grant County) and Arlington (Columbia County), and adjacent to the UW Agronomy winter wheat variety trials at Racine (Racine County) and Chilton (Calumet County). The experimental design was a randomized complete block consisting of five to seven fertilizer N rate treatments and four replications. Nitrogen treatments included rates ranging from 0 to 180 lb/acre in 30 lb increments that were broadcast applied in early spring at about the GS 25 wheat growth stage (Zadok's scale) at Chilton, Racine, and Lancaster using ammonium nitrate to avoid potential N losses through ammonia volatilization. At Arlington, N treatments included rates of 0, 30, 60, 90, and 120 lb N/acre using urea broadcast applied in September just prior to seedbed preparation. Winter wheat was seeded in mid- to late-September using recommended production practices and a seeding rate of about 30-35 seeds/sq. ft. Winter wheat varieties included Cardinal, Dynasty, Kaskaskia, and Pioneer 25R26.

Soil samples were collected from the 0 lb N/acre treatment prior to wheat planting in September (preplant) and in April following soil profile thaw at the GS25 wheat growth stage. These samples were taken to a depth of 3 ft in 1-ft depth increments and were analyzed for nitrate. In addition, UV absorbance at the 200 and 260 nm wavelength of soil extracts were determined in the top ft in September (preplant). Above-ground plant samples were collected from all treatments at GS 30 (May) and dry matter yield, N concentration, and N uptake were determined. Chlorophyll meter readings were taken on the uppermost fully expanded true leaf of about 20 representative plants at GS30 in each N treatment using a Minolta SPAD 502 chlorophyll meter. At maturity, grain yields were determined by harvesting each plot with a plot combine. Grain yields are reported at a 13.5% moisture content. Additional yield component measurements included lodging severity, number of heads per square foot, kernel weight (oz/1000 seeds), seeds/head, grain protein, and grain test weight (lb/bu).

An analysis of variance was performed to determine the effect of N rate on grain yield (SAS Institute, 1992). Optimum N rate and yield were determined by regression analysis and consisted of comparing linear-response plateau and quadratic-response plateau models using PROC NLIN, and linear and quadratic regression models using PROC REG. Economic optimum N rates (EONR) reflect a fertilizer to wheat price ratio calculated from prices of \$0.25/lb fertilizer N and \$3.18/bu of wheat. A standardized method was used to determine the EONR due to the variability of EONR typically determined by the various models (Bundy and Andraski, 1995). Where the effect of N rate was significant ($P < 0.10$), the EONR was identified using the regression model with the highest R^2 value if that value was $\geq$0.25. If the R^2 value was <0.25, mean separation analysis was used to identify the optimum N rate as the lowest N rate treatment in the highest *t*-grouping for yield using PROC ANOVA. If N rate was not significant ($P > 0.10$), the EONR equals zero.

RESULTS AND DISCUSSION

Site Characteristics and Previous Crop Management Effects on Wheat Yield

A summary of site characteristics, previous crop, N rate and time of application to the previous crop, and wheat yields in the study year for 21 site-years from 1996 to 1999 is shown in Table 1. The experimental locations had a range of soil organic matter contents (1.9 to 5.5%) with soil textures in the medium to fine category. Previous crops included corn silage, oat, cabbage, winter wheat, and soybean.

Wheat yields at optimum N rates ranged from 43 to 86 bu/acre depending on year and location (Table 1). Yields ranged from 18 to 76 bu/acre where no N was applied and from 28 to 86 at high N rates. Yields were lower in the high N rate treatment compared with the no N rate treatment at 8 of 21 sites (sites 3, 4, 10, 11, 14, 18, 20, and 21). Yield reductions at high N rates at these sites ranged from 1 to 19 bu/acre and were likely caused by excessive N availability due to the combination of N fertilizer applied to wheat on sites with high residual soil nitrate contents due to high rates of N fertilizer (140 to 300 lb N/acre) applied to the previous crop.

Comparison of Diagnostic N Tests for Wheat

The relationship between several N diagnostic tests and relative grain yield of winter wheat are shown in Table 2. The relationship between preplant soil nitrate-N and relative yield improved as soil sampling depth increased ($r^2 = 0.43, 0.53,$ *and* 0.59 at the 0-1, 0-2, and 0-3 ft depth, respectively). Additional measurements at preplant sampling included the UV200 and UV260 soil tests at the 0-1 ft depth. The UV260 test indicates the amount of dissolved organic matter contained in the soil and the UV200 test indicates the amount of dissolved organic matter plus nitrate-N content in the soil. The relationship between the UV200 test at the 0-1 ft depth and relative yield was similar to the soil nitrate-N test at the 0-1 and 0-2 ft depths with a r^2 value of 0.49, while the UV260 test showed a poor relationship with relative yield ($r^2 = 0.17$). Poor relationships occurred between soil nitrate-N at all depths obtained at the GS25 wheat growth stage (April) and relative yields ($r^2 = 0.07$ *to* 0.16). Tissue N concentration of the above ground plant material of wheat at the GS30 growth stage (May) showed a poor relationship with relative yield ($r^2 = 0.19$), while total N uptake (N concentration and dry matter content) showed a stronger relationship ($r^2 = 0.42$). Similar to the tissue N test, SPAD chlorophyll meter readings at the GS30 growth stage was not strongly related to relative yield ($r^2 = 0.22$). These results indicate that the strongest predictor of relative wheat yield was the soil nitrate-N content at the 0-3 ft depth just prior to wheat planting (preplant) and this relationship is shown graphically in Figure 1.

Residual Soil Nitrate-N and Fertilizer N Rate Effects on Wheat Yield

The relationship between preplant soil nitrate-N content (0-3 ft) plus N fertilizer rate on relative grain yield is shown in Figure 2. Relative yield increased from about 50 to 100% as the amount of soil nitrate-N plus N fertilizer increased from about 10 to 150 lb/acre. As soil nitrate-N plus N fertilizer increased beyond 150 lb/acre, relative yields declined from 100 to about 60%. As previously mentioned, the decline in wheat yield was the result of excessive N availability due to N fertilizer additions on soils containing high residual nitrate-N contents.

Figure 3 shows that over-application of N fertilizer has the same effect as under-application of N fertilizer on economic returns. For example, economic returns were reduced by 12% where N fertilizer rates were either under-applied or over-applied by 70 lb/acre. Similar to corn, these results indicate that excessive N rates result in reduced profits due to increased N fertilizer costs. Unlike corn, the profit reduction due to excessive N fertilizer is magnified in wheat since yields decline as excessive N rates increase. Obviously, the use of a preplant soil nitrate test reduces the risk for economic losses due to excessive N availability by accounting for residual soil nitrate content prior to applying fertilizer N (Fig. 3).

One reason for the yield reduction due to excessive N availability is increased lodging (Fig. 4). A strong relationship ($r^2 = 0.89$) between preplant soil nitrate-N content plus fertilizer N rate and lodging occurred. Lodging values (Belgian scale: 0.2 = none to 9.0 = severe) increased linearly from 0.2 to 7 as soil nitrate-N plus fertilizer N increased from 10 to 500 lb/a. Figure 5 shows a sharp yield decline when lodging values were >4. Another reason for yield reductions appears to be related to the effect of excessive N availability on reduced grain test weight (Fig. 6). A highly significant reduction in grain test weight occurred ($P < 0.01$) as preplant soil nitrate-N content plus fertilizer N rate increased.

PPNT-Based N Rate Recommendations for Winter Wheat

Preplant soil nitrate-N contents, economic optimum N rates (EONR), and base N rate recommendations are shown in Table 3. Current Wisconsin base N rate recommendations for wheat are 60 lb/acre for soils with organic matter contents of 2 to 9.9% (19 sites) and 80 lb/acre for soils with organic matter contents less than 2% (2 sites). Nine sites had EONR higher than base N rate recommendations (4 to 70 lb N/acre higher than base N rate) and averaged 16 lb/acre higher for sites with soil organic matter contents >2% and 45 lb/acre higher for sites with soil organic matter contents <2%. Twelve of the 21 sites had EONR that were less than or equal to the current base N rate recommendations. High precipitation amounts resulting in fertilizer N losses do not appear to be a factor explaining the high EONR at the two sites (Chilton, 1997 and 1998) with low soil organic matter content. Additional N response trials are needed to determine whether higher base N rates are necessary on highly productive wheat soils with low organic matter contents.

Based on results from this study, we developed N rate recommendations for winter wheat using a preplant soil nitrate test (PPNT) to better predict the optimum N rate in order to minimize potential environmental and economic risks associated with excessive N fertilization. The relationship between PPNT values and observed EONR for 21 site-years is shown in Figure 7. There was no response to applied fertilizer N (EONR = 0 lb/acre) where PPNT values were ≥ 108 lb nitrate-N/acre in the top three feet. Economic optimum N rates increased as PPNT values decreased below 108 lb/acre and were near or above current base N recommendations where PPNT values were ≤ 50 lb/acre. These results are similar to current Wisconsin N rate recommendations for corn using the PPNT in that yield response to the full base N recommendation usually occurs where PPNT values are below 50 lb/acre. This is referred to as the background soil nitrate-N content.

Proposed N rate recommendations for winter wheat using the PPNT in Wisconsin where the previous crop is not alfalfa is shown in Table 4. For PPNT values of 50 lb/acre or less, no adjustment in base N rate recommendations is made. For PPNT values greater than 50 lb/acre, the base N rate recommendation is reduced according to the adjusted soil test value (which is the measured value minus the background value of 50 lb N/acre). 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 equals 20 lb/acre [60 - (90 - 50)].

Figure 8 shows the effect of preplant soil nitrate-N content on net economic returns using PPNT-based N rate recommendations for winter wheat. Net economic gains from using the PPNT-based N rate recommendations averaged $15/acre among sites where PPNT values were greater than 50 lb/acre and increased linearly as PPNT values increased ($r^2 = 0.81$). A comparison of N rate recommendations using the base N rate and PPNT-based methods relative to preplant soil nitrate-N content clearly shows the influence of increasing soil nitrate levels on economic losses by not accounting for residual soil nitrate-N contents (Fig. 9).

Predicting the Probability of Economic Return Using the PPNT

Results from this study reveal several factors which indicate whether using a PPNT will result in profitable adjustments to base N rate recommendations for winter wheat (Table 5). The probability of a positive economic return using the PPNT was dependent on the spring N rate applied to the previous crop and summer precipitation amounts received from June to August. Where <100 lb N/acre was spring applied to the previous crop, the probability of a positive economic return using the PPNT was low when summer precipitation was average and very low when precipitation was above average. Conversely, where >100 lb N/acre was spring applied to the previous crop, the probability of a positive economic return using the PPNT was very high when summer precipitation was average and high when precipitation was above-average. The PPNT values ranged from 26 to 43 lb/acre (average 33) where <100 lb N/acre was spring applied to the previous crop and from 82 to 133 lb/acre (average 111) where >100 lb N/acre was spring applied, depending on summer precipitation amounts.

To determine whether shallower soil sampling depths could be used to predict soil nitrate-N contents at deeper depths when using the PPNT, relationships between soil nitrate-N contents at several depth increments and soil nitrate-N contents at the 2 to 3 ft depth increment were determined (Table 6). A fairly good relationship occurred between soil nitrate-N contained in both the top 1 and 2 ft depth increments and soil nitrate-N contents in the 2 to 3 ft depth ($r^2 = 0.45$ *and* 0.54). The soil nitrate-N content at the 1 to 2 ft depth increment provided the best prediction of soil nitrate-N content at the 2 to 3 ft depth, however ($r^2 = 0.74$). Similar results were reported using the PPNT for corn in Wisconsin (Ehrhardt and Bundy, 1995). This will enable user's of the PPNT to reduce the sampling depth from three to two feet with minimal sacrifice to the integrity of the test (Fig. 9). Soil samples should still be separated into 0 to 1 and 1 to 2 ft depth increments in order to calculate the predicted soil nitrate-N content at the 2 to 3 ft depth as shown in Table 6 ($y = 5.8 + 0.51x$: where; x = soil nitrate-N content at the 1-2 ft depth and y = predicted soil nitrate-N content at the 2-3 ft depth).

CONCLUSIONS

1. Preplant soil nitrate-N content had the strongest relationship with winter wheat N response compared with other soil sampling times and diagnostic testing methods.
2. Over-application of N fertilizer has the same effect as under-application of N fertilizer on economic returns as a result of yield reductions caused by increased lodging and decreased test weight with excessive N availability.

3. Use of the PPNT resulted in economic gains as high as $45/acre with an average gain of $15/acre among sites where PPNT values were greater than 50 lb/acre.
4. Soil nitrate-N content at the 1 to 2 ft depth can be used to predict soil nitrate-N content at the 2 to 3 ft depth with minimal sacrifice to the integrity of the PPNT.
5. Proposed N rate recommendations for winter wheat using the PPNT in Wisconsin where the previous crop is not alfalfa are as follows: For PPNT values of 50 lb/acre or less, no adjustment in the base N rate recommendation is made; For PPNT values greater than 50 lb/acre, the base N rate recommendation is reduced according to the adjusted soil test value (which is the measured value minus the background value of 50 lb N/acre). 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 equals 20 lb/acre [60 – (90 – 50].
6. A high to very high probability of a positive economic return using the PPNT occurred when the spring N rate applied to the previous crop was greater than 100 lb/acre.
7. Use of the PPNT for winter wheat should not be used following alfalfa since PPNT values are likely to be low due to minimal N mineralization from alfalfa. Wheat studies evaluating N response following alfalfa are currently being conducted at several Wisconsin locations (Kelling, 1999).

The importance of using PPNT-based N rate recommendations for winter wheat needs to be reiterated. As previously mentioned, excessive N rates applied to winter wheat not only reduce profits due to cost of unneeded fertilizer and pose environmental risks as is the case with corn, but yield reductions due to excessive N availability magnify the economic losses. This risk alone should provide incentives to growers to use the PPNT.

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Table 1. Site characteristics, crop management history, and winter wheat yields from 21 sites at four Wisconsin locations, 1995-1999.

							Winter wheat yield	
Site-yr	Year	Location	Soil name and texture	Soil organic matter	Previous crop	Previous crop N rate and time	At optimum N rate	Range No N – High N
				%		lb N/acre	------------ bu/acre -----------	
1	1996	Arlington	Plano sil	3.8	Corn silage	0	44	31 - 44
2						100 (spring)	44	43 - 43
3						200 (spring)	45	46 - 41
4						300 (spring)	43	46 - 36
5	1997	Chilton	Kewaunee l	1.9	Oats	40 (spring)	86	49 - 86
6		Racine	Varna sil	3.7	Cabbage	140 (spring)	85	60 - 86
7		Lancaster	Fayette sil	2.5	Corn silage	160 (spring)	63	52 - 64
8		Arlington	Plano sil	3.8	Corn silage	0	54	40 - 54
9						100 (spring)	55	38 - 51
10						200 (spring)	51	44 - 43
11						300 (spring)	53	48 - 43
12	1998	Chilton	Kewaunee l	1.9	Winter wheat	80 (fall 1997)	74	36 - 74
13		Racine	Ashkum sicl	2.7	Soybean	0	34	18 - 37
14		Lancaster	Palsgrove sil	2.8	Corn silage	160 (spring)	52	52 - 35
15		Arlington	Plano sil	2.9	Corn silage	0	66	51 - 68
16						100 (spring)	69	58 - 67
17						200 (spring)	69	65 - 69
18						300 (spring)	68	67 - 63
19	1999	Chilton	Kewaunee l	2.4	Winter wheat	60 (fall 1998)	83	72 - 78
20		Racine	Ashkum sicl	5.5	Cabbage	140 (spring)	76	76 - 57
21		Lancaster	Fayette sil	2.5	Corn silage	160 (spring)	47	47 - 28

Table 2. Relationship between several N diagnostic tests and relative yield of winter wheat at three sampling times from 21 trials at four Wisconsin locations, 1995-1999.

Sampling time [1/]	Test [2/]	Soil depth	LRP regression equation [3/]	r^2	Critical test level	Relative yield at C.T. L. [4/]
		ft				%
Preplant soil	UV200	0-1	$Y = 29 + 109x$ if $x \leq 0.629$	0.49	0.629	98
	UV260	0-1	$Y = 54 + 211x$ if $x \leq 0.217$	0.17	0.217	100
	NO_3-N	0-1	$Y = 66 + 0.56$ if $x \leq 62$	0.43	62	100
	NO_3-N	0-2	$Y = 61 + 0.51x$ if $x \leq 77$	0.53	77	100
	NO_3-N	0-3	$Y = 58 + 0.43x$ if $x \leq 98$	0.59	98	100
GS25 soil	NO_3-N	0-1	$Y = 76 + 0.29x$ if $x \leq 98$	0.07	98	104
	NO_3-N	0-2	$Y = 76 + 0.17x$ if $x \leq 146$	0.11	146	101
	NO_3-N	0-3	$Y = 72 + 0.17x$ if $x \leq 163$	0.16	163	100
GS30 plant	SPAD	-	$Y = -9 + 2.30x$ if $x \leq 45.3$	0.22	45.3	95
	Tissue N	-	$Y = 50 + 11.28x$ if $x \leq 4.50$	0.19	4.50	101
	N uptake	-	$Y = 55 + 0.93x$ if $x \leq 49$	0.42	49	101

x = test value (see footnote #2); y = relative yield (%).

[1/] Preplant (September); GS25 growth stage (April); GS30 growth stage (May).

[2/] Units of measurement for UV200 and UV260 = absorbance at 200 and 260 nm wavelength, respectively; NO_3-N = lb/acre; SPAD = actual meter reading; Tissue N = % concentration; N uptake = lb N/acre.

[3/] LRP = linear-response plateau.

[4/] C.T.L. = critical test level.

Table 3. Preplant soil nitrate-N content, economic optimum N rate (EONR), base N rate recommendation for wheat, and N rate difference between observed EONR and base N rate recommendation at 21 winter wheat trials at four Wisconsin locations, 1995-1999.

Year	Location	Preplant soil nitrate-N [1/]	EONR [2/]	Base N rate [3/]	EONR – Base N rate
		------------------------------ lb N/acre ----------------------------------			
1996	Arlington	29	73	60	13
	Arlington	66	0	60	-60
	Arlington	175	0	60	-60
	Arlington	279	0	60	-60
1997	Chilton	39	120	80 *	40
	Racine	56	104	60	44
	Lancaster	52	30	60	-30
	Arlington	19	70	60	10
	Arlington	25	64	60	4
	Arlington	63	44	60	-16
	Arlington	86	30	60	-30
1998	Chilton	29	150	80 *	70
	Racine	20	77	60	17
	Lancaster	103	0	60	-60
	Arlington	26	79	60	19
	Arlington	31	64	60	4
	Arlington	36	0	60	-60
	Arlington	98	0	60	-60
1999	Chilton	70	58	60	-2
	Racine	317	0	60	-60
	Lancaster	168	0	60	-60

[1/] 0-3 ft.

[2/] EONR = based on $0.25/lb N fertilizer and $3.18/bu winter wheat.

[3/] Base N rate recommendation = 80 lb N/a where soil organic matter <2%* and 60 lb N/a where soil organic matter 2-9.9% (see Kelling et al., 1998, UWEX pub. A2809).

Table 4. Nitrogen rate recommendations for winter wheat using the preplant soil nitrate test (PPNT) in Wisconsin where the previous crop is not alfalfa.

Preplant soil nitrate-N (0-3 ft)	PPNT-based N rate recommendation
------------- lb/acre -------------	
0 – 50	Base N rate
> 50	Base N rate – (preplant soil nitrate-N – 50)

Table 5. Effect of spring N application rate and summer precipitation (May through August) on preplant soil nitrate-N (0-3 ft) and on the probability of a positive economic return using PPNT-based N rate recommendations for fall planted winter wheat based on 21 trials at four Wisconsin locations, 1995-1999.

Spring N rate	Average preplant soil NO_3-N	Summer precipitation [1]	Average preplant soil NO_3-N	Probability of economic return[2]
lb/acre	lb/acre		lb/acre	
<100	33	$\leq$ Average	43	Low
		Above average	26	Very low
>100	111	$\leq$ Average	133	Very high
		Above average	82	High

[1] Based on 30-year precipitation average.

[2] See Table 4 for PPNT-based N rate recommendations.

Table 6. Relationships between preplant soil nitrate-N content at several depth increments and preplant soil nitrate-N content in the third-foot from 21 winter wheat trials at four Wisconsin locations, 1995-1998.

Soil depth, ft	Equation	r^2
0 – 1	$y = 9.5 + 0.13x$	0.45
1 – 2	$y = 5.8 + 0.51x$	0.74
0 - 2	$y = 8.3 + 0.11x$	0.54

x = soil NO_3-N content in the 0 – 1, 1 – 2, or 0 – 2 ft depth (lb/acre).
y = soil NO_3-N content in the 2-3 ft depth (lb/acre).