SOIL NITRATE TEST PERFORMANCE ON MEDIUM- AND HIGH-YIELD POTENTIAL SOILS

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ABSTRACT

Improved N recommendation methods for corn (Zea mays L.) are essential for increased profitability and reduction of potential N losses to the environment. A 4-yr study (49 site-yr) was conducted to evaluate the performance of preplant (PPNT) and pre-sidedress soil nitrate tests (PSNT) for predicting optimum N rates for corn at sites with inorganic and organic N inputs. Soil samples were obtained before planting (PPNT) and when corn was 6 to 12 inches tall (PSNT), and analyzed for nitrate-N. Corn yield response to applied N was measured at all sites. The relationship between relative yield and PPNT or PSNT test values was usually improved by separating sites into medium (MYPS) and high (HYPS) soil yield potential categories. The PPNT and PSNT identified N sufficient sites more accurately on HYPS than on MYPS. Use of either test to predict N application rates for corn resulted in more of the sites receiving correct N application rates and fewer sites receiving excessive rates of applied N; however, use of the tests increased the probability for under-application of N especially on inorganic sites. The most reliable prediction of optimum N rates was with the PPNT for inorganic HYPS and with the PSNT for organic HYPS. Separating nitrate test calibration data by soil yield potential may improve the utility of the PPNT and PSNT for making corn N recommendations at nitrate test values in the N responsive range.

INTRODUCTION

Economic and environmental concerns have led to increased research on several N availability indices to predict N requirements of corn on a site-specific basis. Of these indices, soil nitrate tests currently appear to have the greatest practical value for assessing N availability (Bundy and Meisinger, 1994). Preplant soil profile nitrate tests are widely used in semi-arid regions of the USA. The PPNT has recently been incorporated into N recommendations in humid states such as Wisconsin, Michigan, and Minnesota (Bock and Kelley, 1992; Bundy et al., 1992). The lower annual precipitation of the Upper Midwest compared to other humid regions of the USA and the fact that soils are usually frozen for 3 to 4 months during the overwinter period, promote accumulation and overwinter retention of residual nitrate.

The PSNT is available to producers in several Eastern states and Iowa (Magdoff et al., 1984; 1990; Blackmer et al., 1989; Fox et al., 1989; Binford et al., 1992; Meisinger et al., 1992; Klausner et al., 1993). This test has the potential to reflect N availability from recent organic N additions such as legumes or manure since samples are taken 60 to 90 d after PPNT sampling.

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The objectives of this research were to: (i) compare the PPNT and PSNT for predicting N requirements for corn following corn without recent organic N additions; and (ii) compare standard N credit recommendations, the PSNT, and the PPNT used in combination with standard N credits, for predicting N requirements for corn in organic systems such as second-year corn following alfalfa or where manure was recently applied. Preliminary analysis of the results indicated that relationships between N test values and relative yield or optimum corn N rates were affected by soil yield potential. Therefore, the influence of soil yield potential on performance of the N tests was evaluated.

MATERIALS AND METHODS

Field experiments were established at several Wisconsin locations during 1989 through 1992 to evaluate soil tests for predicting N needs of corn in several crop management systems. Forty-nine site-year locations were selected to include the major soil regions used for corn production in the state. Sites included both medium (MYPS) and high yield potential soils (HYPS) according to Wisconsin soil test recommendations (Kelling et al., 1991). Separation of MYPS and HYPS is based on one or more of the following: (i) shallow root zone in MYPS compared to HYPS due to depth to bedrock or coarse-textured subsoil, or poor drainage/high water table; (ii) low water-holding capacity due to coarse soil texture in MYPS compared to HYPS; and (iii) shorter growing season in MYPS compared to HYPS. These characteristics associated with MYPS decrease the potential for soil nitrate retention compared to HYPS due to greater risk of losses through leaching or denitrification. Crop management histories were continuous corn (at least three consecutive years) without a recent manure application (CC<u>C</u>), continuous corn with manure applied in the study year (CCm<u>C</u>), second-year corn following alfalfa with manure applied in the study year (ACm<u>C</u>), and second-year corn following alfalfa without recent manure applications (AC<u>C</u>). Location, soil textural class, relative yield potential, and growing season precipitation relative to normal for four crop management histories are shown in Table 1.

Corn yield response to applied N was measured at all sites. Nitrogen rates were 0, 50, 100, 150, and 200 lb N/acre in 1989 and 1990. In 1991 and 1992, N rates were 0, 30, 60, and 90 lb N/acre where manure was applied and 0, 30, 60, 90, 120, 150, and 180 lb N/acre in the other systems. Soil samples for nitrate analysis were obtained from the control (no N) plots in 1-ft increments from 0 to 3 ft before planting (PPNT) and when corn was 6 to 12 inches tall (PSNT).

Optimum N rate and yield were determined by regression analysis or mean separation techniques. Regression analysis consisted of fitting linear-response plateau (LRP) and quadratic-response plateau (QRP) models using PROC NLIN, and quadratic regression models using PROC REG (SAS Institute, 1985). Mean separation analysis (LSD 0.10) was done using PROC ANOVA.

Optimum N rates for LRP, QRP, and quadratic models reflect a fertilizer/corn price ratio calculated from prices of $0.15/lb of fertilizer N and $2.50/bu of corn. Due to the variability of economic optimum N rates determined by the various models, a standardized method was used to determine the economic optimum N rate for each site-year. Where the effect of N rate

Table 1. Early-season rainfall data and description of research sites used in evaluating the preplant soil nitrate test (PPNT) and pre-sidedress soil nitrate test (PSNT) for corn in Wisconsin, 1989 through 1992.

Year	Relative yield potential	Location	Soil textural class	Crop management history	April through June	
					Total rainfall	Departure from normal†
					------------- inch	--------------
1989	MYPS	Clark	sl	ACC, ACmC	9.55	-1.68
		Grant	sil	CCC, CCmC	7.06	-4.21
		Monroe	sl	CCC, CCmC	11.32	0.77
		Wood	sil	ACC, ACmC	9.64	-1.82
	HYPS	Columbia	sil	CCC, CCmC	5.13	-5.25
		Dane	sil	CCC, CCmC	5.03	-5.35
1990	MYPS	Clark	sl	ACC, ACmC	11.77	0.54
		Grant	sil	CCC, CCmC	13.98	2.71
		Monroe	sl	CCC, CCmC	17.47	6.92
		Sheboygan	sil	CCC, CCmC	13.81	3.60
		Wood	sil	ACC, ACmC	12.80	1.34
	HYPS	Columbia	sil	CCC, CCmC	13.06	2.68
		Dane	sil	CCC, CCmC	14.96	4.58
1991	MYPS	Clark	sl	CCC, CCmC	8.44	-2.79
		Grant	sil	CCC, CCmC	16.12	4.85
		Sheboygan	sil	CCC, CCmC	16.36	6.15
	HYPS	Columbia	sil	CCC, CCmC	9.06	-1.32
		Dane	sil	CCC, CCmC	12.55	2.17
1992	MYPS	Grant	sil	CCC, CCmC, ACC	5.49	-5.78
	HYPS	Columbia	sil	CCC, CCmC, ACC	6.19	-4.19
		Dodge	sil	CCC, CCmC(2), ACC	6.50	-3.64
		Sheboygan	sicl	CCC, CCmC, ACC	6.06	-4.15

† Deviations from long-term mean rainfall.

was significant ($P < 0.10$), the economic optimum N rate was identified using the model (LRP, QRP, or quadratic) with the highest R^2 value if that value was ≥ 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. If N rate was not significant ($P > 0.10$), the optimum N rate equals zero. Relative yield for each site-year was determined by dividing the control treatment (0 lb N/acre) yield by the economic optimum yield.

Critical PPNT and PSNT soil nitrate-N levels were determined using the LRP method. To evaluate the PPNT and PSNT for predicting optimum N rates at any given soil nitrate-N test level, equations using the LRP method were derived from the relationship between the PPNT or PSNT and observed optimum N rates.

RESULTS AND DISCUSSION

Identifying N Sufficient Sites

Since the PPNT measures carryover soil nitrate, and not potential N contributions from organic sources, only data from inorganic (CC<u>C</u>) sites were used to predict critical PPNT levels (Fig. 1a). The PPNT contents at inorganic sites show that substantial nitrate carryover from the previous year occurs in some years at some locations. The critical preplant soil nitrate-N level for all sites was 105 lb/acre at the 0- to 3-ft depths. Categorizing sites into predetermined relative yield potential categories (MYPS and HYPS) increased R^2 values significantly. This separation particularly improved the relationship between relative yield and PPNT values for HYPS. Critical PPNT levels at the 0- to 3-ft depth for this study were 61 lb nitrate-N/acre for MYPS ($R^2 = 0.79$) and 135 lb nitrate-N/acre for HYPS ($R^2 = 0.91$). A critical PPNT level of 134 lb nitrate-N/acre in the top 3 ft was determined in a previous study on three HYPS in Wisconsin (Bundy and Malone, 1988). A recent study by Ehrhardt and Bundy (1994), based on 1 249 soil samples, showed that good test performance was obtained using a 2-ft sampling depth and estimation of third-foot nitrate-N with a predictive model.

Since the potential advantage of the PSNT is its ability to predict N availability from organic sources, the relationship between PSNT and relative yield for all crop management histories (CC<u>C</u>, CCm<u>C</u>, AC<u>C</u>, and ACm<u>C</u>) is shown in Fig. 1b. As for the PPNT, the relationship between yield and PSNT values was improved by separating MYPS and HYPS. Critical PSNT levels were similar for both MYPS (19 ppm nitrate-N) and HYPS (21 ppm nitrate-N); however, PSNT concentrations explained only 30% of the variability in relative yield for MYPS compared with 68% for HYPS.

A comparison of the PPNT and PSNT for identifying N responsive and nonresponsive sites using categories established by Schmitt and Randall (1992) is shown in Table 2. For inorganic sites, neither soil test consistently identified N sufficient sites for MYPS. Using the PPNT on inorganic MYPS shifted errors from the nonresponsive-predicted responsive to the responsive-predicted nonresponsive category compared to the standard recommendation. For

Table 2. Effectiveness of the PPNT and PSNT in identifying N sufficient sites compared to standard Wisconsin N recommendations.

Crop management history	Relative yield potential	n	Method†	Accuracy category‡		
				Correct	NR-PR	R-PNR
				% of observations		
Inorganic	MYPS	9	Standard	67	33	0
			PPNT	67	0	33
			PSNT	45	22	33
	HYPS	9	Standard	56	44	0
			PPNT	89	11	0
			PSNT	100	0	0
Organic	MYPS	18	Standard	83	17	0
			PPNT-BVNC	78	5	17
			PSNT	78	17	5
	HYPS	13	Standard	46	54	0
			PPNT-BVNC	62	23	15
			PSNT	69	16	15

† Standard (inorganic) = standard Wisconsin N recommendation for corn is 120 lb N/acre for MYPS and 160 lb N/acre for HYPS. Standard-BVNC (organic) = standard N recommendation minus standard book value N credits for manure (4 lb N/T) and second-year alfalfa (50 lb N/acre). PPNT (inorganic) = predicted optimum N rate based on PPNT (0-3 ft) equation for MYPS and HYPS (see Fig. 1). PPNT-BVNC (organic) = same as PPNT inorganic minus standard book value N credits for manure and second-year alfalfa. PSNT (inorganic and organic) = predicted optimum N rate based on PSNT (0-1 ft) equation for MYPS and HYPS (see Fig. 2).

‡ NR-PR = nonresponsive-predicted responsive; R-PNR = responsive-predicted nonresponsive; Correct = responsive-predicted responsive or nonresponsive-predicted nonresponsive.

inorganic MYPS, the PSNT identified fewer N sufficient sites correctly than the standard N recommendation. Both tests identified N sufficient sites accurately for HYPS.

For organic sites, comparisons included the standard Wisconsin N recommendation method minus book value N credits for manure and second-year alfalfa (STD-BVNC), PPNT minus book value N credits (PPNT-BVNC), and the PSNT. For organic MYPS, the PPNT-BVNC and PSNT identified 78% of the N sufficient sites correctly compared with 83% for the STD-BVNC method. For organic HYPS, use of the PPNT-BVNC and PSNT correctly identified 62 and 69% of the N- sufficient sites, respectively, compared with 46% using the STD-BVNC method. These results suggest that the use of the PPNT-BVNC or PSNT for organic sites is an advantage over standard N recommendations for HYPS but not MYPS. Although use of the PPNT-BVNC and PSNT resulted in fewer nonresponsive sites receiving N applications, 2 of 13 sites identified as nonresponsive did respond to applied N on HYPS.

Predicting N Application Rates

To evaluate the PPNT and PSNT for predicting the optimum N rate at any given soil nitrate test level, the relationship between soil nitrate-N contents and observed optimum N rates for MYPS and HYPS were determined (Fig. 2 and 3). These response functions were used to calculate N recommendations at soil nitrate-N levels below the critical values for the PPNT and PSNT. Critical PPNT levels (0 to 3 ft) for MYPS (68 lb nitrate-N/acre) and HYPS (144 lb nitrate-N/acre) based on the LRP model (Fig. 2) were similar to those determined by using relative yield (Fig. 1a). Similarly, critical PSNT levels (0 to 1 ft) for MYPS (20 ppm nitrate-N) and HYPS (22 ppm nitrate-N) determined by the LRP model (Fig. 3) were also similar to those determined using relative yield (Fig. 1b).

Underlined values in Fig. 2 and 3 were not included in regression analyses because PPNT or PSNT values for these observations were greater than the critical values for these tests (Fig. 1), and yields were increased by applied N. However, these values are included in the evaluations of PPNT and PSNT test performance in Fig. 4. Separating data into MYPS and HYPS categories substantially improved the predictive value of the relationships illustrated in Fig. 2 and 3, especially for the HYPS sites. When data were combined over yield potential categories (underlined observations excluded), R^2 values for the PPNT and PSNT were 0.43 and 0.35, respectively. Use of soil nitrate tests for inorganic MYPS, reduced the frequency of excessive N application by 56% (PPNT) and 45% (PSNT) compared to standard N recommendations (Fig. 4a). Both tests underestimated observed optimum N rates at 33% of the sites compared to 0% using standard N recommendations. For organic MYPS, N recommendations based on the PPNT-BVNC and PSNT resulted in fewer excessive N applications, while only slightly increasing the chances for under-application of N. Therefore, use of either test to predict N application rates for inorganic or organic MYPS resulted in a greater percentage of sites receiving correct N application rates and fewer sites receiving excessive rates of applied N; however, use of the nitrate tests increased the probability for under-application of N especially on inorganic sites.

For inorganic HYPS, use of soil nitrate tests resulted in 89% (PPNT) and 67% (PSNT) of the sites receiving correct N application rates, compared to only 22% with standard N recommendations. These tests also reduced excessive N applications by 67% (PPNT) and 56% (PSNT). For organic HYPS, use of soil tests resulted in 30% (PPNT-BVNC) and 54% (PSNT) more of the sites receiving correct N application rates, and these tests reduced the frequency of excessive N application rates by 39 and 54%, respectively. A small increase in under-application of N occurred with the use of the PPNT-BVNC. These results show that, while both soil tests improved the prediction of optimum N rates for both inorganic and organic HYPS compared to standard methods, the most reliable predictions of optimum N rates were with the PPNT for inorganic HYPS and with the PSNT for organic HYPS. Changing the criteria for correct prediction of optimum N rates from ±30 lb N/acre to ±20 lb N/acre altered the percent values in some categories, but had little if any effect on the relative performance of the standard recommendation and the soil nitrate tests. For example, with inorganic HYPS, optimum N rates were correctly predicted for 22, 67, and 67% of the observations with the standard, PPNT, and PSNT methods, respectively, when a ±20 lb N/acre range was used to define correct prediction.

Several studies (Fox et al., 1989; Bock and Kelley, 1992; Meisinger et al., 1992; Klausner et al., 1993) indicate that the PSNT is useful for identifying N sufficient sites but does not have good predictive value for making N recommendations in the responsive range. In our work, separating soils according to yield potential often improved the predictive value of the PSNT and PPNT in the N responsive range. Corn N recommendations based on PSNT results are shown in Table 3. This approach may also be useful elsewhere for improving the utility of soil nitrate tests where data from soils with varying yield potentials are included in the test calibration database.

Table 3. Corn N recommendations based on the pre-sidedress soil nitrate test (PSNT)†.

PSNT result	Soil yield potential: Very high/High	Soil yield potential: Medium/Low
ppm N (0-1 ft)	--------- amount to apply, lb N/acre	--------
≤ 10	160	120
11-12	150	80
13-14	125	80
15-17	100	40
18-20	60	40
≥ 20	0	0

† The PSNT should only be used on medium or finer textured soils. If PSNT result is < 21 ppm for first-year corn following alfalfa, N recommendation is 40 lb N/acre.

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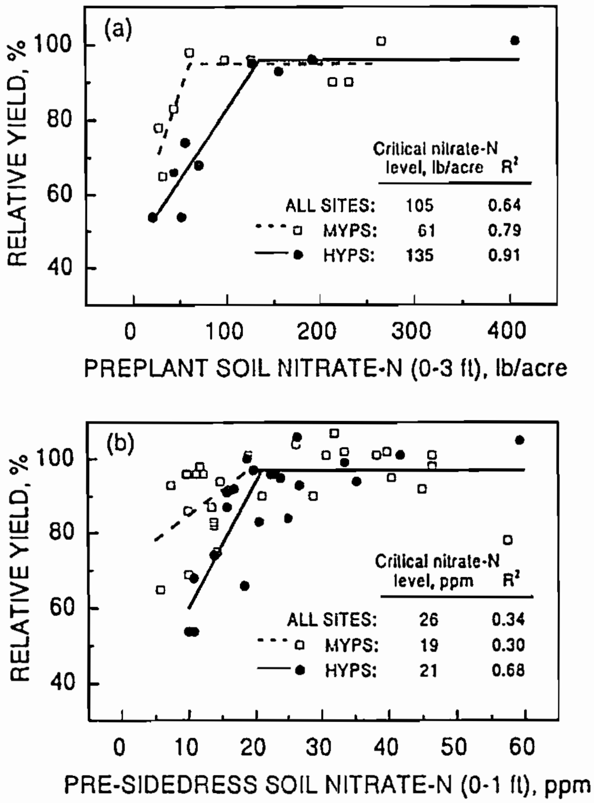

Figure 1. Relationship between preplant (a) or pre-sidedress (b) soil nitrate tests and relative corn yield in Wisconsin, 1989 through 1992.

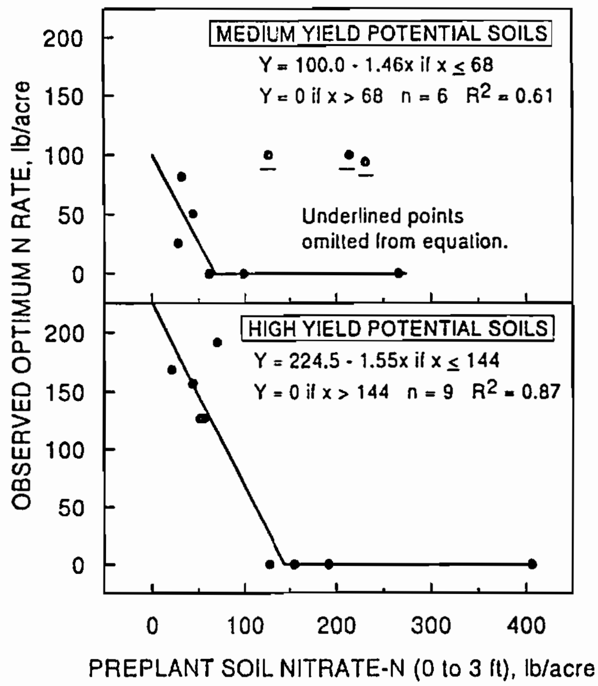

Figure 2. Relationship between observed optimum N rate for corn and PPNT (0 to 3 ft) at inorganic sites (CC<u>C</u>) for MYPS and HYPS in Wisconsin, 1989 through 1992.

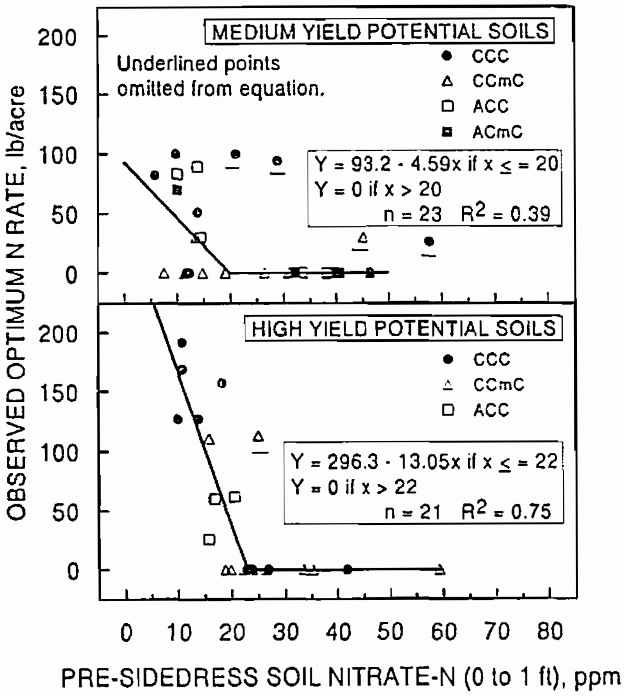

Figure 3. Relationship between observed optimum N rate for corn and PSNT (0 to 1 ft) at inorganic and organic sites (CCC, CCmC, ACC, and ACmC) for MYPS and HYPS in Wisconsin, 1989 through 1992.

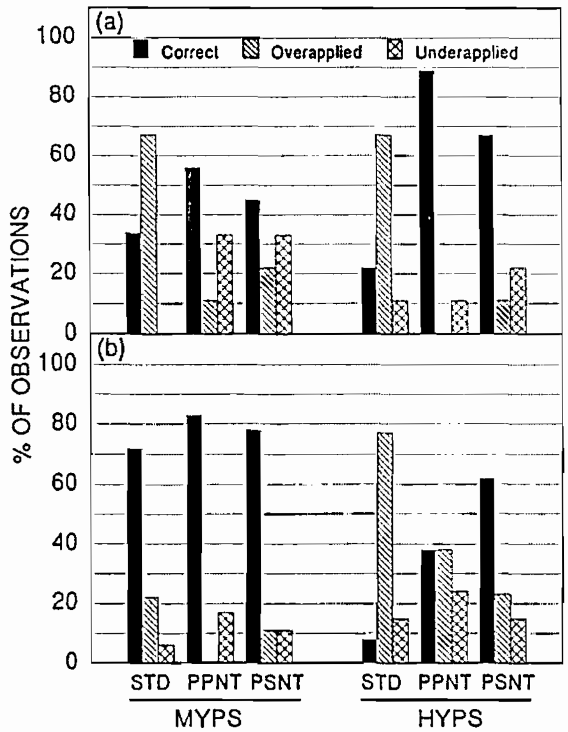

Figure 4. Comparison of soil nitrate tests and standard Wisconsin N recommendations for predicting optimum N rates for corn at sites with inorganic (a) and organic (b) N inputs. STD, standard N recommendation; PPNT, preplant soil nitrate test; PSNT, pre-sidedress soil nitrate test; MYPS, medium yield potential soil; HYPS, high yield potential soil.

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