Site-Specific Prediction of Soybean Nitrogen Contributions [1/]

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Introduction

Soybean has long been recognized for its nitrogen (N) contributions and yield enhancing effects in crop sequences. Soybean N credits in the Midwest range from 20 to 40 lb of N/acre (Kurtz et al., 1984). Several Midwestern states recommend a legume credit of 40 lb of N/acre following an average crop of soybean. Current Wisconsin recommendations suggest a reduction in nitrogen fertilizer rates for corn following soybean of 1 lb N /bushel of soybean yield up to a maximum credit of 40 lb N/acre (Kelling et al., 1991). Data from long-term crop rotation experiments in Iowa (Voss and Shrader, 1984) and Wisconsin (Baldock et al., 1981) are frequently cited to support this soybean N credit. Recent work, however, indicates that the current N credits claimed when a cereal crop such as corn follows soybean in rotation may not adequately reflect the soybean N contribution (Bundy et al., 1993; Meese, 1993; Green and Blackmer, 1995; Stecker et al., 1995). On some soils in Wisconsin, current recommended soybean N credits likely underestimate the apparent N contribution by as much as 120 lb N/acre (Bundy et al., 1993). This represents a production expense of at least $30/acre that could be avoided if the soybean N contributions were more accurately determined. As soybean acreage increases in Wisconsin and other Midwestern states and environmental incentives to avoid excess N fertilizer applications to protect surface and groundwaters continue, the need for site-specific diagnostic techniques to estimate soybean N contributions becomes even more important. In addition, increased interest in use of immature soybean or soybean residue as forage or bedding could affect N credits for subsequent crops.

There have been many attempts to develop accurate N availability indices that can measure or predict a soil's nitrogen supplying capacity under a specific set of conditions. Recently, soil nitrate tests have shown promise for predicting N availability. Soil nitrate tests with the potential for improving soybean N crediting include the preplant test for residual soil nitrate (PPNT) (Bundy et al., 1992) and the pre-sidedress soil nitrate-N test (PSNT) (Magoff et al., 1984, Magdoff, 1991). The UV absorbance of $NaHCO_3$ soil extracts at 200 and 260 nm (Fox and Piekielek, 1978; Hong et al., 1990), and the steam distillation of soil with pH 11.2 phosphate-borate buffer (Gianello and Bremner, 1988) are two chemical N availability tests that have potential for predicting crop N response and improving estimates of soybean N contributions.

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A research study is currently under way to investigate the potential for using soil nitrate tests or other N availability tests to predict soybean N contributions in soybean-corn crop sequences, as well as determine the effects of soybean forage harvest or soybean residue management on yields and N needs of a subsequent corn crop.

Objectives

1.) Determine corn response to applied N where soybean was the previous crop at four sites on soils widely used for corn and soybean production.

2.) Determine the effects of soybean harvest/residue management on apparent soybean N contributions in soybean-corn sequences.

3.) Evaluate soil nitrate tests and other N availability tests for their ability to estimate soybean N contributions at each site.

Materials and Methods

Field experiments were conducted in 1994 and 1995 at four locations where corn followed soybean on medium to fine textured soils typical of those used for soybean production in Wisconsin. The experimental design used at three locations was a randomized complete block with a split-plot treatment arrangement and four replications. The main plot treatments were soybean residue/harvest management variables: 1) grain harvested with residue returned; 2) grain harvested with residue removed; and 3) forage harvested at the R6 growth stage with all the top growth removed. Residue removal after grain harvest was accomplished by hand raking and removing as much of the residue as possible from the treatment area. For the "residue returned" treatment, residue was redistributed to achieve uniform coverage. Forage harvest was simulated by mowing soybean plants just above the soil surface and removing the top growth. The sub-plot treatments were five N fertilizer rates (0, 40, 80, 120, 160 lb N/acre) applied spring preplant in each residue/harvest management treatment as surface broadcast ammonium nitrate. Treatments at the fourth location were the same as those indicated above except for the addition of a tillage variable (no-till or chisel plow) in 1995. The N fertilizer treatments were incorporated by secondary tillage before corn planting in the chisel plow treatment at the fourth location and left surface applied at the remaining sites. Corn was planted at a rate of 30,000 seeds/acre in late April to early May using no-till or chisel plow tillage. Sub-plot dimensions were 10 ft (4 rows) wide and 30 ft long. After emergence corn plants were hand-thinned to a uniform density of 24,000 to 26,000 plants/acre.

After the soybean residue/harvest management variables were imposed in the field experiments, soil samples from the 0 lb N/acre treatments in each harvest management system (HMS) and from each replicate were obtained in the spring before N fertilizer application and corn planting. These soil samples consisted of three cores per plot and were taken in 1-ft increments to a 3-ft depth. After corn planting, soil samples (0-1 ft depth) were obtained from the N treatment check plots (0 lb N/acre) in each HMS and from each replicate at corn emergence and when corn plants were about 12 inches tall. Post-season soil samples were taken at two locations in 1994 and at all four locations following corn grain harvest in 1995. These soil samples were taken in 1-ft increments to a 3-ft depth from the 0 and 160 lb/acre treatments where soybean residue was returned, and were used to determine N rate effects on residual nitrate-N accumulation at the end of the growing season.

Nitrate-N and exchangeable ammonium-N concentrations were determined by automated analysis of 2 M KCl extracts (Bundy and Meisinger, 1994). The amounts of nitrate-N and exchangeable NH_4-N in the 1-ft profile depth increments were calculated using the assumption that 1 acre (1-ft of soil) weighs 2.0 x 10^6 lb. Soil hydrolyzable N in the top 1 ft was determined using the phosphate-borate buffer distillation method of Gianello and Bremner (1988). UV absorbance of $NaHCO_3$ soil extracts (Fox and Piekielek, 1978) was measured at 200 nm and 260 nm using a Perkin Elmer UV-Vis spectrophotometer.

Corn grain yields were determined by mechanically harvesting the two center rows from each plot (60 ft row). Grain subsamples were retained for subsequent moisture determination. All grain yields are reported at 15.5% moisture.

Data were subjected to an analysis of variance appropriate for the experimental design. Treatment effects and interactions were considered significant if probability values were 0.05 or less. Significant differences among residue/harvest management treatment means were evaluated using a protected least significant difference (LSD) test at the 0.05 level (SAS Institute, 1988).

Corn yield response to N rates and economic optimum N rates for each location were determined by regression analysis or mean separation techniques (LSD). 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, 1988). Economic optimum N rates (EONR) for LRP, QRP, and quadratic models reflect a fertilizer/corn price ratio calculated from prices of \$0.25/lb of fertilizer N and \$4.00/bu of corn. Because of the variability of EONR determined by the various models, a standardized method was used to determine the economic optimum N rate for each site-year (Bundy and Andraski, 1995). Where the effect of N rate was significant ($P < 0.05$), the EONR was identified using the model (LRP, QRP, or quadratic) with the highest R^2 value if that value was ≥ 0.25. If models had the same R^2 value, the model with the lowest standard error (S.E.) was selected. If the R^2 value was < 0.25, mean separation analysis (LSD) was used to identify the optimum N rates as the lowest N rate treatment in the highest t-group for yield. If the N rate treatment effect was not significant ($P < 0.05$), the economic optimum N rate equals zero.

Results and Discussion

Corn Grain Yield Response to N

Corn grain yield was significantly increased by applied N each year at all locations except at Platteville in 1994 and Lancaster in 1995 (Tables 1 and 2). The Platteville site received manure additions in 1992, which resulted in high N mineralization and subsequent high soil nitrate-N values that prevented yield response to added N in 1994. There were no significant effects of HMS on corn yields at all locations and years (Tables 1 and 2). There was however, a significant N x HMS interaction at Lancaster in 1995. At this site, the forage and residue removed HMS treatments did not respond to N rate, but, the residue returned treatment showed a yield response to applied N. The effects of HMS and N fertilizer rates on corn grain yields in 1994 and 1995 are shown in Tables 3 and 4. Since HMS did not influence corn grain yields, the data presented are means of the three HMS.

In 1994, the economic optimum N rate (EONR) ranged from 0 to 160 lb N/acre at the four locations (Table 3), while EONR ranged from 0 to 120 lb N/acre in the 1995 experiments (Table 4). These results confirm earlier work (Bundy et al., 1993; Meese, 1993; Green and Blackmer, 1995; Stecker et al., 1995) showing substantial variation across sites and years in the apparent soybean N contribution to a following corn crop.

Post season soil nitrate-N in the top 3 ft after corn harvest at 0 lb N/acre and 160 lb N/acre treatments (Fig. 1) confirmed the observed variation in EONR and showed very large residual nitrate values at the 160 lb N/acre rate especially when EONR was low.

Table 1. Analysis of variance summary of N rate and soybean harvest management system (HMS) effects on corn grain yields at four locations, 1994.

	Location			
Effect	Arlington	Lancaster	Platteville	Belmont
	Pr > F			
N-Rate	0.0007	0.0001	0.8823	0.0010
HMS	0.3174	0.4267	0.7904	0.2726
HMS x N-rate	0.5422	0.9707	0.5587	0.6889
CV%	5.74	11.13	7.57	9.93

Table 2. Analysis of variance summary of N rate and soybean harvest management system (HMS) effects on corn grain yields at four locations, 1995.

Effect	Location			
	Arlington	Lancaster	Platteville	Belmont
	--------Pr > F--------			
N-Rate	0.0264	0.0954	0.0324	0.0075
HMS	0.2643	0.1241	0.1203	0.0604
Tillage (T)	0.1917			
HMS x N-rate	0.8072	0.0030	0.0568	0.9676
T x N-rate	0.4281			
T x HMS	0.5237			
T x HMS x N-rate	0.5195			
CV%	4.41	7.47	7.63	4.63

Table 3. Corn grain yield response to N rate and economic optimum N rate (EONR) at four Wisconsin locations, 1994.

Location	N fertilizer rate, lb/acre					EONR
	0	40	80	120	160	
	--------grain yield, bu/acre--------					lb N/acre
Arlington	185	202	199	202	205	40
Lancaster	125	164	195	210	223	160
Platteville	200	196	197	203	202	0
Belmont	181	197	219	212	208	80

Previous year (1993) soybean yields were Arlington = 66 bu/acre, Lancaster = 25 bu/acre, Platteville = 38 bu/acre, and Belmont = 65 bu/acre.

Table 4. Corn grain yield response to N rate and economic optimum N rate (EONR) at four Wisconsin locations, 1995.

Location		N fertilizer rate, lb/acre 0	40	80	120	160	EONR
		-------------	grain yield, bu/acre	-------------			lb N/acre
Arlington		170	171	177	173	171	80
Lancaster	HMS[†]=1	143	162	157	171	170	120
Lancaster	HMS=2&3	151	160	150	141	140	0
Platteville		140	154	151	154	153	40
Belmont		162	171	169	175	168	40

Previous year (1994) soybean yields were Arlington = 64 bu/acre, Lancaster = 66 bu/acre, Platteville = 65 bu/acre, and Belmont = 60 bu/acre.
[†] 1 = (grain harvest residue returned) 2 = (grain harvest residue removed) and 3 = (forage harvest at R6 growth stage).

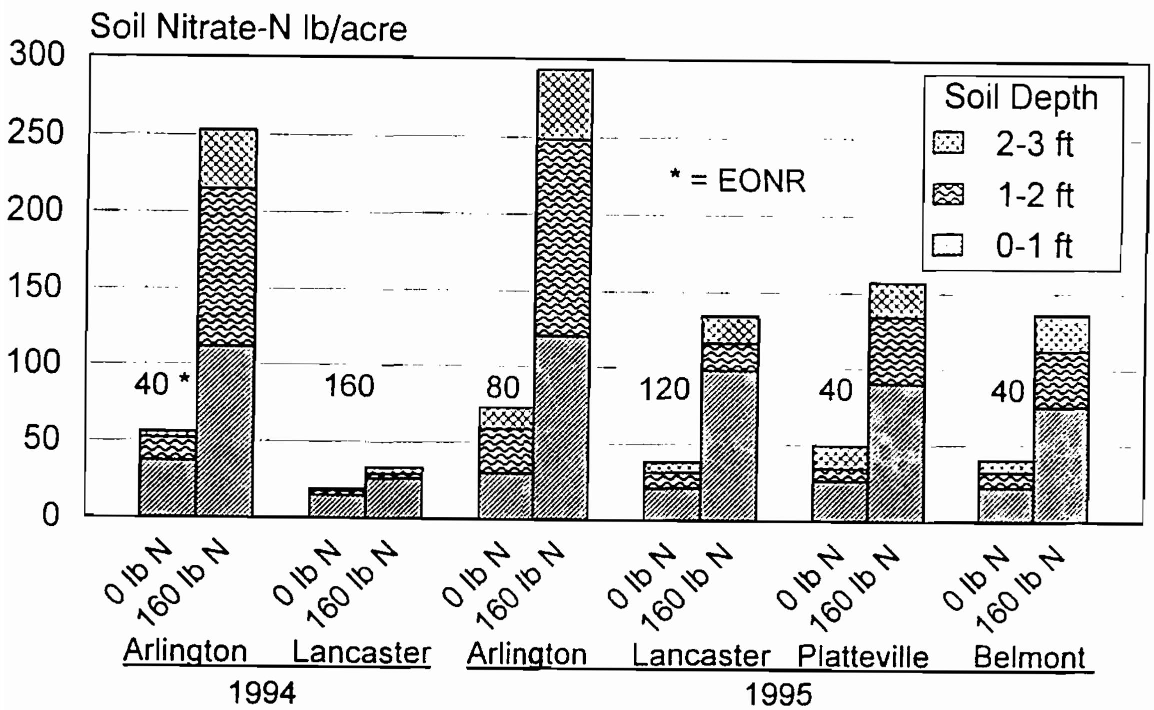

Fig. 1. Comparison of post season soil profile nitrate-N for the soybean residue returned HMS after corn harvest at 0 lb N/acre and 160 lb N/acre treatments, 1994 and 1995.

N Availability Tests to Predict Soybean N Contributions

To better predict N contributions where corn follows soybean, four N availability tests were evaluated for their ability to identify N responsive sites and to predict optimum N rates for corn. The tests were the soil nitrate test, the phosphate-borate buffer distillation test for hydrolyzable N, and the UV absorbance of $NaHCO_3$ soil extracts at 200 and 260 nm. For each test, three sampling times; preplant, emergence, and pre-sidedress were used, and two response models (linear-response plateau and linear) were developed for each test and sampling time. The relationship between test values and relative corn yield are shown in Table 5. The preplant soil nitrate test (0-1ft) and the UV absorbance at 260 nm at all sampling times correlated well with relative yield. The 0-1 ft soil nitrate test at emergence (ENT), and pre-sidedress (PSNT) and the 0-1 ft UV absorbance at 200 nm (PP200, E200 and PS200) showed weaker correlations with relative yield, while the 0-1 ft phosphate-borate buffer test (PPPB, EPB and PSPB) was poorly correlated with relative yield. The 0-3 ft preplant soil nitrate test (PPNT) was also evaluated and found to have an R^2 and critical test value of 0.66 and 94 lb nitrate-N/acre, respectively.

Prediction of Economic Optimum N Rates for Corn Following Soybean

Nitrogen recommendations based on N availability tests require information on the relationship between test results and the economic optimum N rate (EONR) for corn. The linear response plateau (LRP) model, often used to describe these relationships, did not prove satisfactory for most of these data because very few test values were in the nonresponsive range to define the plateau portion of the model, resulting in inappropriate plateau levels and low R^2 values. A linear regression model appeared more appropriate to predict EONR from N test results and was applied only to data from N responsive sites. Data from the nonresponsive sites (EONR=0) was excluded from the linear model. Equations and R^2 values for linear models describing relationships between EONR and the soil nitrate test and the UV absorbance tests at 200 and 260 nm are shown in Table 6. The phosphate-borate buffer test was not included because of its lack of correlation with either relative yield or EONR. The preplant (PP260) and emergence (E260) UV absorbance at 260 nm correlated well with EONR, as did the preplant (PP200) UV absorbance at 200 nm. The pre-sidedress UV absorbance at 260 nm (PS260) and 0-1 ft preplant soil nitrate test (PPNT) had marginal correlation with EONR. The 0-1 ft pre-sidedress nitrate test (PSNT), which has been well correlated with EONR for corn following corn (Magdoff et al., 1984; Bundy and Andraski, 1995) did not correlate well with EONR for corn following soybean.

Table 5. Linear-response plateau equations and R^2 values for the relationship between soil test results at preplant (PP), emergence (E) and pre-sidedress (PS) sampling times and relative yield of corn following soybean , 1994 and 1995.

Soil Test	Soil Depth (ft)	n	Equation	Critical Level	Plateau Yield (%)	S.E.	R^2
PPNT	0-1	9	Y = -84.0 + 28.10x	6†	94	4.8	0.89
ENT	0-1	9	Y = 69.5 + 1.35x	18†	94	13.2	0.17
PSNT	0-1	9	Y = 66.6 + 1.13x	30†	100	12.4	0.27
PPPB	0-1	9	Y = 101.8 - 0.43x	34‡	87	15.1	0.06
EPB	0-1	9	Y = 110.1 - 0.64x	39‡	85	14.8	0.10
PSPB	0-1	9	Y = 83.5 + 0.46x	12‡	89	13.5	0.01
PP200	0-1	9	Y = 64.2 + 30.18x	1.19¶	100	12.6	0.34
E200	0-1	9	Y = 45.8 + 48.82x	0.98¶	94	12.3	0.28
PS200	0-1	9	Y = 44.8 + 35.06x	1.57¶	100	11.1	0.41
PP260	0-1	9	Y = -45.1 + 915.09x	0.152¶	94	5.2	0.89
E260	0-1	9	Y = -56.0 + 1000.00x	0.150¶	94	4.8	0.89
PS260	0-1	9	Y = -33.9 + 718.03x	0.178¶	94	5.5	0.88
PPNT	0-3	9	Y = 44.1 + 0.56x	94§	97	9.1	0.66

†ppm nitrate-N.
‡ppm hydrolyzable N; calculated difference between phosphate-borate buffer extractable and exchangeable ammonium-N content.
§lb N/acre.
¶UV absorbance values.

Table 6. Linear equations and R^2 values for the the relationship between soil test results at preplant (PP), emergence (E) and pre-sidedress (PS) sampling times and economic optimum N-rate of corn following soybean, 1994 and 1995.

Soil Test	Soil Depth (ft)	n	Equation	Critical Level	S.E.	R^2
PPNT	0-1	7	Y = 173.4 - 11.47x	15†	40.5	0.36
ENT	0-1	7	Y = 99.8 - 1.41x	71†	49.9	0.03
PSNT	0-1	7	Y = 133.7 - 3.01x	44†	47.4	0.12
PP200	0-1	7	Y = 199.0 - 149.12x	1.33¶	32.1	0.60
E200	0-1	7	Y = 160.5 - 80.4x	1.99¶	43.5	0.26
PS200	0-1	7	Y = 189.3 - 89.21x	2.12¶	44.6	0.22
PP260	0-1	7	Y = 201.3 - 558.66x	0.360¶	24.7	0.76
E260	0-1	7	Y = 190.5 - 511.67x	0.372¶	27.8	0.70
PS260	0-1	7	Y = 181.2 - 460.98x	0.393¶	38.1	0.43
PPNT	0-3	7	Y = 167.27 - 1.12x	149‡	41.7	0.32

†ppm nitrate-N.
‡lb N/acre.
¶UV absorbance values.

Evaluation of N Recommendation Methods

An acceptable N recommendation method should correctly predict N requirements most of the time with very few under estimations of N requirements. In view of these requirements, three proposed N recommendation approaches based on diagnostic tests evaluated in this work were compared with previously established N recommendations for corn following soybean. The three proposed methods were N recommendations based on the preplant UV absorbance at 260 nm (PP260), the emergence UV absorbance at 260 nm (E260), and the preplant UV absorbance at 200 nm (PP200). The comparison of N rate recommendations based on these tests and derived from previously established N methods with observed EONR in nine field N response studies is shown in Table 7. The standard method specifies 160 lb N/acre for optimum yields of corn without organic inputs from manure or previous legume crops on high yield potential soils (Kelling et al., 1991). The second method includes the standard soybean N credit of 1 lb N/bu of soybean yield up to a maximum of 40 lb N/acre. The maximum credit was appropriate at all sites, except Lancaster and Platteville in 1994, where the previous year soybean yields were less than 40 bu/acre. The remaining previously established N recommendations are based on soil nitrate tests (Bundy

Table 7. Comparison of several previously established N recommendation approaches and proposed N recommendations based on UV absorbance soil tests (PP260 E260 and PP200) with observed economic optimum N rates for corn following soybeans at nine site years, 1994 and 1995.

	Previously established N recommendation†					Proposed N recommendation†			Observed economic optimum
Location	Std	Std-BVNC	PPNT	PPNT-BVNC	PSNT	PP260	E260	PP200	N rate
1994	lb N/acre								
Arlington	160	120	154	114	0	43	33	97	40
Lancaster	160	135	160	135	100	140	133	132	160
Platteville	160	122	65	27	0	54	76	46	0
Belmont	160	120	123	83	0	90	96	94	80
1995									
Arlington	160	120	116	76	0	53	50	88	80
Lancaster-1‡	160	120	131	91	150	121	119	134	120
Lancaster-2&3§	160	120	122	82	0	116	113	125	0
Platteville	160	120	126	86	0	81	84	107	40
Belmont	160	120	104	64	0	32	44	82	40

†Averaged across all harvest management systems (HMS), except Lancaster 1995.
‡1 = (grain harvest residue returned).
§ 2 = (grain harvest residue removed) and 3 = (forage harvest at R6 growth stage).
Book value N credits (BVNC) are 1 lb N/bu of soybean yield up to a maximum of 40 lb.

and Sturgul, 1994). The PPNT-BVNC is a two credit approach, where profile nitrate-N and the soybean N credit are subtracted from the standard recommendation. Recommendations based on the pre-sidedress nitrate test (PSNT) used a previously established critical level of 21 ppm nitrate-N and calibration data relating optimum N rate to PSNT values for corn following corn. (Bundy and Sturgul., 1994).

Figure 2 shows the over or under application of N fertilizer for the established and proposed N recommendation methods averaged across all sites and years. The std-BVNC method had an average over application of 70 lb N/acre and one under application of 25 lb N/acre. The preplant and emergence UV absorbance at 260 nm and the preplant UV absorbance at 200 nm, on the other hand, had an average over application of 38 lb N/acre and an average under application of 22 lb N/acre. The PPNT-BVNC also appears to be an appropriate method for improving N recommendations for corn following soybean with an average over application of 41 lb N/acre and an average under applications of 15 lb N/acre. The standard PSNT did not prove very useful for predicting optimum N rates for corn following soybean due to frequent under applications.

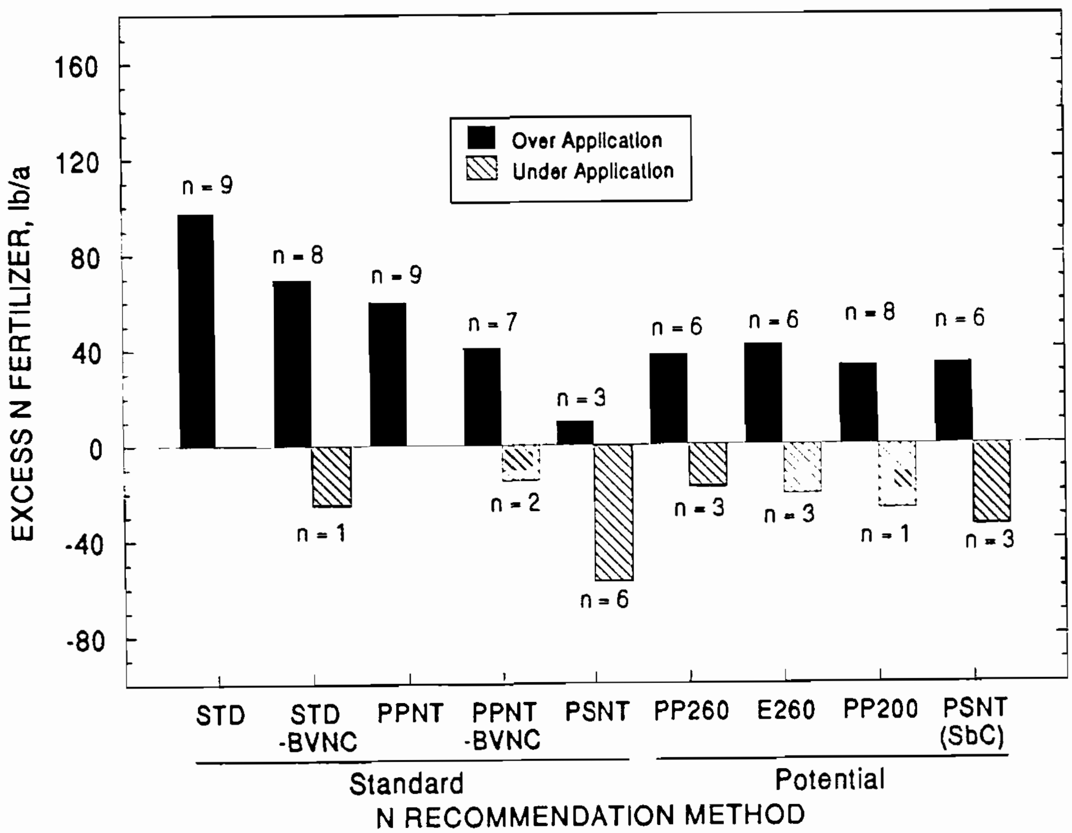

Fig. 2. Excess N applied using standard N recommendation methods and N recommendations based on UV absorbance soil tests relative to observed economic optimum N rates for corn following soybean averaged across years.

Summary

Results from this two year study indicate that soybean forage harvest and residue management have no effect on subsequent corn grain yields. With the exception of one site year (Lancaster 1995) there were no significant HMS x N rate interaction effects on subsequent corn grain yields. Where there was an interaction, the soybean residue returned treatment required a higher application of fertilizer N to maximize yields.

Results from this research project confirmed earlier work that soybean N credits differ markedly among locations and years and that the current fixed value N credits will seldom accurately predict actual soybean N contributions. The evaluation of several soil N availability tests to predict apparent soybean N credits showed that a substantial improvement in predicting soybean N contributions compared to the standard book value credit can be made. The phosphate-borate buffer (PB) N availability test did not prove effective in predicting apparent soybean N credits. The preplant profile soil nitrate test (PPNT) was an improvement over the standard book value N credit; however, it usually overestimated soybean N credits. Using a pre-sidedress nitrate test has potential for predicting optimum N rates for corn following soybean; however, the frequency of under application of fertilizer N makes this method unacceptable. The UV absorbance of $NaHCO_3$ soil extracts at 260 and 200 nm, appear to best predict apparent soybean N credits. These tests more accurately predicted optimum N rates for corn following soybean, and reduced the amount of over application of fertilizer N by an average of 28 to 37 lb N/acre compared to the standard book value N credit. The two credit approach (PPNT-BVNC) where profile nitrate-N and soybean N credits are subtracted from the standard recommendation, also reduced the over application of fertilizer N and increased the accuracy of predicting soybean N credits. The adoption of the UV absorbance at 260 nm and 200 nm or the PPNT-BVNC could reduce some of the variability associated with determining soybean N credits, improve profitability, and reduce the risk of environmental pollution by avoiding excess N applications.

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