SITE-SPECIFIC NITROGEN MANAGEMENT FOR REDUCING SOIL RESIDUAL NITRATE

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Abstract

Site-specific N management has potential for increasing the efficiency of N fertilizer use, and thereby reducing environmental impact. Field studies were conducted in 2000 and 2001 to evaluate the potential for site-specific N management to reduce residual soil nitrate in Missouri cornfields. Field-size side-by-side fertilizer N treatment strips were applied in cooperating farmers' fields. The site-specific crop N requirement (optimal N rate) was determined for sub-blocks that contained a full set of N rate treatments. Residual soil nitrate content was determined for selected N-rate sub-blocks to investigate the relationship between residual soil nitrate and optimal N rates. Prior to establishing the N treatments, apparent bulk profile soil electrical conductivity (EC_a) measurements were collected for each site. Soil sample locations for residual soil nitrate were selected based on the observed contrast in EC_a within each field.

We observed wide variations in the site-specific N requirement for corn. We found that residual soil nitrate (RSN) levels were greater for higher fertilizer N rates and for late-season applications. Most of the RSN was the surface 0-12-in. soil layer, except for the highest (250 lb N acre^{-1}) N treatment. We were not able to confirm a consistent relationship between EC_a and residual soil nitrate, although a relationship may exist among soil samples having greater differences in EC_a. Residual soil nitrate accumulated in soils where the amount of applied N exceeded the optimal N rate. Further analyses will help to determine any spatial relationship in RSN levels within these fields.

Abbreviations: EC_a: Apparent bulk profile soil electrical conductivity; RSN: Residual soil nitrate

Introduction

Nitrogen (N) fertilizer applied to croplands in the Midwest U.S. has been cited as a major source of nitrate-N loading to the Gulf of Mexico. This nitrate-N leads to hypoxic zones in estuarial areas that negatively impact sea life. One way to reduce nitrate-N loading is to increase the efficiency of N fertilizer use, so that less remains in soil after crop harvest. Crop producers can increase N-use efficiency by delaying application until the time of more rapid N uptake by plants, and by avoiding over-application of N fertilizers.

Nitrogen fertilizer applications in excess of crop requirements can lead to the accumulation of nitrate-N that remains after crop harvest (Roth and Fox, 1990). This residual soil nitrate (RSN) is susceptible to leaching or denitrification during heavy rainfall periods the subsequent spring. Two possible strategies for reducing RSN are delayed N fertilizer applications until times when corn plants are rapidly taking up N (e.g., Dinnes et al., 2002), and variable-rate (or site-specific) N application. The goal of site-specific N application (SSNM) is apply N fertilizer to match plant N requirement. However, it has proven difficult to prove any benefit to SSNM because crop productivity, and site-specific N requirement, varies year-to-year with climatic conditions (Doerge, 1999).

In Missouri work has focused on using site-specific technologies to develop relationships between soil electrical conductivity (EC_a) and potential crop productivity (Kitchen et al., 1999). These efforts have been successful to an extent because EC_a can be used as a predictor of topsoil depth on claypan soils, and topsoil depth is a good predictor of plant-available water later in the crop season. However. ECa alone is not sufficient to predict crop productivity, and other information such as insects, weeds, diseases, fertility, crop stand, and topography are needed to refine these predictions.

The goal of this research effort was to determine the effectiveness of SSNM as a strategy for reducing over-application of N fertilizers. The specific objectives of this study were to quantify the site-specific plant N requirement and the relationship between plant N requirement and residual soil nitrate. A secondary objective was to evaluate the potential of using EC_a as a guide for soil sampling for RSN.

Materials and Methods

Residual soil nitrate samples were collected at three sites established on farmer-cooperator fields during the 2000 and 2001 crop years Site characteristics during the study period are given in **Table 1**. Prior to establishing treatments, georeferenced apparent bulk soil electrical conductivity (EC_a) data were collected for field-length transects spaced 30 ft apart. The EC_a data were collected with a mobile Geonics® EM-38 sensor using methods described by (Sudduth et al., 2001). Soil sample transects were chosen where EC_a maps showed the greatest contrast in EC_a values (Figure 0). Soil EC_a data were block-kriged to a 2-m grid using GS+ software (Gamma Design Software, Plainwell, MI). Nitrogen fertilizer treatments as ammonium nitrate were broadcast-applied in 15-ft wide strips (six 30 in-spaced rows) using a tractor-mounted air-flow applicator[1]. Strip length was determined by the dimensions of the field, but was field-length where possible. Ground-speed sensing radar was used to compensate for changes in implement speed. Nitrogen treatments were applied prior to planting, at sidedressing (V6, corn plants were about 30 cm tall), and (or) late vegetative stage (V10, corn plants were about 5 ft tall). The

Table 1. Site descriptions for study areas.

	Claypan (CP)		Missouri River Bottom (RB)		Mississippi River Delta (D)	
	2000	2001	2000	2001	2000	2001
Field location						
Nearby city	Centralia, MO		Napton, MO		Oran, MO	
Lat/Long	39°12'14" N, 92°12'11" W		39°03'25" N, 93°05'39" W		37°05'2" N. 89°43'56" W	
Predominant soils	Adco (Vertic Albaqualfs) Mexico (Aeric Vertic Epiaqualfs)		Sibley (Argiaquic Argialbolls) Wiota (Typic Argiudolls)		Farrenburg (Aquic Hapludalfs) Malden (Typic Udipsamments) Roellen (Vertic Haplaquolls)	
Water source	Rainfed		Rainfed		Irrigated	
Tillage	Till	Till	No-till	No-till	Till	Till
Cropping system[†]	Sb-C	Sb-C	Sb-C	Sb-C	W-Sb-C	W-Sb-C
Corn hybrid	Dekalb 626B+Y	BO-JAC 5557	Pioneer 33A14	Pioneer 33P72	Asgrow RX770	Dekalb 697

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[1] Gandy Orbit-Air® Granular Applicator, Owatonna, MN, 55060-0528

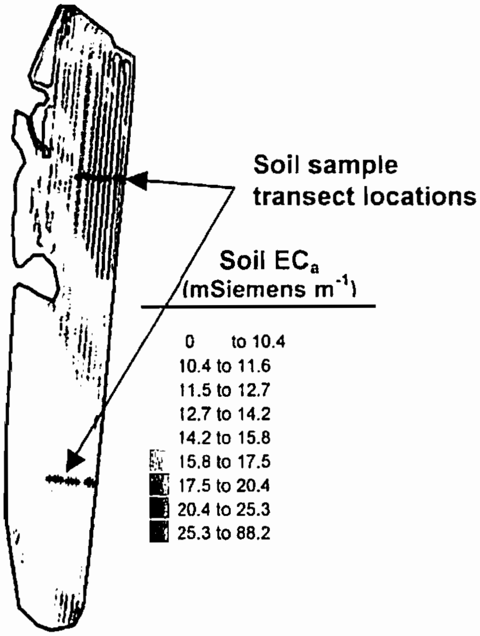


Figure 0. EC_a map for 2000 RB site with soil sample locations.

amount and timing of N fertilizer application for each site- year is shown in Table 2. Treatments were arranged in a randomized complete block design with treatments in strips.

Table 2. N fertilizer treatments for study sites.

2000			2001		
CP	RB	D	CP	RB	D
	Lb N acre^{-1}				
0-0-0†	0-0-0	0-0-0	0-0-0	0-0-0	0-0-0
0+150+0	0+200+0	0+200+0	0+150+0	0+200+0	0+200+0
0+200+0	0+250+0	0+250+0	0+200+0	0+200+0	0+250+0
0+250+0	250+0+0	250+0+0	0+250+0	250+0+0	250+0+0
250+0+0	100+0+50	0+150+50	250+0+0	100+0+50	0+150+50

†Preplant fertilizer application + sidedress application+ late vegetative application

Plots were harvested using a yield monitor-equipped combine using a four-row corn head that harvested the center four rows of each six-row treatment area. Yield monitor data collected every 1 s were merged with differentially-corrected GPS data, and processed using methods described by Birrel et al. (1996). Yield data for each treatment strip were sub-divided into 60-ft long segments. A complete set of 60-ft treatment segments side-by-side within a block formed an N-response sub-block that was 60 ft long by 135 ft wide. The optimum N rate for each N treatment sub-block was calculated using a quadratic-plateau (QP) response function using methods described by Cerrato and Blackmer (1990) and Scharf and Lory (2002). The optimal N rate for each N response sub-block was the N rate at which the first derivative of the quadratic response function was equal to the fertilizer cost-to-crop price ratio (Pr). For this study the Pr was 7.0, consistent with a corn grain price of \$2.00 bu^{-1} and a fertilizer cost of \$0.25 lb^{-1}. The QP calculations were performed using the NLIN procedure in SAS v. 8 (SAS Institute, Inc.).

For each soil sample location two soil cores were collected to depth of 3 ft in 12-in. increments. The soil cores were composited, air-dried at 77°F for 72 hr, and crushed to pass a 2-mm (0.08-

in.) sieve. Soil nitrate-N concentrations were determined by cadmium reduction methods on a colorimetric autoanalyzer (Keeney and Nelson, 1982).

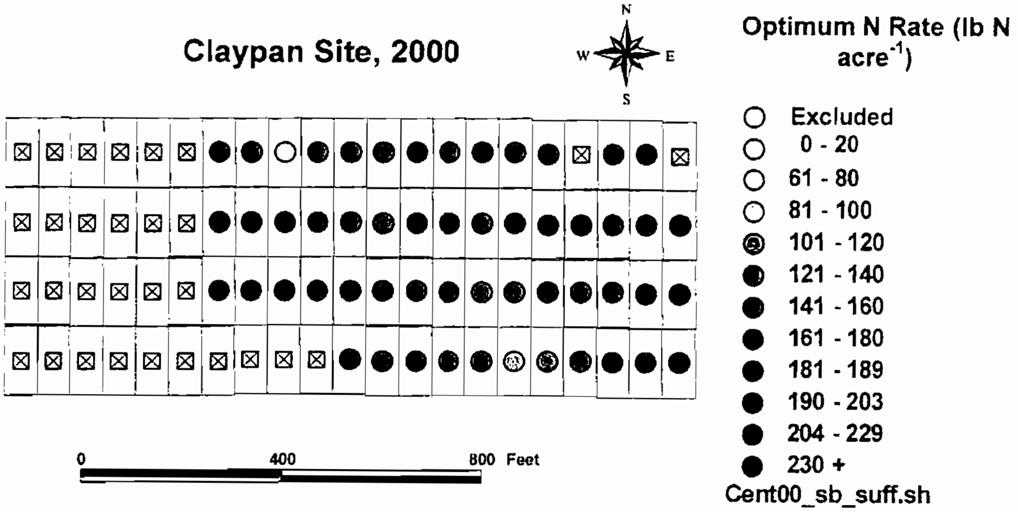
Monthly precipitation totals for the six site-years are shown in Table 3. Growing conditions in both years were favorable for corn production. Monthly totals at the 2001 Delta site were often lower than the 30-yr average. However, typical production levels were maintained because these fields were irrigated.

Table 3. Monthly precipitation totals and 30-yr average for study sites.

Site	Year	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
CP	2000	2.28	2.28	0.82	3.98	5.59	3.49	8.76	2.37
	2001	1.56	1.56	0.64	4.15	6.41	3.16	4.18	1.91
	30-yr avg.	3.17	3.82	4.71	4.49	4.23	3.55	4.46	3.55
RB	2000	3.02	3.02	4.00	4.26	3.68	2.30	1.18	2.51
	2001	2.16	2.45	6.42	5.32	3.41	5.08	4.17	1.90
	30-yr avg.	3.06	3.90	4.77	4.32	3.69	3.41	4.47	3.56
D	2000	1.43	3.86	7.35	8.20	6.77	3.30	3.25	2.49
	2001	3.17	2.64	4.33	2.25	6.65	1.37	1.78	7.47
	30-yr avg.	5.10	4.29	5.15	3.70	3.78	3.26	3.86	2.88

Results and Discussion

Maps showing optimum N rate for the six site-years are shown in Figs. 2 to 4. Summary statistics for all site-years are given in Table 4.



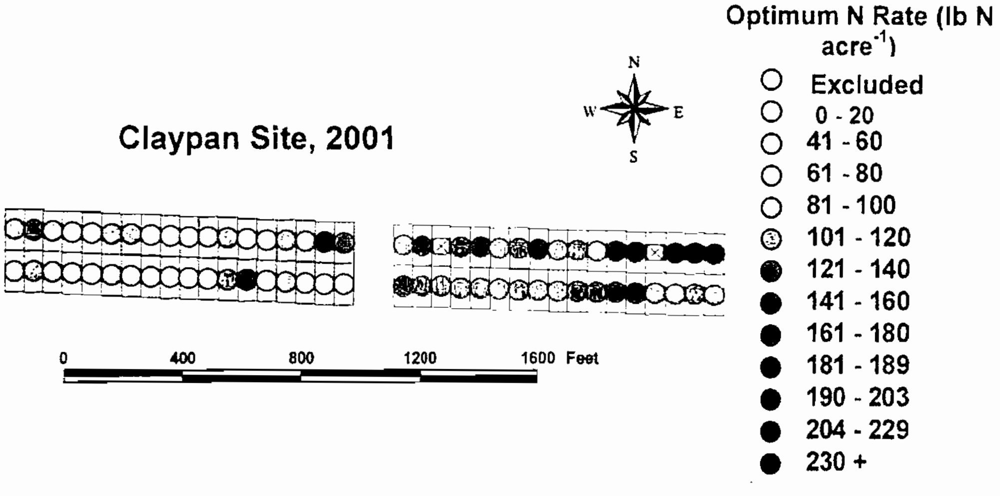


Figure 1. Optimum N rates for treatment sub-blocks at Claypan sites (Centralia) in 2000 and 2001. Sub-blocks excluded in 2000 because of poor plant stand.

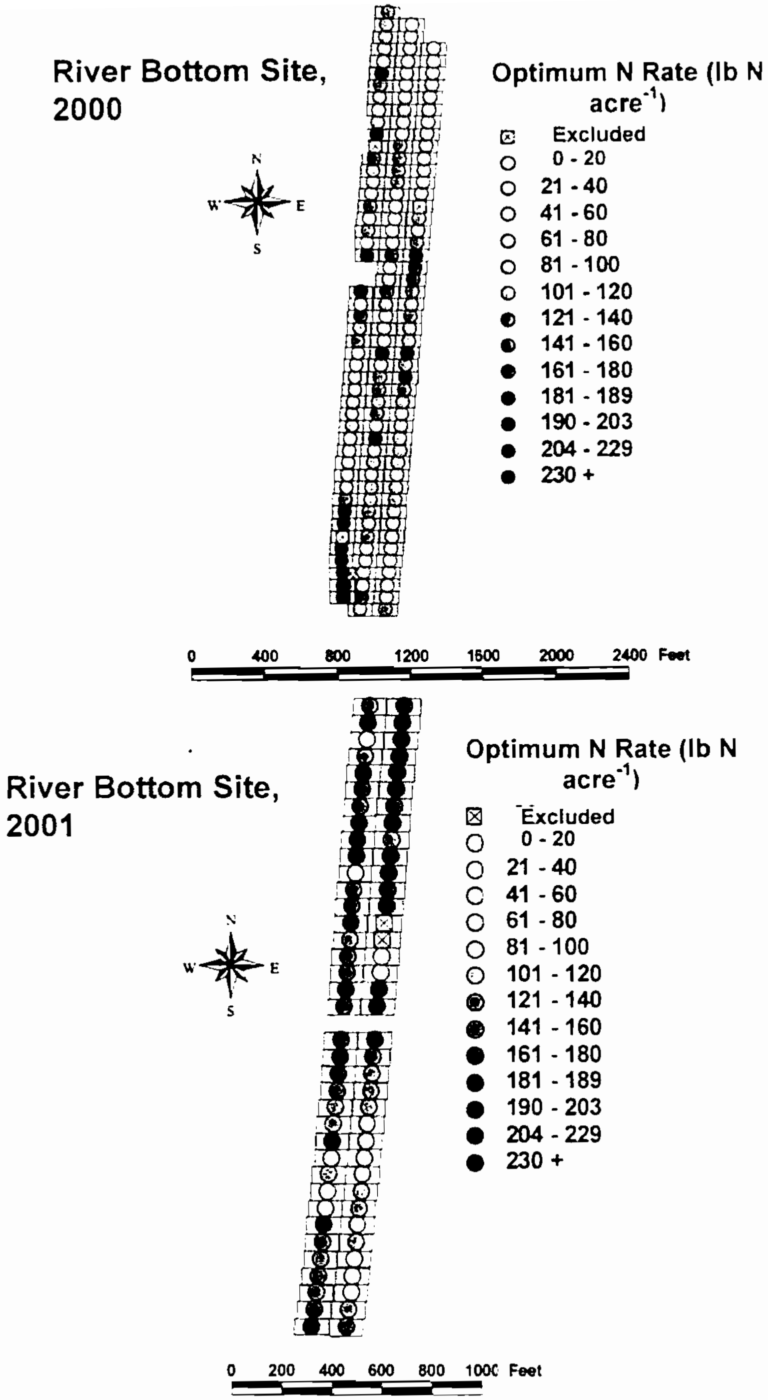


Figure 2. Optimum N rates for treatment sub-blocks at Claypan sites (Centralia) in 2000 and 2001.

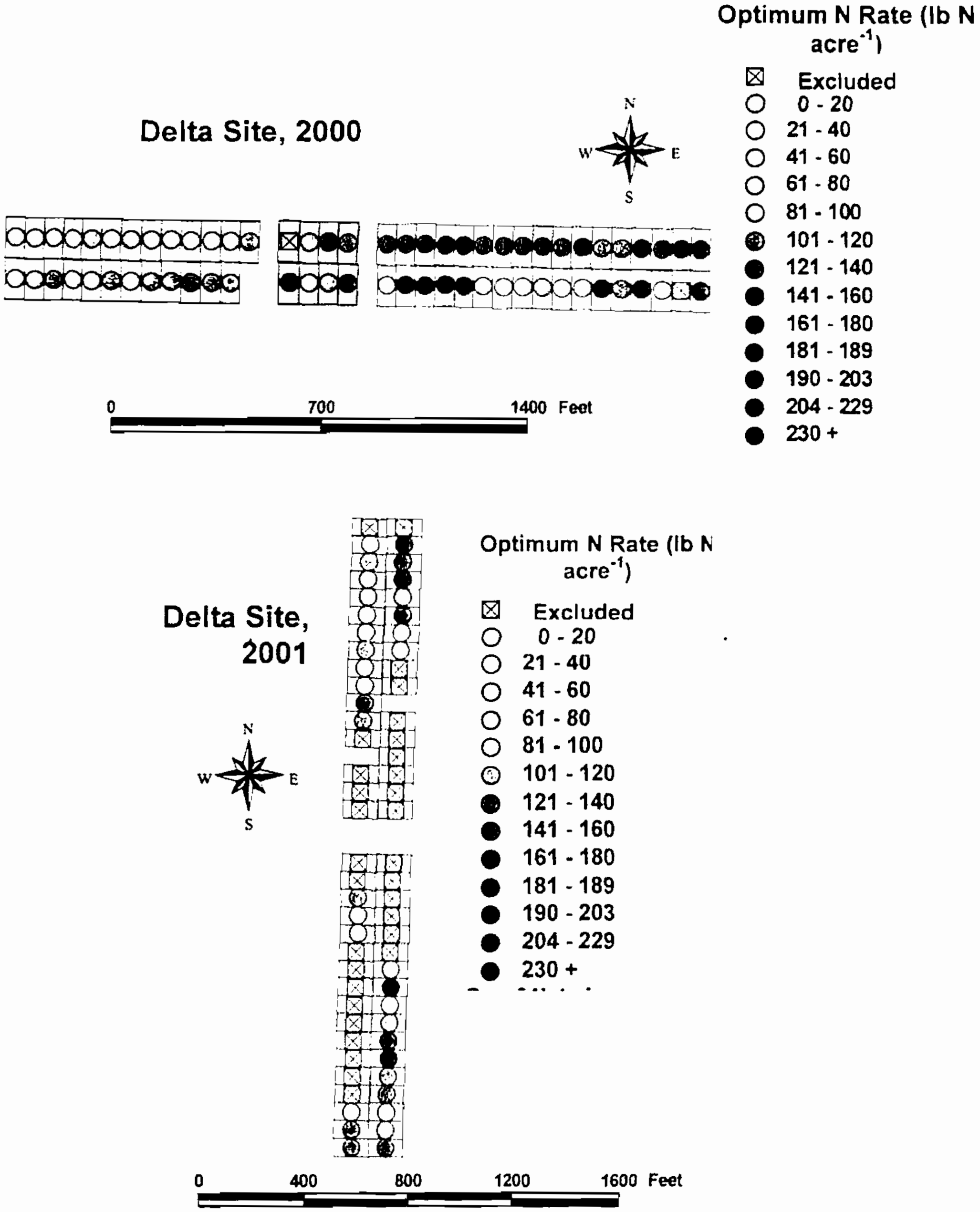


Figure 3. Optimum N rates for treatment sub-blocks at River Bottom sites (Napton) in 2000 and 2001. Sub-blocks excluded in 2001 because of herbicide application error.

Table 4. Summary statistics for optimum N rates for study sites.

Year	Site	Optimum N Rate Min	Max	Mean	CV
		--------- Lb N acre^{-1} ---------			%
2000	CP	68	247	166	20.3
	RB	33	250	112	35.9
	D	42	250	118	43.1
2001	CP	14	250	129	49.4
	RB	58	250	154	27.4
	D	48	188	116	32.6

Optimum N rates varied widely within and among sites. Optimum N rate levels tended to be clustered within maps of the optimum N rate for the six site-years, indicating spatial structure in the data. These findings are consistent with observations from prior variable-rate N studies in the Midwest U.S. and Ontario, Canada (Doerge, 1999).

Residual soil nitrate (RSN) levels in the six fields included in the study are presented in Table 5. Some general trends were observed: (i) RSN levels were higher in the higher N treatments, (ii) RSN levels were higher in the N treatments having a late vegetative stage fertilizer application, and (iii) RSN typically was higher in the top 12-in. soil layer than in the 12-24-in. and 24-36-in. layers. A notable exception to this general trend occurred at the lower EC_a transect of the 2000 RB site, where RSN in the 12-24-in. soil layer was nearly equivalent to RSN in the 0-12-in. layer, at least for the N treatments greater than 200 lb N acre^{-1}. The 2000 crop year had abundant precipitation that could have leached soil nitrate from the surface to the 12-24-in. soil layer.

Other than the 2000 RB site, within-site-year observations of RSN levels for the six fields revealed no clear or consistent differences between the higher and lower EC_a soil sample transects. The soil sample transects were selected based on differences in EC_a, but often the absolute difference in EC_a between transects often was not large. In this study N application rate and timing were the more important factors controlling RSN.

Relationships among RSN, optimum N rate, and applied N fertilizer for the six site-years are shown in Table 5. In this figure RSN content is shown as a function of the relationship between applied N and observed plant N requirement (optimal N rate), as described by Bélanger et al. (2003). The zero point on the x-axis delineates the RSN content when applied fertilizer N just equals the plant N requirement. When less N is applied, RSN would not be expected to accumulate; when applied N exceeds the optimal N rate, RSN may accumulate. RSN did accumulate at all site years when applied N exceeded the optimal N rated. Accumulation of RSN was greater in 2000 than in 2001 for all three sites. An explanation for this finding can be found in examining precipitation patterns just prior to the study period. Very dry conditions during the 1999 crop year persisted until June 2000. It is likely that RSN remained in the soil though the winter and spring months. Even though substantial precipitation occurred from June through the remainder of the crop season in 2000, there was apparently no substantial N loss through leaching or denitrification.

Table 5. Residual soil nitrate for six site-years.

				Soil NO$_3^-$														
				Higher EC$_a$ transect								Lower EC$_a$ transect						
				Blk 1				Blk 2				Blk 1				Blk 2		
Year	Site	Treatment	EC$_a$	0-12 in	12-24 in	24-36 in	EC$_a$	0-12 in	12-24 in	24-36 in	EC$_a$	0-12 in	12-24 in	24-36 in	EC$_a$	0-12 in	12-24 in	24-36 in
		lb N acre^{-1}	mS m^{-1}	--------- lb N acre^{-1} ---------			mS m^{-1}	--------- lb N acre^{-1} ---------			mS m^{-1}	--------- lb N acre^{-1} ---------			mS m^{-1}	--------- lb N acre^{-1} ---------		
						E transect								M transect				
2000	CP	0-0-0	65.5	2.8	0.4	0.0	56.8	7.6	0.4	0.0	58.8	5.2	0.4	2.4	58.5	6.0	0.4	2.8
		0-150-0	64.5	5.2	0.4	0.0	57.9	14.4	3.6	0.8	58.2	5.6	2.0	0.4	59.2	8.0	3.2	0.0
		0-200-0	64.3	7.2	3.6	0.0	58.0	24.4	13.6	0.8	59.2	16.0	17.2	2.0	58.8	16.0	14.4	2.4
		0-250-0	65.1	6.8	3.6	2.8	57.9	44.8	44.4	7.6	59.1	31.6	8.8	0.4	58.8	24.4	23.2	3.6
		250-0-0	64.7	12.4	15.6	4.8	57.9	62.0	16.8	12.4	58.7	36.8	12.4	3.2	58.8	14.0	17.2	3.6
						N transect								S transect				
	RB	0-0-0	40.4	8.8	0.8	0.4	23.2	12.0	0.0	22.4	12.1	22.8	3.2	0.4	12.5	14.4	2.8	2.4
		100-0-50	34.6	89.2	18.0	6.0	20.9	73.2	16.0	9.2	12.0	36.8	10.0	3.6	12.8	44.8	23.2	8.4
		0-200-0	38.2	64.8	26.8	11.2	36.1	28.4	6.4	4.8	12.1	56.0	80.4	19.6	13.0	36.0	11.6	8.4
		0-250-0	40.0	82.8	34.0	8.4	26.3	93.2	4.0	10.4	11.8	74.0	58.0	20.8	12.5	31.6	84.0	7.2
		250-0-0	30.5	33.6	18.4	5.2	21.0	56.8	27.6	10.4	13.3	63.2	66.8	36.8	12.2	47.6	47.6	12.4
						E transect								M transect				
	D	0-0-0	35.5	12.0	4.0	12.4	33.9	6.8	1.2	0.4	43.1	19.2	4.4	3.6	30.3	14.0	1.6	0.8
		0-150-50	35.7	116.4	47.2	64.8	45.1	79.2	42.4	18.8	46.0	46.8	5.6	4.0	40.9	28.8	1.6	3.2
		0-200-0	36.7	19.6	6.4	3.2	45.1	22.0	4.8	2.4	29.1	142.4	8.4	8.4	30.3	33.6	2.4	8.0
		0-250-0	35.1	13.2	5.2	3.6	41.0	32.8	4.4	18.0	29.5	33.2	9.6	11.6	34.2	180.8	14.8	16.4
		250-0-0	39.4	59.6	12.8	8.8	35.9	36.4	6.0	15.2	45.1	40.0	11.2	2.8	34.0	17.6	2.0	2.4
						E transect								M transect				
2001	CP	0-0-0	51.7	13.0	8.0	4.2	47.8	1.5	0.6	0.1	44.4	6.3	1.1	0.2	39.9	4.4	3.5	0.5
		0-150-0	38.5	19.3	9.0	7.0	56.9	6.3	1.4	0.5	42.3	16.6	3.5	2.3	43.1	14.4	8.7	7.4
		0-200-0	63.5	6.0	0.7	1.3	51.1	2.7	0.3	0.6	42.9	12.4	10.8	4.5	40.4	7.5	3.4	3.3
		0-250-0	55.1	4.3	1.7	1.1	48.6	16.7	16.0	13.8	44.0	28.4	40.6	13.0	42.4	33.8	32.3	10.9
		250-0-0	60.4	6.8	1.6	1.1	49.9	6.8	2.0	0.5	45.1	4.6	5.5	3.0	42.8	21.1	7.7	4.6
						N transect								S transect				
	RB	0-0-0	23.3	9.5	1.6	0.5	20.7	6.1	2.2	0.6	14.5	6.8	1.3	0.5	12.3	13.4	1.3	0.3
		100-0-50	22.4	31.1	6.5	1.7	20.8	16.6	3.8	1.3	13.5	17.1	2.2	0.7	12.9	26.2	2.1	0.7
		0-200-0	21.6	16.7	2.6	1.9	19.1	22.2	6.9	0.9	15.1	24.3	4.9	7.8	12.0	43.4	8.0	5.1
		0-250-0	20.6	48.1	16.6	5.3	20.5	86.1	62.6	5.6	13.5	34.0	4.2	4.8	12.4	35.1	5.1	4.8
		250-0-0	20.1	29.2	46.0	8.4	20.9	43.7	28.6	6.4	13.3	34.3	43.2	16.4	12.5	41.6	15.3	14.4
						M transect								S transect				
	D	0-0-0	48.8	3.6	0.3	0.5	42.8	8.0	0.8	1.7	18.1	10.6	2.4	1.0	11.3	15.7	3.4	1.9
		0-150-50	38.0	32.8	7.7	7.9	30.6	34.4	9.0	7.4	12.8	39.4	25.1	18.5	12.0	34.8	7.7	6.3
		0-200-0	65.0	25.1	3.7	2.0	33.2	44.8	4.3	6.7	11.2	13.6	3.7	4.3	11.2	38.2	13.2	8.8
		0-250-0	43.9	23.5	15.7	5.1	38.3	44.3	1.4	3.8	11.1	35.2	12.3	7.6	11.7	31.8	13.2	10.4
		250-0-0	63.5	59.8	49.8	8.4	31.4	46.8	7.9	5.4	25.9	3.4	1.2	14.8	11.6	81.8	40.8	25.2

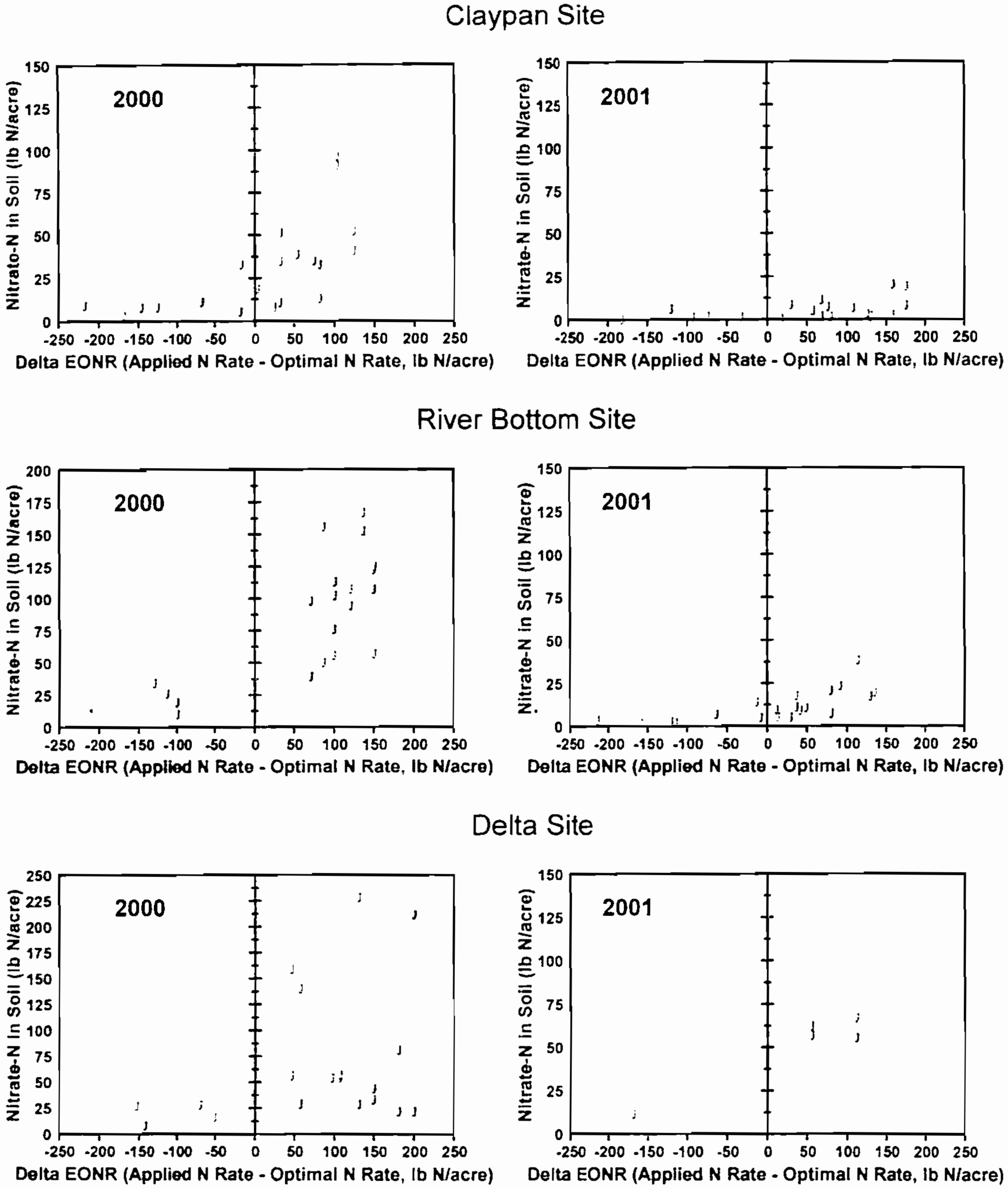


Figure 4. Relationships among residual soil nitrate. optimum N rate, and applied N rate.

Summary

The studies conducted in Missouri tended to confirm variable-rate N studies in the Midwest U.S. and Canada that showed wide variations in within-field optimum N requirement for corn. We found that residual soil nitrate (RSN) levels were greater for higher fertilizer N rates and for late-season applications. Most of the RSN was the surface 0-12-in. soil layer, except for the highest (250 lb N acre^{-1}) N treatment. We were not able to confirm a consistent relationship between EC_a and residual soil nitrate, although a relationship may exist among soil samples having greater differences in EC_a. Residual soil nitrate accumulated in soils where the amount of applied N exceeded the optimal N rate. Further analyses will help to determine any spatial relationship in RSN levels within these fields.

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