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Nitrogen management for corn after corn and corn after soybean

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Nitrogen management for corn after corn and corn after soybean

by

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GENERAL INTRODUCTION

It has been well established that corn (*Zea mays* L.) grown in rotation with soybean [*Glycine max*. (L.) Merr.] often yields more at economic optimum rates of nitrogen (N) fertilization and often requires less fertilizer N to attain these yields than does corn grown in monoculture. Although these benefits of rotation have been widely recognized, few response trials have been conducted with a sufficient number of N rates across a wide range of conditions to permit independent assessments of the yield and N requirement benefits of corn after soybean compared to corn after corn. Trials having only a few N rates tend to lack accuracy either when identifying optimal rates of N application or when identifying the highest yields that can be attained by adding N (i.e., plateau yields). Corn growers need sound information concerning yield and N requirement differences between corn after soybean and corn after corn to make the best management decisions for their operation.

The need for improved N management is indicated by surveys showing amounts of N applied to corn are often well in excess of what is required by the crop. While applying too little N fertilizer can result in lost profits due to reduced yields, applying too much N fertilizer can result in lost profits due to unnecessary applications of N and degradation of water supplies.

The late-spring soil NO^{-}_{3} test is a recently developed tool to assist growers in determining optimal rates of N fertilization. This test involves sampling the surface 30-cm layer of soil when corn plants are 15 to 30 cm tall. Refinement and implementation of this test could improve the profitability of N fertilization for growers as well as help reduce the potential for NO^-_3 contamination of water supplies due to unnecessary applications of N fertilizer. More information concerning the influence of early season rainfall on critical concentrations of late-spring soil NO^-_3 is needed to determine if refinements in recommendations for use of the test for rainfall are needed.

The objectives of the work reported here were (i) to determine plateau yields of corn after corn and corn after soybean, (ii) to determine economic optimum rates of N fertilization for corn after corn and corn after soybean, and (iii) to evaluate the effects of early season rainfall amounts on critical concentrations of late-spring soil NO^-_3.

Explanation of Dissertation Format

The dissertation is presented as two papers suitable for publication. Paper I, "Yields and optimal N rates for corn after corn and corn after soybean" will be submitted to *Agronomy Journal*. Paper II, "Critical concentrations of late-spring soil nitrate for corn" will also be submitted to *Agronomy Journal*. The two papers are preceded by a General Introduction and succeeded by a General Summary. The appendix includes information relevant to Paper I but will not be submitted for publication.

PAPER I. YIELDS AND OPTIMAL N RATES FOR CORN AFTER CORN AND CORN AFTER SOYBEAN

INTRODUCTION

Although not fully understood, the benefits of crop rotation have been widely recognized and utilized by crop producers. The advantages of crop rotation include: reduced need for N fertilizer due to use of legumes; life-cycle disruption of weeds, insects, and diseases; improved soil physical properties; and diversification of time and labor investments (Benson, 1985; Higgs et al., 1990). Other factors suggested to reduce yield potential for continuous corn include allelopathy (Yakle and Cruse, 1984; Anderson et al., 1988) or other negative effects of growing corn continuously (Crookston et al., 1988), nutrient concentration and accumulation (Copeland and Crookston, 1992), and soil-borne bacteria (Turco et al., 1990) or mycorrhizae (Collins Johnson et al., 1992). Crookston and Kurle (1989) suggested that rotation effects were not due to decomposing above-ground residue.

The yield advantage for corn following soybean compared to continuous corn is often in the range of 5 to 15% (Voss and Shrader, 1982; Griffith et al., 1988; Crookston et al., 1991; Meese et al., 1991). This advantage may be greater under low yielding environments such as moisture stress (Hicks and Peterson, 1981; Benson, 1985). Many factors are involved in the determination of corn yields, and the same is true for fertilizer N requirements for corn. The complexity of the N cycle, coupled with the annual variation in environmental factors influencing this cycle and corn growth, make accurate estimation of N fertilizer requirements difficult. This difficulty is illustrated by a report showing a very low correlation between fertilizer N recommendations based on a yield goal system and actual economic optimum rates observed in the field (Blackmer et al., 1992a). The yield goal system involves multiplying the yield goal by an efficiency factor for soil association and then subtracting credits for animal manures or legumes (Peterson and Voss, 1984). For the north central states, credits for soybean range from 11 to 45 kg N ha^{-1} (Peterson and Voss, 1984; Welch, 1984). In Iowa the soybean credit has been 17 g N ha^{-1} for each kg of soybean produced the previous year (Peterson and Voss, 1984). For average soybean yields in Iowa this credit is usually near 45 kg N ha^{-1}. It has been reported, however, that soybean may actually result in a net removal of N from a field (Heichel and Barnes, 1984; Zapata et al., 1987). Consideration of these observations suggests a need for re-evaluation of the N recommendation system based on yield goals and soybean credits. Increased understanding of the factors influencing corn yields and optimal N rates could allow for improved methodologies for determining N recommendations.

It has been well established that rainfall amounts often account for a large amount of the year to year variation in grain yields and fertilizer N requirements of corn (Bondavalli et al., 1970; Voss et al., 1970; Isfan, 1979; Hollinger and Hoeft, 1986). Tools that give site-specific information and reflect the influences of precipitation amounts could be useful in the determination of optimal N rates.

Few response trials have been conducted with a sufficient number of N rates across a wide range of conditions to permit independent assessments of the yield and N requirement benefits of corn after soybean compared to corn after corn. Trials having only a few N rates tend to lack accuracy either when identifying optimal rates of N application or when identifying the highest yields that can be attained by adding N (i.e., plateau yields). This study was conducted to determine economic optimum rates of N fertilization and plateau yields of corn after corn and corn after soybean.

MATERIALS AND METHODS

Thirty-five trials were conducted comparing the N response of corn after corn and corn after soybean over a six-year period (1987 to 1992) in Iowa. Soil descriptions and individual trial information are shown in Tables 1 and 2. Ten rates of N (0, 28, 56, 84, 112, 140, 168, 224, 280, and 336 kg ha^{-1}) were applied as $(NH_4)_2SO_4$ in three replications. The corn after corn plots received the same N treatments each year. Corn after soybean plots received the same N treatments every-other year (N fertilizers were not applied to the soybean crops). The plots were 12.2 by 4.6 m (six 76-cm rows) or 12.2 by 3.9 m (four 97-cm rows) and were arranged in randomized complete-block designs.

Phosphorus was applied at 30 kg P ha^{-1} as triple superphosphate, and K was applied at 55 kg K ha^{-1} as KCl. To avoid possible responses to S from the $(NH_4)_2SO_4$ fertilizer, $CaSO_4 \cdot 2H_2O$ was applied to the 0, 28, 56, and 84 kg N ha^{-1} treatments so that the total amount of S applied to each plot was at least equal to that applied with the 112 kg N ha^{-1} $(NH_4)_2SO_4$ treatment. All fertilizers were broadcast and incorporated shortly before planting.

Corn was usually planted during the last week of April or the first week of May at rates of 60,000 to 72,000 seeds ha^{-1}. Corn root samples were collected in 1988 from six randomly selected plants at silking from nonharvest rows, and washed for visual inspection of damage by rootworm (*Diabratica* spp.). Root damage was rated on a scale of 1 (no damage) to 6 (very severe damage) based on the rating scale of Hills and Peters (1971). Grain yields were determined by hand harvesting segments of the

Table 1. Soil descriptions at each experimental location[a].

Location	Series	Subgroup	pH	N	P	K
				g kg^{-1}	-mg	kg^{-1}-
Holstein	Galva	Typic Hapludoll	5.8	2.2	19	176
Badger	Canisteo	Typic Haplaquoll	7.8	3.3	5	132
Kensett	Crippin	Aquic Hapludoll	7.9	3.0	13	122
Nashua	Readlyn	Aquic Hapludoll	5.8	1.6	15	114
Kalona	Bremer	Typic Argiaquoll	6.5	2.0	108	254
Wyman	Mahaska	Aquic Argiudoll	5.3	1.9	16	176
Calumet	Primghar	Aquic Hapludoll	5.8	2.1	8	167
Wapello	Titus	Fluvaquentic Haplaquoll	6.3	1.9	34	178

[a]Soil samples were taken from the 0- to 30-cm layer of soil; N = Total Kjeldahl-N; P = Bray-1 extractable P; K = exchangeable K.

Table 2. Individual trial information.

Year	Location	Corn Hybrid[a]	Tillage performed[b] Continuous Corn	Corn after Soybean
1987	Kalona	P3377	FC,FD,SD,SE,P,R	FC,SD,SV,P,R
1987	Holstein	P3475	SH,SD,SE,SE,P,R	SE,SE,P,R
1987	Badger	P3475	FH,FC,SE,SE,P,R	SE,SE,P,R
1987	Kensett	P3475	FM,SD,SE,SE,P,R	FC,SE,SE,P,R
1987	Nashua	P3732	SC,SE,SE,P,R,R	SC,SE,SE,P,R,R
1987	Wapello	P3377	FM,SE,SE,P,R	FM,SE,SE,P,R
1988	Kalona	P3377	FV,SD,SE,P,R	FV,SD,SE,P,R
1988	Holstein	P3475	SH,SD,SE,SE,P,R	SE,SE,P,R
1988	Badger	P3475	FH,FC,SE,SE,P,R,R	SE,SE,P,R,R
1988	Kensett	P3475	FM,SE,SE,P,R	FC,SE,SE,P,R
1988	Nashua	P3732	FC,SE,SE,P,R	SE,SE,P,R
1988	Wapello	P3377	FV,SE,SE,P,R	FV,SE,SE,P,R
1989	Kalona	P3379	FV,FD,SD,SE,P,R	FV,FD,SD,SE,P,R
1989	Holstein	P3475	SH,SD,SE,SE,P,R,R	SE,SE,P,R,R
1989	Badger	P3475	FH,FV,SE,SE,P,R,R	SD,SE,P,R,R
1989	Kensett	P3475	FM,SE,SE,P,R	FV,SE,SE,PR
1989	Nashua	P3732	FC,SE,SE,P,R	SE,SE,P,R
1989	Wapello	P3377	FM,SE,SE,P,R	FM,SE,SE,P,R
1990	Kalona	P3379	FC,SD,SE,P,R	SD,SE,P,R
1990	Holstein	P3475	FH,FD,SD,SE,P,R	FD,SE,P,R
1990	Badger	P3467	FH,FV,SE,SE,P,R	SE,SE,P,R
1990	Kensett	P3475	FM,SE,SE,P,R	FC,SE,SE,P,R
1990	Nashua	P3578	FC,SE,SE,P,R	SE,SE,P,R
1990	Wyman	P3379	FC,SD,SE,P,R	SD,SE,P,R
1990	Calumet	DK535	SD,SD,SE,P,R	SD,SE,P,R
1991	Kalona	P3417	FC,SD,SE,P,R	SD,SE,P,R
1991	Holstein	P3475	FD,SD,SE,P,R	FD,SD,SE,P,R
1991	Badger	P3751	FH,FV,SE,SE,P,R	SE,SE,P,R
1991	Kensett	P3615	FM,SE,SE,P,R,R	FC,SE,SE,P,R
1991	Nashua	RX746	FC,SE,SE,P,R	SE,SE,P,R
1991	Wyman	RX746	FC,SD,SE,P,R	SD,SE,P,R
1991	Calumet	DK535	FC,SD,SE,P,R	SD,SE,P,R
1992	Nashua	P3578	FC,SD,SE,P,R	SD,SE,P,R
1992	Wyman	P3394	FC,SD,SE,P,R	SD,SE,P,R
1992	Calumet	P3563	FC,SD,SE,P,R	SD,SE,P,R

[a]P=Pioneer, DK=Dekalb, RX=Asgrow.

[b]F=fall, S=spring; C=chisel, D=disk, E=field cultivator, H=stalk chopper, M=moldboard plow, P=planter, R=row cultivator, V=v-ripper.

center two rows of each plot (7.6-m segments in 1987, 1988, 1989, 1991, and 1992; 6.1-m segments in 1990). Grain yields were adjusted to 155 g kg^{-1} moisture content. Other than fertilizer application and grain harvest, all plots were managed by practices commonly used in production agriculture.

The quadratic, quadratic-response-and-plateau (QRP), linear-response-and-plateau (LRP), and Mitscherlich models were used to describe the relationship between grain yields and fertilizer N applied for each individual trial. Except for the LRP model, predicted economic optimum rates of fertilization were calculated by equating the first derivatives of the response equations to a selected fertilizer-to-corn price ratio and solving for rates of fertilization (Heady et al., 1955; National Academy of Sciences, 1961; Nelson et al., 1985). For the LRP model, economic optimum rates of fertilization were identified by locating the intersection of the two lines (Waugh et al., 1973; Ihnen and Goodnight, 1985). Individual trials were considered nonresponsive to fertilizer N if the model used could not significantly ($P < 0.05$) describe the relationship of grain yields to fertilizer N applied.

Independent analyses were performed to explain the effects of various sources of variability on plateau yields, optimal N rates, and the difference in optimal N rates between rotations. Year, site, and rotation were assumed to be categorical variables in these analyses of variance. No tests of significance are shown because no hypotheses are being tested. Linear regression was used to evaluate the effects of rainfall and plateau yields for purposes of comparing variability explained by various sources.

Returns to fertilization were calculated by multiplying the yield increase above the control treatment by an assumed corn price and then subtracting assumed fertilizer and application costs.

RESULTS AND DISCUSSION

Rainfall amounts varied considerably among the years and locations in which this study was conducted (Table 3). Notable extremes are a severe drought in 1988 and excessive rainfall at many sites in 1990 and 1991.

Plateau yields as calculated by using the QRP model for individual trials ranged from 1.6 to 11.9 Mg ha^{-1} for corn after corn and from 2.9 to 12.0 Mg ha^{-1} for corn after soybean (Table 4). Mean plateau yields for corn after soybean averaged 12% higher than the corresponding means for corn after corn. Frequency distribution diagrams for plateau yields illustrate a general tendency for higher plateau yields for the corn after soybean (Fig. 1). These differences in plateau yields, of course, are due to factors other than N availability.

Moisture availability clearly was a major factor influencing plateau yields. Information concerning soil moisture availability is not available, but plateau yields were significantly influenced by in-season rainfall (Fig. 2). Analysis of variance for the four sites having five years of data revealed that year effects explained more of the variability in plateau yields than did site or rotation (Table 5). Linear regression analysis indicated that in-season rainfall explained 15% of the variability in plateau yields for this data set and 26% of the variability in plateau yields when all sites over all years were analyzed. Because rainfall is less than perfect as an indicator of moisture availability, factors related to moisture availability probably account for much of the variability attributed to "year effects" in the

Table 3. Rainfall data for each location from April through September.

			Rainfall amounts						
Year	Location	Dev.[a]	April	May	June	July	Aug	Sept	Total
			-----------	-----------	-----------	-mm-	-----------	-----------	-----------
1987	Kalona	+9	84	176	83	45	121	83	593
1987	Holstein	+41	36	94	16	253	131	59	589
1987	Badger	-117	50	75	42	164	103	45	479
1987	Kensett	-197	27	44	50	135	92	39	387
1987	Nashua	-117	31	77	60	94	181	58	504
1987	Wapello	-200	23	41	77	43	166	53	403
1988	Kalona	-272	19	27	10	22	191	41	312
1988	Holstein	-37	53	44	87	61	133	133	511
1988	Badger	-117	75	43	59	64	117	124	482
1988	Kensett	-141	88	26	33	57	96	144	444
1988	Nashua	-257	64	29	43	74	80	74	364
1988	Wapello	-298	19	45	57	41	112	30	305
1989	Kalona	+135	67	82	141	101	100	227	719
1989	Holstein	-171	33	46	56	58	58	124	375
1989	Badger	-34	76	85	114	124	40	125	564
1989	Kensett	-186	62	41	40	110	72	74	399
1989	Nashua	-276	69	68	46	57	57	47	344
1989	Wapello	-17	88	55	118	25	91	208	602
1990	Kalona	+278	33	194	254	185	140	65	871
1990	Holstein	+215	61	191	239	209	48	15	763
1990	Badger	+254	57	195	270	203	83	42	850
1990	Kensett	+409	120	106	98	294	328	47	993
1990	Nashua	+353	102	109	175	340	195	53	974
1990	Wyman	+95	48	131	209	120	109	63	680
1990	Calumet	-44	14	92	182	140	72	41	541
1991	Kalona	-241	56	97	79	8	71	36	343
1991	Holstein	+36	127	157	122	18	104	53	582
1991	Badger	+193	229	201	97	56	170	38	790
1991	Kensett	+53	--	340	79	102	117	--	638
1991	Nashua	+127	175	178	155	58	124	53	747
1991	Wyman	-290	69	61	38	13	97	23	297
1991	Calumet	-58	120	119	76	74	81	56	526
1992	Nashua	-65	91	53	54	183	67	107	555
1992	Wyman	+4	59	20	27	264	58	163	592
1992	Calumet	+45	75	112	44	219	120	59	629

[a]Total deviation from long-term mean rainfall from April through September.

Table 4. Plateau yields predicted by the quadratic-response-and-plateau model.

Year	Location	Plateau Yield		R^2 values	
		CC[a]	SC	CC	SC
		- - - Mg/ha - - -			
1987	Kalona	8.42	10.74	0.23	N.S.[b]
1987	Holstein	10.02	10.45	0.92	0.83
1987	Badger	10.89	10.95	0.72	0.31
1987	Kensett	11.93	11.05	0.82	0.61
1987	Nashua	8.86	10.17	0.83	0.81
1987	Wapello	6.35	9.80	N.S.	0.48
1988	Kalona	3.27	5.68	N.S.	N.S.
1988	Holstein	7.41	9.08	0.89	0.61
1988	Badger	4.18	10.99	0.27	N.S.
1988	Kensett	6.44	2.94	0.30	N.S.
1988	Nashua	5.68	6.54	0.65	N.S.
1988	Wapello	1.61	6.55	N.S.	N.S.
1989	Kalona	11.20	10.77	0.58	0.24
1989	Holstein	9.80	8.59	0.91	0.33
1989	Badger	11.15	12.65	0.90	0.67
1989	Kensett	11.70	11.85	0.95	0.85
1989	Nashua	8.17	7.03	0.86	0.46
1989	Wapello	5.55	5.13	N.S.	N.S.
1990	Kalona	11.36	11.46	0.84	0.50
1990	Holstein	9.28	8.98	0.83	0.41
1990	Badger	9.97	10.63	0.88	0.31
1990	Kensett	10.80	10.89	0.92	0.75
1990	Nashua	11.23	12.05	0.80	0.70
1990	Wyman	10.99	11.79	0.46	0.24
1990	Calumet	8.03	8.41	0.77	N.S.
1991	Kalona	7.36	10.69	0.37	N.S.
1991	Holstein	9.71	9.82	0.86	0.45
1991	Badger	10.53	12.10	0.89	0.81
1991	Kensett	10.19	11.64	0.74	0.56
1991	Nashua	9.65	10.34	0.75	0.64
1991	Wyman	6.02	7.90	N.S.	N.S.
1991	Calumet	6.57	7.18	0.81	0.21
1992	Nashua	10.45	12.47	0.84	0.95
1992	Wyman	9.05	11.63	0.66	0.68
1992	Calumet	8.67	9.98	0.86	0.67
Mean		8.59	9.66		

[a]CC=Corn after corn; SC=Corn after soybean.
[b]N.S.=model was non-significant at the $P < 0.05$ level.

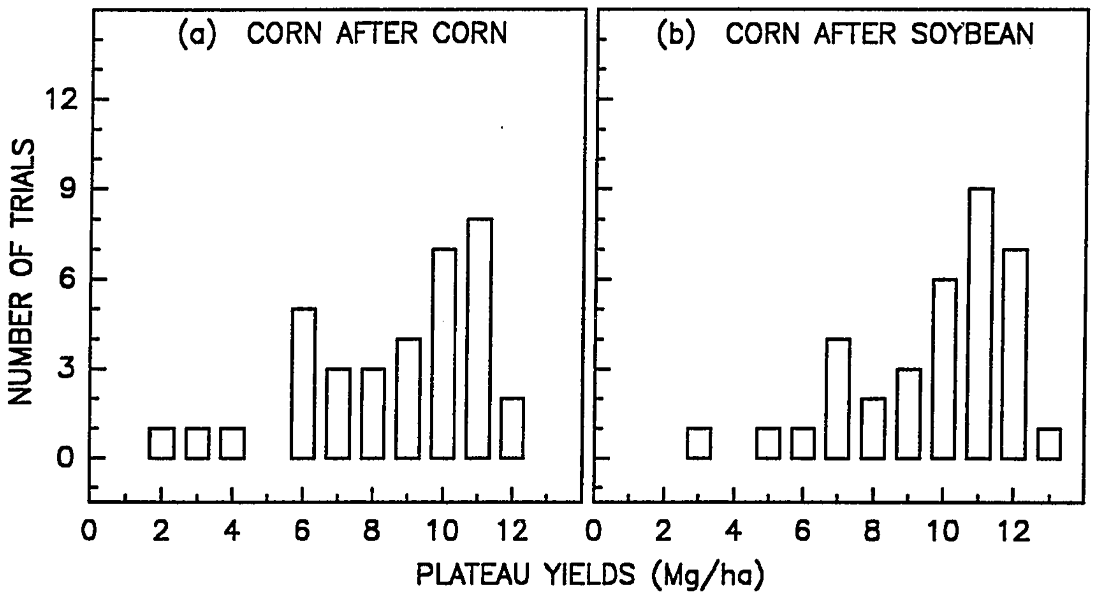

Fig. 1. Frequency distribution of plateau yields determined by the quadratic-response-and-plateau model; (a) corn after corn, (b) corn after soybean.

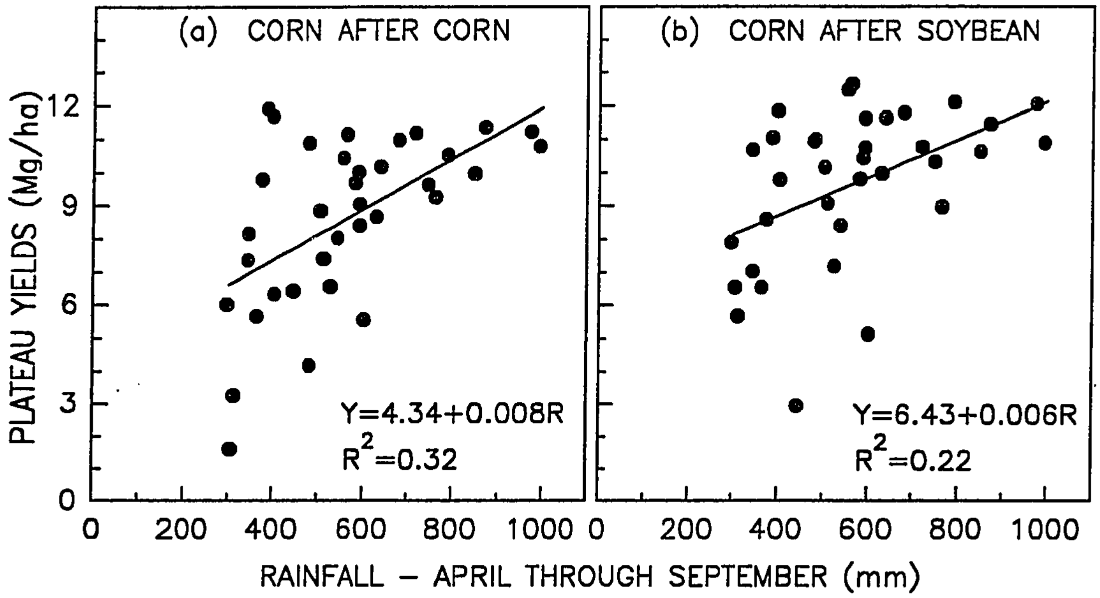

Fig. 2. Relationship between plateau yields and growing season rainfall (April through September); (a) corn after corn, (b) corn after soybean.

Table 5. Variability of plateau yields as influenced by year, site, and rotation for four sites over five years.

Source	Sum of squares	Variability explained
		% of total
Year	120.55	55.9
Site	10.69	5.0
Rotation	6.67	3.1

presented in Table 5.

Marked differences in appearances (height, visual symptoms of moisture stress) were noted between rotations when corn was silking during the drought of 1988. This prompted the rating of root damage caused by feeding of rootworms. The results (Table 6) showed significantly greater damage for corn after corn than for corn after soybean at each of the six sites evaluated. These differences occurred when rootworm insecticide had been applied and when it had not been applied. Differences in root damage and, therefore, inability of the roots to extract water from the soil, offer a partial explanation for the finding that yields of corn after soybean averaged 1.4 times the yields of corn after corn in 1988.

Mean plateau yields were higher for corn after corn than for corn after soybean during 1989. It seems likely that this reversal in yield advantage was related to amounts of stored water at the beginning of the season. Differences in stored moisture were likely because significant rainfall came in late summer of 1988 and because much of this rainfall would have been utilized by the 1988 soybean crop but not the 1988 corn crop; the dry weather in 1988 caused early maturing of the corn but not the soybean. Differences in stored water should be expected to have influence yields in 1989 because the amounts of rainfall were below long-term averages.

Estimates of the amounts of N fertilizer needed to maximize yields were profoundly influenced by the model used to describe the relationships between observed yields and N rates. Data presented in

Table 6. Root damage ratings as influenced by rotation in 1988.

Site[b]	Root damage rating[a] CC[c]		SC
Kalona	1.6	*[d]	1.3
Holstein	2.2	*	1.7
Badger	2.7	*	1.1
Kensett	2.3	*	1.5
Nashua	1.8	*	1.2
Wapello	3.9	*	1.4
Mean	2.4	*	1.4

[a]Based on a scale of 1 (no damage) to 6 (very severe damage).
[b]Insecticides applied:Kalona, 5.6 kg fonofos/ha to CC; Holstein, 9.5 kg terbofos/ha to CC and SC; Badger, 9.5 kg terbofos/ha to CC; Kensett, 12.3 kg terbofos/ha to CC and SC; Nashua, 5.6 kg fonofos/ha to CC.
[c]CC = corn after corn; SC = corn after soybean.
[d]* = difference between rotations is significant at $P < 0.05$.

Table 7 show that mean estimates of economic optimum fertilization rates varied by nearly two-fold for each rotation. Estimates of economic optimum rates of fertilization for individual trials are shown in Appendix Tables 1 through 8.

The yields observed at various N rates are shown in Fig. 3. Lines in this figure show yields predicted by the QRP model in situations where fit of the model indicated statistically significant ($P < 0.05$) effects of fertilizer on yields. This model was used to describe yield responses because analyses presented by Cerrato and Blackmer (1991) indicated that this model was more appropriate than the others.

In addition to the variation due to model selection, estimates of economic optimum rates of fertilization varied greatly with assumed cost of fertilization and assumed value of grain. This problem is illustrated in Table 7, which considers four commonly used models and ranges in prices producers are likely to encounter in the Corn Belt. The prices of fertilizer, for example, represent the usual differences between the two most commonly used forms of N (urea-ammonium-nitrate solutions and anhydrous ammonia) at any given time. Fluctuations in grain prices during the study were as great as the range considered in Table 7.

The fertilization rate that maximized net returns to fertilization when it was applied across all sites varied with assumed price of fertilizer more than it varied with assumed value of corn. The curves presented in Fig. 4 indicate that net returns to fertilization in such multi-site scenarios were not greatly influenced by choice of N rate within a reasonable range of N rates. Comparison of the various optimal

Table 7. Nitrogen needs for corn after corn and corn after soybean as indicated by four models to maximize yields or to maximize profits at four price scenarios. Values listed are means across 35 trials.

Model	Rates to max. yield[a]	Mean economic optimum rates at various prices			
		$98.42/Mg corn		$78.74/Mg corn	
		$0.22/kg N	$0.55/kg N	$0.22/kg N	$0.55/kg N
	kg N/ha				
		Corn after corn			
LRP[b]	129	129	121	129	121
QRP[c]	198	182	159	178	149
Quadratic	224	206	177	201	166
Mitscherlich	348	256	175	237	155
		Corn after soybean			
LRP	87	87	79	87	79
QRP	126	115	100	113	93
Quadratic	242	173	130	162	118
Mitscherlich	334	166	104	148	91
		Corn after corn minus corn after soybean			
LRP	42	42	42	42	42
QRP	72	67	59	65	56
Quadratic	-18	33	47	39	48
Mitscherlich	14	90	71	89	64

[a]Rates listed for the Mitscherlich model are at 99% of maximum yield.
[b]LRP = linear-response-and-plateau model.
[c]QRP = quadratic-response-and-plateau model.

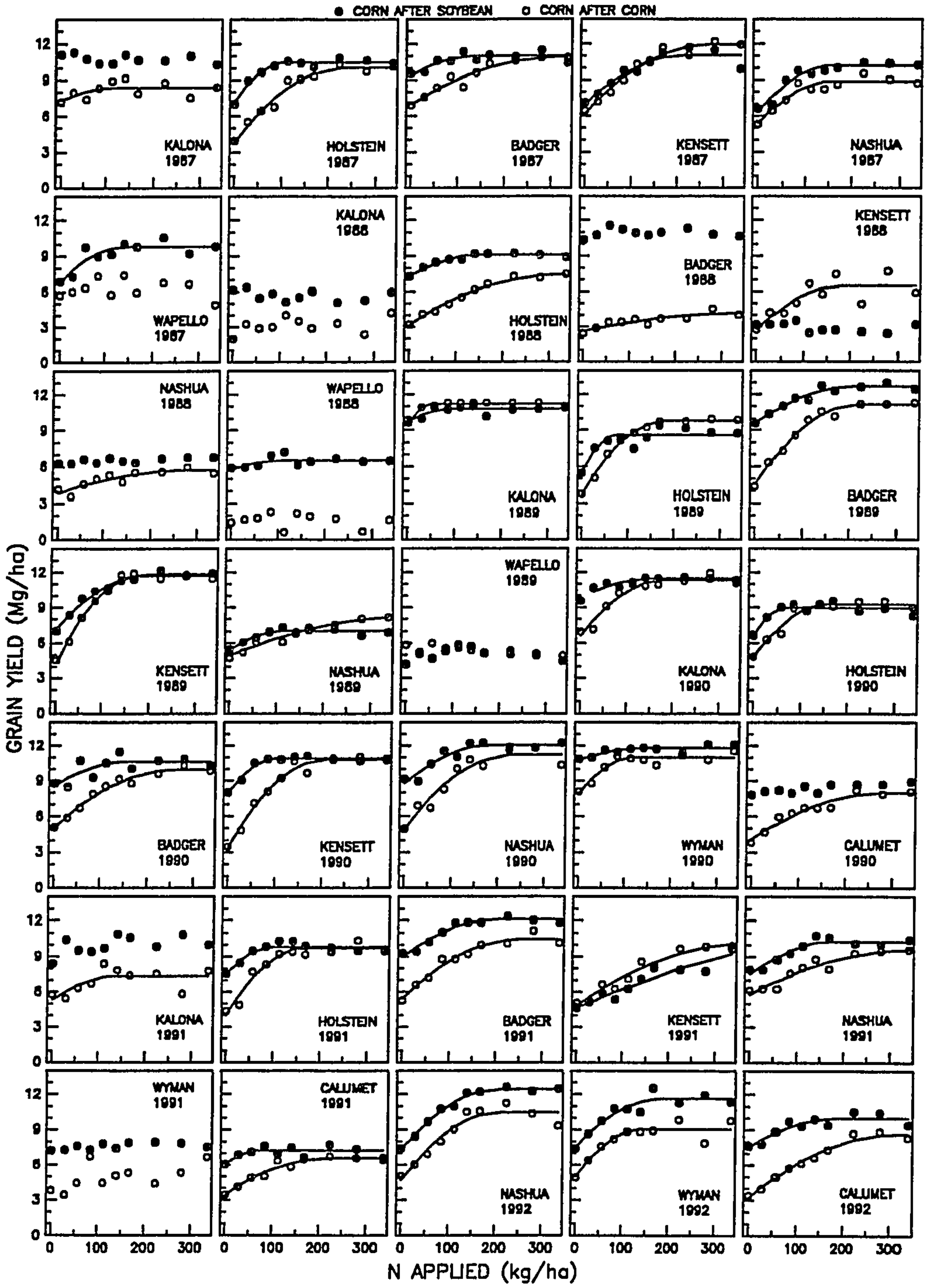

Fig. 3. Relationship between corn grain yields and fertilizer N applied. Predicted values for the QRP model are included where relationships were statistically significant ($P < 0.05$).

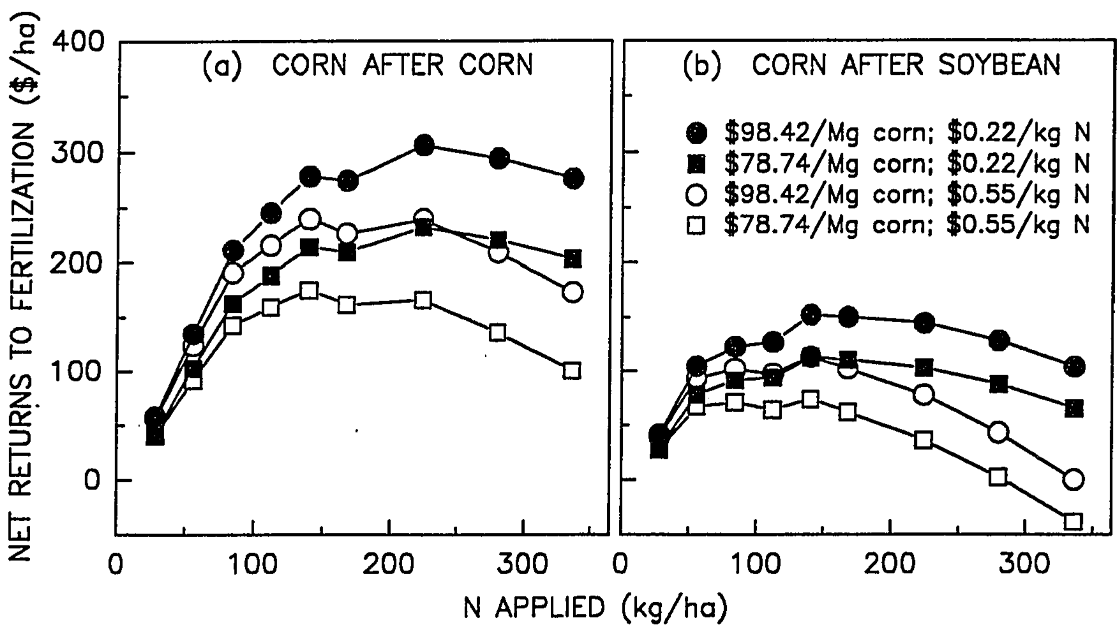

Fig. 4. Net returns to fertilization across 35 trials at various prices for grain and fertilization; (a) corn after corn, (b) corn after soybean.

N rates shown in Table 7 and the curves in Fig. 4 suggest that use of the QRP model to select optimal N rates is at least as defensible as any of the other models.

Figure 4 shows means of net returns to fertilization for each of the ten rates applied across all sites and years. The rates that gave the highest net returns are of interest because they have potential as recommendations for N rates at similar sites in future years; they are denoted as across-site optimal rates in the remainder of this discussion. It is noteworthy that, unlike the economic optimum rates presented in Table 7, the means shown in Fig. 4 are not influenced by bias introduced during curve fitting. They are, however, influenced by prices of fertilizer and value of grain. Within the ranges considered, the profit-maximizing N rates were influenced more by price of fertilizer than by value of grain. Because the price of fertilizer is always known at the time of fertilization, the data presented in Fig. 4 suggest that it could be beneficial to adjust fertilizer recommendations for costs of fertilizer.

The potential value of across-site optimal rates when making fertilizer recommendations for corn is illustrated in Tables 8 and 9. These tables show mean net returns to fertilization and mean rates of fertilization that would have occurred under four systems of selecting N rates in each of four price scenarios. The "prevailing system" is Iowa State University's recommendations based on soil association, yield goal, and credits for N supplied by the soybean. The "ASOR" (across-site optimal rate) system specifies that the rate that maximized net returns

Table 8. Nitrogen rates and net returns to fertilization for 35 trials in corn after corn when various recommendation systems are used.

	Corn at $98.42/Mg		Corn at $78.74/Mg	
Recommendation system	$0.22/kg N	$0.55/kg N	$0.22/kg N	$0.55/kg N
	Nitrogen rates			
	(kg/ha for 35 trials)			
Ideal[a]	182	159	178	149
MEOR[b]	168	168	168	140
ASOR[c]	224	140	224	140
Conventional[d]	206	206	206	206
	Net returns to fertilization[e]			
	$/ha for 35 trials			
Ideal	315.42	263.78	240.62	187.42
MEOR	274.75	226.69	209.69	175.20
ASOR	306.24	239.80	232.42	175.20
Conventional	297.77	237.82	226.52	166.57

[a]Each site recieved its own economic optimum N rate as calculated by using the quadratic-response-and-plateau model. Data presented are means across all sites.
[b]The mean of the economic optimum rates for individual sites was applied to all sites. Data presented are rounded to the nearest rate actually applied.
[c]The rate of those actually applied that provided the highest net returns when one rate was applied to all sites.
[d]The mean rate for all sites by using Iowa State University's recommended rate at each site (based on yield goal, soil association and credits for N supplied by legumes).
[e]Assumes application costs of $13.58/ha for $0.22/kg N and $6.17/ha for $0.55/kg N. Actual rates applied nearest to the determined rates were used to calculate net returns.

Table 9. Nitrogen rates and net returns to fertilization for 35 trials in corn after soybean when various recommendation systems are used.

	Corn at $98.42/Mg		Corn at $78.74/Mg	
Recommendation system	$0.22/kg N	$0.55/kg N	$0.22/kg N	$0.55/kg N
	Nitrogen rates			
	(kg/ha for 35 trials)			
Ideal[a]	105	94	103	89
MEOR[b]	112	84	112	84
ASOR[c]	140	140	140	140
Conventional[d]	175	175	175	175
	Net returns to fertilization[e]			
	$/ha for 35 trials			
Ideal	167.54	135.17	127.60	96.86
MEOR	126.82	101.84	93.80	70.99
ASOR	151.77	112.95	112.54	73.72
Conventional	152.35	101.65	111.41	60.71

[a]Each site recieved its own economic optimum N rate as calculated by using the quadratic-response-and-plateau model. Data presented are means across all sites.
[b]The mean of the economic optimum rates for individual sites was applied to all sites. Data presented are rounded to the nearest rate actually applied.
[c]The rate of those actually applied that provided the highest net returns when one rate was applied to all sites.
[d]The mean rate for all sites by using Iowa State University's recommended rate at each site (based on yield goal, soil association and credits for N supplied by legumes).
[e]Assumes application costs of $13.58/ha for $0.22/kg N and $6.17/ha for $0.55/kg N. Actual rates applied nearest to the determined rates were used to calculate net returns.

when applied across all sites as shown in Fig. 4 be applied to all sites. The "MEOR" (mean of economic optimum rates) system specifies that the mean of economic optimum rates observed at individual sites be applied toall sites. The "ideal" system specifies that each site receive the rate that (after the fact) was determined to be optimal. In each system recommended rates were rounded to the nearest rate actually applied so that observed net returns could be calculated without bias introduced by curve fitting.

Comparisons presented in Tables 8 and 9 show that for $0.55/kg N, the ASOR system resulted in lower N rates than the conventional system, but it provided net returns that were similar to or greater than the conventional system. This finding should not be surprising because the conventional recommendations were not selected to fit this particular dataset. This comparison is of interest, however, because it demonstrates that recommendations for a relatively wide range of conditions result in higher rates of fertilization and lower profits than do recommendations for specific conditions.

Other comparisons in Tables 8 and 9 show that the MEOR system resulted in lower net returns than did either the ASOR or the conventional system. This comparison is of interest because it shows that the means of the economic optimum rates of fertilization observed at individual sites did not provide a good recommendation for the sites from which the observations were made. This problem was recently discussed by Blackmer et al. (1992b), and it raises important questions concerning the procedures by which fertilizer recommendations have been derived from datasets.

Comparisons of the ideal system with the other system shows the potential benefits that could be attained if it were possible to identify exact needs for fertilizer on a site-specific basis. When compared to the other systems, the ideal system would have enabled higher net returns to fertilization with lower rates of fertilization. It should be noted that the term ideal is appropriate only if it is assumed that it is not possible to change method or time of fertilization. The overall point illustrated in Tables 8 and 9 is that optimal rates of fertilization tend to vary with amounts of information available.

Frequency distribution diagrams of optimal rates of fertilization as indicated by the QRP model (Fig. 5) illustrate that N fertilizer requirements were extremely variable within a specified price scenario. An important point illustrated by such diagrams is that any single rate applied to all sites will be above or below the optimal rate at most individual sites. A point that logically follows is that the problem of selecting an appropriate average rate of fertilization for many sites is much less important than adjusting rates for differences between sites and years. Such adjustments would be facilitated by a better understanding of the factors affecting N fertilizer needs.

Rainfall is an obvious factor that could possibly explain differences in N fertilizer requirement among sites and years. Linear regression analysis indicated that in-season rainfall explained 9% of the variability of within-site optimal rates of fertilization as indicated by the QRP model when all sites were analyzed and 3% of the variability of

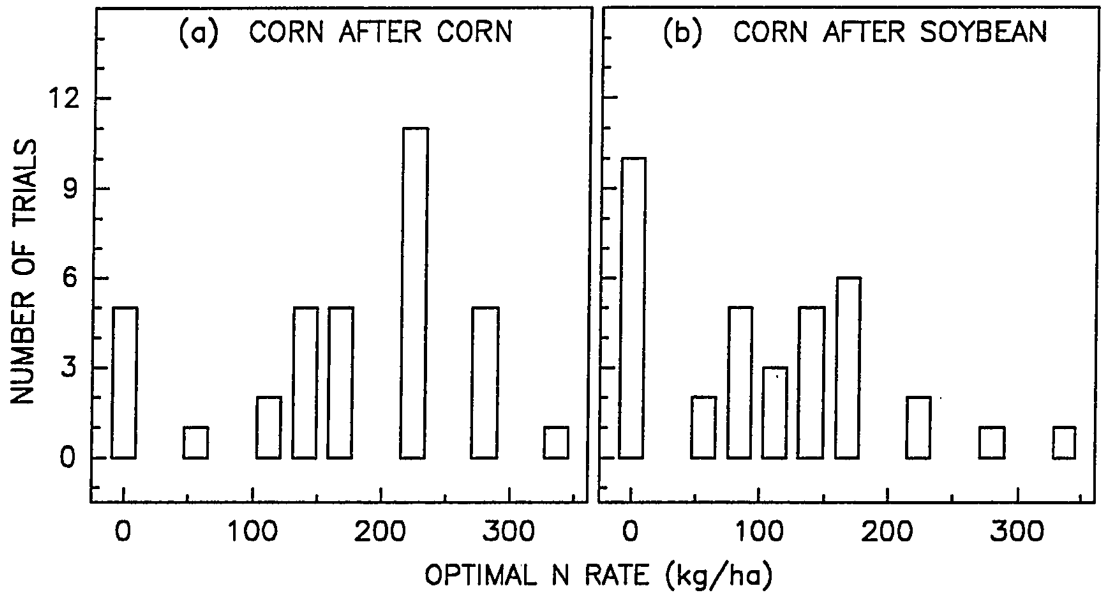

Fig. 5. Frequency distribution of optimal N rates determined by the quadratic-response-and-plateau model at a fertilizer-to-corn price ratio of 3.36; (a) corn after corn, (b) corn after soybean.

optimal N rates for the four sites having five years of data. Analyses of variance for the four sites having five years of data revealed that site and rotation were much more important than rainfall (Table 10). The great importance of site-related factors suggests that data collected at a site over a period of years may provide a better basis for making a recommendation at that site than does data collected at many sites over a period of years.

Yield potential of individual sites is another obvious factor that could possibly explain the importance of sites, and significant relationships between optimal rates and plateau yields were obtained (Fig. 6). However, linear regression analyses for the four sites having five years of data showed that yield plateau explained only 13% of the variability of optimal N rates as identified by the QRP model for corn after corn and 30% for corn after soybean. This indicates that yield potential had little importance as a factor affecting N fertilizer requirements under the conditions of this study.

Differences between rotations in fertilizer N needs are important because fertilizer recommendations for corn after soybean are often based on credits for N seemingly supplied by the soybean. When assessments were made by the QRP model within sites and years, N fertilizer requirements averaged about 60 kg N ha^{-1} greater for corn after corn than for corn after soybean. The mean difference was only slightly influenced by assumed prices of fertilizer and grain; it ranged from 56 to 67 kg N ha^{-1} for the prices considered (Table 7). It should be noted, however, that differences in N fertilizer requirements varied greatly among the

Table 10. Variability of optimal N rates determined by the quadratic-response-and-plateau model as influenced by year, site, and rotation for four sites over five years.

Source	Sum of squares	Variability explained
		% of total
Year	30473	9.3
Site	98057	30.0
Rotation	66097	20.2

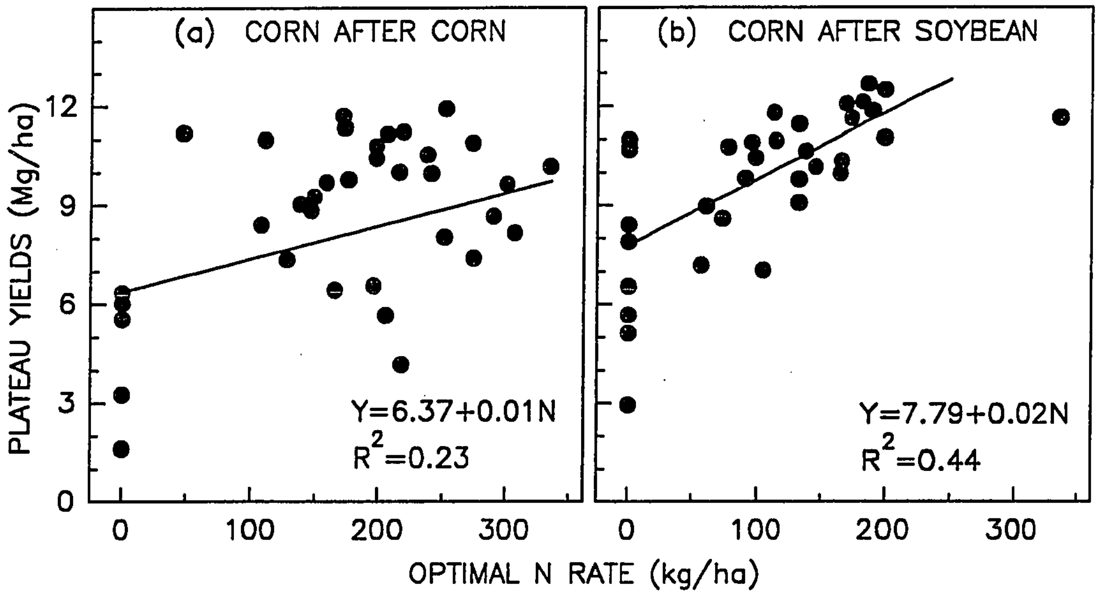

Fig. 6. Relationship between plateau yields and optimal N rates determined by the quadratic-response-and-plateau-model at a fertilizer-to-corn price ratio of 3.36; (a) corn after corn, (b) corn after soybean.

four models considered. This is noteworthy because it suggests that current perceptions of appropriate "nitrogen credits" may be greatly influenced by bias introduced during curve fitting.

The differences in N fertilizer requirement varied greatly among sites and years. Analysis of variance (Table 11) revealed that year effects explained the greatest portion of the variability. Linear regression analysis indicated that the effects of rainfall explained only 1% of the variability of difference in N rates between rotations. The frequency distribution of differences in N fertilizer requirements observed in this study (Fig. 7) clearly indicates that any single value for nitrogen credits would be too high or too low for most sites. These observations give reason to question the assumption that N fertilizer needs for corn after soybean should be estimated by considering N fertilizer for corn after corn and N credits.

Detailed analyses presented in an accompanying manuscript show that concentrations of NO^{-}_{3} in the surface 30-cm layer of soil when corn plants are 15 to 30 cm tall can be used to explain much of variability in fertilizer requirement among the sites and years. Evidence presented suggests that a soil test based on these NO^{-}_{3} concentrations can be used to adjust N fertilization rates toward optimal on a site-specific basis.

Table 11. Variability of the difference in optimal N rates between rotations determined by the quadratic-response-and-plateau model as influenced by year and site for four sites over five years.

Source	Sum of squares	Variability explained
		% of total
Year	30317	36.1
Site	14277	17.0

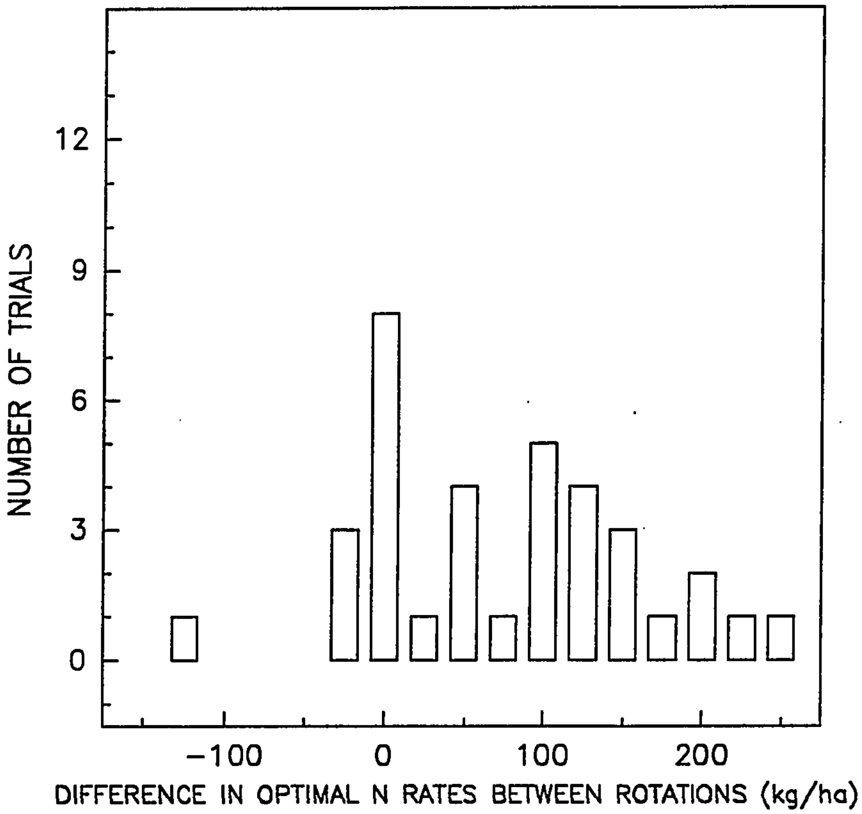

Fig. 7. Frequency distribution of the difference in optimal N rates between rotations determined by the quadratic-response-and-plateau model at a fertilizer-to-corn price ratio of 3.36.

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PAPER II. CRITICAL CONCENTRATIONS OF LATE-SPRING SOIL NITRATE FOR CORN

INTRODUCTION

Soil tests measuring concentrations of NO^-_3 in the surface 30 cm of soil when corn plants are 15 to 30 cm tall have been proposed and established as useful tools for improving N management in corn production (Magdoff et al., 1984, 1990; Blackmer et al., 1989; Fox et al., 1989; Binford et al., 1992a; Meisinger, et al., 1992; Roth et al., 1992). These tests offer growers the advantage of site-specific information for use in determining N fertilizer requirements. The difficulty of predicting N fertilizer requirements without a soil test (Blackmer et al., 1992) and the evidence of excess N in cornfields (El-Hout and Blackmer, 1990; Morris and Blackmer, 1989, 1990) suggests that improvements in fertilizer recommendations could be made by the use of such site-specific information. Remarkable agreement of critical concentrations of soil NO^-_3 separating responsive from non-responsive soils in the range of 20 to 26 mg N kg^{-1} has been observed by researchers across a wide range of environments (Blackmer et al., 1989; Fox et al., 1989; Binford et al., 1992a; Meisinger et al., 1992).

Although close agreement in soil NO^-_3 critical concentrations across environments has been observed, it is possible that the performance of the test could be improved if environments having different critical concentrations could be identified. Morris (1993) demonstrated this possibility by showing that critical concentrations of soil NO^-_3 for corn after alfalfa and second-year corn after alfalfa in Iowa are in the range of 10 to 15 mg N kg^{-1}. The lower critical concentration for these cropping systems was attributed to N from the alfalfa that had not yet mineralized at the time the soil samples were collected, but was available to the corn later in the season.

Another example of an environmental difference that could influence critical concentrations of soil NO^-_3 is early season rainfall. It has been shown that downward movement of NO^-_3 is often significant during the first few weeks after application and that this movement is greatly influenced by preferential movement of water through soil macropores (Cerrato et al., 1985; Pottker et al., 1987). Binford et al. (1992a) found a good correlation between NO^-_3 concentrations in the 0- to 30-cm and the 30- to 60-cm layers of soil. As rainfall moves NO^-_3 through the soil profile, however, it is possible that the ratio of NO^-_3 in the surface layer and the rest of the rooting zone changes. This could result in different critical concentrations when different amounts of rainfall are received. If differences in early season rainfall result in different critical concentrations of soil NO^-_3, this information would be of great use. Growers could monitor rainfall and adjust critical concentrations accordingly.

This study was conducted to evaluate the effects of early season rainfall on critical concentrations of soil NO^-_3 and to evaluate the possibility of adjusting soil NO^-_3 concentrations using early season rainfall. The study was prompted by the casual observation that critical concentrations of soil NO^-_3 tended to be lower in wet years compared to dry years. Relationships between soil NO^-_3 concentrations and corn grain yields for 1990, 1991, and 1992 are presented along with six-year evaluations including data previously reported (Binford et al., 1992a).

MATERIALS AND METHODS

Thirty-four N response trials were conducted in Iowa during 1990, 1991, and 1992 (Tables 1 and 2). Ten rates of N (0, 28, 56, 84, 112, 140, 168, 224, 280, and 336 kg ha^{-1}) were applied as $(NH_4)_2SO_4$ in three replications to corn following corn and corn following soybean. The same N treatments were applied to the corn after corn plots each year. Corn after soybean plots received the same N treatments every-other year (N fertilizers were not applied to the soybean crops). The plots were 12.2 by 4.6 m (six 76-cm rows) or 12.2 by 3.9 m (four 97-cm rows) and were arranged in a randomized complete block design.

Phosphorus and K were applied to all plots at 30 and 55 kg ha^{-1} as triple superphosphate and KCl, respectively. To avoid possible responses to S from the $(NH_4)_2SO_4$ fertilizer, $CaSO_4 \cdot 2H_2O$ was applied to the 0, 28, 56, and 84 kg N ha^{-1} treatments so that the total amount of S applied to each plot was at least equal to that applied with the 112 kg N ha^{-1} $(NH_4)_2SO_4$ treatment. All fertilizers were broadcast and incorporated shortly before planting.

Planting usually occurred during the last week of April or the first week of May at rates of 60,000 to 72,000 seeds ha^{-1}. Grain yields were determined by hand harvesting segments of the center two rows of each plot (6.1-m segments in 1990; 7.6-m segments in 1991 and 1992). Grain yields were adjusted to 155 g kg^{-1} moisture content. With the exception of fertilizer application and grain harvest, all plots were managed by practices commonly used in production agriculture.

Soil samples were collected when corn plants were 15 to 30 cm

Table 1. Soil descriptions at each experimental location.[a]

Location	Series	Subgroup	pH	N	P	K
				g/kg	-- mg/kg --	
Kalona	Bremer	Typic Haplaquoll	6.5	2.0	108	254
Holstein	Galva	Typic Hapludoll	5.8	2.2	19	176
Badger	Canisteo	Typic Haplaquoll	7.8	3.3	5	132
Kensett	Crippin	Aquic Hapludoll	7.9	3.0	13	122
Nashua	Readlyn	Aquic Hapludoll	5.8	1.6	15	114
Wapello	Titus	Fluvaquentic Haplaquoll	6.3	1.9	34	178
Wyman	Mahaska	Aquic Argiudoll	5.3	1.9	16	176
Calumet	Primghar	Aquic Hapludoll	5.8	2.1	8	167

[a]Soil samples were taken from the 0- to 30-cm layer of soil; N = Total Kjeldahl-N; P = Bray-1 extractable P; K = exchangeable K.

Table 2. Individual experiment information.

Year	Location	Previous crop	Corn Hybrid[a]	R^2 of QRP model[b]	Tillage performed[c]
1990	Kalona	Corn	P3379	0.84	FC,SD,SE,P,R
1990	Kalona	Soybean	P3379	0.50	SD,SE,P,R
1990	Holstein	Corn	P3475	0.83	FH,FD,SD,SE,P,R
1990	Holstein	Soybean	P3475	0.41	FD,SE,P,R
1990	Badger	Corn	P3467	0.88	FH,FV,SE,SE,P,R
1990	Badger	Soybean	P3467	0.31	SE,SE,P,R
1990	Kensett	Corn	P3475	0.92	FM,SE,SE,P,R
1990	Kensett	Soybean	P3475	0.75	FC,SE,SE,P,R
1990	Nashua	Corn	P3578	0.80	FC,SE,SE,P,R
1990	Nashua	Soybean	P3578	0.70	SE,SE,P,R
1990	Wyman	Corn	P3379	0.46	FC,SD,SE,P,R
1990	Wyman	Soybean	P3379	0.24	SD,SE,P,R
1990	Calumet	Corn	DK535	0.77	SD,SD,SE,P,R
1990	Calumet	Soybean	DK535	MF	SD,SE,P,R
1991	Kalona	Corn	P3417	0.37	FC,SD,SE,P,R
1991	Kalona	Soybean	P3417	MF	SD,SE,P,R
1991	Holstein	Corn	P3475	0.86	FD,SD,SE,P,R
1991	Holstein	Soybean	P3475	0.45	FD,SD,SE,P,R
1991	Badger	Corn	P3751	0.89	FH,FV,SE,SE,P,R
1991	Badger	Soybean	P3751	0.81	SE,SE,P,R
1991	Kensett	Corn	P3615	0.74	FM,SE,SE,P,R,R
1991	Kensett	Soybean	P3615	0.56	FC,SE,SE,P,R
1991	Nashua	Corn	RX746	0.75	FC,SE,SE,P,R
1991	Nashua	Soybean	RX746	0.64	SE,SE,P,R
1991	Wyman	Corn	RX746	MF	FC,SD,SE,P,R
1991	Wyman	Soybean	RX746	MF	SD,SE,P,R
1991	Calumet	Corn	DK535	0.81	FC,SD,SE,P,R
1991	Calumet	Soybean	DK535	0.21	SD,SE,P,R
1992	Nashua	Corn	P3578	0.84	FC,SD,SE,P,R
1992	Nashua	Soybean	P3578	0.95	SD,SE,P,R
1992	Wyman	Corn	P3394	0.66	FC,SD,SE,P,R
1992	Wyman	Soybean	P3394	0.68	SD,SE,P,R
1992	Calumet	Corn	P3563	0.86	FC,SD,SE,P,R
1992	Calumet	Soybean	P3563	0.67	SD,SE,P,R

[a]P-Pioneer, DK-Dekalb, RX-Asgrow.

[b]R^2 value of the QRP model relating grain yield to fertilizer N applied. MF-model failed to fit data. All R^2 values listed are statistically significant ($P < 0.05$).

[c]F-fall, S-spring; C-chisel plow, D-disk, E-field cultivator, H-stalk chopper, M-moldboard plow, P-planter, R-row cultivator, V-v-ripper.

tall (usually during late May or early June). Sampling was done by randomly collecting eight cores (3.2-cm diam.) from the 0- to 30-cm and the 30- to 60-cm layers of soil in each plot and then compositing each set of eight cores. Soil samples were dried in a forced-air oven at 49°C, ground to pass a 2-mm sieve, and extracted with 2*M* KCl using a 5:1 solution/soil ratio. The resulting solutions were then filtered through Whatman no. 5 paper and analyzed for exchangeable NH^{+}_{4}-N and NO^{-}_{3}-N by using either a MgO-Devarda alloy steam distillation procedure (Keeney and Nelson, 1982), or a Lachat flow-injection procedure (Lachat Instruments, Milwaukee, WI; Methods 12-107-06-2-A and 12-107-04-1-B).

Cornstalk samples were collected from ten plants within each plot 1 to 2 wk after black layer formation on the kernels of most ears. Sample collection involved cutting the stalk at 15 and 35 cm above the ground and removing dried leaves from the resulting 20-cm segment. The samples were dried at 60°C and then ground in a Wiley mill having a 1.0-mm screen. Nitrate concentrations were determined either by (i) shaking a portion of each tissue sample in 100 ml of 2*M* KCl for 30 minutes, filtering the resulting solutions through Whatman no. 5 paper, and analyzing for NO^{-}_{3}-N by using a MgO-Devarda alloy steam-distillation procedure (Keeney and Nelson, 1982), or by (ii) extracting in 0.025*M* $AL_2(SO_4)_3$ using a 1:50 tissue to extractant ratio, adding 1 ml of 2*M* $(NH_4)_2SO_4$ to the solutions to minimize ionic strength differences, and analyzing for NO^{-}_{3}-N using an Orion Model 93-07 NO^{-}_{3} specific electrode (Orion Research Inc., Boston, MA).

The NLIN procedure (Ihnen and Goodnight, 1985) was used to fit the linear-response-and-plateau (LRP) and quadratic-response-and-plateau (QRP) models. The LRP models were used to describe the relationships between grain yields and concentrations of soil NO^-_3 (or $NO^-_3 + NH^+_4$). The soil NO^-_3 (or $NO^-_3 + NH^+_4$) concentration at the intersection of the two lines of the LRP model defines the critical concentration (Waugh et al., 1973). Quadratic-response-and-plateau models were used to describe the relationship between grain yields and fertilizer N applied (Cerrato and Blackmer, 1990). Individual trials were considered nonresponsive to fertilizer N if the QRP model could not significantly ($P < 0.05$) describe the relationship of grain yields to fertilizer N applied.

The term "relative yield" is used to denote yield expressed as a percentage of the plateau yield from the QRP model relating yield to fertilizer N applied within each individual trial. If the QRP model could not significantly ($P < 0.05$) describe the relationship between yield and fertilizer N, then relative yield denotes yield expressed as a percentage of the mean of the four highest-yielding N-treatment means within an individual experiment.

Returns to fertilization were calculated by multiplying the yield increase above the control treatment by an assumed corn price and then subtracting assumed fertilizer and application costs.

RESULTS AND DISCUSSION

Rainfall amounts tended to be similar to or above long-term averages during the 1990, 1991, and 1992 growing seasons (Table 3). Two notable exceptions are Wyman and Kalona in 1991, where below average rainfall occurred. The trials previously described by Binford et al. (1992a) tended to receive below-average rainfall.

Within-trial models relating yields to concentrations of NO^-_3 and NO^-_3 + NH^+_4 in the 0- to 30-cm and in the 0- to 60-cm layers of soil are presented in Table 4. Critical concentrations generally were lower than those observed by Binford et al. (1992a) and Blackmer et al. (1989). The mean critical levels for NO^-_3 to 30 cm, for example, were 19 mg N kg^{-1} in the present study, 29 mg N kg^{-1} in the study reported by Binford et al. (1992a), and 25 mg N kg^{-1} in the study reported by Blackmer et al. (1989). It is likely that these differences were due to differences in amounts of precipitation.

Comparisons of R^2 values for the relationships shown in Table 4 indicate little benefit of sampling to 60 cm instead of only to 30 cm. They also indicate little benefit from including exchangeable NH^+_4 in the soil test. These observations are in agreement with previous reports (Blackmer et al., 1989; Binford et al., 1992a).

The across-trial relationships between relative yields and soil NO^-_3 N for three time periods (1987 to 1992, 1987 to 1989, and 1990 to 1992) are presented in Fig. 1 for corn after corn and in Fig. 2 for corn after soybean. Only N responsive trials are included in these figures because nonresponsive trials provide no basis for identifying critical

Table 3. Rainfall data for each location from April through September.

Year	Location	Dev.[a]	Rainfall amounts						
			April	May	June	July	Aug	Sept	Total
			mm						
1990	Kalona	+278	33	194	254	185	140	65	871
1990	Holstein	+215	61	191	239	209	48	15	763
1990	Badger	+254	57	195	270	203	83	42	850
1990	Kensett	+409	120	106	98	294	328	47	993
1990	Nashua	+353	102	109	175	340	195	53	974
1990	Wyman	+95	48	131	209	120	109	63	680
1990	Calumet	-44	14	92	182	140	72	41	541
1991	Kalona	-241	56	97	79	8	71	36	343
1991	Holstein	+36	127	157	122	18	104	53	582
1991	Badger	+193	229	201	97	56	170	38	790
1991	Kensett	+53	--	340	79	102	117	--	638
1991	Nashua	+127	175	178	155	58	124	53	747
1991	Wyman	-290	69	61	38	13	97	23	297
1991	Calumet	-58	120	119	76	74	81	56	526
1992	Nashua	-65	91	53	54	183	67	107	555
1992	Wyman	+4	59	20	27	264	58	163	592
1992	Calumet	+45	75	112	44	219	120	59	629

[a]Total deviation from long-term mean rainfall from April through September.

Table 4. Parameters for individual experiment models relating grain yields to concentrations of NO_3^- and to concentrations of NO_3^- + NH_4^- in the 0- to 30-cm and 0- to 60-cm layers of soil. Models were not significant ($\underline{P}$ < 0.05) at the four experiments not shown.

			LRP models for NO_3^- to 30 cm or to 60 cm										LRP models for NO_3^- + NH_4^+ to 30 cm or to 60 cm									
		Previous	Intercept		Slope		C.C.[a]		Plateau		R^2		Intercept		Slope		C.C.[a]		Plateau		R^2	
Year	Location	Crop[b]	0-30	0-60	0-30	0-60	0-30	0-60	0-30	0-60	0-30	0-60	0-30	0-60	0-30	0-60	0-30	0-60	0-30	0-60	0-30	0-60
			- Mg/ha -				mg N/kg		- Mg/ha -				- Mg/ha -				mg N/kg		- Mg/ha -			
1990	Kalona	C	5.69	5.21	0.44	0.50	14	13	11.9	11.8	0.75	0.80	4.42	3.47	0.40	0.51	19	17	11.9	11.9	0.70	0.81
1990	Kalona	S	8.88	9.19	0.17	0.16	19	18	12.0	12.1	0.50	0.52	9.04	6.95	0.12	0.31	25	16	12.0	11.9	0.46	0.49
1990	Holstein	C	5.01	3.15	0.25	0.62	17	10	9.3	9.1	0.70	0.78	0.11	-0.46	0.61	0.72	15	13	9.1	9.1	0.78	0.79
1990	Holstein	S	4.64	4.23	0.47	0.59	9	8	9.0	9.0	0.42	0.42	3.94	2.22	0.33	0.54	15	12	9.0	9.0	0.33	0.38
1990	Badger	C	2.65	3.50	0.43	0.40	16	16	9.6	9.7	0.68	0.70	2.00	2.23	0.32	0.36	24	21	9.5	9.6	0.55	0.59
1990	Badger	S	7.36	7.17	0.16	0.21	22	18	10.9	10.9	0.36	0.36	7.31	7.21	0.12	0.16	29	24	10.9	10.9	0.27	0.26
1990	Kensett	C	1.06	1.71	0.57	0.61	16	14	10.4	10.5	0.89	0.92	-1.18	-0.43	0.53	0.62	22	17	10.4	10.5	0.92	0.92
1990	Kensett	S	4.83	5.18	0.47	0.50	13	11	10.8	10.9	0.75	0.85	3.55	3.00	0.37	0.54	20	15	10.9	10.9	0.84	0.89
1990	Nashua	C	4.06	2.34	0.41	0.59	17	15	11.0	10.9	0.72	0.83	2.30	0.54	0.42	0.58	21	18	11.0	10.9	0.73	0.83
1990	Nashua	S	6.01	6.01	0.34	0.40	17	15	11.9	11.9	0.76	0.81	5.34	4.53	0.31	0.43	21	17	11.9	11.9	0.75	0.80
1990	Wyman	C	6.23	5.42	0.34	0.47	14	12	11.0	11.0	0.53	0.56	2.49	2.46	0.47	0.54	18	16	11.0	11.0	0.63	0.65
1990	Wyman	S	10.18	9.55	0.07	0.14	23	16	11.8	11.7	0.25	0.26	9.64	8.64	0.08	0.15	28	21	11.8	11.7	0.25	0.25
1990	Calumet	C	3.98	4.03	0.17	0.18	24	25	8.1	8.7	0.77	0.77	3.12	2.75	0.15	0.21	33	25	8.1	8.1	0.77	0.78
1991	Kalona	C	2.48	3.59	0.29	0.24	16	15	7.2	7.3	0.36	0.33	-3.50	2.94	0.59	0.22	18	20	7.2	7.2	0.40	0.35
1991	Holstein	C	2.14	2.02	0.32	0.46	24	17	9.6	9.7	0.87	0.87	1.49	0.70	0.27	0.41	30	22	9.6	9.6	0.86	0.87
1991	Holstein	S	3.76	5.40	0.46	0.32	13	14	9.7	9.7	0.46	0.46	4.71	4.82	0.22	0.25	23	19	9.7	9.7	0.46	0.43
1991	Badger	C	4.31	3.94	0.45	0.57	13	11	10.3	10.4	0.59	0.66	2.43	1.76	0.44	0.60	18	14	10.2	10.2	0.58	0.65
1991	Badger	S	7.65	7.81	0.29	0.31	15	14	12.1	12.1	0.81	0.83	6.46	6.73	0.28	0.32	20	17	12.1	12.1	0.78	0.80
1991	Kensett	C	2.75	2.49	0.52	0.70	13	10	9.7	9.7	0.83	0.85	1.22	0.35	0.41	0.60	21	15	9.6	9.7	0.65	0.77
1991	Kensett	S	2.58	1.68	0.45	0.68	14	10	8.9	8.6	0.72	0.71	0.98	1.02	0.38	0.47	20	16	8.7	8.7	0.60	0.57
1991	Nashua	C	5.54	5.34	0.21	0.27	20	16	9.7	9.8	0.75	0.76	5.09	4.81	0.19	0.25	24	20	9.7	9.8	0.76	0.78
1991	Nashua	S	6.32	6.44	0.20	0.23	20	17	10.3	10.4	0.62	0.64	5.92	4.79	0.18	0.33	24	16	10.3	10.2	0.62	0.63
1991	Wyman	C	1.33	0.79	0.22	0.37	19	12	5.4	5.4	0.35	0.31	0.44	0.27	0.19	0.26	26	20	5.4	5.5	0.31	0.33
1991	Calumet	C	3.13	2.75	0.11	0.19	32	19	6.7	6.4	0.77	0.66	1.98	2.57	0.13	0.13	33	29	6.4	6.5	0.77	0.67
1992	Nashua	C	3.58	ND[c]	0.30	ND	22	ND	10.3	ND	0.76	ND	3.07	ND	0.24	ND	31	ND	10.3	ND	0.71	ND
1992	Nashua	S	5.44	ND	0.33	ND	21	ND	12.5	ND	0.92	ND	4.71	ND	0.28	ND	28	ND	12.6	ND	0.89	ND
1992	Wyman	C	4.63	ND	0.17	ND	27	ND	9.2	ND	0.60	ND	3.96	ND	0.15	ND	36	ND	9.3	ND	0.61	ND
1992	Wyman	S	4.55	ND	0.33	ND	21	ND	11.5	ND	0.74	ND	3.60	ND	0.30	ND	27	ND	11.5	ND	0.73	ND
1992	Calumet	C	2.60	ND	0.23	ND	26	ND	8.6	ND	0.87	ND	0.86	ND	0.22	ND	35	ND	8.5	ND	0.84	ND
1992	Calumet	S	6.69	ND	0.13	ND	26	ND	10.0	ND	0.64	ND	5.69	ND	0.13	ND	34	ND	10.0	ND	0.64	ND
mean			4.67	4.54	0.31	0.40	19	14	10.0	9.9	0.66	0.65	3.37	3.20	0.29	0.40	25	18	10.0	9.9	0.64	0.64

[a]C.C. = Critical concentration in soil.
[b]C = corn; S = soybean.
[c]ND = No data.

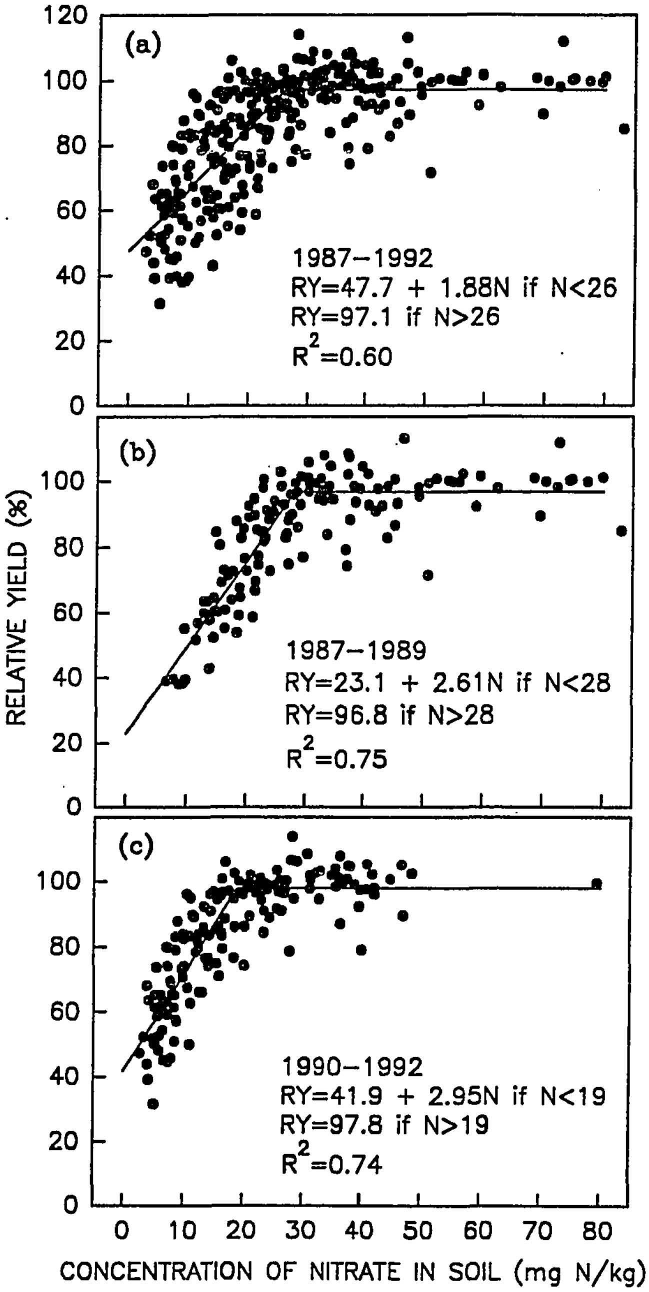

Fig. 1. Relationship between relative yields and concentrations of NO^-_3 in the surface 30 cm of soil for all corn after corn trials responsive to fertilizer N; (a) 1987 to 1992, (b) 1987 to 1989, (c) 1990 to 1992.

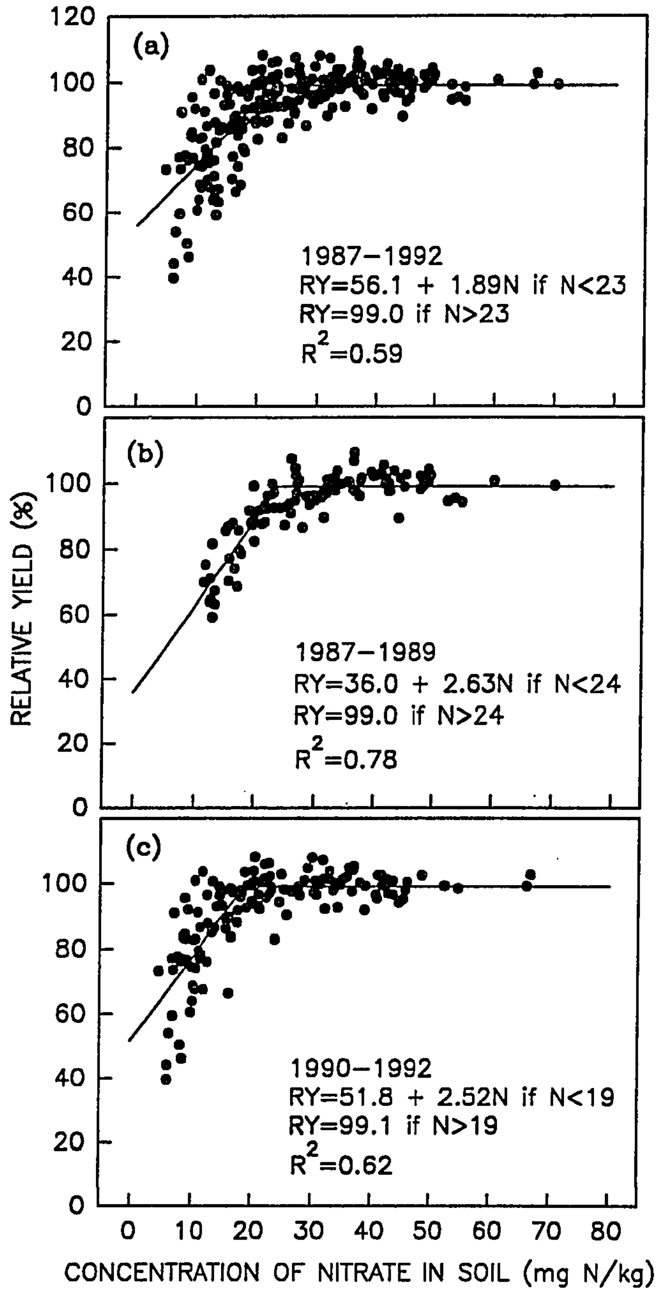

Fig. 2. Relationship between relative yields and concentrations of NO^-_3 in the surface 30 cm of soil for all corn after soybean trials responsive to fertilizer N; (a) 1987 to 1992, (b) 1987 to 1989, (c) 1990 to 1992.

concentrations. Binford et al. (1992a) showed that inclusion of nonresponsive trials decreases R^2 values for models, but had little effect on critical concentrations. Lower critical concentrations were observed during the wetter years (1990 to 1992) than during the drier years (1987 to 1989). For corn after corn the critical concentration was 19 mg N kg^{-1} for the wetter years and 28 mg N kg^{-1} for the drier years. For corn after soybean the critical concentration was 19 mg N kg^{-1} for the wetter years and 24 mg N kg^{-1} for the drier years. Because rainfall was the most obvious difference between the two groups of years, relationships between critical concentrations of soil NO^-_3 and early-season rainfall were studied.

Figure 3 shows that there was a statistically significant relationship between early-season rainfall and critical concentrations of NO^-_3 in individual trials. The relationship, however, did not have a high degree of predictability. Early season rainfall, (that which occurred between 1 April and the time of sample collection for the late-spring soil test), is of interest because users of the test could measure rainfall and make appropriate adjustments in soil test critical concentrations if necessary.

Analyses presented in Fig. 4 reveals that critical concentrations of soil NO^-_3 have little influence on plateau yields. This suggests that the relationship between rainfall and critical concentrations of soil NO^{-3} shown in Fig. 3 should not be attributed to the effects of rainfall on yield level. It seems likely, therefore, that the relationship in Fig. 3 is caused by the effects of rainfall on

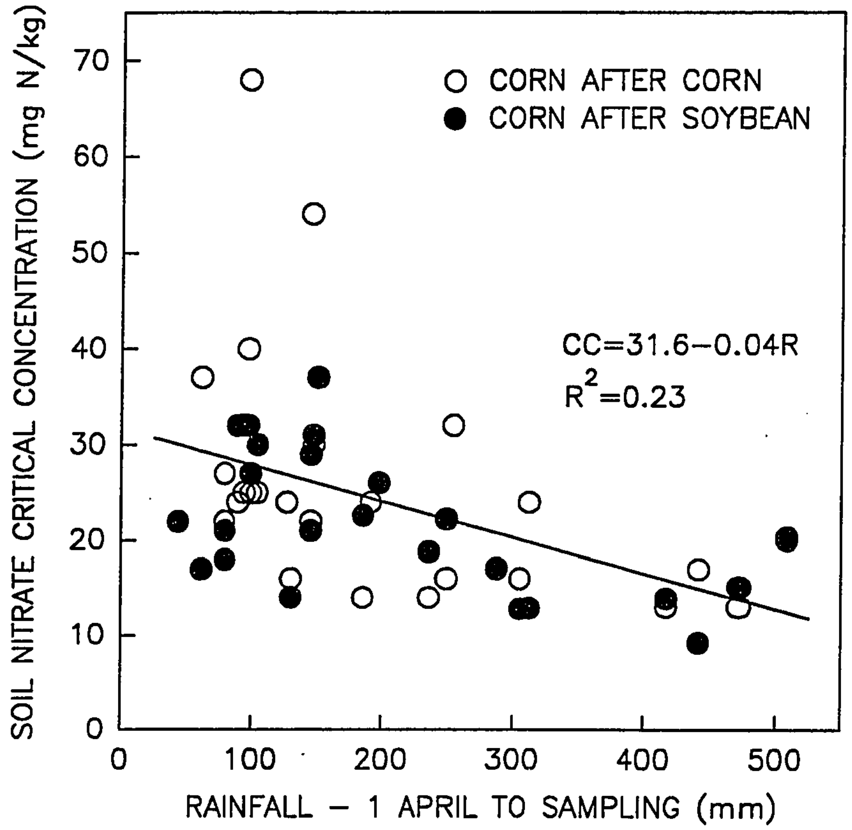

Fig. 3. Relationship between critical concentrations of late-spring soil NO^{-}_{3} in the surface 30 cm and rainfall amounts between 1 April and the time of sampling for all locations responsive to fertilizer N (1987 to 1992).

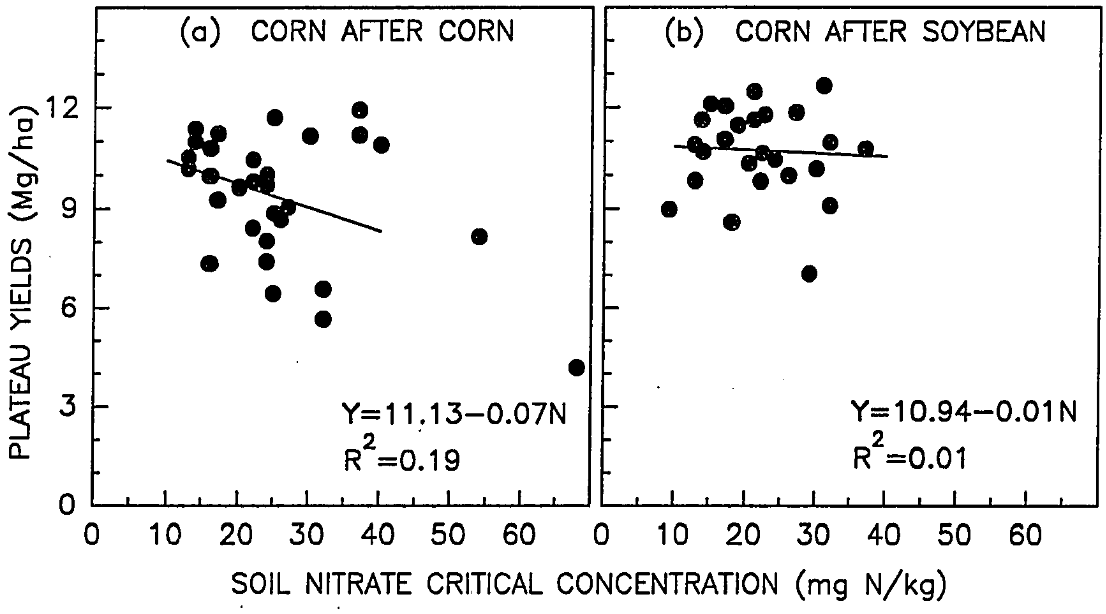

Fig. 4. Relationship between plateau yields determined by the QRP model and critical concentrations of late-spring soil NO^-_3 in the surface 30 cm determined by the LRP model where significant ($P < 0.05$).

distribution of NO^-_3 in the soil. If, for example, early season rainfall tended to move NO^-_3 from the surface layer to deeper layers within the rooting zone, then increasing rainfall would result in lower critical concentrations of NO^-_3. This possibility suggests that adjusting critical concentrations for early season rainfall could improve the reliability of the soil test.

The relationship in Fig. 3 was used to evaluate possible benefits of adjusting critical concentrations of soil NO^-_3 for early season rainfall. For reasons relating to ease of calculation, rainfall was actually used to adjust concentrations of soil NO^-_3. The slope of the line in Fig. 3 was used to make adjustments for rainfall above or below normal, which was assumed to be 140 mm. It was reasoned that this adjustment could be justified if it resulted in better relationships than those shown in Fig. 1 and 2. The relationships obtained are illustrated in Fig. 5 and 6, where NO^-_3 concentrations were adjusted upward for above-normal rainfall and downward for below-normal rainfall. The adjustment improved the predictability of the relationship for corn after corn (compare Fig. 1a and Fig. 5a), but it reduced the predictability of the relationship for corn after soybean (compare Fig. 2a and Fig. 6a). These observations suggest that the adjustment cannot be justified.

Although critical concentrations are usually identified by using relationships like those illustrated in Fig. 1 and 2, this method of identifying critical levels has two major shortcomings. The first, as noted by Blackmer et al. (1989), is that the determined value for critical concentration varies with the model used. The second, as noted

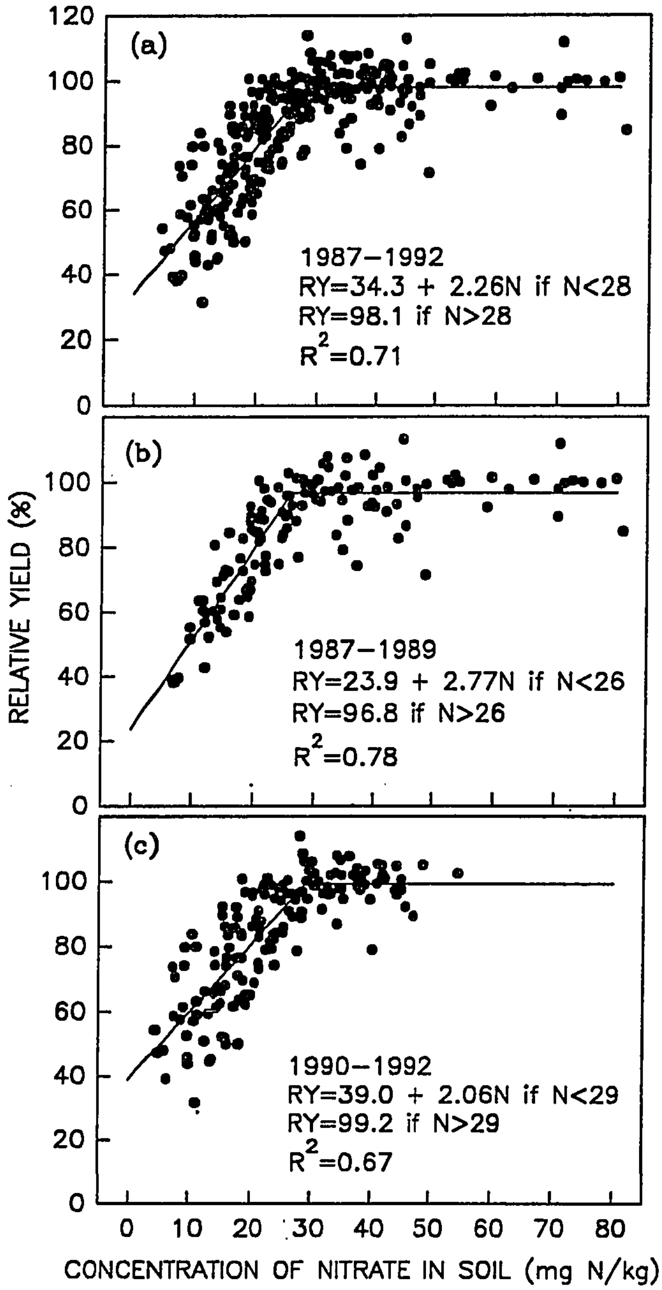

Fig. 5. Relationship between relative yields and rainfall-adjusted concentrations of NO^{-}_3 in the surface 30 cm of soil for all corn after corn trials responsive to fertilizer N; (a) 1987 to 1992, (b) 1987 to 1989, (c) 1990 to 1992.

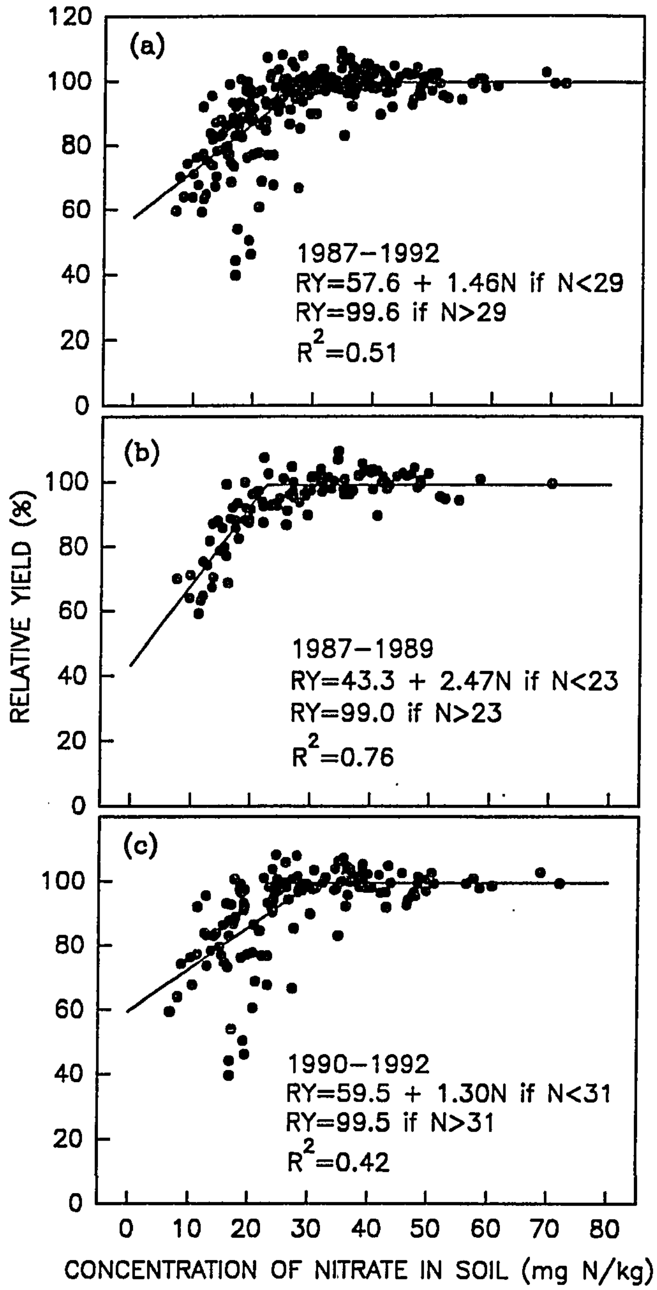

Fig. 6. Relationship between relative yields and rainfall-adjusted concentrations of NO^-_3 in the surface 30 cm of soil for all corn after soybean trials responsive to fertilizer N; (a) 1987 to 1992, (b) 1987 to 1989, (c) 1990 to 1992.

by Mallarino and Blackmer (1992), is that the relationship does not reflect the economic rational of fertilization. Mallarino and Blackmer suggested that these problems can be circumvented by using net returns to fertilization as the criteria for selecting critical concentrations. They proposed that the best critical concentration was the one that maximized net returns to fertilization in multi-field scenarios where the critical concentration was used to guide fertilization.

It was reasoned that an economically defensible critical concentration would be the concentration associated with highest net returns to preplant applications of fertilizer in multi-field scenarios. Figure 7 shows net returns to preplant fertilization associated with various concentrations of soil NO^{-3} in late spring. The scenarios consider two prices of N and two prices of corn. These prices generally bracket those observed during the study. Each data point shown in Fig. 7 represents the mean net returns for a range of NO^{-}_3 concentrations extending from two mg N kg^{-1} below to two mg N kg^{-1} above the concentration indicated. The results show that the profit-maximizing critical concentration of NO^{-}_3 for corn after corn was about 25 mg N kg^{-1}, which is essentially the same as shown in Fig. 1. Net returns to fertilization changed little with NO^{-}_3 concentrations near 25 mg N kg^{-1}. This observation, therefore, suggests that the critical concentration identified in Fig. 2 is appropriate. The finding that net returns to fertilization could not be increased by adjusting NO^{-}_3 concentrations for rainfall (Fig. 8) supports the conclusion that these adjustments cannot be justified.

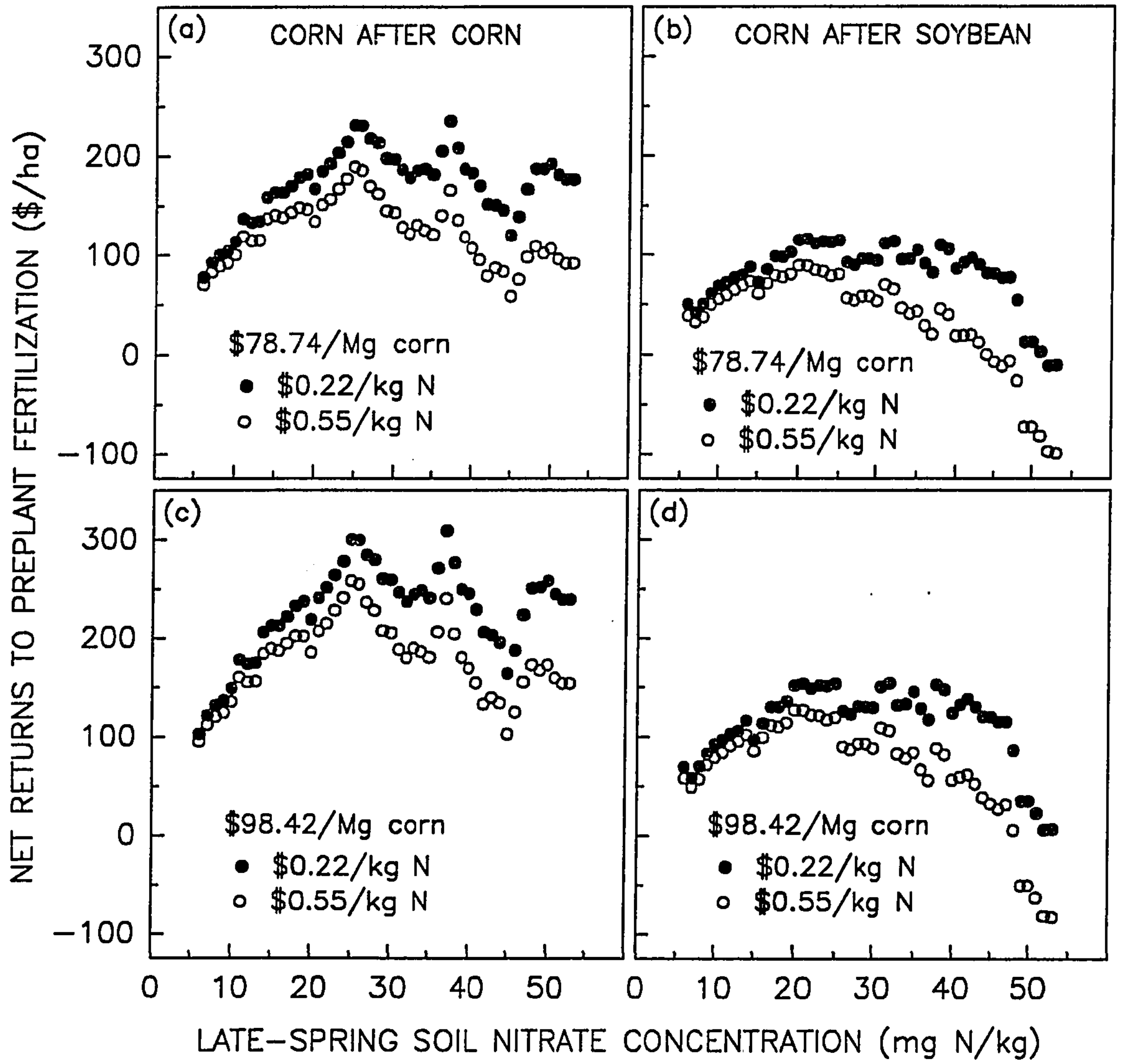

Fig. 7. Relationship between mean returns to preplant N fertilization and late-spring concentrations of NO_3^- in the surface 30 cm of soil at selected corn and N fertilizer prices for corn after corn and corn after soybean.

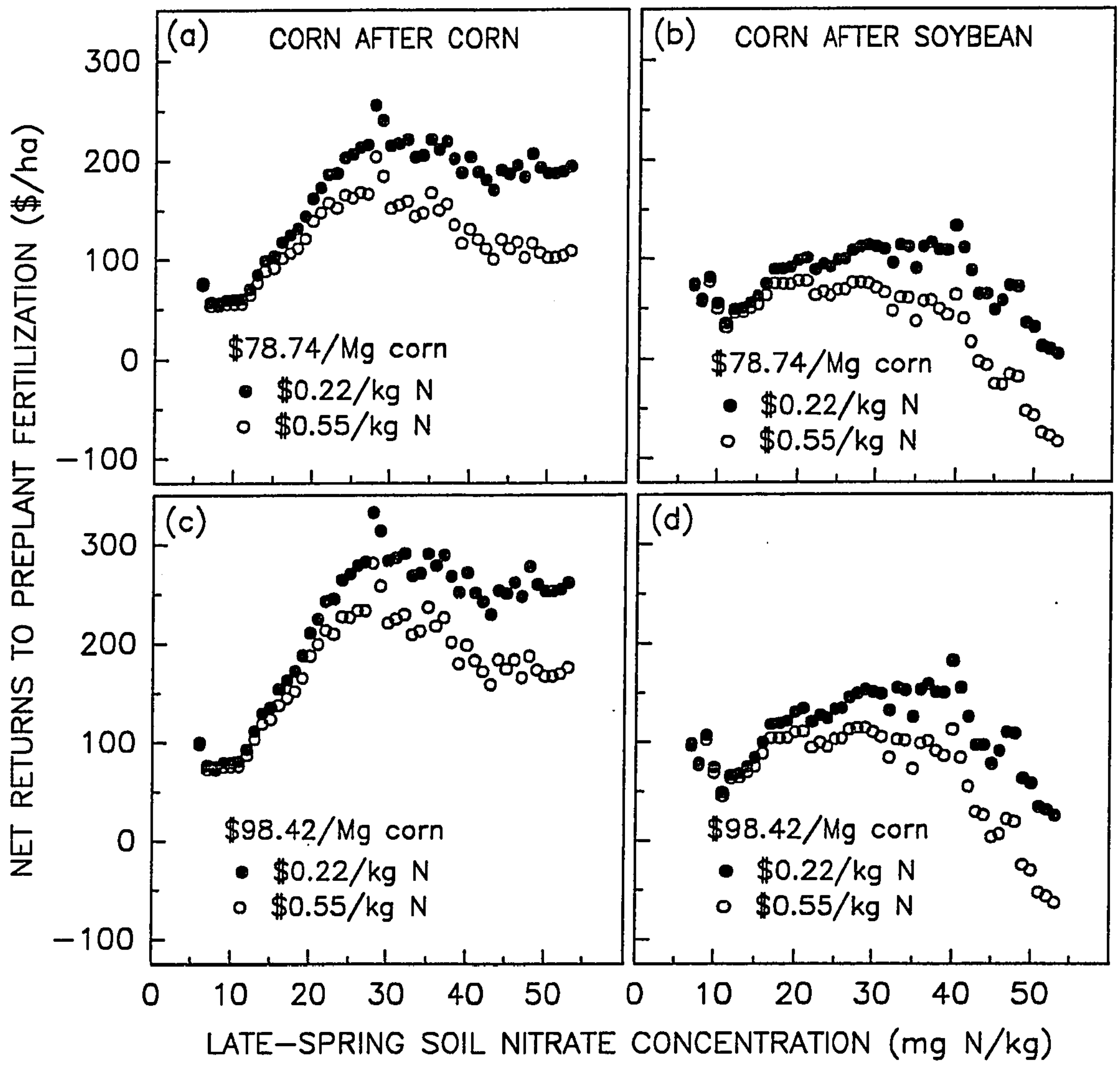

Fig. 8. Relationship between mean returns to preplant N fertilization and rainfall-adjusted concentrations of NO^-_3 in the surface 30 cm of soil at selected corn and N fertilizer prices for corn after corn and corn after soybean.

A third method of evaluating the effect of rainfall on critical concentrations of soil NO^-_3 involves use of the end-of-season cornstalk NO^-_3 test. This test has been shown to be a good indicator of the N status of cornfields at the end of the growing season (Binford et al., 1990; Binford et al., 1992b). It is noteworthy that critical concentrations for this tissue test were determined by considering net returns to fertilization in multi-field scenarios. We reasoned that adjustments of critical concentrations of soil NO^-_3 for rainfall could be justified if they resulted in better relationships with end-of-season stalk NO^-_3 concentrations.

Figures 9 and 10 show relationships between grain yields and soil NO^-_3 concentrations for individual trials from this study and from trials where stalk samples were collected from the previous study (Binford et al., 1992a). The currently recommended critical concentration range for the late-spring soil NO^-_3 test (Blackmer et al., 1991) is indicated with vertical lines on these figures. Stalk NO^-_3 concentrations are also shown by using different symbols to denote concentration ranges associated with deficiencies (<0.7 g N kg^{-1}), optimal supplies (0.7 - 2.0 g N kg^{-1}) or excesses of available N (>2.0 g N kg^{-1}). Agreement between the soil test and the end-of-season cornstalk test is indicated when deficiencies as indicated by the stalk test are observed only below critical concentrations by the soil test and when excesses as indicated by the stalk test are only observed above critical concentrations by the soil test.

The data presented in Fig. 9 and 10 is easier to evaluate when

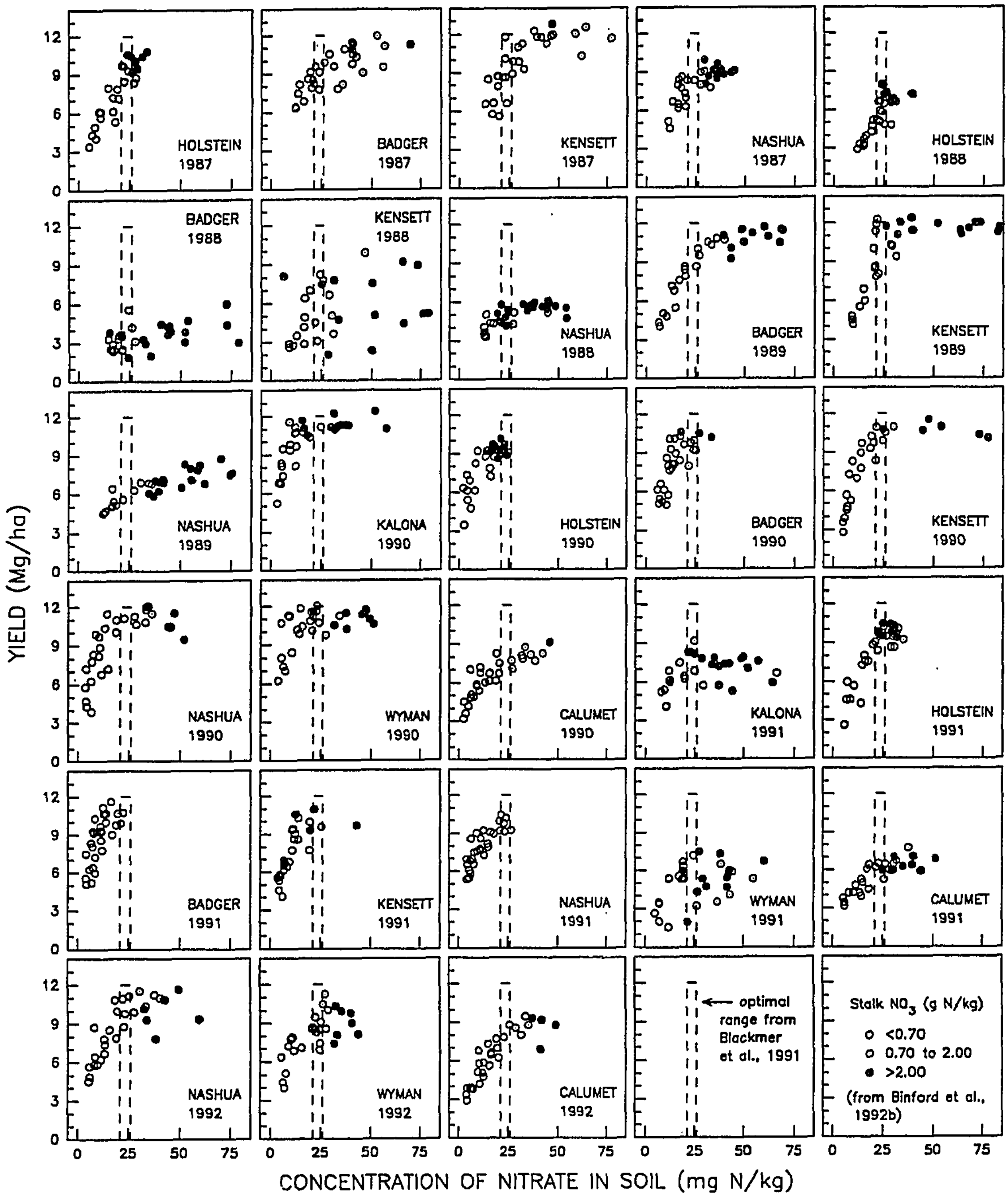

Fig. 9. Relationship between grain yields and concentrations of NO^-_3 in the surface 30 cm of soil for corn after corn.

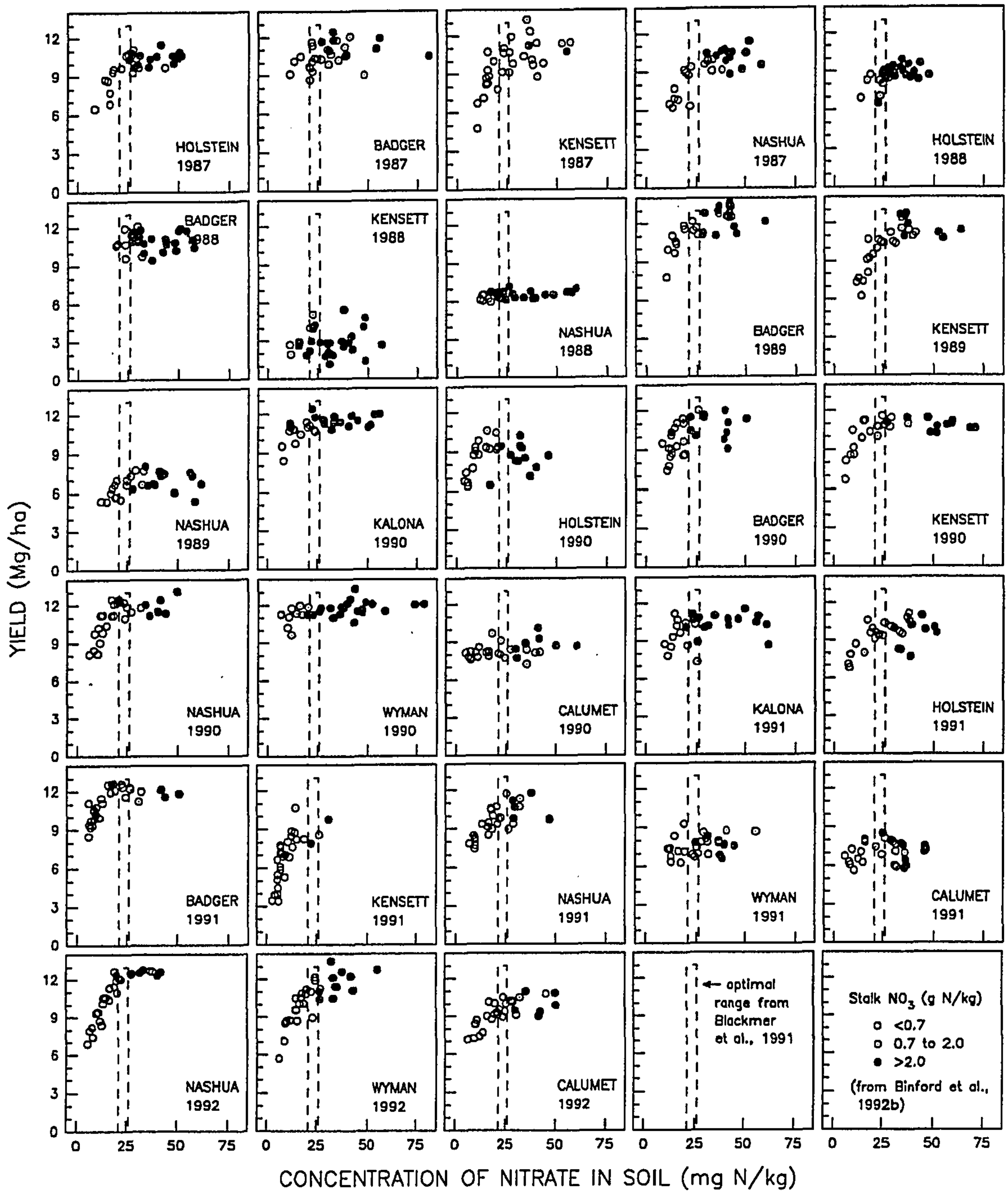

Fig. 10. Relationship between grain yields and concentrations of NO^-_3 in the surface 30 cm of soil for corn after soybean.

it is summarized as shown in Table 5. The range of stalk NO^-_3 concentrations considered deficient by Binford et al. (1990) is included in the table with the concentration ranges considered deficient and excess by Binford et al. (1992b). The summary presented in this table clearly indicates good agreement between the soil test and the end-of-season cornstalk test. We reasoned that adjusting soil NO^-_3 concentrations for rainfall could be justified if it resulted in better agreement between the soil test and the stalk test (i.e., having higher percentages of the cornstalk NO^-_3 fall within the optimal range when soil NO^-_3 concentrations are near the critical concentration). Data presented in Table 6 shows that agreement between the tests was not improved by adjusting soil NO^-_3 concentrations for rainfall. This supports the conclusion that the adjustments cannot be justified.

Overall, the results show that although early season rainfall does have an effect on late-spring soil NO^-_3 concentrations, it does not appear that a simple adjustment of soil NO^-_3 based on rainfall can be justified. The results also suggest that although critical concentrations of late-spring soil NO^-_3 for corn after soybean are sometimes slightly lower than for corn after corn, this difference does not appear large enough to be of practical importance.

Table 5. End-of-season stalk nitrate concentrations as influenced by late-spring soil nitrate concentrations.

Late-spring soil NO^-_3 conc.	Percentage of stalks in specified concentration range: Corn after corn, stalk NO^-_3 conc. (g N/kg) <0.25	<0.70	>2.00	Corn after soybean, stalk NO^-_3 conc. (g N/kg) <0.25	<0.70	>2.00
mg N/kg	%					
			1987-1992			
0-9	97	99	1	98	100	0
10-19	77	88	7	70	80	5
20-24	40	57	21	39	53	22
25-29	33	47	31	14	29	52
30-34	18	27	52	5	17	63
35-44	3	8	69	2	6	77
>44	3	6	80	2	2	89
			1987-1989			
0-9	93	93	7	100	100	0
10-19	83	94	4	72	83	7
20-24	47	67	21	45	55	25
25-29	34	44	34	12	27	59
30-34	21	32	54	7	19	60
35-44	7	13	70	3	8	76
>44	2	5	77	5	5	84
			1990-1992			
0-9	98	99	0	98	100	0
10-19	73	85	8	69	79	3
20-24	34	49	22	35	51	19
25-29	35	48	28	12	32	44
30-34	16	24	50	2	16	64
35-44	0	2	67	1	4	78
>44	7	7	86	0	0	94

Table 6. End-of-season stalk nitrate concentrations as influenced by rainfall-adjusted late-spring soil nitrate concentrations.

Adjusted late-spring soil NO^-_3 conc.	Percentage of stalks in specified concentration range					
	Corn after corn			Corn after soybean		
	stalk NO^-_3 conc. (g N/kg)			stalk NO^-_3 conc. (g N/kg)		
	<0.25	<0.70	>2.00	<0.25	<0.70	>2.00
mg N/kg	%					
			1987-1992			
0-9	100	100	0	85	96	0
10-19	85	92	3	75	83	6
20-24	61	73	16	56	67	17
25-29	38	52	25	23	39	40
30-34	20	33	49	14	25	53
35-44	8	14	56	5	11	68
>44	3	6	84	2	3	88
			1987-1989			
0-9	100	100	0	67	89	0
10-19	76	87	5	70	78	13
20-24	48	66	30	40	52	30
25-29	31	40	38	6	21	62
30-34	8	24	60	5	13	65
35-44	4	9	67	3	8	76
>44	2	6	81	5	5	84
			1990-1992			
0-9	100	100	0	94	100	0
10-19	90	96	2	79	86	2
20-24	68	77	10	65	74	9
25-29	42	61	15	37	54	22
30-34	26	37	44	20	34	45
35-44	11	17	49	6	13	62
>44	6	6	88	0	1	91

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GENERAL SUMMARY

The studies reported in this dissertation were designed to provide useful information for corn growers concerning yields and N fertilization of corn after corn and corn after soybean. Seventeen response trials were conducted comparing these two rotations from 1990 to 1992. Data collected during 1987, 1988, and 1989 was included to provide a six-year analysis for much of the work. The primary objectives of these studies were (i) to determine plateau yields of corn after corn and corn after soybean, (ii) to determine economic optimum rates of N fertilization for corn after corn and corn after soybean, and (iii) to evaluate the effects early season rainfall on critical concentrations of late-spring soil $NO^-{}_3$.

Rainfall amounts varied considerably among the years and locations in which the study was conducted. The results in paper I indicate that moisture availability and other characteristics specific to a given year were the major factors influencing corn yields. Mean plateau yields for corn after soybean averaged 12% higher than the corresponding means for corn after corn. The yield advantage for corn after soybean increased in the drought affected 1988 season and decreased in the 1989 season, possibly due to reduced moisture availability for the corn after soybean.

Nitrogen requirements for each rotation and the difference in N requirements between rotations varied considerably among years and locations in which the study was conducted. Estimates of optimal amounts of N fertilizer were shown to be profoundly influenced by the model used to describe the relationships between yields and N rates applied. Assumed corn and N fertilizer prices were also shown to influence optimal N rates. Site related factors and the interaction of site with year were shown to have the greatest influence on optimal N rates within a given model and price scenario. It was illustrated that an "ideal" system of applying optimal rates of N at each individual site resulted in reduced N rates and greater net returns to fertilization than systems based on the mean economic optimum rate, the across site economic optimum rate, or rates determined from yield goals and credits for legumes. This example showed the potential for improving N recommendations based on site-specific information.

The results in paper II indicated that, although late-spring soil NO^-_3 concentrations for corn after soybean were sometimes slightly lower than for corn after corn, the difference does not appear large enough to be of practical importance. Linear-response-and-plateau model relationships between yields and soil NO^-_3 concentrations, net returns to preplant fertilization, and the end-of-season cornstalk NO^-_3 test were used to evaluate the influence of early season rainfall on critical concentrations of late-spring soil NO^-_3. The relationship between critical concentrations of soil NO^-_3 at individual trials and early season rainfall was used to adjust soil NO^-_3 concentrations. This adjustment, however, gave little improvement in predictability of the late-spring soil test, in returns to N fertilization across NO^-_3 concentrations, or in agreement with end-of-season stalk test results.

Overall, the results of the studies conducted indicate that substantial variability in yields and optimal N rates can be expected. The results also showed the potential that site-specific information such as provided by the late-spring soil NO^-_3 test or end-of-season stalk NO^-_3 test can have for improving N fertilizer recommendations.

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APPENDIX

Table 1. Nitrogen needs for corn after corn as indicated by the linear-response-and-plateau model.

Year	Location	Rates to maximize yield	Economic optimum rates at various prices: $98.42/Mg corn, $0.22/kg N	$98.42/Mg corn, $0.55/kg N	$78.74/Mg corn, $0.22/kg N	$78.74/Mg corn, $0.55/kg N
		kg N/ha				
1987	Kalona	106	106	106	106	106
1987	Holstein	152	152	152	152	152
1987	Badger	201	201	201	201	201
1987	Kensett	170	170	170	170	170
1987	Nashua	87	87	87	87	87
1987	Wapello	0	0	0	0	0
1988	Kalona	0	0	0	0	0
1988	Holstein	199	199	199	199	199
1988	Badger	280	280	0	280	0
1988	Kensett	115	115	115	115	115
1988	Nashua	185	185	185	185	185
1988	Wapello	0	0	0	0	0
1989	Kalona	35	35	35	35	35
1989	Holstein	107	107	107	107	107
1989	Badger	132	132	132	132	132
1989	Kensett	127	127	127	127	127
1989	Nashua	222	222	222	222	222
1989	Wapello	0	0	0	0	0
1990	Kalona	111	111	111	111	111
1990	Holstein	97	97	97	97	97
1990	Badger	150	150	150	150	150
1990	Kensett	133	133	133	133	133
1990	Nashua	144	144	144	144	144
1990	Wyman	82	82	82	82	82
1990	Calumet	213	213	213	213	213
1991	Kalona	112	112	112	112	112
1991	Holstein	104	104	104	104	104
1991	Badger	177	177	177	177	177
1991	Kensett	234	234	234	234	234
1991	Nashua	223	223	223	223	223
1991	Wyman	0	0	0	0	0
1991	Calumet	154	154	154	154	154
1992	Nashua	143	143	143	143	143
1992	Wyman	98	98	98	98	98
1992	Calumet	220	220	220	220	220
Mean		129	129	121	129	121

Table 2. Nitrogen needs for corn after soybean as indicated by the linear-response-and-plateau model.

Year	Location	Rates to maximize yield	Economic optimum rates at various prices			
			$98.42/Mg corn		$78.74/Mg corn	
			$0.22/kg N	$0.55/kg N	$0.22/kg N	$0.55/kg N
		kg N/ha				
1987	Kalona	0	0	0	0	0
1987	Holstein	68	68	68	68	68
1987	Badger	106	106	106	106	106
1987	Kensett	159	159	159	159	159
1987	Nashua	89	89	89	89	89
1987	Wapello	61	61	61	61	61
1988	Kalona	0	0	0	0	0
1988	Holstein	123	123	123	123	123
1988	Badger	0	0	0	0	0
1988	Kensett	0	0	0	0	0
1988	Nashua	0	0	0	0	0
1988	Wapello	0	0	0	0	0
1989	Kalona	56	56	56	56	56
1989	Holstein	41	41	41	41	41
1989	Badger	140	140	140	140	140
1989	Kensett	144	144	144	144	144
1989	Nashua	86	86	86	86	86
1989	Wapello	0	0	0	0	0
1990	Kalona	128	128	128	128	128
1990	Holstein	43	43	43	43	43
1990	Badger	127	127	127	127	127
1990	Kensett	66	66	66	66	66
1990	Nashua	137	137	137	137	137
1990	Wyman	107	107	107	107	107
1990	Calumet	266	266	0	266	0
1991	Kalona	140	140	140	140	140
1991	Holstein	66	66	66	66	66
1991	Badger	125	125	125	125	125
1991	Kensett	253	253	253	253	253
1991	Nashua	140	140	140	140	140
1991	Wyman	0	0	0	0	0
1991	Calumet	39	39	39	39	39
1992	Nashua	146	146	146	146	146
1992	Wyman	99	99	99	99	99
1992	Calumet	92	92	92	92	92
Mean		87	87	79	87	79

Table 3. Nitrogen needs for corn after corn as indicated by the quadratic-response-and-plateau model.

Year	Location	Rates to maximize yield	Economic optimum rates at various prices			
			$98.42/Mg corn		$78.74/Mg corn	
			$0.22/kg N	$0.55/kg N	$0.22/kg N	$0.55/kg N
		kg N/ha				
1987	Kalona	131	116	93	112	83
1987	Holstein	237	226	211	224	204
1987	Badger	315	287	245	280	227
1987	Kensett	273	259	237	255	228
1987	Nashua	159	151	139	149	134
1987	Wapello	0	0	0	0	0
1988	Kalona	0	0	0	0	0
1988	Holstein	313	287	248	280	232
1988	Badger	360	265	124	242	65
1988	Kensett	181	171	156	169	150
1988	Nashua	276	229	160	218	131
1988	Wapello	0	0	0	0	0
1989	Kalona	50	48	45	48	44
1989	Holstein	186	179	170	178	166
1989	Badger	220	212	199	210	194
1989	Kensett	179	175	167	173	164
1989	Nashua	382	332	257	319	225
1989	Wapello	0	0	0	0	0
1990	Kalona	185	177	165	175	160
1990	Holstein	158	152	143	150	139
1990	Badger	265	249	225	245	215
1990	Kensett	207	201	191	199	187
1990	Nashua	233	224	209	221	203
1990	Wyman	119	114	106	112	103
1990	Calumet	285	262	228	257	214
1991	Kalona	146	134	116	131	109
1991	Holstein	167	161	153	160	150
1991	Badger	260	245	223	241	214
1991	Kensett	381	350	305	343	287
1991	Nashua	358	320	264	311	240
1991	Wyman	0	0	0	0	0
1991	Calumet	222	204	178	200	167
1992	Nashua	211	203	190	201	184
1992	Wyman	146	140	132	139	128
1992	Calumet	321	300	269	295	255
Mean		198	182	159	178	149

Table 4. Nitrogen needs for corn after soybean as indicated by the quadratic-response-and-plateau model.

Year	Location	Rates to maximize yield	Economic optimum rates at various prices			
			$98.42/Mg corn		$78.74/Mg corn	
			$0.22/kg N	$0.55/kg N	$0.22/kg N	$0.55/kg N
		kg N/ha				
1987	Kalona	0	0	0	0	0
1987	Holstein	104	100	95	99	92
1987	Badger	133	121	102	118	94
1987	Kensett	219	206	186	203	178
1987	Nashua	156	149	138	147	134
1987	Wapello	143	135	124	133	119
1988	Kalona	0	0	0	0	0
1988	Holstein	155	140	117	136	107
1988	Badger	0	0	0	0	0
1988	Kensett	0	0	0	0	0
1988	Nashua	0	0	0	0	0
1988	Wapello	0	0	0	0	0
1989	Kalona	91	82	68	80	63
1989	Holstein	76	74	71	73	70
1989	Badger	212	195	171	191	161
1989	Kensett	205	195	180	192	173
1989	Nashua	119	109	95	107	89
1989	Wapello	0	0	0	0	0
1990	Kalona	158	141	116	137	105
1990	Holstein	64	62	59	62	58
1990	Badger	157	144	124	141	116
1990	Kensett	101	97	91	96	89
1990	Nashua	189	176	158	173	151
1990	Wyman	153	127	86	120	69
1990	Calumet	0	0	0	0	0
1991	Kalona	0	0	0	0	0
1991	Holstein	97	93	86	91	83
1991	Badger	206	190	168	187	158
1991	Kensett	819	711	550	685	483
1991	Nashua	187	173	152	169	143
1991	Wyman	0	0	0	0	0
1991	Calumet	62	59	53	58	51
1992	Nashua	214	204	189	201	183
1992	Wyman	188	179	164	176	158
1992	Calumet	190	173	149	169	139
Mean		126	115	100	113	93

Table 5. Nitrogen needs for corn after corn as indicated by the quadratic model.

Year	Location	Rates to maximize yield	Economic optimum rates at various prices			
			$98.42/Mg corn		$78.74/Mg corn	
			$0.22/kg N	$0.55/kg N	$0.22/kg N	$0.55/kg N
		kg N/ha				
1987	Kalona	0	0	0	0	0
1987	Holstein	262	250	231	247	224
1987	Badger	315	287	245	280	227
1987	Kensett	285	269	246	265	236
1987	Nashua	236	219	193	214	182
1987	Wapello	0	0	0	0	0
1988	Kalona	0	0	0	0	0
1988	Holstein	316	290	251	283	234
1988	Badger	360	265	124	242	65
1988	Kensett	234	218	194	214	184
1988	Nashua	267	224	161	214	134
1988	Wapello	0	0	0	0	0
1989	Kalona	195	165	119	157	100
1989	Holstein	244	233	217	231	211
1989	Badger	260	249	232	246	225
1989	Kensett	234	226	214	224	209
1989	Nashua	382	332	257	319	225
1989	Wapello	0	0	0	0	0
1990	Kalona	240	227	208	224	200
1990	Holstein	226	214	196	211	188
1990	Badger	278	261	235	256	224
1990	Kensett	251	242	228	239	222
1990	Nashua	245	235	220	232	213
1990	Wyman	249	225	188	219	173
1990	Calumet	297	273	236	266	220
1991	Kalona	206	183	147	177	132
1991	Holstein	240	229	212	226	206
1991	Badger	267	252	229	248	219
1991	Kensett	381	350	305	343	287
1991	Nashua	358	320	264	311	240
1991	Wyman	0	0	0	0	0
1991	Calumet	248	227	195	222	182
1992	Nashua	226	217	203	215	198
1992	Wyman	237	222	198	218	188
1992	Calumet	317	297	266	291	253
Mean		224	206	177	201	166

Table 6. Nitrogen needs for corn after soybean as indicated by the quadratic model.

		Rates to maximize	Economic optimum rates at various prices			
			$98.42/Mg corn		$78.74/Mg corn	
Year	Location	yield	$0.22/kg N	$0.55/kg N	$0.22/kg N	$0.55/kg N
		kg N/ha				
1987	Kalona	0	0	0	0	0
1987	Holstein	221	204	177	199	166
1987	Badger	208	180	137	173	120
1987	Kensett	224	212	193	209	185
1987	Nashua	239	222	197	218	187
1987	Wapello	220	202	176	198	165
1988	Kalona	0	0	0	0	0
1988	Holstein	219	190	146	183	128
1988	Badger	0	0	0	0	0
1988	Kensett	0	0	0	0	0
1988	Nashua	876	0	0	0	0
1988	Wapello	0	0	0	0	0
1989	Kalona	0	0	0	0	0
1989	Holstein	231	210	180	205	167
1989	Badger	245	224	193	219	180
1989	Kensett	250	235	213	232	204
1989	Nashua	204	176	133	169	116
1989	Wapello	166	137	95	130	77
1990	Kalona	228	194	144	186	122
1990	Holstein	186	168	140	163	129
1990	Badger	218	194	159	188	144
1990	Kensett	212	194	167	189	156
1990	Nashua	243	223	193	218	181
1990	Wyman	342	206	3	173	0
1990	Calumet	1127	365	0	175	0
1991	Kalona	222	187	134	178	112
1991	Holstein	194	174	145	169	133
1991	Badger	237	218	189	213	177
1991	Kensett	819	711	550	685	483
1991	Nashua	234	213	181	207	167
1991	Wyman	0	0	0	0	0
1991	Calumet	185	149	95	140	73
1992	Nashua	250	237	217	234	209
1992	Wyman	235	221	199	217	190
1992	Calumet	226	205	173	200	160
Mean		242	173	130	162	118

Table 7. Nitrogen needs for corn after corn as indicated by the mitscherlich model.

		Rates at 99% of	Economic optimum rates at various prices			
			$98.42/Mg corn		$78.74/Mg corn	
Year	Location	max. yld.	$0.22/kg N	$0.55/kg N	$0.22/kg N	$0.55/kg N
		kg N/ha				
1987	Kalona	0	0	0	0	0
1987	Holstein	414	339	248	317	225
1987	Badger	582	407	263	372	228
1987	Kensett	500	398	282	369	253
1987	Nashua	235	207	149	193	135
1987	Wapello	0	0	0	0	0
1988	Kalona	0	0	0	0	0
1988	Holstein	672	430	281	394	245
1988	Badger	617	264	112	227	75
1988	Kensett	292	229	163	213	147
1988	Nashua	431	246	135	219	108
1988	Wapello	0	0	0	0	0
1989	Kalona	50	68	51	64	47
1989	Holstein	305	270	203	254	187
1989	Badger	369	321	239	301	219
1989	Kensett	292	274	210	258	194
1989	Nashua	735	429	253	386	210
1989	Wapello	0	0	0	0	0
1990	Kalona	292	262	191	245	174
1990	Holstein	240	218	161	204	148
1990	Badger	446	347	244	322	219
1990	Kensett	357	315	239	296	220
1990	Nashua	387	330	243	309	222
1990	Wyman	177	174	126	162	114
1990	Calumet	470	334	226	308	200
1991	Kalona	180	153	103	140	91
1991	Holstein	289	258	193	242	177
1991	Badger	413	333	238	310	214
1991	Kensett	1007	636	410	581	356
1991	Nashua	803	493	300	446	253
1991	Wyman	0	0	0	0	0
1991	Calumet	348	252	171	233	152
1992	Nashua	334	289	214	271	195
1992	Wyman	215	198	147	185	134
1992	Calumet	736	496	336	457	297
Mean		348	256	175	237	155

Table 8. Nitrogen needs for corn after soybean as indicated by the mitscherlich model.

Year	Location	Rates at 99% of max. yld.	Economic optimum rates at various prices: $98.42/Mg corn, $0.22/kg N	$98.42/Mg corn, $0.55/kg N	$78.74/Mg corn, $0.22/kg N	$78.74/Mg corn, $0.55/kg N
		kg N/ha				
1987	Kalona	0	0	0	0	0
1987	Holstein	129	138	104	130	96
1987	Badger	144	140	91	128	79
1987	Kensett	294	256	183	238	165
1987	Nashua	238	216	157	201	142
1987	Wapello	176	169	123	158	112
1988	Kalona	0	0	0	0	0
1988	Holstein	158	145	97	133	85
1988	Badger	0	0	0	0	0
1988	Kensett	0	0	0	0	0
1988	Nashua	1472	0	0	0	0
1988	Wapello	0	0	0	0	0
1989	Kalona	78	90	58	82	50
1989	Holstein	142	142	105	133	97
1989	Badger	269	239	164	221	145
1989	Kensett	286	259	189	242	172
1989	Nashua	130	119	82	110	73
1989	Wapello	0	0	0	0	0
1990	Kalona	129	133	91	123	80
1990	Holstein	69	82	63	78	59
1990	Badger	187	171	115	158	101
1990	Kensett	126	135	101	127	92
1990	Nashua	266	236	164	219	146
1990	Wyman	170	141	69	123	52
1990	Calumet	3169	382	0	171	0
1991	Kalona	14	25	21	24	19
1991	Holstein	100	111	82	104	75
1991	Badger	280	243	165	224	147
1991	Kensett	2553	1245	694	1111	560
1991	Nashua	263	222	149	204	132
1991	Wyman	0	0	0	0	0
1991	Calumet	53	63	46	59	42
1992	Nashua	327	291	212	272	192
1992	Wyman	247	229	167	214	152
1992	Calumet	232	200	135	184	120
Mean		334	166	104	148	91