Nitrogen Fertilizer Response Potential of Corn and Sorghum in Continuous and Rotated Crop Sequences

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Crop management systems need to be designed to maintain economic profitability and minimize negative environmental impact. The objective of this study was to determine the effects of previous crop, yield potential, and residual soil nitrate (RSN) on grain yield response to N fertilizer of sorghum [*Sorghum bicolor* (L.) Moench.] and corn (*Zea mays* L.). Trials were conducted on 38 farms in 14 counties in eastern Nebraska during 1988 to 1990 and separated by previous crop into three groups, including (i) cereal [either sorghum, corn, oat (*Avena sativa* L.), wheat (*Triticum aestivum* L.), or rye (*Secale cereale* L.)], (ii) soybean [*Glycine max* (L.) Merr.], and (iii) forage legume [either alfalfa (Medicago sativa L.), sweet clover (*Melilotus officinalis* Lam.), or red clover (*Trifolium pratense* L.)]. The potential for a response to N fertilizer was described by relating initially available N to yield level (N/Y). Initially available N included RSN to a depth of 40 in., preplant and starter fertillizer N, and NO_3-N in irrigation water. Yield level was assumed to be equal to the maximum predicted yield from regression analysis in individual trials. The critical level of N/Y at which 95% of maximum predicted yield was attained without N fertilizer application, was 0.80 lb initial N/bu grain for sorghum following cereal, 1.44 lb initial N/bu grain for corn following cereal, 0.65 lb initial N/bu grain for corn following soybean, and zero lb initial N/bu for corn following forage legume. Knowledge of initially available N relative to expected yield for individual fields will help farmers make sound economic and environmental decisions on the need for N fertilizer in continuous and rotated crop sequences.

Crop management systems can be designed for greater sustainability by reducing risk and increasing diversity in the farming operation (Flora, 1990). Investigating and encouraging the use of sustainable agricultural practices has become a part of several research and extension programs of university, private, and nonprofit centers (Francis, 1990). Crop rotations are usually an integral part of sustainable agricultural systems because of the reduction in external inputs, maintenance of soil fertility, reduction in risk of total crop failure, and diversification of labor input and income source.

Current University of Nebraska N fertilizer recommendations for sorghum and corn grown in rotation with legumes suggest that the farmer subtract an average N credit (dependent upon previous crop) from the expected N requirement of cereals grown in monoculture. It has long been known that cereal crops grown in rotation, especially following legumes, require less N fertilizer to attain similar yields as in monoculture. Attempts to determine an average N credit for cereal crops following legumes, however, have been largely inadequate. For example in Nebraska, fertilizer N equivalence values (FNE, calculated as the amount of N fertilizer required in continuous cropping in order to achieve the same yield under rotation without N fertilizer) obtained in different years for the same soil have ranged from 12 to 226 lb N/acre for corn following soybean (Peterson and Varvel, 1989b), 0 to 161 lb N/acre for sorghum following soybean (Peterson and Varvel, 1989a), and 29 to 111 lb N/acre for sorghum following soybean (Clegg, 1982; Gakale and Clegg, 1987). In Missouri, FNE values ranged from 50 to 160 lb N/acre on the same soil for sorghum following soybeans (Hanson et al., 1988) and 64 to 119 lb N/acre for corn following alfalfa (Asghari and Hanson, 1984). In Illinois, Nafziger et al. (1984) observed yearly variations in FNE on the same soil from 64 to 81 lb N/acre for corn following soybean and 96 to 124 lb N/acre for corn following alfalfa. Calculation of an average FNE may not be acceptable as a basis for fertilizer recommendations considering the economic loss from a reduction in yield if the crop is under-fertilized, as well as the cost of fertilizer and potential negative environmental impact if the crop is over-fertilized.

One possible explanation for variation observed in FNE values obtained in the previously mentioned studies may have been differences among years in available soil N, although actual data supporting this hypothesis are absent. In Nebraska, it has been clearly demonstrated that RSN to a depth of 6 ft can significantly alter the response of continuous corn grain yield to N fertilizer (Olson et al., 1976). In Wisconsin, Bundy and Malone (1988) have shown that optimum continuous corn grain yields were obtained with significantly less N fertilizer when RSN to a depth of 3 ft was >160 lb N/acre as a result of previous N fertilizer practices.

Recovery of RSN will depend upon leaching load from rainfall and irrigation, distribution with depth, and crop demand. Magdoff et al. (1984) suggested that RSN to a depth of 1 ft taken when corn is 6 to 12 in. tall be used to determine N fertilizer needs. The time of sampling reflects losses and gains in NO_3 during the period following the previous year's harvest up to spring warming and early plant growth. Although a strong relationship between relative yield and nitrate-N in the 1-ft layer have been observed (Blackmer et al., 1989), the later sampling time and shallower depth compared with traditional sampling for RSN in winter and early spring to deeper depths requires greater management at a time when workload is already great and does not account for RSN that may

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Abbreviations: RSN, residual soil nitrate; N/Y, available nitrogen to yield level; FNE, fertilizer nitrogen equivalence.

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Table 1. Location of participating farmers with representative soil texture and subgrouping.

County (district) Farmer	Soil texture†	Soil subgroup	County (district) Farmer	Soil texture	Soil subgroup
Buffalo: (Central)			Merrick: (East)		
J. Keilig	SiL	Typic Argiustoll	J. Ferris	L	Udic Argiustoll
Butler: (East)			D. Lewis	SL	Cumulic Haplustoll
T. Medinger	SiL	Udic Argiustoll	G. Senkbile	L	Udic Argiustoll
Cuming: (Northeast)			Nance: (East)		
G. Anderson	SiCL	Udic Haplustoll	A. Urkoski	L	Udic Argiustoll
M. DeBlauw	SiL	Typic Ustorthent	Nuckolls: (Southeast)		
M. Heimes	SiCL	Cumulic Haplaquoll	W. Buescher	SiL	Pachic Argiustoll
M. Lange	SiL	Typic Ustorthent	M. Mazour	SiL	Udic Argiustoll
G. Olson	L	Udic Argiustoll	R. Mazour	SiL	Udic Argiustoll
G. Young	SiL	Udic Haplustoll	R. Meyer	SiL	Udic Argiustoll
Cuming: (Northeast)			Sarpy: (East)		
D. Mandel	SiCL	Udic Haplustoll	M. Johnson	SiCL	Aquic Hapludoll
E. Mandel	SiCL	Udic Haplustoll	Saunders: (East)		
D. Miller	SiCL	Udic Haplustoll	G. Zicafoose	SiCL	Typic Argiudoll
A. Steffensmeier	SiCL	Udic Haplustoll	Stanton: (Northeast)		
Dodge: (East)			B. Chilcoat	SiL	Typic Ustorthent
L. Ladehoff	SiCL	Udic Haplustoll	D. Wolf	SiL	Fluvaquentic Haplustoll
D. Von Seggren	SiCL	Udic Haplustoll	Washington: (East)		
Knox: (Northeast)			H. Hovendick	SiCL	Typic Hapludoll
D. Bloomquist	SiL	Typic Ustorthent	M. Nelsen	SiL	Cumulic Hapludoll
J. Condon	L	Cumulic Haplaquoll	R. Schurman	SiCL	Udic Haplustoll
D. Morrill	SiCL	Udic Haplustoll	J. Wollsmann	SiL	Typic Hapludoll
R. Naprstek	SiL	Typic Ustorthent			
G. Stevens	SiL	Udic Argiustoll			
M. Wilmes	SiL	Typic Ustorthent			
Madison: (Northeast)					
N. Acklie	LFS	Udic Haplustoll			
R. Warrick	LFS	Udic Haplustoll			

† L = loam, LFS = loamy fine sand, SL = sandy loam, SiCL = silty clay loam, SiL = silt loam.

be concentrated immediately below the 1-ft sampling depth. Rainfall in Nebraska during spring is variable among years, but seldom would be expected to provide sufficient leaching load to remove a major portion of RSN from the root zone before crop uptake. Herron et al. (1968) using ^{15}N tracer techniques, found that corn recovered 41, 45, 55, and 61% of labeled N at depths of 18, 30, 42, and 54 in., respectively. Gass et al. (1971) used small amounts of ^{15}N-labelled KNO_3 placed at depths of 4, 24, 48, and 72 in. without additional N fertilization during the study period to determine the recovery of residual mineral N by corn from an irrigated silty clay loam soil in Nebraska. Residual mineral N accumulation was 365 and 520 lb N/acre to a depth of 6 ft following annual application rates of 75 and 225 lb N/acre in the three previous years, respectively. Average grain yield during the three previous years was >150 bu/acre. The proportion of N recovered with 75 lb N/acre/yr was 32% at 4 in., 28% at 24 in., 29% at 48 in., and 11% at 72 in. The proportion of N recovered with 225 lb N/acre/yr was 59% at 4 in., 33% at 24 in., 7% at 48 in., and 1% at 72 in. These results indicate that RSN to a depth of ≤4 ft can be effectively utilized by corn in Nebraska. Excessive application of N fertilizer without adjusting for RSN can result in decreased uptake of RSN from lower depths that may lead to leaching below the crop root zone.

In response to these findings, the University of Nebraska currently utilizes RSN for predicting N fertilizer requirement of grain crops grown continuously (Ferguson and Wiese, 1989; Sander and Frank, 1980) as well as an average N credit for grain crops grown in rotation with legumes. These recommendations are based upon an expected yield level, either reported by the farmer or predicted based upon soil type or management. An average N credit following legumes and RSN are subtracted from the assumed total N requirement.

Grain yield in rotation is often greater than in monoculture, due to a yet to be fully described rotation effect (Crookston et al.,1991), which leads to greater total N requirement (Bundy et al., 1993). The evidence of greater yield potential of cereals grown in rotation combined with the highly variable FNE values obtained in monoculture-rotation studies indicates that prediction of N fertilizer requirements for cereals grown in rotation from N fertilizer requirements grown in monoculture may not be appropriate.

The large variation in FNE values with legume as previous crop, the difference in yield level due to the rotation effect, and the lack of sufficient data to support a common approach to N fertilizer recommendations in continuous and rotated crop sequences led us to investigate these relationships further. We report here the combined effect of initially available N and yield level on the response of sorghum and corn grain yield to N fertilizer in continuous and rotated crop sequence grown in eastern Nebraska.

MATERIALS AND METHODS

Thirty-eight farmers in 14 counties of eastern Nebraska participated in 86 N fertilizer trials on their farms as

Table 2. Long-term average and observed monthly rainfall and air temperature for the four extension districts† during 1988 to 1990.

Month	Mean								1988				1989				1990			
	NE	E	SE	C	NE	E	SE	C	NE	E	SE	C	NE	E	SE	C	NE	E	SE	C
	°F				in.															
January	18	21	23	22	05	0.7	0.7	0.5	0.9	0 5	0.5	1.2	0.9	1.1	1.1	0.6	0.5	0.5	0.9	0.6
February	25	27	29	28	09	1.0	1.0	0.7	0.3	0 1	0.3	0.2	0.5	0.8	0.8	0.6	0.3	0.3	0.3	0.3
March	34	37	39	36	16	1.8	2.0	1.4	0.2	0.1	0.1	0.2	0.9	0.2	0.4	0.4	2.3	3.1	3.6	2.8
April	50	51	53	50	34	2.8	2.8	2.4	2.7	2.2	2.2	2.3	1.0	0.7	0.4	0.2	1.4	0.4	0.8	0.8
May	61	62	63	60	39	4.1	4.0	3.6	3.3	3.5	3.1	3.5	1.6	1.4	2.1	2.5	4.8	4.8	5.1	4.1
June	71	72	73	70	42	4.3	4.4	3.9	1.3	2.3	1.6	3.9	2.3	4.2	4.7	5.7	5.7	5.1	4.9	4.9
July	76	77	78	76	32	3.3	3.8	3.2	3.1	2.7	3.6	3.1	3.0	2.6	3.4	2.8	3.7	6.7	3.4	2.0
August	74	75	76	74	31	3.6	3.8	2.7	2.9	1.4	2.0	3.0	2.4	2.9	4.9	2.8	2.5	2.1	3.5	3.3
September	64	65	67	64	24	3.1	3.5	2.2	4.3	5.1	3.1	3.5	3.4	6.6	5.3	3.7	0.9	0.7	0.8	1.0
October	52	54	56	53	15	1.9	2.2	1.3	0.1	0.1	0.1	0.1	0.6	1.1	0.9	0.6	1.7	1.5	1.3	1.4
November	37	39	40	37	09	1.1	1.3	0.7	1.1	1.6	1.3	0.5	0.1	0.1	0.0	0.0	1.3	1.1	1.2	1.4
December	25	27	29	27	07	0.8	0.8	0.6	0.5	0.7	0.5	0.4	0.7	0.6	0.5	0.3	0.7	0.9	0.8	0.4
Total	49	51	52	50	26	29	30	23	21	20	18	22	17	22	25	20	26	27	27	23

† Extension districts are NE (northeast), E (east), SE (southeast), and C (central).

part of a University of Nebraska Cooperative Extension program during 1988 through 1990. Location, soil texture, and classification of each farm are listed in Table 1. Details of selection criteria and participatory activities of farmers can be found in Franzluebbers and Francis (1991). The long-term average and yearly observed rainfall and air temperature in the four extension districts are listed in Table 2. Management systems of participating farmers can be characterized as follows. Livestock was a part of the farming system on 85% of the farms. Banding a herbicide in combination with timely tillage and crop rotation sequencing was used as weed control on 18% of the farms. Timely tillage and crop rotation sequences only, without herbicides, were used for weed control on 39% of the farms. The remaining 42% of farms used a broadcast herbicide program with conventional or minimum tillage. Either pivot or furrow irrigation was used by 26% of the farmers. More than 90% of the fields were ≥ 10 acres in size.

Nitrogen fertilizer application was the common treatment in all 86 trials. Fifty-nine percent of the trials were conducted with only two N rates with one rate being a control without N fertilizer or with only preplant fertilizer that was included in the initially available N. The second N rate averaged 55 lb N fertilizer/acre and ranged from 10 to 100 lb N fertilizer/acre. Eighty percent of the trials with only two N rates were with legume as previous crop and, therefore, yield response to N fertilizer was expected to be minimal. The remaining 20% of the trials with only two N rates were with cereal as previous crop and initially available N prior to treatment averaging 123 lb N/acre. Due to the high initially available N status, no significant yield response to N fertilizer was expected. Only one N fertilizer application rate was chosen to minimize unnecessary resource input. The remaining 41% of the trials were conducted with three to six N rates (one rate always as a control without N fertilizer). The maximum N fertilizer application rate in these latter trials averaged 101 lb N/acre and ranged from 60 to 160 lb N/acre.

Replication of each N rate within a trial varied from none to seven. In 8% of the trials, N fertilizer rate was not replicated. Mean values for each N fertilizer rate within replicated trials and values obtained from unreplicated trials comprised the data set. Variation among replicates of N fertilizer rate within a trial were not considered in the analyses presented here. Individual trials were, therefore, considered as replications within each previous crop group (Stroup et al., 1991).

Timing and type of N fertilizer application was selected by each farmer, including (i) preplant as anhydrous ammonia or dry mixture with P and/or K, (ii) at planting as dry or liquid mixture, (ii) at cultivation as liquid mixture, or (iv) at sidedressing as liquid mixture or anhydrous ammonia. Fertilizer was applied by the farmer in long, narrow strips ranging from four to 20 rows wide and 385 to 3056 ft long. Where N fertilizer application was not normally practiced by participating farmers because of long-term rotation benefits to soil N supply, fertilization of experimental plots within farmers' fields was performed by the project coordinator (24% of trials). Ammonium nitrate was broadcast several days to 2 wk after planting and within a week before incorporation with rotary hoeing or cultivation by the farmer. Plots were eight rows wide and 50 ft long in 1988 and 1989 and six rows wide and 30 ft long in 1990.

Deep soil samples for determination of RSN were taken prior to the growing season of sorghum and corn (March to early May). Eight to 16 soil cores (2 in. diam.) representing 0- to 8-, 8- to 24-, and 24- to 40-in. depth were collected, mixed, and subsampled in the field and air dried prior to analysis. Surface samples (0 to 8 in.) were analyzed for pH (1:1, soil/water), organic matter by the colorimetric method (Schulte, 1988), NO_3-N by the cadmium reduction method (Gelderman and Fixen, 1988), Bray-1 phosphorus (Knudsen and Beegle, 1988), and exchangeable potassium (Brown and Warncke, 1988). Samples representing 8 to 24 in. and 24 to 40 in. were analyzed only for NO_3-N.

Planting occurred during late April to late May for corn and early June for sorghum. All management practices other than N fertilization were under the control of each individual farmer, including tillage, planting, weed and insect control, and irrigation if applicable. Grain sorghum and corn were harvested with the farmer's equipment and grain was weighed on a portable field scale in most cases. The small plots fertilized by the project coordinator and some of the long strips were harvested by hand after physiological maturity from one or two 20- to 25-ft long rows. Grain yield was adjusted to 14% moisture content for sorghum and 15.5% moisture content for corn.

Mean grain yield of each N fertilizer rate of each trial was used for regression analysis. The data set consisted of 228 observations separated into groups of: (i) sorghum following cereal (either sorghum, wheat, or rye), (ii) sorghum following soybean or forage legume (either alfalfa, sweet clover, or 1 yr of sorghum or rye following alfalfa), (iii) corn following cereal (either corn, oat, or wheat), (iv) corn following soybean, and (v) corn following forage legume (either alfalfa, sweet clover, red clover, or 1 yr of corn following alfalfa).

The ratio of initially available N to yield level (N/Y) was calculated for each individual trial. Initially available N consisted of RSN to a depth of 40 in., preplant and starter fertilizer N (if fertilizer was applied on the whole field), and NO_3-N in 9 in. of irrigation water (if applicable). Yield level of trials with more than two N fertilizer rates was assumed to be the maximum predicted yield within the range of N fertilizer rates tested for each trial based upon a linear plus quadratic regression equation on mean values. For trials with only two N fertilizer rates when no response to N fertilizer was oberved ($P \leq 0.1$), the highest absolute yield was selected as the yield level so that relative yield without N fertilizer would not exceed 100%. Three trials with only two N fertilizer rates showed a response to N fertilizer and were not included in the analysis of relative yield without N fertilizer regressed upon N/Y, because of the uncertainty of reaching maximum yield in these trials.

Average grain yield response for each crop by previous crop group was regressed upon N fertilizer rate and included N/Y as an interaction term with N fertilizer rate using the GLM procedure of SAS (SAS Institute, 1985). The interaction of N/Y with N fertilizer rate was used to test if N/Y altered grain yield intercept.

In order to test if previous crop altered grain yield response to N fertilizer, previous crop was used as an interaction term with N fertilizer rate. An additional interaction term was included to test differences in yield response to N fertilizer with respect to previous crop and N/Y together.

In order to characterize the level of N/Y at which yield response diminished, relative yield (grain yield without N fertilizer relative to yield level) was regressed upon N/Y. This was done for each crop by previous crop group. Only those sites with yield level >50 bu/acre were included in order to reduce confounding influences of severe drought. This resulted in deletion of 14% of the trials in addition to the three trials with only two N fertilizer rates that responded significantly to N fertilizer (as mentioned previously).

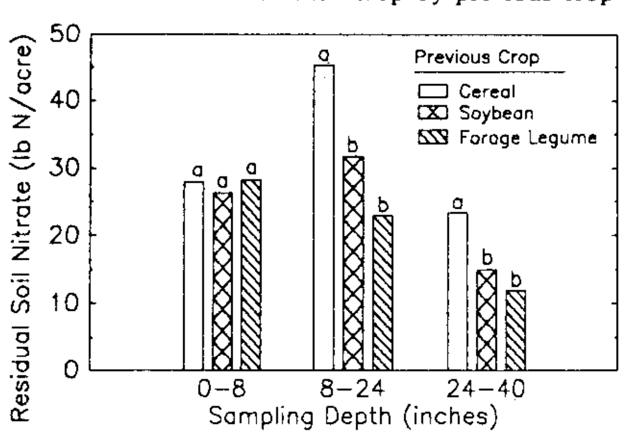

Fig. 1. Average residual soil NO_3 with depth as affected by previous crops. Means among previous crops within a depth sharing the same letter are not different at the 10% probability level by LSD test.

The approach of pooling data from several farms has been suggested by Hildebrand and Poey (1985) as a means of developing and evaluating recommendations for different groups of farmers. This approach assumes that negligible interaction of N fertilizer response among farms within a previous crop group occurs. If this assumption were not met, then the variability in yield response within a previous crop would be too large to detect significant differences among previous crops in yield response to N fertilizer. Participation of many farmers with different management practices (e.g., tillage, hybrid selection, weed control, and fertilizer timing, source, and rate) and different soil (e.g., type, depth, organic matter content, and pH) and environmental conditions (e.g., rainfall, temperature, and ecological zone) was viewed positively, because these variations reflect the diversity of eastern Nebraska farmers and may provide a more appropriate scope of inference for prediction. This approach would increase the scope of inference to a larger community of farmers beyond that of an approach using standardized conditions (Lockeretz, 1993).

RESULTS

Average RSN to a depth of 40 in. was 76 lb N/acre for all trials and ranged from 15 to 227 lb N/acre. Residual soil NO_3 in the 0- to 8-in. sampling depth was unaffected by previous crop and averaged 27 lb N/acre (Fig. 1). In the 8- to 24-in. and 24- to 40-in. depths, however, fields with cereal as previous crop had greater RSN than fields with soybean or forage legume as previous crop.

Other soil test parameters, including potassium, organic matter, and pH, were similar for cereal and legume as previous crop. A greater level of phosphorus, however, was observed following soybean compared with following forage legumes ($P = 0.07$). Soil test level and standard deviation averaged over all trials were 22 ± 20 ppm for Bray-1 phosphorus, 306 ± 124 ppm for exchangeable potassium, 2.4 ± 0.8% for organic matter, and 6.4 ± 0.8 for pH.

Sorghum grain yield response to N fertilizer was tested on 15 fields of three farms. Yield of sorghum in these trials varied from 19 to 104 bu/acre, while N/Y ranged from 0.3 to 3.8 lb N/bu. Average sorghum grain yield in these trials was 65 bu/acre, which was the same as the average county yield at these locations during 1988 to 1990. Corn grain yield response to N fertilizer was tested on 71 fields of 34 farms. Yield of corn ranged from 18 to 211 bu/acre, while N/Y varied from 0.2 to 2.8 lb N/bu. Average corn grain yield in these trials was 88 bu/acre, while the average corn grain yield in these 13 counties during 1988 to 1990 was 81 bu/acre.

With cereal as previous crop, sorghum grain yield responded positively to N fertilizer rate in a linear manner (Table 3). However, the magnitude of the linear

Table 3. Analysis of variance and regression parameters for sorghum and corn grain yield with cereal and legume as previous crop.

	Sorghum				Corn					
	Cereal		Legume		Cereal		Soybean		Forage legume	
Source of variation	df	Mean squares	df	Mean squares	df	Mean squares	df	Mean squares	df	Mean squares
Trial	6	390***	7	500**	17	3 861***	25	132 393***	26	2 720***
N-linear	1	525***	1	80	1	2 116***	1	81***	1	2
N-quadratic	1	7		NA‡	1	106	1	4	1	23
N-linear × N/Y	1	218**	1	8**	1	1 103***	1	121†	1	2
N-quadratic × N/Y	1	24		NA	1	45	1	7	1	5
Error	10	22	7	57	29	74	50	36	28	22
Regression coefficients:										
Intercept	70		44		78		103		77	
N-linear	0.443		0.107		0.359		0.090		0.106	
N-quadratic	−0.0005		NA		0.0016		0.0003		−0.0015	
N-linear × N/Y	−0.124		−0.029		−0.114		−0.066		−0.031	
N-quadratic × N/Y	−0.0037		NA		−0.0019		−0.0006		0.0005	

,* Significant at the 0.01 and 0.001 probability levels, respectively.
† Significant at 0.1 probability level.
‡ NA = not applicable.

response decreased with increasing N/Y, as evidenced by the significant interaction of the linear response with N/Y. This indicated that fields with greater N/Y responded less to N fertilizer than those with lower N/Y. With legumes as previous crop, neither N fertilizer rate nor the interaction of N fertilizer rate with N/Y has a significant effect on sorghum grain yield. Coefficient of variation with legume as previous crop was 17%, but only 7% with cereal as previous crop, suggesting that greater variability in response occurred with legume as previous crop. The greater variability masked any possible effects of N fertilizer and N/Y on sorghum grain yield.

Corn grain yield with cereal as previous crop also responded positively to N fertilizer rate in a linear manner (Table 3). The magnitude of the linear response of N fertilizer decreased with increasing N/Y, similarly to that observed for sorghum with cereal as previous crop. With soybean as previous crop, the response of corn grain yield to N fertilizer was not significant, although the interaction of N/Y with the linear response to N fertilizer rate was significant. Yield response to N fertilizer was, therefore, related to level of N/Y. Only those fields with very low levels of N/Y would be expected to exhibit a significant yield response to N fertilizer. With forage legume as previous crop, there was no effect of N fertilizer rate or of the interaction between N fertilizer rate and N/Y on corn grain yield.

When sorghum yield data with cereal and legume previous crops were pooled, the yield response to N fertilizer among previous crops was not significantly different (Table 4). Sorghum grain yield without N fertilizer was lower with legume as previous crop compared to cereal as previous crop. The interactive effects of (i) previous crops with N fertilizer, (ii) N/Y with N fertilizer, and (iii) previous crop with N/Y had probability levels ranging from 12 to 19%, suggesting a trend towards differences among previous crops, but masked due to the greater variability with legume as previous crop. For corn, response to N fertilizer was greater following cereal than following legume ($P \leq 0.0001$). Average corn yield response decreased with increasing N/Y, but the magnitude of reduction was greater following cereal than following legume ($P \leq 0.0001$). When N/Y is assumed to

Table 4. Pooled analysis of variances for sorghum and corn grain yield.

	Sorghum		Corn	
Source of variation	df	Mean squares	df	Mean squares
Previous crop	1	3102†	1	2229
Error *a*	13	472	69	4433
N-linear	1	517***	1	811***
N-linear × PC	1	88	1	1345***
N-linear × N/Y	1	68	1	624***
N-linear × PC × N/Y	1	100	1	642***
Error *b*	19	37	115	41

*** Significant at 0.001 probability level.
† Significant at 0.1 probability level.

be zero, the linear coefficient of yield response to N fertilizer was greater following cereal ($b = 0.36$) than following soybean ($b = 0.09$) and forage legume ($b = 0.11$). This large difference in yield response between cereal and legume previous crops at low N/Y explains why there was an interaction between N fertilizer, previous crop, and N/Y. Yield response with legume as previous crop was minimal, despite the low level of N/Y. Therefore, an increase in N/Y had only a minor influence on corn yield response to N fertilizer.

Relative sorghum and corn grain yield were significantly increased with increasing level of N/Y with cereal as previous crop (Fig. 2a). This relationship was used to identify the critical level of N/Y at which yield response to N fertilizer was minimal. For sorghum with cereal as previous crop, 95% of relative yield was attained at a level of N/Y equal to 0.80 lb N/bu. For corn with cereal as previous crop, 95% of relative yield was attained at 1.44 lb N/bu.

With soybean or forage legume as previous crop, relative corn grain yield was not significantly influenced by N/Y (Fig. 2b). At least 95% of relative yield was achieved at a level of N/Y ≥ 0.65 lb N/bu for corn following soybean and zero lb N/bu for corn following forage legume based on the nonlinear regression lines plotted in Fig. 2b. Table 5 lists alternative relative yield levels with the corresponding N requirement coefficients that might be selected in order to achieve different economic or environmental goals. The N requirement coefficient for each crop and previous crop combination was determined by entering the appropriate relative yield level into the equations given in Fig. 2 and solving for N/Y.

DISCUSSION

The difference in level of RSN from fields with cereal versus legume as previous crop was mostly due to the large RSN levels observed in fields following corn (data not shown). Nitrogen fertilizer recommendations for corn are often higher than for any other crop in Nebraska and, therefore, the potential for N carryover is greater than for other cereals. In addition, dry weather conditions during the 1988 and 1989 growing seasons limited crop yields and N uptake at some locations. Since farmers provide management inputs to meet the needs of average to above average yields, carryover of N after less than optimal growing seasons will probably occur. Sampling for RSN, therefore, becomes a necessary practice to efficiently utilize initially available N to increase profitability and decrease potential negative environmental impact.

Fields sampled following sorghum were, on average, lower in RSN than those following corn. Past fertilization history reported by farmers did not exceed 90 lb N/acre for sorghum and, therefore, the potential for carryover of N was limited. Gakale and Clegg (1987) observed much lower RSN levels when sorghum was grown continuously or in rotation with soybean with low levels of N fertilizer as compared with high levels of N fertilizer, especially under continuous sorghum cropping.

When sorghum was preceded by a legume, a lower

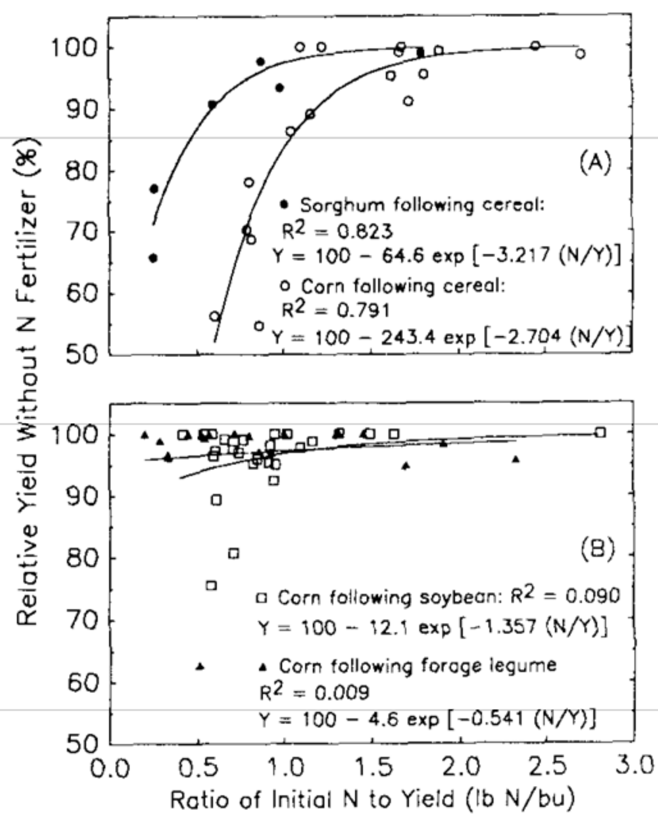

Fig. 2. Relative grain yield without N fertilizer as affected by level of N/Y for (A) sorghum or corn following cereal and (B) corn following soybean or forage legume.

Table 5. Nitrogen requirement coefficients (N/Y)† for different levels of relative yield for sorghum and corn with cereal, soybean, and forage legume as previous crop.

Crop	Previous crop	Relative yield level, % 90	93	95	97	98
		N/Y				
Sorghum	Cereal	0.58	0.69	0.80	0.96	1.08
Corn	Cereal	1.18	1.31	1.44	1.63	1.78
	Soybean	0.14	0.40	0.65	1.03	1.33
	Forage legume	0.00	0.00	0.00	0.79	1.54

† Nitrogen requirement coefficients are calculated from the following regression equations derived in Fig. 2:
Corn following cereal: $Y = 100 - 64.6 \exp[-3.217 \times (N/Y)]$
Corn following cereal: $Y = 100 - 243.4 \exp[-2.704 \times (N/Y)]$
Corn following soybean: $Y = 100 - 12.1 \exp[-1.357 \times (N/Y)]$
Corn following forage legume: $Y = 100 - 4.6 \exp[-0.541 \times (N/Y)]$

average yield was observed than when preceded by a cereal. This lower yield level may have partially contributed to the absence of yield response to N fertilizer with legume as previous crop. Differences in available soil moisture among farms during soil sampling were observed (data not shown) and may have contributed to the lower yield level following legume. Time of soil sampling was not on the same day for all farms in the same year so differences in soil moisture were confounded with rainfall events during the period of soil sampling.

For both sorghum and corn, the level of N/Y was significantly related to grain yield response to N fertilizer when cereal was previous crop. Initially available N and yield level varied independently, and therefore, each trial had a unique value of N/Y. The value, N/Y, was calculated primarily to scale the influence of different levels of initially available N to observed yields at specific sites within the broad region of eastern Nebraska. The significant effect of N/Y on relative sorghum and corn grain yield without N fertilizer with cereal as previous crop strongly suggests the use of N/Y as an indicator of the potential yield response to N fertilizer.

With soybean and forage legume as previous crop, maximum yield level was achieved with less N fertilizer and lower N/Y. The N available to sorghum or corn following a legume, which could not be accounted for by measuring initially available N may be a result of timely N mineralization from N-rich legume residues (Fribourg and Bartholomew, 1956; Hesterman et al., 1987), changes in soil chemical or biological properties during or after the growth of a legume (Birch and Dougall, 1967; Crookston et al., 1991), changes in the pattern of microbial biomass N pool size (Bonde et al., 1988), and/or differences in microbial biomass N turnover (Myrold and Tiedje, 1986).

Both initially available N (Bundy and Malone, 1988; Olson et al., 1976; Stanford et al., 1977) and yield level (Stanford, 1973) have been previously reported to influence the amount of N fertilizer required to obtain optimal yield in continuous crop sequences; however, these reports did not combine the two effects. The ratio of initially available N (lb NO_3-N/acre/3 ft) to corn grain yield level was calculated from the data reported by Bundy and Malone (1988) in order to make a comparison with our findings. The calculations reveal that 95% of yield level (yield level assumed as the average yield of

Table 6. Nitrogen fertilizer recommendations for corn based upon previous crop, expected yield, and initially available N (assuming a N requirement coefficient at 95% maximum yield).

Expected yield	Initially available N†	Previous crop: Corn NR‡	Corn FN§	Soybean NR	Soybean FN	Soybean NC¶	Forage legume NR	Forage legume FN	Forage legume NC
bu/acre	lb N/acre								
60	50	86	36	39	0	36	0	0	36
60	100	86	0	39	0	0	0	0	0
60	150	86	0	39	0	0	0	0	0
90	50	130	80	59	9	71	0	0	80
90	100	130	30	59	0	30	0	0	30
90	150	130	0	59	0	0	0	0	0
120	50	173	123	78	28	95	0	0	123
120	100	173	73	78	0	73	0	0	73
120	150	173	23	78	0	23	0	0	23
150	50	216	166	98	48	118	0	0	166
150	100	216	116	98	0	116	0	0	116
150	150	216	66	98	0	66	0	0	66
200	50	288	238	130	80	158	0	0	238
200	100	288	188	130	30	158	0	0	188
200	150	288	138	130	0	138	0	0	138

† Initially available N = NO_3-N/acre-40 in. + preplant N + starter N + NO_3-N/acre-9 in. irrigation water.

‡ NR (N requirement) = expected yield × N requirement coefficient (i.e., 1.44 following corn, 0.65 following soybean, and 0.00 following forage legume).

§ FN [Fertilizer N (i.e., recommended amount of fertilizer)] = NR − initially available N.

¶ NC (N credit) = $FN_{(following\ corn)} - FN_{(following\ either\ soybean\ or\ forage\ legume)}$.

the 142 and 213 lb N/acre treatments) was achieved without N fertilizer in six of eight experiments which had a level of N/Y >1.1 lb N/bu. When the ratio was <1.1 lb N/bu, yields without N fertilizer were 73, 76, 88, and 96% of maximum yield in four experiments. Our results for corn with cereal as previous crop are in general agreement with the trend calculated from results reported by Bundy and Malone (1988) in Wisconsin.

Major differences in the critical level of N/Y for corn following cereals and legumes suggest that root-soil interactions with respect to previous crop may preclude the use of N fertilizer recommendations for cereals grown in rotation with legumes based upon results obtained for cereals grown in continuous crop sequences. This lack of consistency is highlighted by the large variation in FNE values commonly found in continuous-rotation study comparisons. The concept of using a different critical level of N/Y with respect to previous crop, allows for a fluctuating N credit that is dependent upon initially available N and yield level. Assigning a N credit to sorghum or corn following a legume would only be of academic interest, however, since N fertilizer recommendations could be derived with knowledge of initially available N, yield level, and the appropriate N requireement coefficient (i.e., the critical level of N/Y at which yield response is minimal), which is dependent upon previous crop (Table 6). For example, corn following soybean with an expected yield level of 120 bu/acre and 38 lb NO_3-N/acre/40 in. as RSN would require 40 lb N fertilizer/acre [i.e., (120 bu/acre × 0.65 lb N/bu) − 38 lb N/acre]. In this same scenario, except with corn following a cereal, the N fertilizer required would be 135 lb N/acre − 40 lb N/acre). If, however, the yield level were only 60 bu/acre and RSN were the same for both previous crops, then the N credit would only be 47 lb N/acre. Additionally, the N credit would increase or decrease if RSN were lower or higher following a cereal compared with a legume, respectively. This fluctuation in N credit following a legume due to changes in initially available N and yield level could help explain variation in FNE values observed in previous research.

The results of this study illustrate that the level of N/Y could be used as a good indicator of the likelihood and magnitude of grain yield response to N fertilizer. Major differences in the critical level of N/Y were found between (i) sorghum and corn with cereal as previous crop and (ii) corn with cereal as previous crop and corn with soybean or forage legume as previous crop. Although the exact reason for the reduced requirement of N fertilizer of sorghum or corn grown with legume as previous crop compared with cereal as previous crop was not mechanistically defined, the *rotation effect* can still be exploited with an improvement in determining appropriate N fertilizer application in rotated crop sequences to achieve economically and environmentally optimum yield. Measurement of RSN, selecting a realistic yield goal, and accounting for previous cropping history are management strategies that can increase the profitability of farming operations and decrease the potential negative environmental consequences of N fertilizer carryover.

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NEW BOOKS RECEIVED

Agricultural Economics and Agribusiness—*Gail L. Cramer and Clarence W. Jensen.* John Wiley and Sons, 605 Third Ave., New York NY 10158. $62.95. 534 p.

Agricultural Price Analysis and Forecasting—*John W. Goodwin.* John Wiley and Sons, 605 Third Ave., New York NY 10158. $52.95. 344 p.

Energy and Protein Requirements of Ruminants—*AFRC Technical Committee on Responses to Nutrients.* CAB International, 845 N. Park Ave., Tucson AZ 85719. $34. 159 p.

Experimental Research Design and Analysis—*A. Reza Hoshmand.* CRC Press, 2000 Corporate Blvd. NW, Boca Raton FL 33431. $59.95.

Livestock Handling and Transport—*Temple Grandin.* CAB International, 845 N. Park Ave., Tucson AZ 85719. $95. 320 p.

Nitrogen Management in Irrigated Agriculture—*Roy S. Rauschkolb and Arthur G. Hornsby.* Oxford University Press, 200 Madison Ave., New York NY 10016. $49.95. 251 p.

Nothing but Conservation (Memoirs)—*Roy H. Dingle.* Hynek Printing, Richland Center WI 53581. 344 p.

Pasture Management—*D.R. Kemp and D.L. Michalk (ed.)* CSIRO Information Services, P.O. Box 89, East Melbourne Victoria 3002 Australia. 177 p.

Plant Breeding: Theory and Practice—*Neal C. Stoskopf, Dwight T. Tomes, and B.R. Christie.* Westview Press, 5500 Central Ave., Boulder CO 80301-2847. $65.85. 531 p.

Recombinant Microbes for Industrial and Agricultural Applications—*Yoshikatsu Murooka and Tadayuki Imanaka (ed.)* Marcel Dekker, 270 Madison Ave., New York NY 10016. $195. 904 p.

Remarkable Agaves and Cacti—*Park S. Nobel.* Oxford University Press, 200 Madison Ave., New York NY 10016. $39.95 ($19.95 paper). 166p.

Soil Microscopy and Micromorphology—*E.A. FitzPatrick.* John Wiley and Sons, 605 Third Ave., New York NY 10158. 304 p.

ERRATA

There are three errors in the paper "Nitrogen Fertilizer Response Potential of Corn and Sorghum in Continuous and Rotated Crop Sequences" by A.J. Franzluebbers, C.A. Francis, and D.T. Walters in the April-June 1994 (Vol. 7, no. 2) issue of the *Journal of Production Agriculture.*

Paragraph 3 on column 1 of page 280 should have read:

Average grain yield response for each crop by previous crop group was regressed upon N fertilizer rate and included N/Y as an interaction term with N fertilizer rate using the GLM procedure of SAS (SAS Institute, 1985). The interaction of N/Y with N fertilizer rate was used to test if N/Y altered grain yield response. Individual trials were blocked to account for differences in yield among trials and obtain an average intercept.

The first full paragraph on page 283 should have read:

Major differences in the critical level of N/Y for corn following cereals and legumes suggest that root-soil interactions with respect to previous crop may preclude the use of N fertilizer recommendations for cereals grown in rotation with legumes based upon results obtained for cereals grown in continuous crop sequences. This lack of consistency is highlighted by the large variation in FNE values commonly found in continuous-rotation study comparisons. The concept of using a different critical level of N/Y with respect to previous crop, allows for a fluctuating N credit that is dependent upon initially available N and yield level. Assigning a N credit to sorghum or corn following a legume would only be of academic interest, however, since N fertilizer recommendations could be derived with knowledge of initially available N, yield level, and the appropriate N requireement coefficient (i.e., the critical level of N/Y at which yield response is minimal), which is dependent upon previous crop (Table 6). For example, corn following soybean with an expected yield level of 120 bu/acre and 38 lb NO_3-N/acre/40 in. as RSN would require 40 lb N fertilizer/acre [i.e., (120 bu/acre × 0.65 lb N/bu) − 38 lb N/acre]. In this same scenario, except with corn following a cereal, the N fertilizer required would be 135 lb N/acre if RSN were also 38 lb NO_3-N/acre/40 in. The N credit would be calculated as 95 lb N/acre (i.e., 135 lb N/acre − 40 lb N/acre). If, however, the yield level were only 60 bu/acre and RSN were the same for both previous crops, then the N credit would only be 47 lb N/acre. Additionally, the N credit would increase or decrease if RSN were lower or higher following a cereal compared with a legume, respectively. This fluctuation in N credit following a legume due to changes in initially available N and yield level could help explain variation in FNE values observed in previous research.

Table 2 on page 279 should have read:

Table 2. Long-term average and observed monthly rainfall and air temperature for the four extension districts† during 1988 to 1990.

	Mean								1988				1989				1990			
Month	NE	E	SE	C	NE	E	SE	C	NE	E	SE	C	NE	E	SE	C	NE	E	SE	C
	°F				in.															
January	18	21	23	22	0.5	0.7	0.7	0.5	0.9	0.5	0.5	1.2	0.9	1.1	1.1	0.6	0.5	0.5	0.9	0.6
February	25	27	29	28	0.9	1.0	1.0	0.7	0.3	0.1	0.3	0.2	0.5	0.8	0.8	0.6	0.3	0.3	0.3	0.3
March	34	37	39	36	1.6	1.8	2.0	1.4	0.2	0.1	0.1	0.2	0.9	0.2	0.4	0.4	2.3	3.1	3.6	2.8
April	50	51	53	50	3.4	2.8	2.8	2.4	2.7	2.2	2.2	2.3	1.0	0.7	0.4	0.2	1.4	0.4	0.8	0.8
May	61	62	63	60	3.9	4.1	4.0	3.6	3.3	3.5	3.1	3.5	1.6	1.4	2.1	2.5	4.8	4.8	5.1	4.1
June	71	72	73	70	4.2	4.3	4.4	3.9	1.3	2.3	1.6	3.9	2.3	4.2	4.7	5.7	5.7	5.1	4.9	4.9
July	76	77	78	76	3.2	3.3	3.8	3.2	3.1	2.7	3.6	3.1	3.0	2.6	3.4	2.8	3.7	6.7	3.4	2.0
August	74	75	76	74	3.1	3.6	3.8	2.7	2.9	1.4	2.0	3.0	2.4	2.9	4.9	2.8	2.5	2.1	3.5	3.3
September	64	65	67	64	2.4	3.1	3.5	2.2	4.3	5.1	3.1	3.5	3.4	6.6	5.3	3.7	0.9	0.7	0.8	1.0
October	52	54	56	53	1.5	1.9	2.2	1.3	0.1	0.1	0.1	0.1	0.6	1.1	0.9	0.6	1.7	1.5	1.3	1.4
November	37	39	40	37	0.9	1.1	1.3	0.7	1.1	1.6	1.3	0.5	0.1	0.1	0.0	0.0	1.3	1.1	1.2	1.4
December	25	27	29	27	0.7	0.8	0.8	0.6	0.5	0.7	0.5	0.4	0.7	0.6	0.5	0.3	0.7	0.9	0.8	0.4
Total	49	51	52	50	26	29	30	23	21	20	18	22	17	22	25	20	26	27	27	23

† Extension districts are NE (northeast), E (east), SE (southeast), and C (central).

Nitrogen Fertilizer Response Potential of Corn and Sorghum in Continuous and Rotated Crop Sequences

A. J. Franzleubbers, C. A. Francis, and D.T. Walters

Research Question

Crop management systems need to be designed to maintain economic profitability and minimize negative environmental impact. Crop rotations are an integral part of sustainable agricultural systems, but satisfactory N fertilizer recommendations for cereals in rotation with legumes are not available. This study was conducted to determine the combined effects of previous crop, initially available N, and yield level on grain yield response to N fertilizer of sorghum and corn grown in eastern Nebraska.

Literature Summary

Current N fertilizer recommendations for both continuous and rotated crop sequences are based upon yield response observed in monoculture with subtraction of an average N credit for a particular previous crop when grown in rotation. Highly variable N credit values have been observed for a particular previous crop within the same study. One possible explanation for this large variation in observed N credit may have been differences among years and crop sequences in residual soil nitrate (RSN), although data supporting this hypothesis are absent. In addition, grain yield in rotation is often greater than in monoculture due to a rotation effect, which leads to greater N requirement, despite observation of less N fertilizer required in rotation compared with monoculture.Sufficient data relating N credit values to initially available N and yield level are lacking.

Study Description

Thirty-eight farmers in 14 counties of eastern Nebraska participated in 86 N fertilizer trials as part of a University of Nebraska Cooperative Extension program during 1988 through 1990. The ratio of initially available N to yield level (N/Y) was calculated for each individual trial. Initially available N consisted of RSN to a depth of 40 in., preplant and starter fertilizer N (if applicable), and NO_3-N in 9 in. of irrigation water (if applicable). Yield level of each farm was assumed to be the maximum predicted yield within the range of N fertilizer rates tested for each trial based upon a regression equation. Sorghum and corn grain yield response to N fertilizer was evaluated with respect to previous crop (i.e., cereal, soybean, or forage legume) and N/Y.

Applied Question

Can the combined use of residual soil nitrate and yield level improve N fertilizer recommendations for sorghum and corn grown in monoculture and in rotation with legumes?

Average sorghum and corn grain yield responded positively to addition of N fertilizer with cereal as previous crop. The magnitude of the linear response, however, decreased with increasing N/Y. With soybean and forage legume as previous crop, N fertilizer and N/Y had no effect on sorghum grain yield. Corn grain yield was also unaffected by the addition of N fertilizer with soybean or forage legume as previous crop. With soybean as previous crop, however, the interaction of N/Y with N

Full scientific article from which this summary was written begins on page 277 of this issue.

fertilizer rate indicated that grain yield responded to N fertilizer only under conditions of very low N/Y.

Relative sorghum and corn grain yield without N fertilizer increased with increasing level of N/Y with cereal as previous crop. This relationship was used to identify the critical level of N/Y at which yield response to N fertilizer was minimal. Considering 95% of maximum yield level as optimum to meet economic and environmental criteria, the optimum yield of sorghum and corn with cereal as previous crop was attained at a level of N/Y of 0.80 and 1.44 lb N/bu, respectively. At least 95% of maximum yield level was achieved at a level of N/Y of 0.65 lb N/bu for corn following soybean and 0 lb N/bu for corn following forage legume.

The results of this study suggest that initially available N relative to yield level is an important parameter for predicting N fertilizer response potential of sorghum and corn grown in eastern Nebraska. Major difference in the critical level of N/Y observed with respect to previous crop coincides with previous observations that cereals preceded by leguminous crops generally exhibit a reduced requirement for N fertilizer. The concept of using a different critical level of N/Y with respect to previous crop, allows for a fluctuating N credit that is dependent upon initially available N and yield level. This fluctuating N credit with legume as previous crop is consistent with highly variable N credit values found in previous research. Although the exact reason for the reduced requirement of N fertilizer of sorghum and corn grown with legume as previous crop compared with cereal as previous crop was not mechanistically defined, the *rotation effect* can still be exploited with an improvement in determining appropriate N fertilizer application in rotated crop sequences to achieve economically and environmentally optimum yield (Table 1). The combined effects of measuring RSN, selecting a realistic yield goal, and accounting for previous cropping history are management strategies that can increase the profitability of farming operations and decrease the potential negative environmental impact of N fertilizer carryover.

Table 1. Nitrogen fertilizer recommendations for corn based upon previous crop, expected yield, and initially available N (assuming a N requirement coefficient at 95% maximum yield).

		Previous crop					
		Corn		Soybean		Forage legume	
Expected yield	Initially available N	N required‡	Fert. N§	N required	Fert. N	N required	Fert. N
bu/acre	lb N/acre						
60	50	86	36	39	0	0	0
60	100	86	0	39	0	0	0
60	150	86	0	39	0	0	0
90	50	130	80	59	9	0	0
90	100	130	30	59	0	0	0
90	150	130	0	59	0	0	0
120	50	173	123	78	28	0	0
120	100	173	73	78	0	0	0
120	150	173	23	78	0	0	0
150	50	216	166	98	48	0	0
150	100	216	116	98	0	0	0
150	150	216	66	98	0	0	0
200	50	288	238	130	80	0	0
200	100	288	188	130	30	0	0
200	150	288	138	130	0	0	0

† Initially available N = NO_3-N/acre-40 in. + preplant N + starter N + NO_3-N/acre-9 in. irrigation water.
‡ N required = expected yield × N requirement coefficient (i.e., 1.44 following corn, 0.65 following soybean, and 0.00 following forage legume).
§ Fertilizer N (i.e., recommended amount of fertilzier) = N required − initially available N.