Reprinted from the *Journal of Production Agriculture*
Volume 8, no. 2, April–June 1995
677 South Segoe Rd., Madison, WI 53711 USA

Corn Response to Long-Term Nitrogen and Phosphorus Fertilization

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Accurate fertilizer N recommendations for irrigated continuous corn (*Zea mays* L.) production in the Great Plains are important for maximizing productivity and profit, while minimizing environmental impact of fertilizer use. The objectives of this study were to determine the effects of long-term N and P fertilization on grain yield and fertilizer recovery by irrigated continuous corn and to compare predicted N recommendations with actual N requirements. Six rates of N (0, 40, 80, 120, 160, and 200 lb/acre) and two rates of P (0 and 18 lb P/acre) in a factorial arrangement were applied annually from 1961 to 1991 on a Ulysses silt loam (fine silty, mixed, mesic Aridic Haplustoll) near Tribune, KS. Grain yields were greater with a combination of N and P than with either applied alone. The optimal N rate was about 160 lb N/acre and was relatively constant over time. Averaged over the last 10 yr, application of 160 lb N/acre increased grain yields 46% without P and 103% with P. The yield benefit from applied P has increased over time. With adequate N, P increased grain yields by 29% averaged over 31 yr and 48% over the last 10 yr. Phosphorus fertilization reduced grain moisture from 28 to 23%. Apparent fertilizer N recovery in the grain at 160 lb N/acre was twice as high with P as without P. A N recommendation model was used to compare estimated N requirements with actual N rates required to meet yield goals. Yields obtained with 160 lb N/acre were estimated to require 220 to 260 lb N/acre, or an overestimation of 30 to 60%. These data suggest that the crop factor used in the model may need to be reduced to improve accuracy of N recommendations.

The central Great Plains has about 12 million acres of irrigated land, and N fertilizers are applied routinely to maximize grain yields (Powers and Schepers, 1989). Quantifying the optimum rate of fertilizer N is essential to maximize productivity and to minimize residual fertilizer N (Bock, 1984). Nitrogen fertilizer requirements depend on many factors including yield goal, inorganic soil N, potential N mineralization, soil type, and numerous environmental factors. The fertilizer N requirement of a crop often is overpredicted when yield goals are overestimated or the quantity of inorganic soil N is underestimated. Schepers et al. (1986) reported that irrigated corn producers used yield goals that were 38 bu/acre greater than those achieved, thereby overestimating fertilizer N requirement by 40 lb N/acre. Many studies have reported minimal carryover of residual fertilizer N when the N application rate was nearly equivalent to crop need (Dahnke and Johnson, 1990; Bundy and Malone, 1988; Oberle and Keeney, 1990a). These authors demonstrated that failure to quantify residual fertilizer N resulted in overapplication of N and accumulation of profile N.

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Published in J. Prod. Agric. 8:181–185 (1995).

Fertilizer N rates for maximum or optimum yield also vary widely between locations (or soils) and years (Onken et al., 1985). In long-term studies with corn, the N rate required for maximum yield varied from 155 to 215 lb N/acre on several rainfed silt loam Wisconsin soils, compared with 165 to 230 lb N/acre on irrigated sandy loam and loamy sand soils (Oberle and Keeney, 1990a). Fertilizer N recommendations for irrigated corn in western and south central Nebraska varied between 50 and 164 lb N/acre and depended on soil profile and nitrate-N content of irrigation water (Ferguson et al., 1991).

Several studies have shown that fertilizer N remaining in the soil profile increases with increasing N rate (Legg and Meisinger, 1982; Hooker et al., 1983). In irrigated corn, for example, Broadbent (1980) reported that the fertilizer N remaining in the soil ranged from 40 to 62% when fertilizer N was increased from 100 to 500 lb N/acre, respectively. Interestingly, the quantity of N recovered by the grain was relatively constant at about 100 lb N/acre with N rates of 220 lb N/acre or greater.

Maximizing the quantity of fertilizer N recovered by the crop, or minimizing the quantity of residual fertilizer N after harvest, generally will reduce potential groundwater contamination (Keeney, 1987; Bock, 1984). Apparent fertilizer N recovery (AFNR) generally ranges between 30 and 70% (Legg and Meisinger, 1982) and depends on many factors including location or soil type, inorganic soil N content, N rate, and other N or water management factors (Bock, 1984; Walters and Malzer, 1990). Generally, AFNR decreases with increasing N rate (Oberle and Keeney, 1990b). In their study, AFNR was higher in coarse-textured soils than in fine-textured soils because of greater N mineralization in the fine-textured soils. The effect of N rate on AFNR may not be as great as the effect of profile nitrate-N level, because some studies have shown that increasing residual N decreased AFNR (Onken et al., 1985; Bock, 1984).

In addition to N rate and water, management of other inputs may affect crop yield response to applied N and AFNR. Generally, any factor that limits yield potential will reduce AFNR and the quantity of N required for optimum yield. For example, in deficient soils, adequate P fertilization increases yield response to fertilizer N and N uptake or AFNR (Black, 1970; Halvorson and Black, 1985; Halvorson and Havlin, 1992). Reviews of N and P nutrient interactions in winter wheat (Havlin and Halvorson, 1990) and grain sorghum (Havlin and Lamond, 1988) showed increased AFNR with adequate P fertilization in P-responsive soils.

Recent concern about the impact of fertilizer N use on groundwater quality has generated considerable interest

Abbreviation: AFNR, apparent fertilizer N recovery.

Table 1. Selected soil chemical properties of the unfertilized plots.

	Year		
Soil property	1961	1989	1991
CEC, meq/100 g	--	--	24
pH (1:1)	7.9	8.1	8.1
OM, %	1.4	--	2.0
Bray 1-P, ppm	17	6	6
NH_4OAc-K, ppm	500	580	560
DTPA-ZN, ppm	--	0.9	1.1
DTPA-Fe, ppm	--	5.9	5.6
Nitrate-N (0–6 in.), ppm	--	4.1	0.8
Nitrate-N (6–12 in.), ppm	--	3.0	0.5
Nitrate-N (12–24 in.), ppm	--	2.2	0.3
Nitrate-N (24–36 in.), ppm	--	1.9	0.5
Nitrate-N (36–48 in.), ppm	--	1.5	0.4

in fertilizer N management. Although N source, placement, and timing are important management considerations, accurately identifying the quantity of fertilizer N required for optimum yield often may be the primary decision (Hergert, 1987; Ferguson et al., 1991).

The objectives of this study were to (i) quantify the grain yield response and recovery of fertilizer N and P by irrigated continuous corn and (ii) compare predicted N recommendations with actual N requirements.

MATERIALS AND METHODS

Nitrogen and P fertilizers were applied annually from 1961 to 1991 to irrigated continuous corn grown on a Ulysses silt loam at the Tribune Unit, Southwest Research-Extension Center in west central KS. Selected chemical properties of the surface soil were measured periodically (Table 1). A complete factorial of six N rates (0, 40, 80, 120, 160, and 200 lb N/acre) and two P rates (0 and 18 lb P/acre) was arranged in a randomized complete block design replicated five times. The N source was ammonium nitrate (34–0–0), and the P source was triple superphosphate (0–45–0). All treatments were hand broadcast to the same plot each year in the spring and immediately incorporated with a disc. Plot size was 12 by 60 ft.

Cultural practices varied over the course of the experiment to incorporate improved technologies. Typical tillage practices were shredding the stalks and discing in the fall along with several spring discings. An adapted corn hybrid was planted in late April or early May. Pre- and postemergence herbicides were used to control weeds along with mechanical cultivation. The study area was furrowed to facilitate flood irrigation. Growing season rainfall ranged from 6.6 to 14.8 in., requiring supplemental irrigation of about 14 to 22 in. to meet the evapotranspiration demand. The quality of the irrigation water was excellent containing about 2 ppm nitrate-N (0.45 lb/acre-inch), 4 ppm K, 13 ppm Mg, 55 ppm Ca, and 19 ppm sulfate-S with a pH of 7.9.

Leaf samples at silking were collected, dried, ground to pass a 0.04 in. (1 mm) screen, and digested using a sulfuric acid and hydrogen peroxide digest (Isaac, 1977). Total N and P were determined with a Technicon Autoanalyzer using Technicon Industrial Method 334-74 W/B (Technicon Industrial Systems, 1977). After corn reached physiological maturity, the center two rows of each plot were combine harvested, usually in early October. Grain yield was adjusted to 15.5% moisture. Grain samples were dried, ground, and analyzed for N and P with the same procedures used for tissue analyses.

The total amount of N removed by grain was calculated by multiplying grain yield by % grain N. The AFNR was calculated by subtracting the grain N in the control treatment from the total amount of grain N in the treatment receiving N and dividing the difference by the N rate. The same approach was used for calculating apparent fertilizer P recovery.

Analysis of variance was performed to evaluate treatment effects on dependent variables using the General Linear Models routine of SAS (SAS Institute, 1985). The main effect of N rate and the interaction of N × P were partitioned into single degree of freedom orthogonal polynomial contrasts with linear and quadratic relationships reported.

RESULTS AND DISCUSSION

Grain yield of irrigated corn was increased significantly by N and P in each year of this long term study (Table 2). Yields also were affected by climatic factors. For example, yields in 1983 were suppressed by higher-than-normal temperatures from July to September, along with an early frost that reduced the growing season by 30 d. In the last 10 yr, grain yield was increased 46% (38 bu/acre) without P and 103% (90 bu/acre) with P when 160 lb N/acre was applied. An average maximum grain yield (1982–1991) of 177 bu/acre was obtained with 160 lb N/acre with P or about 0.9 lb of N/bu of corn. Increasing the N rate above 160 lb N/acre did not further increase grain yield in any year, which is consistent with the optimum N rate observed in the first 21 yr of the study (Hooker et al., 1983).

Irrigation water was not a significant source of N, because it supplied less than 10 lb N/acre annually. This is in contrast to other research where nitrate-N in the irrigation water strongly influenced corn response to fertilizer N and N recovery (Ferguson et al., 1991).

A quadratic N response function was developed for the 10- and 31-yr average yields with and without P (Fig. 1). Phosphorus application increased the optimum N rate by about 10 lb/acre. With P, the N rate that maximized yield remained relatively constant throughout the study at about 160 lb N/acre. The grain yield response to P has increased over time. At 160 lb N/acre, P increased grain yields by 29% (38 bu/acre) averaged over 31 yr, by 48% (57 bu/acre) over 10 yr, and by 131% (117 bu/acre) in 1991. However, soil P levels declined from 17 ppm Bray 1-P initially to about 10 ppm Bray 1-P when P was applied with 160 lb N/acre or more, indicating that the level of P fertilization (18 lb P/acre) was too low.

Grain moisture content at harvest was reduced greatly by P fertilization (Fig. 2). At 160 lb N/acre, grain moisture was 28.8% without P compared with 23.8% with P. A reduction in grain moisture decreases drying costs, reduces crop loss potential, and allows for earlier harvest.

Leaf N increased linearly with increased rates of N fertilizer (Table 3). With P, leaf N was not increased by N

Table 2. Grain yield response of corn to N and P, 1982–1991, Tribune, KS.

N	P	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1982–1991	1961–1991†
		Year											
— lb/acre —		bu/acre											
0	0	100	91	115	72	107	52	62	82	71	64	82	70
40	0	135	110	147	104	130	93	86	106	94	82	109	107
80	0	135	104	153	98	138	102	104	118	124	82	115	121
120	0	138	112	149	93	132	98	98	111	120	90	114	124
160	0	133	119	168	99	144	109	105	122	118	89	120	131
200	0	130	112	158	97	149	95	107	121	130	92	119	132
0	18	106	105	126	68	112	53	59	96	73	78	87	73
40	18	154	124	174	117	161	107	101	134	125	119	131	119
80	18	157	133	169	133	165	135	128	164	160	158	150	143
120	18	176	124	193	135	194	146	150	170	195	180	166	159
160	18	176	133	194	144	200	158	172	180	212	206	177	169
200	18	170	134	194	139	190	157	169	182	207	196	173	166
ANOVA ($P > F$)													
N		0.001	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
N linear		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
N quad.		0.001	0.069	0.003	0.001	0.015	0.001	0.001	0.001	0.001	0.001	0.001	0.001
P		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
N × P		0.024	0.736	0.471	0.001	0.060	0.001	0.001	0.001	0.001	0.001	0.001	0.001
N_l × P		0.001	0.812	0.152	0.001	0.014	0.001	0.001	0.001	0.001	0.001	0.001	0.001
N_q × P		0.399	0.901	0.574	0.009	0.078	0.321	0.213	0.076	0.012	0.004	0.001	0.001

† For 1961 to 1981 yields, see Hooker et al. (1983).

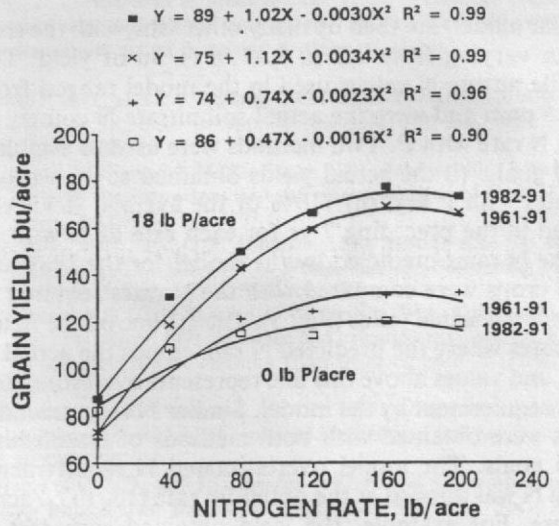

Fig. 1. Average grain yield response of corn to N and P for 1982–1991 and 1961–1991, Tribune, KS.

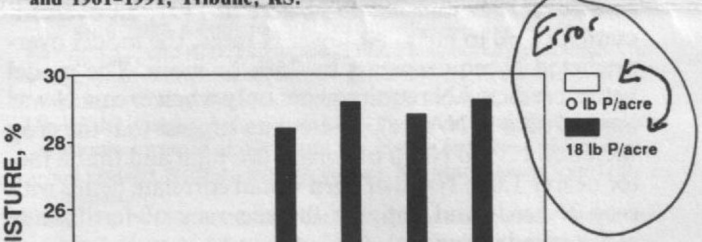

Fig. 2. Effect of fertilizer P on corn grain moisture content, 1988–1991. LSD 0.05 *N* = 0.8% and LSD 0.05 *P* = 0.6%.

Table 3. Leaf N and P responses of corn to fertilizer N and P, 1988–1991, Tribune, KS.

N	P	Leaf N 1988	Leaf N 1989	Leaf N 1990	Leaf N 1991	Leaf P 1988	Leaf P 1989	Leaf P 1990	Leaf P 1991
— lb/acre —		%							
0	0	1.47	1.41	1.30	1.41	--	0.15	0.12	0.15
40	0	1.87	1.84	1.54	1.77	--	0.14	0.11	0.14
80	0	2.21	2.12	1.77	2.08	--	0.14	0.12	0.14
120	0	2.30	2.16	1.84	2.14	--	0.14	0.12	0.14
160	0	2.27	2.21	1.89	2.16	--	0.14	0.12	0.15
200	0	2.27	2.27	1.92	2.19	--	0.15	0.12	0.16
0	18	1.51	1.39	1.10	1.27	--	0.21	0.19	0.20
40	18	1.55	1.61	1.06	1.15	--	0.19	0.15	0.16
80	18	1.88	2.07	1.60	1.56	--	0.20	0.17	0.17
120	18	2.09	2.21	1.67	1.92	--	0.21	0.18	0.18
160	18	2.21	2.31	1.94	2.13	--	0.22	0.20	0.20
200	18	2.24	2.47	1.98	2.08	--	0.24	0.21	0.20
ANOVA									
N		0.001	0.001	0.001	0.001	--	0.001	0.001	0.001
N linear		0.001	0.001	0.001	0.001	--	0.001	0.001	0.001
N quad.		0.001	0.001	0.009	0.010	--	0.006	0.001	0.001
P		0.001	0.860	0.001	0.001	--	0.001	0.001	0.001
N × P		0.007	0.138	0.004	0.001	--	0.227	0.001	0.012
N_l × P		0.414	0.023	0.001	0.001	--	0.028	0.004	0.488
N_q × P		0.001	0.297	0.212	0.001	--	0.265	0.002	0.042

rates above 160 lb N/acre, indicating adequate N availability at this rate. At the optimum N rate with P, leaf N content averaged 2.15%, which is similar to a critical leaf N concentration of 2.1% reported by Cerrato and Blackmer (1991) but less than other published critical concentrations of 3.0% N or above (Hanson et al., 1987; Melsted et al., 1969). Leaf P concentration decreased with the first increment of N, probably because of nutrient dilution. With N rates above 40 lb N/acre, however, leaf P increased with increased N. In general, P fertilization increased leaf P content by about 0.05%. Leaf P never exceeded 0.25% P, which is less than the critical range of 0.30 to 0.45% P reported by other workers (Schulte and Kelling, 1986).

Grain N increased substantially with increasing N rates (Table 4). With P, grain N was 18 to 36% greater with the highest N rate than with zero N. In general, P fertili-

Table 4. Grain N and P responses of corn to fertilizer N and P, 1988–1991, Tribune, KS.

		Grain N				Grain P			
N	P	1988	1989	1990	1991	1988	1989	1990	1991
— lb/acre —		%							
0	0	0.98	0.95	0.89	0.99	0.21	0.21	0.22	0.22
40	0	1.06	1.06	0.95	1.14	0.18	0.20	0.18	0.20
80	0	1.21	1.19	1.08	1.37	0.16	0.17	0.18	0.18
120	0	1.32	1.23	1.14	1.44	0.15	0.18	0.17	0.19
160	0	1.31	1.21	1.20	1.45	0.16	0.17	0.17	0.20
200	0	1.36	1.24	1.14	1.48	0.17	0.19	0.17	0.19
0	18	1.02	0.91	0.81	0.94	0.23	0.26	0.31	0.31
40	18	0.99	0.98	0.83	0.95	0.23	0.25	0.28	0.29
80	18	1.02	1.09	0.89	1.03	0.21	0.24	0.25	0.27
120	18	1.11	1.13	0.96	1.13	0.20	0.22	0.21	0.24
160	18	1.18	1.17	1.04	1.22	0.19	0.24	0.22	0.23
200	18	1.20	1.18	1.08	1.27	0.19	0.22	0.22	0.23
ANOVA									
N		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
N linear		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
N quad.		0.245	0.001	0.047	0.004	0.001	0.005	0.001	0.001
P		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
N × P		0.001	0.660	0.034	0.001	0.001	0.259	0.001	0.001
N_1 × P		0.001	0.966	0.782	0.024	0.695	0.731	0.001	0.001
N_q × P		0.001	0.210	0.001	0.001	0.001	0.420	0.631	0.947

zation decreased grain N. Grain P decreased with increased N rates, whereas addition of P fertilizer increased grain P concentration.

The AFNR in the grain was less than 55% and decreased linearly with increasing N rate (Table 5). Averaged over 4 yr, P fertilization with 160 lb N/acre more than doubled AFNR compared with the same N rate without P. Similar results were obtained with dryland winter wheat in Kansas (Havlin and Halvorson, 1990). Assuming that 60% of the N in the aboveground biomass is contained in the grain (Oberle and Keeney, 1990b), total N recovery in the biomass at 160 lb N/acre would be 35% without fertilizer P compared with 75% with P, which agrees with other estimates of total N recovery (Bock, 1984; Legg and Meisinger, 1982). Therefore, estimated residual fertilizer N would be 40 lb N/acre with fertilizer P compared with 104 lb N/acre without P. The apparent fertilizer P recovery increased with increased N rates up to 160 lb N/acre and then decreased at the highest N rate.

A N recommendation model (Kansas State University Soil Testing Lab) was used to estimate N fertilizer recommendations for 1989 and 1991 (years with data available on residual soil nitrate-N for all treatments). Grain yields in 1989 were similar to the 10-yr average yields (1982–1991), whereas 1991 grain yields were 10% higher than the 10-yr average. The model determines N recommendations based on yield goal (1.35 lb N/bu of expected yield) adjusted for residual soil nitrate-N with credits for previous legume crops or manure applications, if applicable. Because manure applications and previous legume crops were not included in the study, the model used was:

$$N_{rec} = (1.35 \times YG) - (7.5 \times N_{soil})$$

where

N_{rec} = Recommended N rate (lb/acre)
YG = Yield goal (bu/acre)
N_{soil} = Profile nitrate-N (ppm 0–2 ft)

Table 5. Apparent recovery of fertilizer N and P in corn grain, 1988–1991, Tribune, KS.

		AFNR†				AFPR‡			
N	P	1988	1989	1990	1991	1988	1989	1990	1991
— lb/acre —		%							
0	0	--	--	--	--	--	--	--	--
40	0	35	40	30	34	--	--	--	--
80	0	39	37	41	29	--	--	--	--
120	0	27	23	29	26	--	--	--	--
160	0	22	20	23	19	--	--	--	--
200	0	20	17	20	17	--	--	--	--
0	18	--	--	--	--	1	20	18	27
40	18	47	50	53	49	22	33	49	51
80	18	42	54	49	54	28	49	48	74
120	18	42	40	50	52	42	44	55	72
160	18	42	36	47	53	47	61	72	80
200	18	34	30	39	42	38	49	61	76
ANOVA									
N		0.004	0.001	0.001	0.005	0.001	0.001	0.001	0.001
N linear		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
N quad.		0.640	0.979	0.056	0.145	0.039	0.503	0.253	0.018
P		0.001	0.001	0.001	0.001	--	--	--	--
N × P		0.306	0.936	0.104	0.118	--	--	--	--
N_1 × P		0.226	0.851	0.679	0.066	--	--	--	--
N_q × P		0.975	0.402	0.601	0.098				

† AFNR = Apparent fertilizer N recovery.
‡ AFPR = Apparent fertilizer P recovery.

Similar models are used by many other labs, with the crop factor varying from 1.2 to 1.35 lb N/bu of yield. The profile nitrate-N values used in the model ranged from 1 to 5 ppm and were the actual soil nitrate-N content at each N rate with P. Two methods were used to establish yield goals: (i) the actual yields obtained at the various N rates with P and (ii) 110% of the average yields obtained in the preceding 7 yr for each rate of N with P.

The N rates predicted by the model for the 1989 and 1991 crops were compared with the N rates required to achieve the actual yields (Fig. 3). The 1:1 line on the figure indicates where the predicted N rate equals the actual N rate, and values above this line represents overestimation of N requirement by the model. Similar N recommendations were obtained with both methods of establishing yield goals. The model overestimated N requirements when N was applied at the optimum rate (160 lb N/acre) or less. For example, the yield obtained with 160 lb N/acre was predicted by the model to require 220 lb N/acre in 1989 and 260 lb N/acre in 1991, an overestimation of 30 to 60%. At lower N rates, the model overpredicted N requirements by 75% or more. The model better predicted N requirements only when excess N was applied (200 lb N/acre). These data suggest that the crop factor of 1.35 lb N/bu of corn is too high and that a factor nearer 1.0 lb N/bu of corn would correlate better with crop N needs and improve the accuracy of fertilizer N recommendations.

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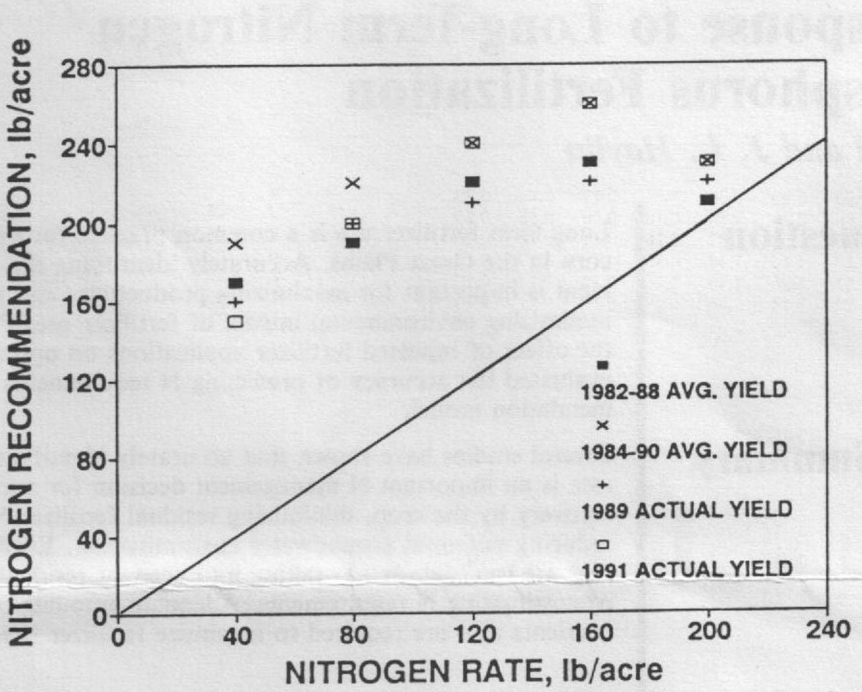

Fig. 3. Comparison of predicted and actual N fertilizer requirements to meet yield goals at each N rate determined by two methods: the actual yields obtained in 1989 and 1991 and 110% of the yield average of the 7 yr prior to 1989 and 1991. The 1:1 line represents where N recommendations equal actual N needed to attain yield goal.

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Corn Response to Long-Term Nitrogen and Phosphorus Fertilization

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Research Question

Long term fertilizer use is a common practice for irrigated continuous corn in the Great Plains. Accurately identifying the fertilizer N requirement is important for maximizing productivity and profit, while minimizing environmental impact of fertilizer use. This study quantified the effect of repeated fertilizer applications on optimal N rate and evaluated the accuracy of predicting N requirements using a N recommendation model.

Literature Summary

Several studies have shown that accurately identifying the optimal N rate is an important N management decision for maximizing fertilizer N recovery by the crop, minimizing residual fertilizer N after harvest, and reducing potential groundwater contamination. Establishing yield goals that are too high or not taking into account residual soil N can result in overestimating N requirements. Adequate amounts of other plant nutrients also are required to maximize fertilizer N recovery.

Study Description

Six rates of N fertilizer (0, 40, 80, 120, 160, and 200 lb N/acre) and two rates of P (0 and 18 lb P/acre) were applied annually (1961–1991) to irrigated continuous corn on a Ulysses silt loam. Measurements included grain yield, grain N and P, grain moisture, and apparent fertilizer recovery.

Applied Questions

What is the optimum N rate for irrigated continuous corn?

In this long-term study, the optimum N rate was about 160 lb N/acre and was relatively constant across years (Table 1). Although fertilizer P was needed to maximize grain yield, it had little effect on optimal N rate.

What effect does P have on fertilizer N efficiency and grain production?

With optimal N, fertilizer P doubled apparent N fertilizer recovery. Fertilizer P decreased grain moisture and increased grain yields by 48% averaged over 10 yr when applied with optimal N.

Do current N recommendation models accurately predict N requirements?

No. In 2 yr of the study with average or above average yields, the model overpredicted N needs by 30 to 60% compared with observed optimal N rate.

Table 1. Grain yield response of corn to N and P.

	1982–1991		1961–1991	
N rate	−P	+P	−P	+P
lb/acre	bu/acre			
0	82	87	70	73
40	109	131	107	119
80	115	150	121	143
120	114	166	124	159
160	120	177	131	169
200	119	173	132	166

Full scientific article from which this summary was written begins on page 181 of this issue.