Corn production as affected by daily fertilization with ammonium, nitrate, and phosphorus

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ABSTRACT

Manipulation of N fertilization to control NH_4^+/NO_3^- ratios in the soil can affect corn (*Zea mays* L.) growth and yield. Field study of these effects, however, has been difficult to conduct because nitrification of NH_4^+ and/or NO_3^- leaching often occurs during the growing season. The objectives of this 4-year field experiment, were to investigate the effects of daily fertilization with various N sources and P on corn growth and yield. Pioneer 3343 was fertilized with solutions of urea (U), NH_4Cl, $Ca(NO_3)_2$(CN), or U+CN (1:1 N ratio) with and without a solution of H_3PO_4. Solutions were applied to the root zone with a porous pipe subirrigation system. Nitrogen sources caused changes in KCl-extractable soil NH_4^+ and NO_3^-. Dry matter (DM) accumulation was not affected by N source at any stage of corn development. The effects of N source on N uptake, P uptake, and root growth varied by year, showing no consistent superiority of any of the N sources used. Corn yield was larger when NO_3^- was included as an N source (CN or U+CN) than when only U was used in 1991. In the next two years, yield was not affected by N source; in the last year, NH_4^+ (U or NH_4Cl) increased yield over CN. There was little correlation between yield, N uptake, or P uptake. Overall, no clear difference for maximizing corn growth and yield was observed between NH_4^+, NO_3^-, or the mixture $NH_4^+ + NO_3^-$.

Introduction

Ammonium, NO_3^-, or a mixture of these N forms may have different effects on corn growth and grain yield. Prior to tasseling and under greenhouse conditions, however, the superiority of any of these N forms for maximizing growth is not clear. Total dry weight was found to be 2.3 times greater with NH_4^++NI than with NO_3^- (Teyker and Hobbs, 1992); 1.4 times greater with NO_3^- compared to NH_4^++NI at a low K rate (Dibb and Welch, 1976); 1.7 and 13.8 times greater with NO_3^- compared to either a 1:1 NH_4^+-N:NO_3^- -N mixture or NH_4^+ when several P rates were used (Bennett et al., 1964); and 1.5 times greater with various mixtures of $NH_4^+ + NO_3^-$ than with either NH_4^+ or NO_3^- alone (Schrader et al., 1972). At maturity, results from outdoors-hydroponic studies support the concept that mixtures of NH_4^+ and NO_3^- maximize growth (Reddy et al., 1991), and, depending on the hybrid, increase grain yield 8 or 14% over NO_3^- alone (Below and Gentry, 1987).

The benefits of manipulating soil NH_4^+/NO_3^- ratios on corn yield under field conditions, however, have not been clearly established. Hybrids with > 1.5 ear per plant averaged 11% more dry matter, 12% more grain yield, and N uptake was 7% higher when they were supplied with U+NI compared to CN (Pan et al., 1984). In the second year of experimentation, however, U+NI reduced yield in a non-prolific genotype by 28%. Differences in grain yield or dry matter at maturity were not observed between NH_4^+- and NO_3^--fertilized plants in two out of three years (Barber et al., 1992). In the second year of the study, however, the application of NH_4^++NI alone or in combination with NO_3^- increased yield between 3 and 9% when compared to the application of NO_3^-+NI. Split N applications were used in both studies to minimize NH_4^+ nitrification and NO_3^- leaching. Nitrogen applications of 20 lb a^{-1} at planting, and 45 lb a^{-1} at 35, 49, 63, and 77 days after planting for a total of 200 lb N a^{-1} (Pan et al., 1984), and applications of 70 lb N a^{-1} at preplant, V6, and tasseling (Barber et al., 1992) were used. More frequent N applications, however, may have been necessary to reduce the annual variability of yield response to N source. In addition, none of these studies looked at the interactive effects of N form and P on grain yield. The increased fertilizer P uptake in the presence of NH_4^+ (Blair et al, 1970) may also occur in soils with high levels of available P if P fertilizer is applied daily.

The objectives of this field study were to evaluate the effects of daily applications of NH_4^+, NO_3^-, $NH_4^+ + NO_3^-$, and P placed in the root zone on N uptake, P uptake, dry matter accumulation, and grain yield.

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MATERIALS AND METHODS:

Porous pipes 0.75 inches inside diameter were installed 12 inches deep along every other row middle on a Kokomo silty clay loam at the Western Branch of The Ohio Agricultural Research and Development Center near Springfield, Ohio. Micropores are uniformly distributed over the surface of the pipe and allow water to go through at more than 0.5 gal per 100 feet per minute.

Alfalfa (*Medicago sativa* L.) was grown in the experimental site for 3 consecutive years before the initiation of the study, and it was moldboard plowed in the fall of 1990. The study was conducted from 1991 through the growing season of 1994. Pioneer 3343 was planted in rows 30 inches apart so that each porous pipe fertilized and irrigated two corn rows, each of which was 15 inches from the feeding porous pipe. Plots were 35 feet long with 4 corn rows. The tillage system consisted of a moldboard plow in late fall and a spring disking before planting.

Two P rates (0 and 50 lb a^{-1}), and two sources of N in three combinations (U, CN, and U+CN) were applied from 1991 to 1993 in factorial combination with treatments arranged in randomized complete blocks with three replications. Fertilization with NH_4Cl replaced the U+CN treatment in 1994. Two controls (-N-P, -N+P) were also included. Phosphorus was supplied as a solution of H_3PO_4 (6.6% P v/v).

Nitrogen and P fertilizer solutions were applied daily with a computerized porous pipe subirrigation system. Weekly N and P requirements were determined with the model for N and P uptake developed by Ritchie and Hanway (1984)(Table 1).

This experimental set up (replication + treatments + porous pipes) was installed in two adjacent areas. In the Eastern area, corn was planted in 1991, soybean (*Glycine max* L.) in 1992, corn in 1993, and soybean in 1994. The West area was planted with soybean, corn, soybean, and corn during the same years. The data collected for corn are presented here.

Soil characteristics were nearly the same in both areas. Average initial measurements of exchangeable Ca, Mg, K , and CEC in the upper 8 inches of soil were 7040 lb, 1776 lb, 470 lb per acre, and 29 meq/100g using 1M NH_4OAc as the extractant solution (Brown and Warncke, 1988); Bray #1 P was 126 lb per acres (Knudsen and Beegle, 1988); pH and lime test index were 6.6 and 67 (Eckert, 1988), and KCl-extractable soil NH_4^+ and NO_3^- were 22 and 14 lb per acre. At the pipe depth, soil pH was 6.8, Bray #1 P was 32 lb per acre, and KCl-extractable soil NH_4^+ and NO_3^- were 10 and 14 lb per acre.

Soil cores were collected from a depth of 11 to 12 inches at a distance of 0 to 1 inch from the porous pipe in 1992. Samples were collected at growth stages V6, V10, V14, V16, R1, and R3 as defined by Ritchie and Hanway (1984) by combining three cores from each plot. To study the movement of N sources in the soil, additional samples were taken at tasseling in 1992 and 1993 at depths of 0-6, 6-12 and 12-18 inches, at distances of 0, 2.5, 7.5, 10, and 15 inches from the porous pipe. In 1991 samples were taken at the same depths at 0 and 7.5 inches from the porous pipe. Moist samples were extracted with a 2N KCl solution (Bremner and Keeney, 1966), and concentrations of NH_4^+ and NO_3^- in the extract were determined colorimetrically (Lachat Instruments, 1993).

Grain yield was measured at maturity in the two middle rows of each plot. The grain moisture was determined and stand counts were taken. Grain yield was adjusted to a moisture content of 15.5 percent on a wet basis.

Whole plant samples were collected at approximately growth stages V6, tasseling, and harvest. Ten plants per plot were collected at growth stage V6, while 5 plants were selected at tasseling and maturity. Samples at V6 were dried and weighed. Samples at tasseling and maturity were weighed fresh, passed through a plant chopper, subsampled, and dried for at least 48 hours in a forced-air oven at 60°C. Dry matter accumulation was calculated by multiplying the fresh weight by the percent dry matter in the subsample.

RESULTS

Soil:

Daily application of fertilizers varied according to the corn growth stage (Table 1), and resulted in total N application rates of 154, 312, 295, and 304 lb a^{-1} for 1991, 1992, 1993, and 1994. Soil NH_4^+ at the 0 to 1 inch from the porous pipe, was higher in the U fertilized plots than in the CN fertilized plots from growth stage V10 to R3 (Table 3). Conversely, soil NO_3^- at the same distance was higher in the CN fertilized plots than in the U fertilized plots from growth stage V6 to R3. At V6, differences in KCl-extractable NH_4^+ and NO_3^- were not detected when treatments receiving no N were compared to treatments fertilized with N sources. More subsamples per plot may have been needed to detect treatment differences in NH_4^+ and NO_3^- at V6. Fertilization with P had no effect on KCl-extractable soil NH_4^+ and NO_3^-; therefore, the data are averages across P levels.

Significant changes in the soil NH_4^+/NO_3^- ratio occurred mostly 0 to 7.5 inches from the porous pipe for all N sources in 1991, 1992, and 1993; but small concentrations of U were detected at 10 and 15 inches from the porous pipe in the U fertilized plots in 1993 (Data not shown). Inorganic N (NH_4^++NO_3^-), averaged across growth stage, was less in CN fertilized plots than in U fertilized plots (95 vs. 59 ppm N). This smaller concentration of inorganic N may result from the higher mobility of NO_3^- in the soil.

Dry matter:

Nitrogen sources compared to treatments without N increased dry matter accumulation at tasseling, and at maturity in each year (Table 4). This increase in dry matter accumulation, however, was statistically the same when N was supplied as NH_4^+, NO_3^-, or NH_4^++NO_3^-. Similar results were found with non-prolific hybrids by Pan et al. (1984), and Barber et al. (1992). The latter, however, found larger dry matter accumulation at V6 with NH_4^+ than with NO_3^- in one out of three years.

Nitrogen applied with P, averaged across N sources, resulted in higher dry matter accumulation at maturity than N applied alone in 1992 (22.4 vs. 21.5 tons a^{-1}), and 1994 (26.7 vs. 23.0 tons a^{-1}). The application of P alone also increased dry matter accumulation at maturity in 1991 compared to the treatment without N or P, but depressed dry matter at tasseling in 1992. In 1993, P fertilization had no effect on dry matter accumulation.

N uptake:

Nitrogen sources affected N uptake at V6 and tasseling in 1993, and at maturity in 1994 (Table 5). The effect of N sources on N uptake at V6 varied depending on the P rate. Nitrogen uptake was similar with NH_4^+, NO_3^-, or NH_4^++NO_3^- when they were applied alone. Phosphorus fertilization reduced N uptake when applied with NH_4^++NO_3^-, increased N uptake with NO_3^-, and had no effect on N uptake with NH_4^+. The increase in N uptake with NO_3^- alone is in disagreement with results of Barber et al. (1992) who reported higher N uptake at V6 when NH_4^+ was included as an N source than when NO_3^- was used alone. Effects of N sources on N uptake at V6 indicate that applied N from all sources was available at early growth stages. Therefore, the lack of differences in DM accumulation at V6 should not be attributed to lack of early availability of applied NH_4^+ or NO_3^-. At tasseling N uptake was higher with NO_3^- than with NH_4^+ (92 vs. 75 lb N a^{-1}). In contrast, N uptake was higher with NH_4^+ than with NO_3^- at maturity in 1994 (199 vs 182 lb N a^{-1}). In 1992 N sources did not affect N uptake and there was no difference between treatments with N and treatments without N.

The physiological bases for the higher N uptake with NO_3^- than with NH_4^+ at V6 and tasseling in 1993 is unknown. We speculate, however, that some N was taken up as urea, which is usually taken up at a lower rate than NH_4^+ (Hentschel, 1970) and results in lower yield than NO_3^- (Kirkby and Mengel, 1970). Possibly, the rate of urea hydrolysis increased after V6 building up soil NH_4^+, thus eliminating the treatment difference due to N source at latter stages of corn development. Lack of N source effect on N uptake at advanced stages of corn development has been reported by Barber et al. (1992). Other studies, however, have shown increased N uptake at maturity with NH_4^+ or a mixture NH_4^++NO_3^- in soils with high NO_3^- leaching potential (Jung et al., 1972) and in field hydroponic systems which allowed good control of NH_4^+/NO_3^- ratios in the entire root zone (Below and Gentry, 1987).

P uptake:

Nitrogen sources affected P uptake at tasseling in 1993, and at maturity in 1992 with the effects dependent on the P rate (Table 6). At tasseling, P uptake was higher with NH_4^+ than with NO_3^- when N sources were applied alone. Phosphorus fertilization increased P uptake when applied with NO_3^- compared to NO_3^- applied alone, reduced P uptake with NH_4^+ compared to NH_4^+ alone, and had no effect on P uptake with $NH_4^+ + NO_3^-$. At maturity, in contrast, P fertilization increased P uptake when applied with $NH_4^+ + NO_3^-$, but had no effect on P uptake when applied with NH_4^+ or NO_3^- alone. Corn plants fertilized with NH_4^+ or a mixture $NH_4^+ + NO_3^-$ may take up more P than plants fertilized with NO_3^- because of changes in soil pH (Blair et al., 1970) and plant metabolism (Below and Gentry, 1987). Increased P uptake with NH_4^+ fertilization, however, is not always observed (Reddy et al., 1991). In 1994, P fertilization did not increase P uptake. The changes observed in P uptake, therefore, do not explain the increased DM accumulation observed in 1992 and 1994 when P was applied.

Phosphorus fertilization alone did not increase P uptake in any year at any stage of development. This lack of increase in P uptake with P fertilization is consistent with the high level of available P in the soil.

Grain Yield:

Grain yield response to N source varied by year (Table 7). Yield in 1991, averaged across P rate, was higher with $NH_4^+ + NO_3$ than with either NH_4^+ or NO_3^- alone (240 vs. 227 bu a^{-1}), and higher with NO_3^- than with NH_4^+ (236 vs. 222 bu a^{-1}). Yield in 1994, in contrast, was higher with NH_4^+ than with NO_3^- (249 vs 230 bu a^{-1}). Higher grain yield with NH_4^+ compared to NO_3^- has been reported in other studies (Barber et al., 1992; Jung et al., 1972; Pan et al., 1984). No differences in grain yield were observed among N source in 1992. In 1993, the response to N source depended on the P rate. Corn fertilized with NH_4^++P had lower grain yield than that fertilized with NO_3^-+P.

Phosphorus fertilization, averaged across N source, increased yield in 1992. In contrast, the application of P with NH_4^+ reduced grain yield compared to NH_4^+ alone in 1993. This reduction, was not related to differences in N uptake or P uptake at maturity, but it was related to reduced root density in the soil 0 to 2 inches from the porous pipe and to reduced P uptake at tasseling. No response to P fertilization was observed in 1991 or 1994. In general, P fertilization did not increase yield when N sources were also applied may be because of the high level of available P in this soil. We speculate, that the yield increase with P fertilization, regardless of N source, observed in 1992 was not related to increased P availability since P fertilization did not increase P uptake when applied with NH_4^+ or NO_3^-. Similarly, P fertilization alone increased yield compared to the -N-P control in 1991, and 1994, but these increases in yield were not related to increases in N or P uptake.

DISCUSSION

Several mechanisms have been proposed to explain the effects of NH_4^+ on biomass accumulation: (1) NH_4^+-fertilized corn may produce higher yield because less energy is required to assimilate NH_4^+ than to assimilate NO_3^- (Salsac et al., 1987); (2) fertilization with NH_4^+ stimulates earshoot development (Below and Gentry, 1987); (3) leaching of NH_4^+ out of the rooting zone is lesser than that of NO_3^- in sandy soils (Jung et al., 1972); and (4) NH_4^+ increases P availability and uptake (Blair et al., 1970). In contrast, NH_4^+ toxicity is a mechanism usually proposed to explain detrimental effects of NH_4^+ on plant growth (Allred and Ohlrogge, 1964; Dibb and Welch, 1976; Bennett et al., 1964).

In this study, the yield increase with NH_4^+ compared to NO_3^- observed in 1994 occurred with an increase in N uptake but without changes in root growth or P uptake. In 1993, yield reduction with NH_4^+ compared to NO_3^-, when P was applied, occurred together with a reduction in P uptake at tasseling, but no difference in N or P uptake were detected at maturity. Because we were certain that N sources were applied to the soil on a daily basis and that N uptake, or P uptake do not always explain yield response to N sources, we speculate that the yield differences due to N source observed in this study are also related to changes in the plant metabolism caused by treatment effects on the soil NH_4^+/NO_3^- ratio. Annual differences in the rate of urea hydrolysis and urea uptake may have also contributed to the annual variability in yield response to N sources. Nevertheless, no attempt was made to study the factors controlling urea hydrolysis in this production system. The mechanisms through which N source affected yield in field conditions, and the factors controlling the annual variability are still little understood. We know, however, that management of N fertilization to supply different NH_4^+/NO_3^- ratios daily throughout the growing season affects corn grain yield in a Kokomo soil and that yield differences due to N source are approximately 10%. The superiority of NH_4^+, NO_3^-, or a mixture $NH_4^+ + NO_3^-$, alone or with P, for consistently maximizing corn grain yield in field conditions, however, could not be demonstrated in this study.

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Table 1. **Percentage and daily amounts of N and P applied to corn plants at various growth stages.**

Corn Growth Stage[*]	DAE[†] 1991	N	P	Nitrogen 1991	Nitrogen 1992-94	Phosphorus 1991-94
		%	%	lb a^{-1}	lb a^{-1}	lb a^{-1}
VE-V3	13	3.3	3.1	0.71	1.43	0.10
V3-V6	25	4.4	3.5	0.96	1.91	0.12
V6-V9	36	4.7	10.5	1.02	2.04	0.34
V9-V12	44	11.5	13.2	2.49	4.99	0.42
V12-V15	53	20.3	14.0	4.40	8.80	0.45
V15-V18	58	14.3	7.0	3.10	6.21	0.22
V18-VT	63	6.0	5.7	1.30	2.60	0.18
VT-R1	65	3.3	5.7	0.71	1.43	0.18
R1	70	3.8	5.7	0.82	1.65	0.18
R1-R2	75	4.1	4.4	0.89	1.78	0.14
R2	77	3.8	4.8	0.82	1.65	0.15
R3	87	4.4	4.4	0.96	1.91	0.14
R3-R4	91	3.8	4.4	0.82	1.65	0.14
R4	95	4.1	5.7	0.89	1.78	0.18
R4-R5	101	4.4	4.4	0.96	1.91	0.14
R5	110	3.8	3.5	0.82	1.65	0.12
Total		100.0	100.0			

* V = vegetative stage, R = reproductive stage as defined by Ritchie and Hanway (1984).

† DAE = days after emergence.

Table 2. **Rainfall and irrigation during the growing seasons.**

Date		Rainfall 1991	Rainfall 1992	Rainfall 1993	Rainfall 1994	Rainfall avg.[*]	Irrigation 1991	Irrigation 1992	Irrigation 1993	Irrigation 1994
Month	Days	inches	inches	inches	inches	inches	inches	inches	inches	inches
Apr.	1-15	2.6	0.6	1.8	3.0	2.2	--	--	--	--
Apr.	16-30	1.0	2.1	1.6	0	1.9	--	--	--	--
May	1-15	0.5	0.4	0.7	0.8	2.1	--	--	--	--
May	16-31	2.8	1.8	0	0.9	2.6	0	0.2	0.2	--
June	1-15	0.9	0.9	0.8	0.1	2.1	0.6	0.2	0.3	--
June	16-30	0.8	1.3	2.8	2.3	2.1	4.3	0.2	1.6	1.5
July	1-15	1.0	2.7	4.2	2.7	2.0	1.6	0.9	1.0	2.8
July	16-31	0.4	4.4	3.5	1.1	2.0	3.9	0.4	0.4	0.9
Aug	1-15	1.3	0.2	0.5	0.8	2.0	1.9	0.2	1.3	0.6
Aug.	16-31	1.3	1.6	0.4	2.4	1.6	4.0	0.7	1.3	0.4
Sep.	1-30	2.9	1.7	3.3	1.3	3.1	3.2	0	0	0.2
Total		15.5	17.7	19.6	15.3	23.7	3.5	2.9	6.1	6.5

* 45-year average. Western Research Center - 1991.

Table 3. KCl-extractable NH_4^+ and NO_3^- in the soil 0-1 inch from the porous pipe at a depth of 11 to 13 inches as affected by N-source at various stages of corn development in 1992.

	Corn Growth Stage‡											
N source	V6	V10	V14	V16	R1	R3	V6	V10	V14	V16	R1	R3
	NH_4^+-N ppm						NO_3^--N ppm					
1. No N	7	6	2	4	1	1	13	6	4	4	5	4
2. Urea	8	21	85	166	82	112	11	10	8	7	12	54
3. Urea+CN	7	27	58	65	49	50	12	27	29	43	43	72
4. CN	8	6	4	17	8	1	15	52	67	79	50	47
Contrasts†												
NH_4^+ vs. NO_3^-	NS	*	**	**	**	**	*	**	**	**	**	*
Mix vs. NH_4^+, NO_3^-	NS	*	NS	NS	NS	NS	NS	NS	*	NS	*	*
N vs. No N	NS	*	*	*	**	*	NS	**	**	**	**	**

*, $P \leq 0.05$; **, $P \leq 0.01$; NS, not significant; CN, $Ca(NO_3)_2$

† NH_4^+ vs. NO_3^- (2. vs. 3.); Mix vs. NH_4^+, NO_3^- (3. vs. 2., 4.); N vs No N (1. vs. 2., 3., 4.).

‡ Growth stages according to Ritchie and Hanway (1984).

Table 4. Above ground dry matter at growth stage V6 (collar of leaf six visible), VT (tasseling), and MT (maturity) in response to daily fertilization with N source and P.

	N	P_2O_5	N Source	V6 1992	V6 1993	VT 1992	VT 1993	MT 1991	MT 1992	MT 1993	MT 1994
	lb a^{-1}			tons a^{-1}							
1.	0	0	None	0.4	0.4	6.6	5.4	19.3	18.8	13.7	19.0
2.	300	0	Urea	0.4	0.4	7.1	7.2	22.4	21.4	17.2	22.8
3.	300	0	Urea+CN	0.4	0.4	8.6	6.6	23.8	21.7	18.7	--
4.	300	0	CN	0.4	0.4	8.0	7.1	22.9	21.4	19.9	21.0
5.	300	0	NH_4Cl	--	--	--	--	--	--	--	25.4
6.	0	50	None	0.5	0.4	5.3	4.8	22.1	19.6	15.5	20.0
7.	300	50	Urea	0.5	0.4	7.7	5.9	22.3	22.2	20.4	25.4
8.	300	50	Urea+CN	0.5	0.4	7.3	6.0	23.7	22.3	18.2	--
9.	300	50	CN	0.4	0.5	7.2	6.7	23.9	22.8	20.4	26.8
10.	300	50	NH_4Cl	--	--	--	--	--	--	--	28.0
Contrasts†											
NH_4^+ vs. NO_3^-				NS	NS	NS	NS	NS	NS	NS	
Mix vs. NH_4^+, NO_3^-				NS	NS	NS	NS	NS	NS	NS	----
P within N source				NS	NS	NS	NS	NS	*	NS	**
P*(NH_4^+ vs. NO_3^-)				NS	NS	NS	NS	NS	NS	NS	NS
P*(Mix vs. NH_4^+, NO_3^-)				NS	NS	NS	NS	NS	NS	NS	----
N vs. No N				NS	NS	**	**	**	**	**	**
P(-N) vs. No P(-N)				NS	NS	**	NS	**	NS	NS	NS

*, $P \leq 0.05$; **, $P \leq 0.01$; NS, not significant; CN, $Ca(NO_3)_2$

† NH_4^+ vs. NO_3^- (2., 7. vs. 4., 9.); Mix vs. NH_4^+, NO_3^- (3., 8. vs. 2., 4., 7., 9.); P within N source (2., 3., 4. vs. 7., 8., 9.). In 1994,
NH_4^+ vs. NO_3^- (2., 5., 7., 10. vs. 4., 9.); P within N source (2., 4., 5. vs.7.,9., 10.)

Table 5. Above ground N uptake at growth stage V6 (collar of leaf six visible), VT (tasseling), and MT (maturity) in response to daily fertilization with N source and P.

	N	P_2O_5	N Source	V6 1992	V6 1993	VT 1992	VT 1993	MT 1992	MT 1993	MT 1994
	lb a^{-1}			lb N a^{-1}						
1.	0	0	None	8.0	13.1	91.1	48.2	112.5	88.4	108.9
2.	300	0	Urea	10.0	14.2	131.3	87.5	146.4	136.6	173.2
3.	300	0	Urea+CN	11.1	14.3	126.8	77.7	163.4	147.3	--
4.	300	0	CN	10.0	13.3	107.1	96.4	146.4	179.5	154.5
5.	300	0	NH_4Cl	--	--	--	--	--	--	202.7
6.	0	50	None	7.0	13.8	78.6	42.0	157.1	95.5	119.7
7.	300	50	Urea	11.2	13.7	122.3	61.6	152.7	176.8	192.0
8.	300	50	Urea+CN	11.9	12.4	91.1	67.9	170.5	141.1	--
9.	300	50	CN	14.4	16.4	99.1	86.6	169.6	175.9	208.9
10.	300	50	NH_4Cl	--	--	--	--	--	--	226.8
Contrasts†										
NH_4^+ vs. NO_3^-				NS	NS	NS	*	NS	NS	**
Mix vs. NH_4^+, NO_3^-				NS	NS	NS	NS	NS	NS	--
P within N source				NS	NS	NS	*	NS	NS	*
P*(NH_4^+ vs. NO_3^-)				NS	*	NS	NS	NS	NS	NS
P*(Mix vs. NH_4^+, NO_3^-)				NS	*	NS	NS	NS	NS	--
N vs. No N				NS	NS	NS	**	NS	**	**
P(-N) vs. No P(-N)				NS	NS	NS	NS	NS	NS	NS

*, $P \leq 0.05$; **, $P \leq 0.01$; NS, not significant; CN, $Ca(NO_3)_2$

† NH_4^+ vs. NO_3^- (2., 7. vs. 4., 9.); Mix vs. NH_4^+, NO_3^- (3., 8. vs.2., 4., 7., 9.); P within N source (2., 3., 4. vs. 7., 8., 9.). In 1994, NH_4^+ vs. NO_3^- (2., 5., 7., 10. vs. 4., 9.); P within N source (2., 4., 5. vs. 7.,9., 10.).

Table 6. Above ground P uptake at growth stage V6 (collar of leaf six visible), VT (tasseling), and MT (maturity) in response to daily fertilization with N source and P.

	N	P_2O_5	N Source	V6 1992	V6 1993	VT 1992	VT 1993	MT 1992	MT 1993	MT 1994
	lb a^{-1}			lb P a^{-1}						
1.	0	0	None	2.1	2.1	20.0	11.6	45.5	32.1	24.1
2.	300	0	Urea	1.8	2.2	25.0	15.2	38.4	38.4	17.9
3.	300	0	Urea+CN	2.1	2.3	25.0	12.5	34.8	42.9	--
4.	300	0	CN	1.9	2.0	21.4	11.6	43.8	38.4	16.1
5.	300	0	NH_4Cl	--	--	--	--	--	--	17.9
6.	0	50	None	2.2	2.1	16.0	9.8	42.0	39.3	24.1
7.	300	50	Urea	2.1	2.3	25.0	11.6	37.5	40.2	16.1
8.	300	50	Urea+CN	2.3	2.1	22.3	12.5	51.8	37.5	--
9.	300	50	CN	2.0	2.6	21.4	14.3	43.8	37.5	16.1
10.	300	50	NH_4Cl	--	--	--	--	--	--	22.3
Contrasts†										
NH_4^+ vs. NO_3^-				NS	NS	NS	NS	NS	NS	NS
Mix vs. NH_4^+, NO_3^-				NS	NS	NS	NS	NS	NS	--
P within N source				NS	NS	NS	NS	*	NS	NS
P*(NH_4^+ vs. NO_3^-)				NS	NS	NS	*	NS	NS	NS
P*(Mix vs. NH_4^+, NO_3^-)				NS	NS	NS	NS	**	NS	--
N vs. No N				NS	NS	*	*	NS	NS	**
P(-N) vs. No P(-N)				NS	NS	NS	NS	NS	NS	NS

*, $P \le 0.05$; **, $P \le 0.01$; NS, not significant; CN, $Ca(NO_3)_2$.

† NH_4^+ vs. NO_3^- (2., 7. vs. 4., 9.); Mix vs. NH_4^+, NO_3^- (3., 8. vs.2., 4., 7., 9.); P within N source (2., 3., 4. vs. 7., 8., 9.). In 1994, NH_4^+ vs. NO_3^- (2., 5., 7., 10. vs. 4., 9.); P within N source (2., 4., 5. vs. 7.,9., 10.).

Table 7. **Corn grain yield in response to daily N source and P fertilization.**

	N	P_2O_5	N source	1991	1992	1993	1994
	lb a^{-1}			bu a^{-1}			
1.	0	0	None	177	147	124	177
2.	300	0	Urea	222	182	190	244
3.	300	0	Urea+CN	241	187	182	--
4.	300	0	CN	228	184	180	225
5.	300	0	NH_4Cl	--	--	--	255
6.	0	50	None	219	158	120	211
7.	300	50	Urea	220	195	168	251
8.	300	50	Urea+CN	241	195	185	--
9.	300	50	CN	244	203	182	235
10.	300	50	NH_4Cl	--	--	--	247

Contrasts†	1991	1992	1993	1994
NH_4^+ vs. NO_3^-	**	NS	NS	**
Mix vs. NH_4^+, NO_3^-	*	NS	NS	--
P within N source	NS	*	NS	NS
P*(NH_4^+ vs. NO_3^-)	NS	NS	*	NS
P*(Mix vs. NH_4^-, NO_3^-)	NS	NS	NS	--
N vs. No N	**	**	**	**
P(-N) vs. No P(-N)	**	NS	NS	*

*, $P \leq 0.05$; **, $P \leq 0.01$; NS, not significant; CN, $Ca(NO_3)_2$

† NH_4^+ vs. NO_3^- (2., 7. vs. 4., 9.); Mix vs. NH_4^+, NO_3^- (3., 8. vs. 2., 4., 7., 9.); P within N source (2., 3., 4. vs. 7., 8., 9.). In 1994, NH_4^+ vs. NO_3^- (2., 5., 7., 10. vs. 4., 9.); P within N source (2., 4., 5. vs. 7., 9., 10.).

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