Phosphorus Fertilizer Carriers and Their Placement for Minimum Till Corn Under Sprinkler Irrigation[1]

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ABSTRACT

Several methods of placement and sources of P were evaluated for sprinkler irrigated corn (*Zea mays* L.) grown under minimum tillage on a Sharpsburg silty clay loam (Typic Argiudoll) and a Coly silt loam (Typic Ustorthent). Nitrogen and P, dual placed in a localized band (anhydrous ammonia applied with liquid P sources), accomplished greater P uptake and higher corn grain yields on a P deficient calcareous soil than P banded to the side of the seed or banded below the seed, although both methods increased early plant growth compared to either broadcast or P dual placed with NH_3. Broadcast preplant applications of P were equally as effective as dual placed P in this study. Explanation of yield and P uptake enhancement by dual placement may lie in the synergistic effect of ammoniacal N and P placed together. The superior performance of the broadcast method of P application was apparently due to root activity near the surface of the soil or in the soil residue interface. In contrast, starter band applications gave higher yields than broadcast or dual placed methods of P application on a slightly acid medium P soil. While it is not known why differences were obtained between the performance of methods of P application on these two soils, low subsoil P levels in the calcareous soil compared to the acid soil was believed to be a contributive factor. Enhanced early P uptake with such row applications may increase yields where high subsurface P levels exist. Urea phosphate (UP) provided greater yields, grain P uptake, and total P uptake than ammonium polyphosphate (APP) and diammonium phosphate (DAP) at the calcareous site—especially when band (side), broadcast, and dual placement methods of P application were used. Total P concentration from plant tissue taken at the eight-leaf stage was greater for UP than APP and DAP on the slightly acid soil, but no yield differences could be attributed to sources at this site.

***Additional Index Words:* *Zea mays* L., dual application, row vs. broadcast, fertilizer P efficiency, reduced tillage, subsoil P.**

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MINIMUM TILLAGE OR NO-TILLAGE METHODS of corn (*Zea mays* L.) production have several specific advantages over conventional tillage. Among those reported are increased surface soil organic matter, residual nitrate N, N recovery, surface accumulation of P and K, and soil moisture availability (27). In addition, microbial biomass, crop uptake of micronutrients, and availability of P have been reported to be greater under minimum tillage (12). These have also been related to greater stover and grain yields (19). Finally, soil erosion has been shown to decrease when minimum tillage is employed, perhaps the most important advantage of its use (13). Disadvantages of this method included increased N requirements the first few years, N immobilization rates, surface acidity, potential for increased nitrate leaching, and denitrification losses (28).

Surface broadcast applications of P have proved to be satisfactory for minimum tillage crop production in several environments (3, 8, 19, 25). This method of placement effectively reduces the surface area of the soil in contact with the fertilizer, therefore reducing P fixation (25). This could be viewed as a form of band placement in no-till (3). By contrast, localized band placements of P in conventional tillage have commonly demonstrated increased uptake efficiencies and yields as compared to broadcast methods (21, 22, 29).

Dual placement (N and P applied in a single localized band) methods of application have led to yield increases, increased P fertilizer efficiency, and increased P availability and uptake in neutral to calcareous soils (20,30). Most results with dual placement suggest that a synergistic effect on plant uptake exists when N and P are dual placed, especially when the ammoniacal form of N is present (14, 20). Other work with dual placement indicates decreased P precipitation at the soil-root interface when NH_4-N is applied with P (16).

A decreased rhizocylinder pH and an increased $H_2PO_4^-/HPO_4^{2-}$ ratio have been found when NH_3 and P are applied together. This effect is most pronounced in alkaline soils where slight reductions in pH alter greatly the concentrations of $H_2PO_4^-$ (4). Increased P absorption when it is applied with N is in part due to an enhanced physiological capacity of roots to absorb P brought about by greater root development in an N-P band (20).

The phosphoric acid component in urea phosphate (UP) has been found to retard the enzymatic hydrolysis of the urea by soil urease, thereby reducing gaseous losses of urea N as NH_3 (7). When applied as DAP, more P was found concentrated within the application zone and more of the added P remained water soluble after 4 weeks as compared to ammonium polyphosphate (APP) (11). Cations of Fe and Al were found to be complexed by APP, thereby delaying the precipitation of P in acid soils (15). As the contact time with soil increases, reaction products of various P sources are expected to become more nearly alike for a given soil (6).

Stand reductions have been found when NH_3-containing or NH_3-generating fertilizers were used in proximity of seed (9, 18, 23). This effect is pronounced in alkaline-calcareous soils where NH_3 losses are also generally greater (17). Seed injury caused by NH_3 toxicity can be especially damaging when diammonium phosphate (DAP) is placed too close to the seed (1).

Advantages of broadcast, band and dual placed methods of P placement under different tillage systems are not well-documented. In addition very little research has been conducted in evaluating liquid P sources on irrigated corn fertilized with anhydrous ammonia. Therefore, the objectives of this study were to determine the effectiveness of different methods of

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P application and P sources on corn yields and P uptake in a minimum tillage system under sprinkler irrigation.

MATERIALS AND METHODS

Field studies were conducted in 1983, 1984, and 1985 at the Mead Field Laboratory (Mead, NE) on a Sharpsburg sicl (fine montmorillonitic mesic Typic Argiudolls) and at Loup City, NE, on a Coly sil [fine silty mixed (calcareous) mesic Typic Ustorthents]. A randomized complete block design with a factorial treatment arrangement and three replications were used. No soil tillage operations were made other than planting with a Buffalo till all-flex planter. Weeds were controlled by annual broadcast applications of herbicides immediately following planting. 'Pioneer 3377' corn was planted at both locations all 3 yr at a population of 69 000 seeds ha^{-1} in 76 cm rows. The complete factorial arrangement consisted of four P placement methods, three liquid P sources, and two rates. Methods of P placement were: banded 2.5 cm below the seed (BB), banded to the side of the seed (BS) (6 cm to the side, 6 cm below the soil surface), dual placement (DP) (P injected preplant with anhydrous ammonia 15 cm deep in 38-cm spacings), and broadcast preplant (BRP). Liquid sources of P were ammonium polyphosphate (APP: 10–14.8–0), urea phosphate (UP: 7–7.8–0), and diammonium phosphate suspension (DAP: 12–13.5–0). Rates applied were 9 and 18 kg P ha^{-1}. Conductivity of fertilizers was 670, 519, and 221 dS m^{-1} for APP, DAP and UP, respectively. All plots received a total of 200 kg N ha^{-1} as anhydrous ammonia adjusted for the N component in the P source. Ammonia was knifed in all nondual placed treatments to a depth of 15 cm and a 38-cm spacing similar to the dual placed treatments. Experimental units consisted of eight row plots (76 cm-row spacing) by 10 m in length. Water was sprinkler applied at both locations.

Plant tissue samples were taken at the eight-leaf stage (eight whole plants per plot) at both locations, all 3 yr at Loup City and in 1983 and 1985 at Mead. Tissue samples were dried in a forced air oven at 70°C and then ground to pass a 0.85 mm screen. Ears were hand harvested the first 2 yr and shelled from two rows, 3 m in length. Two rows 10 m in length were machine harvested the last year for grain yield. Plant population was determined at harvest by counting plants in 6 m of row. Grain was subsampled for moisture and total P analysis. Hand harvested stalks were cut, weighed, ground, subsampled, and analyzed for total P. Grain, stover, and tissue P was determined colorimetrically by the vanadomolybdate method without the use of H_2SO_4 in the digest (2, 5). Grain P uptake, stover P uptake, and total P uptake (grain + stover) values were determined by multiplying the percent P by the respective yield component.

Initial soil tests from each location are listed in Table 1. Standard analysis of variance with single degree of freedom contrasts were used to evaluate treatments. Analysis over locations was not used since yield responses were not the same for method, sources, and rates across the two locations.

RESULTS AND DISCUSSION

The two sites were selected to observe P fertilization response under medium (Mead) and low (Loup City) soil P conditions, the former a slightly acid Sharpsburg sicl and the latter a calcareous Coly sil in order to test the effect of soil pH on response to differing P sources and placements (Table 1).

Statistical results are presented in Tables 3, 4, 6, and 7. Tables 3 and 6 show the analysis of variance with a breakdown into various nonorthogonal contrasts for each main or interaction effect. Tables 4 and 7 show only those means associated with important significant contrasts. The interaction contrasts need to be clarified for interpretation. For example, in Table 3, the method × source (MxS) interaction is evaluated by six contrasts. The first contrast, [DP vs. (BB, BS, BRP)] × [UP vs. (APP, DAP)], is shown to be significant at the 5% level for total P uptake. The means associated with this contrast are shown in Table 4. It is apparent that total P uptake was greater when urea phosphate was dual placed (25.7 kg ha^{-1} compared to 19.0, 18.0, and 16.4 kg ha^{-1} for other treatment-method combinations). This is obviously the reason for the statistically significant contrast. Similar interpretation is made for other contrasts in Tables 3, 4, 6 and 7.

Table 1. Initial soil characteristics at experimental locations.

Depth	NO_3-N†	NH_4-N‡	P§	K¶	pH#	CEC††	Ca‡‡
cm	mg kg^{-1}					cmol kg^{-1}	
			Mead (Sharpsburg sicl)				
0–30	3.3	3.4	5.5	232	6.4	24.9	16.3
30–60	4.1	3.0	7.1	165	6.6	23.3	15.4
60–90	4.9	2.8	9.9	161	6.7	20.4	12.0
90–120	3.6	1.9	8.6	116	7.2	14.7	16.7
120–150	4.1	2.2	13.3	143	7.4	14.4	14.9
			Loup City (Coly sil)				
0–30	3.3	8.0	1.5	385	7.4	18.4	28.1
30–60	1.8	7.3	0.4	318	7.5	18.6	27.8
60–90	1.6	7.9	0.9	480	7.5	18.3	23.6
90–120	1.8	10.7	0.4	555	7.8	18.6	19.6
120–150	1.9	4.9	1.3	645	8.0	18.3	21.4

† Phenoldisulfonic acid procedure.
‡ Steam distillation.
§ Available P by Bray & Kurtz P1 for Sharpsburg, and $NaHCO_3$-P for Coly soil.
¶ 1 *M* NH_4OAc extraction, using a flame photometer with propane gas.
# 1:1, soil/water.
†† Reference (24).
‡‡ Reference (26).

Loup City 1983 to 1985 (Calcareous Coly Sil)

Grain yields were increased by P fertilization and were significantly greater at the higher P rate than the lower rate. Grain yields, grain P uptake, total P uptake, and plant populations all showed significant responses to both methods and sources of P application (Tables 2 and 3). Dual placed and broadcast methods of P application produced superior results compared to band (side) and band (below) for each of these variables, although methods of P application performed differently depending on P source. Broadcast P was quite effective considering the fact that the fertilizer P was sprayed on the soil surface on top of the residue without any incorporation. However, the results were consistent with other research demonstrating the advantages of this method in reduced tillage crop production, at least under humid region cropping conditions (3, 8). Although yields when P was dual placed or broadcast did not differ, total P uptake was slightly greater for dual placed P. This may be due to enhanced P uptake in the presence of ammonium ion, increased root growth within an N-P band, and increased $H_2PO_4^-/HPO_4^{2-}$ ratio in the calcareous soil resulting from lower rhizosphere pH values induced by ammonium uptake (4, 20). Following the dual N-P application, a high pH within the injection zone allows formation of moderately soluble calcium phos-

Table 2. Effect of method of P application, P source, and P rate on irrigated corn yield P uptake, P concentration at eight-leaf stage, and plant population (Loup City, NE, 1983–85).

P method	P source†	Grain yield	Stover yield	Grain P	Stover P	Total P	P concentration eight-leaf	Plant population
		Mg ha^{-1}		kg ha^{-1}			mg g^{-1}	No. ha^{-1} × 10^3
Band (below seed)	APP	6.00	7.49	12.0	3.9	15.9	4.0	50.6
	DAP	6.12	7.27	13.7	4.4	18.1	4.0	50.6
	UP	5.94	6.57	11.9	3.2	15.1	4.1	51.1
	Mean	6.02	7.11	12.6	3.8	16.4	4.1	40.8
Band (side of seed)	APP	5.59	6.46	10.9	3.2	14.1	4.0	52.2
	DAP	4.75	7.06	8.7	3.9	12.6	3.6	51.4
	UP	6.18	7.21	12.3	3.7	16.0	4.0	54.8
	Mean	5.51	6.91	10.6	3.6	14.2	3.9	52.8
Broadcast	APP	7.60	7.32	16.6	4.1	20.7	4.1	55.8
	DAP	5.99	7.59	12.8	4.3	17.2	4.2	49.0
	UP	8.30	7.69	18.8	4.2	23.0	4.2	57.8
	Mean	7.30	7.53	16.1	4.2	20.3	4.2	54.2
Dual placement (knife)	APP	6.58	7.03	13.1	3.7	16.7	4.0	56.3
	DAP	8.22	7.31	17.4	4.0	21.4	4.2	56.7
	UP	8.32	7.85	20.2	5.5	25.7	4.4	56.1
	Mean	7.71	7.40	16.9	4.4	21.3	4.2	56.4
P source	APP	6.44	7.07	13.2	3.7	16.9	4.0	53.7
	DAP	6.24	7.31	13.2	4.2	17.3	4.0	51.9
	UP	7.19	7.33	15.8	4.2	20.0	4.2	55.0
P rate, kg•ha^{-1}	0	4.13	7.40	8.9	4.2	13.1	3.7	56.5
	9	6.19	7.04	12.4	3.8	16.3	4.0	52.1
	18	7.07	7.43	12.6	4.2	19.8	4.2	54.9
Year 1983		4.88	6.92	8.9	3.1	12.0	3.0	56.6
1984		5.57	7.42	11.0	4.0	15.1	4.6	46.3
1985		9.45	7.37	22.2	4.9	27.1	4.6	57.7

† APP = ammonium polyphosphate, DAP = diammonium phosphate, and UP = urea phosphate.

phate fertilizer reaction products (10). This dynamic change of pH in the injection zone allows the soluble reaction products to persist, resulting in higher P solubility and more available P forms than with nondual N-P applications.

A significant method × rate interaction involving grain yield, grain P, and total P uptake showed that the primary advantage of dual placed P over other methods of P application occurred at the higher P rate (Fig. 1). While the reason for this interaction is not apparent, it is possible that it is related to P fertilizer distribution as affected by the application pump (squeeze pump) at low rates. Low P rates with narrow knife spacings result in a discontinuous band that could produce differential root-fertilizer P contact or increased soil fertilizer P contact, both of which could influence P fertilizer availability (B. Eghball, 1986, personal communication).

Grain yield and P uptake as affected by P method and source are shown in Tables 2, 3, and 4. Urea phosphate was a significantly superior P fertilizer compared to APP and DAP in terms of grain yield and P availability, as shown by both total P uptake and P concentration at the eight-leaf stage. However, P sources performed differently with the different methods of P application (Tables 3 and 4). This interaction indicates that UP's superiority as a P source compared to APP and DAP occurred primarily with broadcast or dual placement methods of P application. Urea phosphate was not a better P source than APP and DAP with band (below) or band (side) methods of application. The excellent performance of UP when dual placed with NH_3 may be due in part to enhanced P uptake in the presence of NH_4 ion along with the phosphoric acid component (present in UP) that could aid in reducing the pH of the N-P injection zone. However, Westfall and Hanson (31) found that neither UP or APP changed the injection zone pH in a calcareous soil (5.2% $CaCO_3$), but that $NaHCO_3$ P levels were higher with UP than with APP applied without ammonium. In this experiment the superiority of UP appears to be independent of NH_3 application since the broadcast UP treatment performed equally as well as dual placed P. However, it should be noted that while not significant, dual placed UP had the highest yield and P uptake at both the eight-leaf and harvest stages of any treatment.

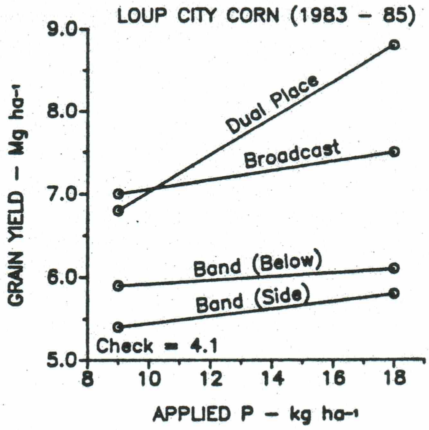

Fig. 1. Corn grain yield as affected by the significant interaction between method of P application and rate of applied P (Loup City, NE, 1983–85).

Table 3. Analysis of variance and single degree of freedom contrasts for grain yield, stover yield, grain P uptake, stover P uptake, total P uptake, P concentration at the eight-leaf stage, and plant population (Loup City, Nebraska, 1983–85).

Source of variation	df†	Grain yield	Stover yield	Grain P uptake	Stover P uptake	Total P uptake	P concentration eight-leaf	Plant population
		Mg ha^{-1}		kg ha^{-1}			Mg g^{-1}	$\text{No. ha}^{-1} \times 10^3$
Method (M)	3	**	+	**	–	**	NS	**
DP vs. BRP	1	NS	NS	NS	NS	NS	NS	NS
BS vs. BB	1	NS	NS	NS	NS	NS	NS	NS
BB, BS vs. DP	1	**	+	**	*	**	+	**
Source (S)	2	*	NS	*	NS	*	NS	+
APP vs. DAP	1	NS	NS	NS	NS	NS	NS	NS
UP vs. APP, DAP	1	**	NS	**	NS	**	+	*
Rate	1	**	*	**	NS	**	*	**
M × S	6	*	NS	*	+	*	NS	NS
DP vs. REST × UP vs. APP, DAP	1	NS	NS	NS	**	*	NS	NS
BRP vs. REST × UP vs. APP, DAP	1	NS	NS	NS	NS	NS	NS	+
BB, BS vs. BRP, DP × UP vs. APP, DAP	1	NS	NS	*	*	*	NS	NS
BRP vs. DP × DAP vs. APP, UP	1	**	NS	**	NS	+	NS	**
DP vs. REST × DAP vs. APP, UP	1	*	NS	NS	+	NS	NS	NS
BB vs. REST × UP vs. APP, DAP	1	+	**	*	*	*	NS	NS
M × R	3	NS	NS	NS	NS	NS	NS	NS
DP vs. BRP × 9 vs. 18	1	NS	NS	NS	NS	NS	NS	NS
DP vs. REST × 9 vs. 18	1	+	NS	*	NS	*	NS	NS
BS vs. BB × 9 vs. 18	1	NS	NS	NS	NS	NS	NS	+
S × R	2	NS	NS	NS	NS	NS	NS	NS
APP vs. UP, DAP 9 vs. 18	1	NS	NS	NS	NS	NS	NS	+
UP vs. APP, DAP 9 vs. 18	1	NS	NS	NS	NS	NS	NS	NS
M × S × R	6	NS	NS	NS	NS	NS	NS	*
Year (Y)	2	**	**	**	**	**	**	**
Y × M		NS	NS	NS	NS	NS	NS	NS
Y × S		NS	NS	NS	NS	NS	NS	NS
Y × R		NS	NS	NS	NS	NS	NS	NS
Check vs. Rest		**	NS	**	NS	*	*	*
Coefficient of variation (%)		19	18	24	41	21	12	17

**,*,+ = significant at 0.01, 0.05, and 0.10 probability levels, respectively.

† df = degrees of freedom, NS = not significant, BB = band below the seed, BS = band to the side of the seed, BRP = broadcast preplant, DP = dual placement, APP = ammonium polyphosphate, DAP = diammonium phosphate, and UP = urea phosphate.

It is not known why UP was not a better P source when banded, especially when banded below the seed, except that both of these application methods significantly reduced plant populations compared to broadcast or dual placed P. This may have affected yields and P uptake. There is no evidence that UP was worse in this regard than APP or DAP. Plant populations were reduced by 6 and 9% for band (side) and band (below) methods, respectively, as compared to dual placed or broadcast P. Salt rates (N component averaged over sources) were 7 and 14 kg ha^{-1} for P rates 9 and 18 kg ha^{-1}, respectively. These rates exceed the recommended limits of salt applied with the seed (18). Field evaluation of band (below) and band (side) treatments did show marked root burn in many of the plants. It is a matter of concern as to how close solution fertilizers can be placed to the seed without reducing final stand. Consistent with results found in another study conducted with solution fertilizers, there were no differences among sources in corn plant emergence (23).

The performance of DAP was inconsistent within methods of application. This P source was significantly better in terms of grain yield and stover P uptake compared to APP and UP when dual placed, but was especially poor in terms of grain yield and P uptake when broadcast. The low yields and P uptake associated with DAP broadcast may have been due to lower plant populations resulting from planting into wheel tracks caused from an added trip over the plot required to broadcast this highly viscous P source.

Both band (below) and band (side) methods did provide for early P uptake which resulted in an observed increased early growth compared to other methods of P application, although P concentration at the eight-leaf stage was significantly higher when P was dual placed. Obviously, roots in dual placed P treatments had reached the N-P fertilized zone by the eight-leaf stage. However, early season plant growth was slower at this location when P was dual placed as compared to band (below) or band (side) placement, resulting in this treatment having a slightly delayed maturity all 3 yr.

The poor performance of the band (below) and band (side) treatments were surprising in that this has been and is the recommended method of P application especially for reduced tillage systems. The increased residues associated with these systems often result in low spring soil temperatures and high soil moisture at planting providing a need for starter fertilizers. Apparently in this experiment on this very P deficient soil, band (below) and band (side) methods of application did not provide adequate P to maximize yields compared to either broadcast or dual placed P. It is suspected that band (below) and band (side) methods of P application did not provide adequate root contact in later stages of growth, especially in view of the soils very low subsoil P availability.

The dual placement method of application placed fertilizer P in bands 15 cm deep in a spacing of 38 cm. Since band (below) and band (side) methods placed P in bands spaced 76 cm similar to the row spacing, root contact was probably less even though the fertilizer band was closer to the row than when P was dual placed.

The excellent results from broadcast treatments were not expected, since the fertilizer was sprayed on the soil surface and corn planted with a ridge type planter. The planter was set to move the old stalk residues and surface soil into the center of the row. Therefore all fertilizer P broadcast preplant in the old row area was moved with the residue between the rows. Since there was no preplant incorporation or cultivation, P uptake resulting from the broadcast treatment was apparently from root activity near or at the soil surface (3).

Grain yields and P uptake were higher in 1985 than in 1983 and 1984. However, there were no significant interactions between years and methods of P applications or P sources.

Mead, 1983 to 1985 (Slightly Acid Sharpsburg sicl)

Grain yields were much higher on the Sharpsburg soil than on the Coly soil, averaging 9.2 and 4.1 Mg ha^{-1}, respectively, where no P was applied (Table 5).

Table 4. The interaction between P method and P source showing the significant contrasts for corn yield, P uptake, and plant population (Loup City, NE, 1983–85).

Comparison†							
P method	P source	Grain yield	Stover yield	Grain P uptake	Stover P uptake	Total P uptake	Plant population
		— Mg ha^{-1} —		—— kg ha^{-1} ——			No. ha^{-1} × 10^3
Contrast = [DP vs. (BB, BS, BRP)] × [UP vs. (APP, DAP)]							
DP	UP				5.5	25.7	
	APP, DAP				3.8	19.0	
BB, BS, BRP	UP				3.7	18.0	
	APP, DAP				4.0	16.4	
Contrast = [(BB, BS) vs. (BRP, DP)] × (UP vs. (APP, DAP)]							
BB, BS	UP			12.1	3.4	15.6	
	APP, DAP			11.3	3.8	15.2	
BRP, DP	UP			19.5	4.8	24.4	
	APP, DAP			15.0	4.0	19.0	
Contast = [BRP vs. DP) × [DAP vs. (APP, UP)]							
BRP	DAP	5.99	17.2	12.8		17.2	49.0
	APP, UP	7.95	21.8	17.7		21.8	56.8
DP	DAP	8.22	21.4	17.4		21.4	56.7
	APP, UP	7.45	21.2	16.6		21.2	56.2
Contrast = [DP vs. (BB, BS, BRP)] × [DAP vs. (APP, UP)]							
DP	DAP	8.22			4.0		
	APP, UP	7.45			4.6		
BB, BS, BRP	DAP	5.62			4.2		
	APP, UP	6.60			3.7		
Contrast = [BB vs. (BS, DP, BRP)] × [UP vs. (APP, DAP)]							
BB	UP	5.94	6.57	11.9	3.2	15.1	
	APP, DAP	6.06	7.38	12.8	4.2	17.0	
BS, DP, BRP	UP	7.60	17.4	17.1	4.5	21.6	
	APP, DAP	6.46	13.5	13.2	3.9	17.1	

† Abbreviations are defined in methods and in Table 2.

Table 5. Effect of method of P application, P source, and P rate on irrigated corn yield P uptake, P concentration at eight-leaf stage, and plant population (Mead, NE, 1983–85).

P method	P source†	Grain yield	Stover yield	Grain P	Stover P	Total P	P concentration eight-leaf‡	Plant population‡
		—— Mg ha^{-1} ——		—— kg ha^{-1} ——			mg g^{-1}	No. ha^{-1} × 10^3
BB	APP	10.32	5.12	30.8	4.5	35.2	3.72	59.7
	DAP	10.59	5.45	32.5	4.6	37.0	4.11	62.6
	UP	10.80	5.88	31.6	5.0	36.6	4.07	58.3
	Mean	10.57	5.48	31.6	4.7	36.3	3.97	60.2
BS	APP	10.68	6.25	32.8	5.9	38.7	4.20	61.5
	DAP	11.15	5.50	33.8	5.5	39.4	3.97	58.6
	UP	10.66	6.65	31.6	5.6	37.2	3.97	60.0
	Mean	10.83	6.13	32.7	5.7	38.4	4.05	60.0
BRP	APP	10.37	5.63	30.9	4.9	35.8	3.58	60.5
	DAP	10.03	5.67	32.6	5.5	38.1	3.70	61.4
	UP	10.36	5.63	30.7	4.6	35.3	3.76	58.1
	Mean	10.25	5.65	31.4	5.0	36.4	3.68	60.1
DP	APP	9.57	5.97	30.3	6.2	36.5	3.86	59.0
	DAP	10.07	5.22	29.8	4.8	34.7	3.98	64.1
	UP	11.12	5.88	34.3	5.4	39.7	4.03	59.9
	Mean	10.25	5.69	31.5	5.5	36.9	3.96	61.0
P source	APP	10.23	5.74	31.2	5.4	36.6	3.84	60.2
	DAP	10.46	5.46	32.2	5.1	37.3	3.94	61.7
	UP	10.73	6.01	32.0	5.2	37.2	3.96	59.1
P rate, kg/ha	0	9.21	5.64	26.7	4.6	31.3	3.57	60.7
	9	10.35	5.43	31.0	4.9	36.9	3.88	60.4
	18	10.60	6.05	32.6	5.5	38.1	3.95	60.3
Year 1983		8.10	5.64	21.4	4.3	25.7	3.53	57.1
1984		8.86	6.35	26.7	5.6	32.3	4.24	54.4
1985		14.47	5.22	47.4	5.7	53.1		63.6

† Abbreviations are defined in methods and Table 3.

‡ 1983 and 1984 data only.

Table 6. Analysis of variance and single degree of freedom contrasts for grain yield, stover yield, grain P uptake, stover P uptake, total P uptake, P concentration at the eight-leaf stage, and plant population (Mead, NE, 1983–85).

Source of variation	df†	Grain yield	Stover yield	Grain P uptake	Stover P uptake	Total P uptake	P concentration eight-leaf‡	Plant population‡
		——Mg ha-1——		———	kg ha⁻¹	———	Mg g⁻¹	No. ha⁻¹ × 10³
Method (M)	3	NS	NS	NS	NS	NS	*	NS
DP vs. BRP	1	NS	NS	NS	NS	NS	*	NS
BS vs. BB	1	NS	+	NS	*	NS	NS	NS
BS vs. REST	1	+	*	NS	+	NS	+	NS
Source (S)	2	NS	NS	NS	NS	NS	NS	NS
APP vs. DAP	1	NS	NS	NS	NS	NS	NS	NS
UP vs. APP, DAP	1	NS	+	NS	NS	NS	NS	+
Rate	1	NS	**	+	*	*	NS	NS
M × S	6	NS	NS	NS	NS	NS	NS	NS
DP vs. REST × UP vs. APP, DAP	1	+	NS	*	NS	*	NS	NS
BRP vs. REST × UP vs. APP, DAP	1	NS	NS	NS	NS	NS	NS	NS
BB, BS vs. BRP, DP × UP vs. APP, DAP	1	NS	NS	NS	NS	NS	NS	NS
BRP vs. DP × UP vs. APP	1	NS	NS	NS	NS	NS	NS	NS
DP vs. REST × DAP vs. APP, UP	1	NS	NS	NS	NS	*	NS	NS
BB vs. REST × UP vs. APP, DAP	1	NS	NS	NS	NS	NS	NS	NS
M × R	3	NS	NS	NS	NS	NS	NS	NS
DP vs. BRP × 9 vs. 18	1	NS	NS	NS	NS	NS	NS	NS
DP vs. REST × 9 vs. 18	1	NS	NS	NS	NS	NS	NS	+
BS vs. BB × 9 vs. 18	1	+	NS	NS	*	NS	NS	NS
S × R	2	NS	NS	NS	NS	NS	NS	NS
APP vs. UP, DAP 9 vs. 18	1	NS	NS	NS	NS	NS	NS	NS
UP vs. APP, DAP 9 vs. 18	1	NS	NS	NS	NS	NS	*	NS
M × S × R	6	NS	NS	NS	NS	NS	NS	NS
Year (Y)	2	**	**	**	**	**	**	**
Y × M		NS	NS	NS	NS	NS	NS	NS
Y × S		NS	NS	NS	NS	NS	NS	*
Y × R		NS	NS	NS	*	NS	*	NS
Check vs. Rest		*	NS	*	NS	+	*	NS
Coefficient of variation (%)		15	34	18	41	17	8	9

**,*,+ = significant at 0.01, 0.05, and 0.10 probability levels, respectively.

† df = degrees of freedom, NS = not significant, BB = band below the seed, BS = band to the side of the seed, BRP = broadcast preplant, DP = dual placement, APP = ammonium polyphosphate, DAP = diammonium phosphate, and UP = urea phosphate.

‡ 1983 and 1984 data only.

Applied P increased yields on the very P deficient Coly soil 2.9 Mg ha^{-1} compared to only 1.4 Mg ha^{-1} in the Sharpsburg soil. This difference in P availability between the soils resulted in rather striking differences in the way corn responded to the different methods and rates of P application on these two soils. Grain yields were significantly increased by P fertilization on the Sharpsburg soil but increased only to the 9 kg ha^{-1} application rate. Stover yields and P uptake were increased as P rate increased from 9 to 18 kg ha^{-1} (Tables 5 and 6).

In contrast to the results on the Coly soil, the band (side) method of P application consistently increased yield and P uptake more than other methods of application, especially broadcast and dual placed P. The band (side) method produced significantly higher stover yield and stover P uptake than band (below) placement which may have caused early primary root damage.

There was relatively little difference among P sources with respect to yield or P uptake although UP produced significantly more stover and had the highest grain yield. All P sources were similar in terms of the measured parameters regardless of how they were applied (Table 5, 6, and 7). There was no significant method by source interaction although UP seemed to be a better P source when dual placed compared to other methods of application. This was similar to results on the Coly soil. While DAP appeared to be a poor P source when dual placed, this is in contrast to results on the Coly soil and probably has no biological significance.

Significant reductions in plant populations were found from UP compared with APP and DAP. Whether these reductions were due to the phosphoric acid component or biuret in UP is not known. Concentration of plant P at the eight-leaf stage for DAP was greater at the higher P rate compared to APP. Recent work evaluating the fertilizer P-soil reaction products of these two sources has shown the advantages of DAP where higher available P in the application zone decreased P precipitation and increased plant availability of the soil-fertilizer reaction products (11, 15).

Methods of application did not affect plant population at Mead. This was likely due to an 8-cm irrigation immediately following planting that assured good stands. Leaching of salts from the application zone was expected thus negating any harmful salt effects on seedling emergence.

Table 7. The interaction between P method and P source showing significant contrasts for corn yield and P uptake (Mead, NE, 1983-85).

Comparison†		Grain yield	P uptake		
P method	P source		Grain	Stover	Total
		Mg ha^{-1}	kg ha^{-1}		
Contrast = [DP vs. (BB, BS, BRP)] × [UP vs. (APP, DAP)]					
DP	UP	11.12	34.3		39.7
	APP, DAP	9.82	30.0		35.6
BB, BS, BRP	UP	10.61	31.3		36.3
	APP, DAP	10.52	32.2		37.4
Contrast = [DP vs. (BB, BS, BRP)] × [DAP vs. (APP, UP)]					
DP	DAP				34.7
	APP, UP				38.1
BB, BS, BRP	DAP				38.2
	APP, UP				36.5

† Abbreviations are defined in methods and in Table 2.

Corn grown on the Sharpsburg soil responded much differently to the method of P application as compared to the Coly soil. It is hypothesized that the much higher P availability of the Sharpsburg soil, especially at deeper depths, may be responsible. It is apparent on the Sharpsburg soil that early P uptake and growth associated with banding P near the row resulted in increased yields and P uptake. It is not known why broadcast and dual placed P did not produce similar results as on the Coly soil.

Yield and P uptake was significantly higher in 1985 than in 1983 or 1984, similar to the Loup City location. While the environment for corn growth in 1985 was much superior to that of the previous 2 yr at this site, interactions affecting the performance of methods of application and P sources were mostly nonsignificant.

CONCLUSIONS

Dual placed N and P and broadcast P applications for corn proved equally effective for reduced tillage irrigated corn production on a calcareous Coly soil in terms of grain yield and P uptake, both being superior to band (below) and band (side) P fertilization methods. The dual placement method of application probably results in greater root-fertilizer contact since spacing between bands was half that of the banded treatments. Dual placed P bands were also located at a deeper depth than band (below) or band (side) methods that provided P uptake for the entire season. Advantages of dual placement may also lie in synergistic effects of NH_4 ion on P uptake when the two are placed together in a localized band, and where increased $H_2PO_4^-/HPO_4^{2-}$ ratios and higher solubility calcium phosphate reaction products exist in calcareous soils, as others have reported. Plants in the broadcast preplant P treatments probably benefited from increased soil water and roots in the surface application zone, and by a lack of root pruning in minimum tillage systems as compared to cultivated corn systems. Reduced plant populations explain in part the lower efficiency of band (below) and band (side) methods on the Coly soil. Increased probability of seed and/or primary root fertilizer burn is expected when these methods are employed. The higher grain yields and total P uptake achieved by UP than by DAP or APP on this calcareous soil attribute to the benefits of this more acidic material in extending P availability in the placement zone.

On a slightly acid Sharpsburg soil with a higher subsoil P, greater yields and early P uptake were found from band applications of P than from broadcast and dual placed methods of P application. This provides evidence that starter fertilizers can be beneficial on these soils. Reduced plant populations from band applications were not apparent at this site where 8 cm of water was applied at planting each year.

It appeared that subsoil P may have been a factor explaining the difference in the way methods of P application performed in these two soils. The late P uptake that may occur when roots reach the lower depths of the root zone could be an important factor in both yield response to applied P and the method by which it is applied. Row application of P may not provide adequate root contact for P needs later in the growing season in soils that have very low P availability. Contrasting results as to methods of P application on these two soils suggest that greater research is needed to evaluate the effect of subsoil P on optimum methods of P application for corn.

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Effect of Phenylphosphorodiamidate on Ammonia Volatilization as Affected by Soil Temperature and Rates and Distribution of Urea[1]

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ABSTRACT

Laboratory incubation studies were conducted to evaluate the ability of phenylphosphorodiamidate (PPD) to inhibit urea hydrolysis and control NH_3 volatilization losses. Complete hydrolysis of the uninhibited urea occurred within 8 d at all temperatures studied, and resulted in volatilization of more than 25% of the applied N within 10 d. Application of 20 mg PPD kg^{-1} of soil essentially prevented urea hydrolysis and resultant NH_3 losses for 1, 2, 4, 8, and 17 d at 35, 25, 15, 10, and 5°C, respectively. This delay in the onset of NH_3 losses due to PPD application kept NH_3 losses during the first 10 d to <7% of the applied N at the three lower temperatures, but had little effect upon NH_3 losses at 25 and 35°C. Such limited effectiveness of PPD at higher temperatures will no doubt reduce its utility for application to soils with surface temperatures above 25°C. Application of lower concentrations of urea gave reduced NH_3 losses, both with and without PPD, likely due to a greater ability of other N transformations to compete for the reduced ammonium pools. Ammonia losses were also reduced, with and without PPD, when the urea was distributed throughout a larger soil volume, presumably due to a greater proportion of the urea being hydrolyzed below the immediate soil surface.

Additional Index Words: **PPD, urease inhibitor, urea hydrolysis, placement.**

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UREASE INHIBITORS have received considerable recent attention as a means to increase the efficiency of applied urea and urea-ammonium nitrate (UAN) solutions. Current literature indicates that urea-based fertilizers applied to the soil surface are often much less efficient than less volatile N sources or comparable N applications applied below the soil surface. This decreased efficiency is normally attributed to NH_3 volatilization, but such surface applications are also known to enhance immobilization of N, especially when applied to systems having an accumulation of surface plant residues (Hendrickson et al., 1987). Applications of urease inhibitors are intended to reduce NH_3 volatilization and immobilization by delaying urea hydrolysis until the urea has been leached into the soil profile by rainfall or irrigation.

Phenylphosphorodiamidate (PPD) has received more attention to date than other compounds proposed as urease inhibitors. This compound has been shown to be very effective in inhibiting urea hydrolysis under laboratory conditions (Martens and Bremner, 1984), and has been shown effective in East German field studies (Heber et al., 1979), but has been quite ineffective in field studies conducted in the USA and Canada (Broadbent et al., 1985; Tomar et al., 1985). The reasons for such inconsistent field results and the disparity between the high activity of PPD in the laboratory and its performance in the field are not well understood.

Field conditions are obviously difficult to effectively simulate in the laboratory, yet a systematic evaluation of several interacting variables is feasible only in the laboratory. As such, several laboratory studies were conducted to determine the effects of soil temperature, and the rate and distribution of N on urease inhibition and resultant NH_3 losses from a simulated soil surface. These results were then extrapolated to a field scale to enable comparisons with data obtained in field experiments.

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