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Utility of Phosphorus Enhancers and Strip-Tillage for Corn Production

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Abstract

Farmers are seeking ways to diminish phosphorus (P) fertilizer rates and increase plant P uptake by means of enhanced efficiency P treatments. The objectives of this study were to determine the effects of tillage/fertilizer placement [no-till-surface broadcast (NT-BC) or strip-till-deep band (ST-DB)], monoammonium phosphate (MAP) rate (0, 56, and 112 kg ha^{-1}), and the presence or absence of enhanced phosphorus efficiency products (Avail® and P_2O_5-Max®) on corn (*Zea mays* L.) production. The field study was conducted in 2010 and 2011 at Novelty and Albany, MO. The two P enhancers had no effect on plant population, silage dry weights, grain moisture, yield, grain protein, grain starch, plant nitrogen (N), potassium (K) uptake, or apparent P recovery efficiency (APRE) at either location (P>0.10). In the NT-BC and ST-DB treatments, the addition of Avail® or P_2O_5-Max® did not increase plant P uptake over the non-treated controls. ST-DB increased plant populations 3,500 to 15,500 plants ha^{-1} compared to NT-BC. At Novelty, yields increased 1.57 Mg ha^{-1} with use of ST-DB over NT-BC, but at Albany yields were affected by tillage/fertilizer placement and MAP rate. Corn grain yields with MAP at 0 kg ha^{-1} were 0.30 to 0.36 Mg ha^{-1} more than MAP at 56 or 112 kg P_2O_5 ha^{-1}, which was probably due to the added ammonium nitrate used to balance the N contribution in MAP. Strip-till is a viable option to increase corn populations and yields on poorly drained soils, but P enhancers are not recommended for similar soil types.

Keywords: enhanced efficiency fertilizer products, fertilizer placement, monoammonium phosphate, no-till, phosphorus recovery

1. Introduction

Phosphorus (P) is a vital plant macronutrient. It serves as an important structural element in nucleic acids (RNA and DNA), as an energy transfer element (ATP), and it has a critical role in cellular regulation and carbon partitioning. Phosphorus fertilizers are used in large quantities in agriculture. The U. S. used 2.0 x 10^8 Mg of P_2O_5 from 1960 to 2010 (USDA, 2012). In Missouri alone, P fertilizer use for corn production has increased from 4.4 x 10^4 Mg P_2O_5 in 1990 to 8 x 10^4 Mg P_2O_5 in 2010 (USDA, 2011).

In response to high fertilizer expenses, farmers seek ways to diminish P fertilizer application rates and use of P enhancers to increase P use efficiency. The manufacturers of Avail® (Specialty Fertilizer Products, Leawood, KS) and P_2O_5-Max® (P-Max, Rosen's Inc., Fairmont, MN) promoted these products as enhancing the efficiency of P-based fertilizers. Avail® is a P enhancer for liquid P fertilizers and granular phosphate fertilizers, including DAP and MAP. Avail® was intended to reduce the effect of cations (i.e., Ca, Fe, Mn, and Al) surrounding fertilizer granules on soil P sorption and plant P uptake. The maleic-itaconic copolymer in the product binds with these cations in soil solution to prevent P precipitation (SFP, 2009). P_2O_5-Max®, containing the active ingredient poly-amino acid (L-aspartic acid)-sodium salt, reportedly increases P uptake and results in better nutrient absorption by improving root surface area (Rosen's Inc, 2012). However, mechanisms associated with product function are less clear.

Little published research has investigated plant growth and yields in the presence of Avail®. A study conducted in Kansas evaluated Avail® effectiveness in 2008 and 2009 at five locations under corn and wheat cropping systems (Ward, 2010). Plant biomass, grain yields, or P uptake for corn and wheat were not significantly affected by Avail®. Two trials in Canada evaluated three rates of seed-placed MAP (6.5, 13, 19.5 kg P ha^{-1}) and a nonfertilized control with or without Avail® (Karamanos & Puurveen, 2011). For both wheat yield and P uptake, there was neither a significant effect of treating MAP with Avail®, nor a significant interaction between Avail® treatment and rate of P.

When evaluating fertilizer effectiveness, placement may increase efficiency. Erosion transports less P offsite when it is placed deep or incorporated as compared to broadcast surface application. Deep placement increased plant growth and yields compared to broadcast surface application (Hairston et al., 1990; Malhi et al., 2001). Malhi et al. (2001) compared the effectiveness of broadcast to deep banding of annual and one-time P fertilizer applications on alfalfa (*Medicago sativa* L.). Banding increased dry matter yield (DMY) between 742 to 954 kg ha^{-1} and protein yield between 173 to 205 kg ha^{-1} compared to broadcast application. Banding resulted in greater P-use efficiency of applied P (58 kg DMY kg^{-1} P ha^{-1}) compared to broadcast for an annual application and for the one-time application (47 kg DMY kg^{-1} P ha^{-1}). Similarly, recovery of fertilizer P with deep banding was 16% greater for an annual application and 12% greater for the one-time application compared to broadcast application. However, the response of P fertilizers to deep placement has been inconsistent (Patrick et al., 1959; Mallarino et al., 1999; Borges & Mallarino, 2001). Weather conditions also can affect plant response to deep P placement. Robertson et al. (1958) found significant corn yield increases with deep placement when residual P was present in the surface soil and total rainfall was adequate for plant growth with dry periods during early growth. However, deep placement did not affect yields when soil contained adequate residual P and rainfall was above average and well distributed throughout the growing season.

Conservation tillage practices, such as NT, have reduced erosion and lowered production costs. Minimal soil disturbance associated with no-till increased soil fertility, structure, and reduced potential for soil erosion (Triplett & Dick, 2008). Adequate soil drainage and previous crop characteristics helped determine yield response to NT systems (Dick & Van Doren, 1985; Guy & Oplinger, 1989). Well-drained soils, crop rotation, and more southern latitudes generally benefited from NT during soybean production compared to poorly drained soils, continuous corn cropping systems, and northern latitudes (Griffith & Wollenhaupt, 1994). On a Houston Black clay soil (fine, smectitic, thermic Udic Haplusterts), NT produced higher corn yields than a chisel tillage system without beds and a chisel tillage system with raised wide beds (Torbert et al., 2001).

No-till has reduced yields in some instances compared to conventional tillage (CT) due to lower soil temperatures and higher soil moisture early in the growing season, which reduced seedling emergence and slowed early growth (Burrows & Larson, 1962; Fortin & Pierce, 1990; Vyn & Raimbult, 1993; Uri, 2000). No-till soils generally have greater bulk densities and penetrometer resistance (Bauder et al., 1981; Hill, 1990; Pierce et al., 1992) which can restrict root growth and affect fertilizer uptake. Studies have shown that NT corn yields were reduced by as much as 35% compared with CT for moderately well to poorly drained soils (Erbach et al., 1992; Hussain et al., 1999). Halvorson et al. (2006) found CT produced 16% higher yields than NT in Colorado. Lower grain yields associated with NT resulted from slow early-spring growth and delayed tasseling compared with the CT system as a result of cooler spring soil temperatures in NT. Cooler soil temperatures were due to greater residue cover on the soil surface in NT (89%) than in CT (14%). Howard et al. (2002) studied yield response between disk-till and NT in Tennessee. Disk-till yields were 0.59 to 1.34 Mg ha^{-1} greater than NT in 5 of the 11 site-years. However, P yield response was greater with NT production. No-till with P fertilizer application of 20 kg ha^{-1} increased yields 0.62 Mg ha^{-1}, while disk-till yields increased 0.44 Mg ha^{-1} with P application at 39 kg P ha^{-1}.

Strip-till is another conservation tillage practice that aims to combine the yield benefits of tillage with the environmental improvements of NT. The practice consist of an implement tilling a narrow band, generally 15 to 20 cm wide and 15 to 20 cm deep, while leaving the rest of the soil undisturbed. In poorly drained soils, strip-till increased soil moisture evaporation, increased soil temperature (Bolton & Booster, 1981) and decreased soil bulk densities in the row compared with NT (Drury et al., 2003; Overstreet & Hoyt, 2008), which improves seedbed environment. Strip-till has been shown to increase corn yields compared to NT (Vetsch et al., 2007) and was equal to CT (Griffith et al., 1973; Randall et al., 2001). On continuous corn production in Minnesota, Vetsch and Randall (2002) observed a 0.4 Mg ha^{-1} increase with ST compared to NT.

However, other research found limited yield differences between NT and ST (Mallarino et al., 1999; Al-Kaisi & Lichet, 2004; Al-Kaisi & Kwaw-Mensah, 2007; Archer & Reicosky, 2009). In Iowa, Licht and Al-Kaisi (2005a) found that ST had no effect on N uptake, dry matter production, and corn grain yields compared to chisel plow and NT. Vetsch and Randall (2004) showed that CT increased corn grain yields 0.3 Mg ha^{-1} over ST and 0.5 Mg ha^{-1} over NT. However, silage yields were 0.8 Mg ha^{-1} greater for ST and 0.9 Mg ha^{-1} greater for CT compared to NT. Nitrogen uptake was also greater for ST (193 kg ha^{-1}) and CT (198 kg ha^{-1}) compared with NT (181 kg ha^{-1}). Perez-Bidegain et al. (2007) evaluated different tillage effects on corn and soybean yields in Iowa. No differences were observed for soybean yields between tillage systems, while corn planted with disk-chisel tillage yielded 0.8 Mg ha^{-1} more than the mean yield of ST and NT.

Increased fertilizer expenses, challenges of corn production with NT, and innovative P enhancer products available on the market prompted this research investigating techniques to enhance P fertilizer efficiency. The objective of this study was to assess the effect of tillage/fertilizer placement, P rate, and two P enhancer products on corn production, grain quality, P uptake, and apparent P recovery efficiency.

2. Materials and Methods

Field research was conducted in 2010 and 2011 at the Greenley Memorial Research Center (40°01'N, 92°11'W) near Novelty, Mo., on a Kilwinning silt loam (fine, smectitic, mesis, Vertic Epiaqualfs) and at the Hundley-Whaley Center (40°14'N, 94°20'W) near Albany, Mo., on a Bremer silty clay loam (fine, smectitic, mesic, Typic Argiaquolls). Each site was arranged as a factorial randomized complete block design with four replications. Corn was planted following soybean. Pre-treatment soil conditions were evaluated from 15-cm depth samples randomly collected from each replication and analyzed by the University of Missouri Soil and Plant Testing Laboratory using standard methods (Nathan et al., 2006) including soil pH (0.01 M $CaCl_2$), Bray-1 P, exchangeable potassium, calcium, magnesium (1 M NH_4OA_C), zinc (DTPA extraction), soil organic matter (loss-on-ignition), neutralizable acidity (Woodruff buffer), and effective cation exchange capacity (Table 1).

Table 1. Selected initial soil properties for the P placement, rate, and enhancer experiments at Novelty and Albany in 2010 and 2011

Soil properties	Novelty		Albany	
	2010	2011	2010	2011
pH_s (0.01 M $CaCl_2$)	6.8±0.3[†]	6.6±0.2	6.4±0.4	6.0±0.3
Bray-1 P (kg ha^{-1})	50±26	27±8	90±48	90±11
Exchangeable (1 M NH_4OA_C)				
Potassium (kg ha^{-1})	275±41	158±25	293±25	315±44
Calcium (kg ha^{-1})	6039±528	5585±242	6466±417	6513±692
Magnesium (kg ha^{-1})	470±83	502±54	713±200	779±109
Zinc (mg kg^{-1}) (DTPA Extraction)	0.75±0.24	0.35±0.13	0.80±0.24	0.88±0.17
Soil organic matter (g kg^{-1})	24±8	26±1	25±1	27±7
Neutralizable acidity ($cmol_c$ kg^{-1})	0.25±0.5	0.75±0.29	1.25±1.19	2±0.82
Cation exchange capacity ($cmol_c$ kg^{-1})	16±1	15±1	19±2	20±3

Treatments included a three-factor arrangement of fertilizer placement (NT/surface broadcast or strip-till/deep band), monoammonium phosphate (MAP) rate (0, 56 kg P_2O_5 ha^{-1}, 112 kg P_2O_5 ha^{-1}), and the presence or absence of two enhanced phosphorus efficiency products [non-treated control, Avail® at 2.1 L Mg^{-1} of fertilizer, and P_2O_5 Max® at 4.2 L Mg^{-1} of fertilizer]. At Novelty, P fertilizer treatments were deep banded using a Yetter® 2984 strip-till system equipped with high residue Maverick® units (Yetter Manufacturing, Inc., Colchester, IL), a rolling basket, and dry fertilizer application tubes. At Albany, P fertilizer treatments also were deep banded using a Yetter® 2984 strip-till system equipped with residue manager wheels, B-33 mole knife, and opposing closing wheel disks. A Gandy Orbit Air® (Gandy Company, Owatonna, MN) dry fertilizer applicator metered and delivered fertilizer behind the applicator knife in the strip till system. Phosphorus was applied with a hand spreader in the NT surface broadcast treatment. Ammonium nitrate fertilizer was broadcast-applied for the appropriate treatments to balance the N contribution of MAP as the rate was reduced. The planter was equipped with Shark-tooth® (Yetter Manufacturing, Inc., Colchester, IL) residue cleaners used in tandem with a NT coulter. The residue cleaners performed well in heavy residue of the NT plots and provided a smooth seedbed above strip-tilled plots. The row spacing was 0.76-m. Management information is presented in Table 2.

Table 2. Field and management information for P placement, rate, and enhancer experiments at Novelty and Albany in 2010 and 2011

Management	Novelty		Albany	
information	2010	2011	2010	2011
Plot size	3 by 23 m	3 by 23 m	4.6 by 23 m	4.6 by 23 m
Hybrid	DK 62-54 VT3	DK 62-54 VT3	DK 63-84 VT3	DK 63-84 VT3
Planting date	14 Apr.	31 Mar.	30 May	13 Apr.
Seeding rate	74,100 seeds ha^{-1}	74,100 seeds ha^{-1}	74,100 seeds ha^{-1}	72,900 seeds ha^{-1}
Tissue harvest date	7 Sep.	25 Aug.	9 Sep.	26 Aug.
Harvest date	30 Oct.	8 Sep.	15 Oct.	27 Sep.
P fertilizer application date	13 Apr.	30 Mar.	15 Apr.	15 Nov.
Additional fertilizer (date, source, & rate)	6 May, Urea (202 kg N ha^{-1}) + NBPT (4 L Mg^{-1})	31 Oct. 2010, Anhydrous ammonia (179 kg N ha^{-1}) + Nitrapyrin (0.56 kg a.i. ha^{-1})	19 Apr., Urea (168 kg N ha^{-1}) + NBPT (4 L Mg^{-1})	14 Apr., Urea (168 kg ha^{-1})
Weed management‡				
Burndown	NA	11 Apr., Glyphosate (1.06 kg a.i. ha^{-1}) + DS (0.36 kg a.i. ha^{-1}) + DAS (512 mL ha^{-1})	NA	NA
Preemergence	16 Apr., S-metolachlor (2.25 kg a.i. ha^{-1}) + Atrazine (0.84 kg a.i. ha^{-1}) + Mesotrione (0.23 kg a.i. ha^{-1}) + DSD (0.56 kg a.i. ha^{-1})	13 Apr., Acetochlor (2.35 kg a.i. ha^{-1}) + Atrazine (1.77 kg a.i. ha^{-1})	15 Apr., S-metolachlor (2.4 kg a.i. ha^{-1}) + Atrazine (0.9 kg a.i. ha^{-1}) + Mesotrione (0.24 kg a.i. ha^{-1}); 30 May, Isoxaflutole (0.14 kg a.i. ha^{-1})	16 Apr., S-metolachlor (2.4 kg a.i. ha^{-1}) + Atrazine (0.9 kg a.i. ha^{-1}) + Mesotrione (0.24 kg a.i. ha^{-1})
Postemergence	22 June, Glyphosate (1.45 kg a.i. ha^{-1}) + DAS (0.04 kg a.i. ha^{-1})	NA	21 June, Glyphosate (1.16 kg a.i. ha^{-1})	7 June, Glyphosate (1.16 kg a.i. ha^{-1})

†Abbreviations: DAS, Diammonium sulfate; DS, Dimethylamine salt; DSD, Dimethylamine salt of dicamba; NA, None applied.

‡Acetochlor (2-chloro-2'-methyl-6'ethyl-N-ethoxymethylacetanilide); atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine); diammonium sulfate ((NH4)2SO4); dimethylamine salt (2,4-Dichlorophenoxyacetic acid); dimethylamine salt of dicamba (3,6-dichloro-0-anisic acid); glyphosate (N-(phosphonomethyl)glycine); isoxaflutole (5-cyclopropyl-4-(2-methylsulfonyl-4-trifluoromethylbenzoyl) isoxazole); mesotrione (2-[4-(Methylsulfonyl)-2-nitrobenzoyl]cyclohexane-1,3-dione); nitrapyrin (2-chloro-6-(trichloromethyl) pyridine); NBPT (N-(n-butyl) thiophosphoric triamide); S-metolachlor (2-chloro-N-(2-ethyl-6-methylphenyl)-N-[(1S)-2-methoxy-1-methylethyl]acctamide).

The two center rows of each plot were harvested with a plot combine (Wintersteiger Delta, Salt Lake City, UT) and were used to measure corn grain yield and moisture content. Grain starch, protein, and oil concentration (Foss Infratec, Eden Prairie, MN) were collected from each plot. Grain yields were adjusted to 155 g kg^{-1} moisture before analysis. At physiological maturity, 1.5 m of one row was harvested and used to measure corn silage yield expressed on a dry matter basis. The silage samples underwent a H_2SO_4-H_2O_2 digestion and were analyzed for total N (colorimetric Indophenols blue), P (colorimetric ammonium molybdate), and K (atomic absorption) concentration. Apparent P recovery efficiency (APRE) was calculated as [((kg P uptake ha^{-1} of treated - kg P uptake ha^{-1} of control)/(kg fertilizer applied P ha^{-1}))*100]. All data were subjected to analysis of variance and means separation using Fisher's Protected LSD (*P*=0.1). Data were combined over factors and locations when appropriate as indicated by the analysis of variance (data not presented). Plant population at Novelty and Albany, and grain oil concentration at Novelty were subjected to an *F Max* test for homogeneity (Kuehl, 1994) and combined over site-years when variances were homogenous.

3. Results and Discussions

Precipitation at the study sites during the 2010 growing season was 265 mm at Albany and 523 mm at Novelty greater than during 2011 (Figure 1). At Novelty, the 2010 growing season received the greatest precipitation (1082 mm) of all four site years which was 362 mm greater than the average precipitation for the past decade (Nelson et al., 2010). Soil temperatures at a depth of 5.1 cm were similar for all locations within a particular year, but temperatures differed by year (Figure 2). No four-way interactions (year*P enhancer*placement*MAP rate) existed for the parameters evaluated; thus, main effects are reported and interactions presented when appropriate.

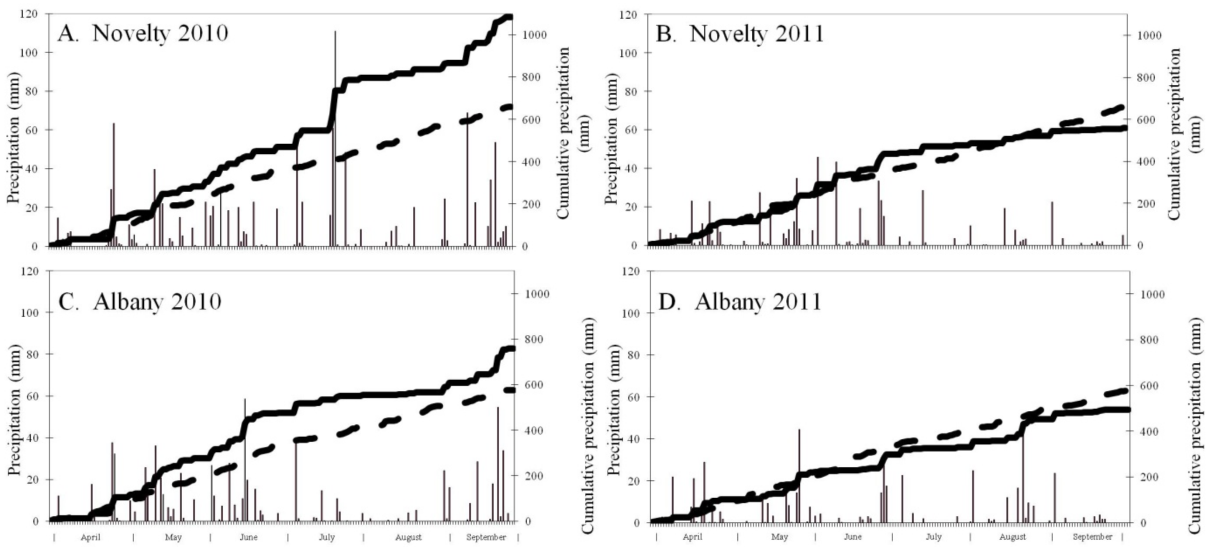

Figure 1. Daily (bars) and cumulative (solid line) precipitation from March through September of 2010 and 2011 at Novelty (A and B) and Albany (C and D). Dashed lines are the cumulative precipitation from the last decade for each location

3.1 Phosphorus Enhancer

Table 3. The effect of P enhancer on grain oil and P uptake

P enhancer	Oil		P uptake	
			Placement	
	Novelty[†]	Albany[†]	NT/broadcast	ST/deep banding
	---------- g kg^{-1} ----------		-----------------kg ha^{-1}-----------------	
Non-treated	36.8	37.7	39.6	38.1
Avail®	36.4	36.9	38.0	39.8
P_2O_5-Max®	36.9	36.4	40.0	34.1
LSD (*P*=0.1)	NS[‡]	0.7	------------------4.1------------------	
P-value	0.74	0.01	-----------------0.09-----------------	

[†]Data were combined over years (2010 and 2011).

[‡]Data were combined over site-year and MAP (monoammonium phosphate) rate.

[§]NS = Not significant.

The P enhancers did not affect plant population (*P*=0.51), silage dry weights (*P*=0.81), grain moisture (*P*=0.54), yield (*P*=0.83), grain protein (*P*=0.74), grain starch (*P*=0.63), N uptake (*P*=0.42), K uptake (*P*=0.82), or APRE (*P*=0.32) during the four site-years (data not presented). At Albany, oil concentration in the non-treated control was 1.3 g kg^{-1} greater than P_2O_5-Max® (Table 3). In the NT-BC and ST-DB treatments, the addition of Avail® or P_2O_5-Max® did not increase P uptake over the non-treated controls. Avail® increased P uptake 5.7 kg ha^{-1} over P_2O_5-Max® with ST-DB, and no differences were observed between products in the NT-BC treatment.

Phosphorus uptake increased 5.9 kg ha^{-1} when P fertilizer was applied with P_2O_5-Max® and NT-BC instead of ST-DB. In Kansas, Ward (2010) found similar results with no significant effect of Avail® for corn or wheat biomass production, P uptake, or grain yields of either crop. Neither a significant effect of treating MAP with Avail®, nor a significant interaction between Avail® treatment and rate of P on the yield of wheat and P uptake was shown in Canada (Karamanos & Puurveen, 2011).

3.2 Phosphorus Placement

Strip-till/deep band increased plant populations 15,500 plants ha^{-1} at Novelty and 3,500 plants ha^{-1} at Albany compared to NT-BC (Table 4). The claypan soil at Novelty has poorer internal drainage than the Bremer silt loam at Albany. With ST, an improved the seedbed environment likely caused the greater plant populations. In poorly drained soils, strip-till can increased soil moisture evaporation, increased soil temperature (Bolton & Booster, 1981) and decreased soil bulk densities in the row compared with NT (Drury et al., 2003; Overstreet & Hoyt, 2008), which improves seedbed environment. This was particularly important early in the growing season. Licht and Al-Kaisi (2005b) evaluated the effect of tillage on soil temperature. In the top 5 cm, ST increased soil temperature 1.2°C to 1.4°C over NT. This caused the corn emergence rate index of ST to be slightly greater than NT throughout the four site years (Licht & Al-Kaisi, 2005b). This effect could have been important in maintaining a good corn stand during April and early May when there was higher rainfall (Figure 1) and cooler soil temperatures (Figure 2).

Table 4. Phosphorus placement effect on plant population, grain moisture, yield, and apparent P recovery efficiency (APRE)

Placement	Plant population		Grain moisture	Grain yield				APRE
					Albany†			
					MAP rate (kg P_2O_5 ha^{-1})			
	Novelty†	Albany†		Novelty†	0	56	112	
	----plants ha^{-1}-----		g kg^{-1}	--------------------Mg ha^{-1}--------------------				%
NT/broadcast	50,600	57,600	172.2	6.74	9.32	8.61	8.97	21.4
ST/deep banding	66,100	61,100	168.9	8.31	8.77	8.90	9.05	0.7
LSD (*P*=0.1)	2,600	2,900	2.4	0.36	---------------0.47---------------			11.5

†Data were combined over years (2010 and 2011).

‡NT = No-till; ST = Strip-till.

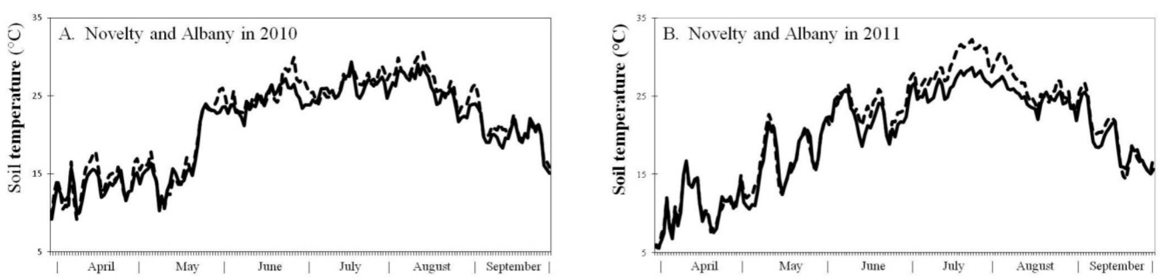

Figure 2. Average daily soil temperature at 51 mm depth from March through September in 2010 (A) and 2011 (B) at Novelty and Albany. The solid line is Novelty and the dashed line is Albany

Tillage/fertilizer placement did not affect silage dry weights, N, or K uptake. However, grain moisture was 3.3 g kg^{-1} greater in NT-BC compared to ST-DB (Table 4). No-till/broadcast increased APRE 20.7% over ST-DB. At Novelty, yields increased 1.57 Mg ha^{-1} with use of ST-DB over NT-BC, but yields at Albany were affected by tillage/fertilizer placement and MAP rate. When no MAP was added at Albany, NT-BC increased grain yields 0.55 Mg ha^{-1} over ST-DB. However, no difference was observed between NT-BC and ST-DB with MAP at 56 or 112 kg P_2O_5 ha^{-1}. Fertilization with MAP at 0 kg P_2O_5 ha^{-1} yielded 0.71 Mg ha^{-1} more than MAP at 56 kg P_2O_5 ha^{-1} under NT-BC, but no difference was observed with MAP at 112 kg P_2O_5 ha^{-1}. This difference may be due to the addition of ammonium nitrate in the 0 kg P_2O_5 ha^{-1} control to balance the N contribution as the MAP rate increased. The soils in these experiments have a high potential for gaseous fertilizer N loss due to poor internal soil drainage and long periods of soil saturation, especially when urea is the N source (Nash et al., 2012). Urea was selected as the N source at three of the four site-years due the inability to apply anhydrous ammonia. The lack of response at Albany to the addition of MAP could also result from greater initial Bray-1 P compared to Novelty (Table 1). Strip-till has been shown to increase corn yields compared to NT (Vetsch et al., 2007), and had yields similar to CT in other research (Griffith et al., 1973; Randall et al., 2001). In Minnesota, Vetsch and Randall (2002) found in continuous corn that yield increased 0.4 Mg ha^{-1} with ST compared to NT. However, studies have shown yield differences between NT and ST ranging from none to limited (Mallarino et al., 1999; Al-Kaisi & Lichet, 2004; Al-Kaisi & Kwaw-Mensah, 2007; Archer & Reicosky, 2009). In Iowa, Licht and Al-Kaisi (2005a) found that ST did not affect N uptake, dry matter production, or corn grain yields compared to chisel plow and NT. Also in Iowa, Perez-Bidegain et al. (2007) evaluated different tillage effects on corn and soybean yields. They observed no differences for soybean yields between tillage systems, while corn planted with disk-chisel tillage yielded 0.8 Mg ha^{-1} more than the mean yield of ST and NT.

Grain protein and starch concentrations exhibited an interaction between year and placement at Novelty, but not at Albany (Table 5). The NT-BC treatment had 14 g kg^{-1} greater protein concentration in 2010 than ST-DB and 6 g kg^{-1} greater protein concentration in 2011. In 2010 and 2011, ST-DB increased starch concentration by 8 and 3 g kg^{-1}, respectively. Grain oil concentration was affected by location, placement, and MAP rate. At Novelty, NT-BC with MAP at 0 kg P_2O_5 ha^{-1} had at least 1.7 g kg^{-1} less oil concentration than any other placement-MAP rate combination. At Albany, ST-DB with MAP at 0 kg P_2O_5 ha^{-1} had a lower oil concentration than any other placement-MAP rate combination except for NT-BC MAP at 112 kg P_2O_5 ha^{-1}. The effect of tillage on plant stand was less pronounced at Albany than at Novelty which may have affected grain quality.

Table 5. Placement effect on grain protein, starch, and oil. Data were combined over MAP rate and P stabilizer except for grain oil which was combined over site-year and P stabilizer

							Oil					
	Protein			Starch			Novelty†			Albany†		
	Novelty			Novelty			MAP rate (kg P_2O_5 ha^{-1})			MAP rate (kg P_2O_5 ha^{-1})		
Placement	2010	2011	Albany†	2010	2011	Albany†	0	56	112	0	56	112
	------------- g kg^{-1} -------------			------------- g kg^{-1} -------------			---------- g kg^{-1} ----------			---------- g kg^{-1} ----------		
NT/broadcast	84	93	84	739	729	723	34.8	37.3	36.5	37.4	37.3	36.8
ST/deep banding	70	87	85	747	732	722	37.5	37.5	36.7	36.0	37.6	37.0
LSD (P=0.1)	2	2	NS‡	2	2	NS	----------1.4----------			----------1.0----------		

†Data were combined over years (2010 and 2011).
‡NS = Not significant; NT = No-till; ST = Strip-till.

3.3 Monoammonium Phosphate Rate

MAP rate did not affect plant population, silage dry weights, and grain moisture at all four site-years (data not presented). Corn grain yields with MAP at 0 kg ha^{-1} were 0.30 to 0.36 Mg ha^{-1} more than MAP at 56 or 112 kg P_2O_5 ha^{-1} (Table 6). This difference may be due to the addition of ammonium nitrate to the 0 kg P_2O_5 ha^{-1} control that was added to balance the N contribution as the MAP rate increased to 112 kg ha^{-1}. There were no significant differences in N uptake between MAP rates, but the MAP rate at 0 kg P_2O_5 ha^{-1} indicated greater N uptake than MAP at 56 or 112 kg P_2O_5 ha^{-1}. The effectiveness of DAP as a dual source of P and N for corn was evaluated in a greenhouse study (Lu et al., 1987). On a calcareous clay soil, DAP was compared with urea plus single superphosphate (SSP) placed at different depths (deep banding, surface broadcast, and incorporation). Soil treated with DAP contained less Olsen P than soil treated with urea plus SSP regardless of fertilizer placement. Reduced P accessibility to the plant roots resulting in lower P uptake and plant yield occurred with both fertilizers when they were surface broadcast compared to the incorporation treatments. When the fertilizers were incorporated or deep-placed, N uptake was as great with DAP as with urea plus SSP. However, surface application resulted in higher N uptake from urea plus SSP than DAP. Regardless of fertilizer placement, urea plus SSP produced greater plant yields than those obtained with DAP.

Table 6. Yield, N uptake, protein, and starch concentration as affected by MAP rate. Data were combined over site-year, location, placement, and P stabilizer except for grain protein and starch

			Protein			Starch	
			Novelty				
MAP Rate	Yield	N uptake	2010	2011	Albany†	Novelty†	Albany†
kg P_2O_5 ha^{-1}	Mg ha^{-1}	kg ha^{-1}	----------- g kg^{-1} ----------			------- g kg^{-1} -------	
0	8.44	440.7	77	88	85	737	723
56	8.08	429.6	77	91	84	735	722
112	8.14	428.7	76	91	84	737	723
LSD (*P*=0.1)	0.25	NS‡	NS	2	NS	2	NS

†Data were combined over years (2010 and 2011).

‡NS = Not significant.

At Novelty in 2011, grain protein concentration increased 3 g kg^{-1} with MAP at 56 and 112 kg P_2O_5 ha^{-1} compared to the non-treated control, but at Novelty in 2010 and Albany (2010 and 2011) no differences were observed (Table 6). MAP at 0 and 112 kg P_2O_5 ha^{-1} increased starch concentration 2 g kg^{-1} over MAP at 56 P_2O_5 ha^{-1} at Novelty, but not Albany. Plant N, P, K uptake, and APRE were not affected by MAP rate during all four site-years evaluated in this research (data not presented).

4. Conclusions

The two P enhanced efficiency products this study evaluated did not consistently increase agronomic performance, including apparent P recovery efficiency, at the sites and environmental conditions in interaction with several fertilization rates and tillage practices evaluated in this research. Additionally, the P enhancers did not affect plant population, silage dry weights, grain moisture, yield, grain protein, grain starch, N, K uptake, or apparent P recovery efficiency. In the NT-BC and ST-DB treatments, the addition of Avail® or P_2O_5-Max® did not increase P uptake over non-treated controls. Since soils in this study were acidic, more research should be performed evaluating Avail® or P_2O_5-Max® use on alkaline soils. Strip-till/deep banding increased plant populations by 3,500 to 15,500 plants ha^{-1} compared to NT/broacast. At Novelty, greater plant populations associated with ST increased grain yields 1.57 Mg ha^{-1} compared to NT. Poorly drained claypan soils in Northeast Missouri responded more to ST than silty clay soils in Northwest Missouri. Corn grain yields with MAP at 0 kg ha^{-1} were 0.30 to 0.36 Mg ha^{-1} more than MAP at 56 or 112 kg P_2O_5 ha^{-1}.This difference may be due to adding ammonium nitrate to balance the N contribution as the MAP rate increased to 112 kg ha^{-1}.

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