Enhanced Efficiency Phosphorus Application for a Corn-Soybean Rotation

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Objectives and Relevance:

Phosphorus (P) is an essential plant nutrient that is taken up by plants as inorganic ions ($H_2PO_4^-$ and HPO_4^{-2}) found in soil solution. Phosphorus in plants is an important structural element in nucleic acids (RNA and DNA), serves as an energy transfer element (ATP), and has a critical role in cellular regulation, and carbon partitioning. Soluble forms of P or P bound to clay particles can be lost from agricultural land through runoff and surface erosion. Unless the soil is coarse-textured, has a shallow depth to bedrock, has preferential flow paths, has high initial soil test P, or artificial drainage is present, the potential for P leaching is generally considered very low. Soil P sorption reactions (i.e., adsorption and precipitation) reduce plant available P in the soil solution and the relative capacity of a soil for P sorption is dependent on such soil properties as the type and proportion of clay in the soil, the soil pH, and the amount of soil organic matter (Pierzynski et al., 2005)

With high fertilizer costs, farmers are evaluating application rates and considering enhanced efficiency P applications or treatments. AVAIL® (Specialty Fertilizer Products, Leawood, KS) and P_2O_5 Max® (P-Max, Rosen's Inc., Fairmont, MN) are two new products that may enhance the efficiency of P-based fertilizers. AVAIL is a P enhancing product for granular phosphate fertilizers including DAP (diammonium phosphate), MAP (monoammonium phosphate), and other phosphate fertilizers. It was designed to reduce the impact of metals in the soil around the fertilizer granule on plant uptake, and P sorption, and allow P to be more available to the plant. This product primarily binds with calcium, iron, manganese, and aluminum to prevent precipitation of P. When applied to single crops, Blevins (2009) reported a 19 to 22 bu/acre increase in corn grain yields when AVAIL was added to MAP at 20 lbs P_2O_5/acre and applied as a broadcast or banded treatment. Dunn (2009) reported increased Bray-P1 soil test P availability and a 4 bu/acre increase in soybean yield after applying 50 lbs P_2O_5/acre with AVAIL. Similarly, rice yields increased 8 bu/acre when reduced rates of triple super phosphate were applied (25 lbs P_2O_5/acre) with AVAIL. P-Max increases P uptake and improves root surface area resulting in better nutrient absorption and higher yields (Rosen's Diversified Inc, 2010). In addition, banded applications of P may also increase P efficiency (Minor et al., 1993). Phosphate placement in the rooting zone of moist soil was suggested to improve efficiency if farmers desired to apply reduced rates. Strip-till applications may also limit P loss if soil particles were eroded into surface waters.

The objectives of this research were to:

1. evaluate the effect of P placement, rate, and P enhanced efficiency products on grain yield and P uptake in a corn-soybean rotation, and

2. determine the effect of P source, P enhancer, and ag lime on grain yield and P uptake in a corn-soybean rotation.

Procedures:

General. A two-year rotational crop study utilizing P fertilizer applications for corn was initiated in 2010, and evaluated the subsequent impact on soybean yield and/or uptake. Research trials were established at the Greenley Memorial Research Center near Novelty, Delta Center near Portageville, and Hundley-Whaley Center near Albany. Each site was arranged as a randomized complete block design with four replications. Soils were initially characterized for soil total organic C, pH (0.01 *M* $CaCl_2$), and exchangeable K, Ca and Mg at each site (Tables 1 and 2). Soil test P (Bray-1 P) concentrations were determined prior to application from each replication at each site. Soil test P was determined following soybean harvest for each treatment. Grain yields were determined and grain collected (Novelty and Albany) to evaluate for starch, protein, and oil concentration (Foss Infratec, Eden Prairie, MN). Whole plant tissue samples were collected at plant maturity and nitrogen, phosphorus, and potassium levels were determined. Apparent P recovery efficiency (APRE) was calculated as [((lbs P uptake/acre of treated - lbs P uptake/acre of control)/(lbs fertilizer applied P/acre))*100]. Grain moisture was adjusted to 15.5% prior to analysis. All data were subjected to analysis of variance and means separated using Fisher's Protected LSD (P = 0.05 or 0.1). Data were combined over factors and locations when appropriate as indicated by the analysis of variance (data not presented). The soybean tissue and soil data in 2012 is currently being analyzed (data not presented).

P placement, rate, and enhancer. Sites to accomplish objective 1 included Novelty and Albany. Corn fields were initiated at both locations in 2010 and 2011. Soybean followed corn in the same plots in 2011 and 2012. Treatments included a factorial arrangement of application placement (i.e., surface broadcast or strip-till), MAP rate (0, half the recommended rate, and recommended rate), and the presence and absence of two enhanced phosphorus efficiency products [AVAIL®(Specialty Fertilizer Products, Leawood, KS) at 0.5 gal/ton and P_2O_5 Max® (P-Max, Rosen's Inc., Fairmont, MN) at 1 gal/ton]. Plots were 10 by 75 ft at Novelty and 15 by 75 ft at Albany. The previous crop before corn production was soybean at both locations. Phosphorus treatments were deep banded using a Yetter® 2984 strip-till system equipped with high residue Maverick® units (Yetter Manufacturing, Inc., Colchester, IL) with a rolling basket and dry fertilizer application tubes at the Novelty site. Phosphorus treatments were deep banded using a Yetter® 2984 strip-till system equipped with residue manager wheels (Yetter Manufacturing, Inc., Colchester, IL), B-33 mole knife, and opposing closing wheel disks at the Albany site. A Gandy Orbit Air® (Gandy Company, Owatonna, MN) fertilizer applicator was used to deliver fertilizer behind the applicator knife in the strip-till system. Phosphorus was broadcast surface applied with a hand spreader. 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 no-till coulter. The residue cleaners performed well in heavy residue of the no-till plots and provided a smooth seedbed above strip-tilled plots. Management information is available in Table 3. Corn and soybean tissue samples were collected to determine crop N, P, and K uptake due to the effects of the treatments at both locations. Soil

samples and soybean tissue for 2012 is currently being analyzed analyzed by the University of Missouri Soil and Plant Testing Laboratory (data not presented).

P source, P enhancer, and ag lime. Research to accomplish objective 2 was conducted at Novelty in 2010 and 2011 and Portageville in 2010. Corn fields were initiated at Novelty and Portageville in 2010 with an additional field started at Novelty in 2011. The field site at Portageville in 2011 was abandoned due to the impact of excessive rainfall on corn plant populations. Soybean followed the corn at Novelty and Portageville in 2011 and at Novelty in 2012. Treatments included a factorial arrangement of P sources [non-treated control and a broadcast application of DAP (diammonium phosphate) or TSP (triple superphosphate], presence or absence of the phosphorus efficiency products [AVAIL®(Specialty Fertilizer Products, Leawood, KS) at 0.5 gal/ton and P_2O_5 Max® (P-Max, Rosen's Inc., Fairmont, MN) at 1 gal/ton], and broadcast surface application of ag lime [0 and recommended (3.6 ton/acre at Novelty 2010, 1.5 ton/acre at Novelty 2011, and 2.0 ton/acre at Portageville 2010)]. Plots were 10 by 45 ft. The Novelty site was no-till and rain fed, while the Portageville was conventional tillage with furrow irrigation. Management information is available in Table 4. Tissue (Novelty and Portageville) samples from both corn and soybeans were collected to determine crop N, P, and K uptake. Soil samples and soybean tissue for 2012 is currently being analyzed analyzed by the University of Missouri Soil and Plant Testing Laboratory (data not presented).

Results:

Corn-P placement, rate, and P stabilizer. The results from the corn portion of objective 1 were accepted for publication in the *Journal of Agricultural Science* (Dudenhoeffer et al., 2013). Strip-till/deep banding increased plant populations 6,200 plants/acre at Novelty and 1,400 plants/acre at Albany (Table 5). There was no effect of fertilizer placement on silage dry weights, but grain moisture was 0.3% greater in no-till compared to strip-till. Yields increased 24 bu/acre with use of strip-till/deep banding over no-till/broadcast at Novelty, but yields at Albany were affected by placement and MAP rate. When no MAP was added at Albany, no-till/broadcast increased grain yields 9 bu/acre over strip-till/deep banding. However, no difference was observed between no-till/broadcast and strip-till/deep banding with MAP at 50 or 100 lbs P_2O_5/acre. MAP at 0 lbs P_2O_5/acre yielded 11 bu/acre more than MAP at 50 lbs P_2O_5/acre rate under no-till/broadcast, but no difference was observed with MAP at 100 lbs P_2O_5/acre. This difference may be due to the ammonium nitrate that was added to balance the N contribution as the MAP rate increased.

Grain protein and starch concentrations had an interaction between year and placement at Novelty, but not Albany (Table 6). No-till/broadcast had 1.4% higher protein concentration point in 2010 than strip-till/deep banding and 0.6% higher protein concentration in 2011. In 2010, strip-till/deep banding increased starch by 0.8%, starch increased 0.3% in 2011. Grain oil concentration was affected by location, placement, and MAP rate. At Novelty, no-till/broadcast with MAP rate 0 lbs P_2O_5/acre had lower oil concentration than any other placement-MAP rate combinations. At Albany, strip-till/deep banding with MAP at 0 lbs P_2O_5/acre had a lower oil concentration than any other placement-MAP rate combination except for no-till/broadcast MAP at 100 lbs P_2O_5/acre. There was no effect of fertilizer placement on N, or K uptake, but no-till/broadcast increased APRE 20.7% over strip-till/deep banding (Table 7).

Plant population, silage dry weights, and grain moisture were not affected by MAP rate at the four site-years evaluated in this research (Table 8). MAP rate had a significant (P=0.1) effect

on yields with P_2O_5 at 0 lbs/acre yielding 4 to 6 bu/acre more than MAP at 50 or 100 lbs P_2O_5/acre. This difference may be due to the ammonium nitrate that was added to balance the N contribution as the MAP rate increased. Grain protein concentration increased 0.3% with MAP at 50 and 100 lbs P_2O_5/acre compared to the non-treated control at Novelty in 2011, but no differences were observed at Novelty in 2010 or Albany. MAP at 0 and 100 lbs P_2O_5/acre increased starch concentration 0.2% over MAP at 50 lbs P_2O_5/acre at Novelty, but not at Albany. Plant tissue N, tissue P, tissue K, and APRE were not affected by MAP rate (Table 9).

Enhanced efficiency P products did not affect plant population, silage dry weights, grain moisture, yield, grain protein, or starch concentrations at the four site-years (Table 10). The non-treated control oil concentration at Albany was 0.2% greater than the P-Max treatment. Plant N uptake, plant K uptake, and APRE were not affected by P stabilizer (Table 11). Tissue P concentrations were affected by fertilizer placement and P stabilizer. In the no-till/broadcast and strip-till/deep banding, the addition of AVAIL or P-Max did not increase tissue P uptake over the non-treated controls. AVAIL increased tissue P uptake 5.1 lbs/acre over P-Max with strip-till/deep banding, while no differences between products were observed with no-till/broadcast. Phosphorus uptake increased 5.3 lbs/acre when P fertilizer was applied with P-Max and no-till/broadcast instead of strip-till/deep banding.

Corn-P source, P stabilizer, and ag lime. The results from the corn portion of objective 2 were published in the *Journal of Agricultural Science* (Dudenhoeffer et al., 2012). The recommended liming rate was 3.6 ton/acre at Novelty in 2010, 1.5 ton/acre at Novelty in 2011, and 2.0 ton/acre at Portageville in 2010. Plant population was 1,000 plants/acre greater in the non-limed control compared to the recommended rate in 2011 at Novelty, while plant population was not affected at Portageville (Table 12). The recommended amount of lime increased grain yields 12 bu/acre at Portageville, but there was no effect at Novelty. Grain moisture, oil, protein, and starch concentrations were not affected by the lime treatment at either location.

Silage dry weights increased 1.0 ton/acre with an application of lime in the non-treated control, but no dry weight differences between lime treatments were observed in the presence of DAP or TSP (Table 13). TSP increased silage dry weights 0.9 ton/acre over the non-treated control when no lime was applied. An application of TSP or DAP decreased grain moisture 0.9 to 1.3% compared to the non-treated control. Grain yield increased 5 bu/acre with TSP compared to the non-treated control. However, grain oil, protein, starch concentration, tissue N or APRE was not affected by P source. Enhanced efficiency P products did not affect plant populations, silage dry weights, grain moisture, yield, grain oil, protein, starch, tissue N, or APRE (P= 0.31 to 0.97) compared to the non-treated control (Table 14).

Plant tissue N and tissue K was not affected by a lime application (Table 15). Phosphorus uptake increased 3 lbs/acre with the application of lime at Novelty, but was not affected at Portageville. However, the lime application decreased APRE 13.4 %. Plant P uptake was affected by P source and P stabilizer at Novelty, while P uptake was not affected at Portageville (Table 16). When the fertilizer was not treated with a P stabilizer, the tissue P uptake of DAP was 7.4 to 8.0 lbs/acre greater than the non-treated control and TSP. Neither of the P stabilizer combined with DAP increased P uptake over the non-treated control. Triple superphosphate treated with AVAIL increased tissue P uptake 7.7 lbs/acre compared to non-treated TSP and 6.3 lbs/acre compared to P-Max.

Plant K uptake was not affected by P stabilizer at Portageville or the 2011 growing season at Novelty (Table 16). The 2010 growing season at Novelty showed an interaction between P source and P stabilizer for K uptake. TSP treated with AVAIL increased tissue K uptake over all other P source-P stabilizer combinations except for P-Max applied with the non-treated P-source. When TSP was the P source, AVAIL increased K uptake 135 lbs/acre compared to the non-treated TSP and 89 lbs/acre compared to P-Max. The non-treated P source had higher tissue K uptake (67 lbs/acre) than TSP when no P stabilizer was applied.

Soybean-P placement, rate, and P stabilizer. There was no effect of fertilizer placement on soybean plant population or soybean dry weights (Table 17). Placement was the only factor that had an effect on soybean yields. Soybean following corn with no-till/broadcast yielded 0.8 bu/acre higher than strip-till/deep banding. Soybean dry weights and grain yields were not affected by MAP rates applied to corn the previous year at the four site-years evaluated in this research (Table 18). P-Max applied with 50 lbs P_2O_5/acre MAP had slightly lower plant populations compared to P-Max applied the other fertilizer rates and non-treated P, but P-Max applied with the 100 lbs P_2O_5/acre MAP increased plant populations 9,100 plants/acre over the same MAP rate with no enhancer (Table 19). However, there was no effect of P stabilizers on soybean dry weights or yields.

Soybean-P source, P stabilizer, and ag lime. When no P enhancer was applied at Novelty, the non-limed treatment increased soybean dry weights 0.23 ton/acre more compared to the lime treatment (Table 20). Soybean dry weights with AVAIL and P-Max were 0.18 to 0.22 ton/acre lower than the non-treated when no lime was applied. AVAIL increased soybean dry weights 0.21 ton/acre when lime was not applied compared to when lime was added. At Portageville, AVAIL applied with no lime increased dry weights 0.45 ton/acre over the non-treated control with no lime application and 0.63 ton/acre compared to AVAIL in conjunction with a lime application. Soybean dry weights were not affected by P source (Table 21). In 2011 at Novelty, TSP in conjunction with lime, DAP with no application of lime, and the non-P fertilized lime treatment had higher yields compared to DAP in combination with a lime application. DAP yielded 1.8 bu/acre lower than the non-treated control at Novelty in 2012. At Portageville, applying no fertilizer resulted in lower yields compared to when either DAP or TSP was applied. P-Max paired with TSP had soybean yields 3.8 bu/acre lower than P-Max paired with DAP, 2.8 bu/acre lower than AVAIL paired with TSP, and 2.5 bu/acre lower than TSP with no P stabilizer.

<u>Summary of Accomplishments:</u>

- Strip-till increased corn plant populations 6,200 plants/acre at Novelty and 1,400 plants/acre at Albany. Corn yields increased 24 bu/acre with use of strip-till/deep banding over no-till/broadcast at Novelty, but yields at Albany were affected by placement and MAP rate. When no MAP was added at Albany, no-till/broadcast increased grain yields 9 bu/acre over strip-till/deep banding. However, no difference was observed between no-till/broadcast and strip-till/deep banding, with MAP at 50 or 100 lbs P_2O_5/acre.
- Soybean with strip-till/deep banding placement had slightly lower grain yields (0.8 bu/acre) compared a no-till broadcast application of fertilizer to corn the previous year. Neither MAP rate, nor enhanced efficiency P products affected soybean yields the following year in this experiment (Objective #1).

- Enhanced efficiency P products did not affect corn plant population, dry weights, grain moisture, or yield in either objective at any of locations or site years.
    - In objective #2, triple superphosphate treated with AVAIL increased corn tissue P uptake 7.7 lbs/acre compared to non-treated TSP and 6.3 lbs/acre compared to P-Max.
- P enhancers showed limited improvements to soybean production when they were applied to the prior corn crop under the conditions observed in this experiment.
    - In objective #2, AVAIL applied with no lime increased dry weights 0.45 ton/acre over the non-treated control with no lime application only at Portageville.
    - P-Max with DAP increased soybean yields 2.9 bu/acre compared to the non-treated control at Portageville.
- TSP increased corn yields 5 bu/acre compared to the non-treated control in 2010 and 2011 at Novelty and in 2010 at Portageville. However, grain oil, protein, and starch concentration was not affected by P source.
- Lime increased grain yields 12 bu/acre at Portageville in 2010, but had no effect at Novelty.
- The application of lime to corn before soybeans had no effect on soybean dry weights or yields.

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Table 1. Soil analysis information for the P placement, rate, and enhancer experiment at Novelty and Albany in 2010 and 2011 prior to planting corn (Objective 1).

	Novelty		Albany	
	2010	2011	2010	2011
pHs	6.8 ±0.3	6.6 ±0.2	6.4 ±0.4	6.0 ±0.3
Phosphorus (lbs/acre)	45 ±23	24 ±7	80 ±43	80 ±10
Potassium (lbs/acre)	245 ±37	141 ±22	261 ±22	281 ±39
Calcium (lbs/acre)	5387 ±471	4982 ±216	5768 ±372	5810 ±617
Manganese (lbs/acre)	419 ±74	448 ±48	636 ±178	695 ±97
Zinc (ppm)	0.75 ±0.24	0.35 ±0.13	0.8 ±0.24	0.875 ±0.17
Organic matter (%)	2.4 ±0.8	2.6 ±0.1	2.5 ±0.1	2.7 ±0.7
Neutralizable acidity (meq/100 g)	0.25 ±0.5	0.75 ±0.29	1.25 ±1.19	2 ±0.82
Cation Exch. Capacity (meq/100 g)	16 ±1	15 ±1	19 ±2	20 ±3

Table 2. Soil analysis for the P source, P enhancer, and ag lime experiment at Portageville in 2010 and Novelty in 2010 and 2011prior to planting corn (Objective 2).

	Novelty		Portageville
	2010	2011	2010
pHs	5.4 ±0.1	5.8 ±0.1	5.2 ±0.3
Phosphorus (lbs/acre)	27 ±7	9 ±2	105 ±27
Potassium (lbs/acre)	254 ±24	71 ±12	248 ±77
Calcium (lbs/acre)	4467 ±138	3495 ±307	1726 ±342
Manganese (lbs/acre)	402 ±75	290 ±29	307 ±85
Zinc (ppm)	0.78 ±0.15	0.35 ±0.06	
Organic matter (%)	2.6 ±0.2	2.2 ±0.1	1.4 ±0.2
Neutralizable acidity (meq/100 g)	4 ±0.8	1.9 ±0.3	2.9 ±0.8
Cation Exch. Capacity (meq/100 g)	17 ±1	12 ±1	9 ±1

Table 3 . Management information for the P placement, rate, and enhancer experiment at Novelty and Albany for corn (2010 and 2011) followed by soybean (2011 and 2012).

	Novelty				Albany			
Management Information	Corn 2010 followed by soybean 2011		Corn 2011followed by soybean 2012		Corn 2010 followed by soybean 2011		Corn 2011 followed by soybean 2012	
Previous crop	Soybean	Corn	Soybean	Corn	Soybean	Corn	Soybean	Corn
Hybrid or cultivar	DK 62-54	Ag 3731	DK 62-54	Ag 3731	DK 63-84	Ag 3803	DK 63-84	Ag 3803
Planting Date	14 Apr.	2 May	31 Mar.	12 Apr.	30 May	6 May	13 April	10 May
Seeding rate (seeds/acre)	30,000	160,000	30,000	180,000	30,000	160,000	29,500	160,000
Tissue harvest date	7 Sep.	29 Aug.	25 Aug.	9 Aug	9 Sep.	2 Sep.	26 Aug.	11 Sep.
Harvest date	30 Oct.	28 Sep.	8 Sep.	2 Oct.	15 Oct.	7 Oct.	27 Sept.	10 Oct.
Fertilizer								
P application date	13 Apr.	NA	30 Mar.	NA	15 Apr.	NA	15 Nov.	NA
Additional fertilizer (date, source, & rate)	6 May, Urea (180 lbs N/acre)+ Agrotain (1 gal/ton)	NA	NA	NA	19 Apr., urea (150 lbs N/acre)+ Agrotain (1 gal/ton)	NA	14 Apr., urea (150 lb)	NA
Weed management								
Burndown	NA	11 May, Roundup PowerMAX (22 oz/acre)+ 2,4-D (2/3 pt/acre)+ Quest (7 oz/acre)	11 Apr., Roundup PowerMAX (22 oz/acre)+ 2,4-D (2/3 pt/acre)+ Quest (7 oz/acre)	2 Apr., Verdict (5 oz/acre)+ Roundup PowerMAX (22 oz/acre)+ 32% UAN (1 qt/acre)+ NIS (0.25% v/v)	NA	NA	NA	10 May Roundup PowerMAX (24 oz/A)
Preemergence	16 Apr., Lumax (3 qt/acre)+ Banvel (1 pt/acre)	3 May, Optil (2 oz/acre)	13 Apr., Keystone (2.8 qt/acre)	11 May, Reflex (1.25 pt/acre)+ Roundup PowerMAX (32 oz/acre)+ 32% UAN (1 qt/acre)+ NIS (0.25% v/v)	15 Apr., Lumax (3.2 qt/acre); 30 May, Balance Pro (4 oz/acre)	7 May, Boundary (2.5 pt/acre)+ Roundup PowerMAX (24 oz/acre)	16 April., Lumax (3.2qt/acre)	10 May Boundary (2.5 pt/ acre)+ Roundup PowerMAX (24 oz/ acre)
Postemergence	22 June, Roundup PowerMAX (30 oz/acre)+ AMS (17 lbs/100 gal)	NA	NA	21 June, Roundup PowerMAX (32 oz/acre)+ NIS (0.25% v/v)+ AMS (17 lbs/100 gal)+ Warrior (20 oz/acre)+ Headline (6 oz/acre)	21 June, Roundup PowerMAX (24 oz/acre)	NA	7 June, Roundup PowerMAX (24 oz/acre)	NA
Insect management	16 Apr., Warrior (1.5 oz/acre)	NA	NA	16 Jul., Dimethoate (1 pt/acre)	NA	NA	NA	NA

†Abbreviations: NA, None applied; NIS, non-ionic surfactant; UAN, 32% urea ammonium nitrate.

Table 4. Management information for the P source, P enhancer, and agriculture lime experiment at Portageville in 2010 and Novelty in 2010 and 2011 followed by soybean at Portageville in 2011 and Novelty in 2011 and 2012.

	Novelty				Portageville	
Management information	Corn in 2010 followed by soybean in 2011		Corn in 2011 followed by soybean in 2012		Corn in 2010 followed by soybean in 2011	
Previous crop	Corn	Corn	Wheat	Corn	Corn	Corn
Hybrid or cultivar	DK 61-69 VT3	Ag 3731	DKC 63-42	Ag 3731	CROPLAN 68-31	Pioneer P94Y70
Planting date	26 May	2 May	10 May	12 Apr.	7 Apr.	25 Apr.
Seeding rate (seeds/acre)	30,000	160,000	30,800	180,000	30,000	140,000
Tissue harvest date	7 Sep.	31 Aug.	25 Aug.	9 Aug.	16 Aug.	8 Sep.
Harvest date	1 Oct.	28 Sep.	14 Sep.	4 Oct.	8-9 Sep.	25 Sep.
Fertilizer						
P application date	27 Apr.	NA	31 Mar.	NA	6 Apr.	NA
Lime application date	1 Apr.	NA	29 Mar.	NA	1 Apr.	NA
Additional fertilizer (date, source, & rate)	12 Apr., Anhydrous ammonia (235 lbs N/acre)	NA	31 Mar., Anhydrous ammonia (180 lbs N/acre)	NA	7 Apr., Urea (50 lbs N/acre) + Agrotain (1 gal/ton)	NA
Sidedress N	11 June, 32% UAN (150 lbs N/acre)	NA	NA	NA	5 May, Urea (150 lbs N/acre) + Agrotain (1 gal/ton)	NA
Weed management						
Burndown	21 Apr., Roundup PowerMAX (15 oz/acre)	11 May, Roundup PowerMAX (22 oz/acre)+ 2,4-D (2/3 pt/acre)+ Quest (7 oz/acre)	11 Apr., Roundup PowerMax (22 oz/acre) + 2,4-D (2/3 pt/acre) + Quest (7 oz/acre)	2 Apr., Verdict (5 oz/acre)+ Roundup PowerMAX (22 oz/acre)+ 32% UAN (1 qt/acre)+ NIS (0.25% v/v)	5 Apr., Conerstone (32 oz/acre)	30 Apr., Glyphosate (32 oz/acre) + Prefix (3 pt/acre) + Sonic (6.45 oz/acre)
Preemergence	21 Apr., Bicep II Magnum (1.65 qt/acre)	3 May, Optil (2 oz/acre)	13 Apr., Bicep II Magnum (2.5 qt/acre)	11 May, Reflex (1.25 pt/acre)+ Roundup PowerMAX (32 oz/acre)+ 32% UAN (1 qt/acre)+ NIS (0.25% v/v)	9 Apr., Bicep II Magnum (1.5 qt/acre) + Atrazine (2 qt/acre)	NA
Postemergence	22 June, Roundup PowerMAX (22 oz/acre)	NA	NA	21 June, Roundup PowerMAX (32 oz/acre)+ NIS (0.25% v/v)+ AMS (17 lbs/100 gal)+ Warrior (20 oz/acre)+ Headline (6 oz/acre)	8 May, Atrazine (1 qt/acre) + Glyphosate (32 oz/acre)	13 June, Flexstar GT (2.6 pt/acre)

†Abbreviations: NA, None applied; NIS, non-ionic surfactant; UAN, 32% urea ammonium nitrate.

Table 5. Phosphorus placement effect on plant population, silage dry weights, grain moisture, and yield. Data were combined over site-year, monoammonium phosphate (MAP) rate, and P stabilizer except for plant population and yield.

	Plant population				Yield			
						Albany†		
						MAP rate (lb P_2O_5/acre)		
Placement	Novelty†	Albany†	Silage dry weights	Grain moisture	Novelty†	0	50	100
	----plants/acre-----		ton/acre	%	----------bu/acre----------			
Broadcast	20,500	23,300	6.5	17.2	100	139	128	133
Strip-till	26,700	24,700	6.6	16.9	124	130	132	135
LSD (*P*=0.1)	1,300	1,200	NS	0.3	5	----------7----------		

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

Table 6. Placement effect on grain protein, starch, and oil. Data were combined over monoammonium phosphate (MAP) rate and P stabilizer except for grain oil which was combined over site year and P stabilizer.

	Protein			Starch			Oil					
							Novelty†			Albany†		
	Novelty			Novelty			MAP rate(lb P_2O_5/acre)			MAP rate(lb P_2O_5/acre)		
Placement	2010	2011	Albany†	2010	2011	Albany†	0	50	100	0	50	100
	----------%----------			----------%----------			----------%----------			----------%----------		
Broadcast	8.4	9.3	8.4	73.9	72.9	72.3	3.5	3.7	3.7	3.7	3.7	3.7
Strip-till	7.0	8.7	8.5	74.7	73.2	72.2	3.7	3.7	3.7	3.6	3.8	3.7
LSD (*P*=0.05)	0.3	0.2	NS	0.20	0.24	NS	----------0.1----------			----------0.1----------		

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

Table 7. Total tissue N and K uptake, and apparent P recovery efficiency (APRE) as affected by P fertilizer placement. Data were combined over site-year, P stabilizer, and monoammonium phosphate (MAP) rate.

Placement	Tissue N	Tissue K	APRE
	lbs/acre	lbs/acre	%
Broadcast	384	255	21.4
Strip-till	388	247	0.7
LSD (*P*=0.1)	NS	NS	11.5

Table 8. Plant population, silage dry weights, grain moisture, yield, protein, and starch as affected by monoammonium phosphate (MAP) rate. Data were combined over site-year, placement, and P stabilizer except for grain protein and starch.

					Protein			Starch	
					Novelty				
MAP Rate	Plant population	Silage dry weights	Grain moisture	Yield	2010	2011	Albany†	Novelty†	Albany†
lb P_2O_5/acre	plants/acre	ton/acre	%	bu/acre	----------%----------			-------%-------	
0	23,800	6.8	17.1	126	7.7	8.8	8.5	73.7	72.3
50	23,900	6.5	17.0	120	7.7	9.1	8.4	73.5	72.2
100	23,800	6.5	17.0	122	7.6	9.1	8.4	73.7	72.3
LSD (*P*=0.1)	NS	NS	NS	4	NS	0.2	NS	0.2	NS

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

Table 9. The effect of monoammonium phosphate (MAP) rate on total tissue N, tissue P, tissue K, and apparent P recovery efficiency (APRE). Data were combined over site-year, P stabilizer, and placement.

MAP rate	Tissue N	Tissue P	Tissue K	APRE
lb P_2O_5/acre	----------lbs/acre----------			%
0	393	33.2	258	
50	383	34.0	241	12.9
100	383	35.2	254	9.1
LSD (*P*=0.1)	NS	NS	NS	NS

Table 10. The effect of P stabilizer on plant population, silage dry weights, moisture, yield, grain oil, grain protein, and grain starch. Data were combined over site-year, placement, and monoammonium phosphate (MAP) rate except for grain oil concentration.

					Oil			
P stabilizer	Plant population	Silage dry weights	Grain moisture	Yield	Novelty†	Albany†	Protein	Starch
	plants/acre	ton/acre	%	bu/acre	----------%----------		%	%
Non-treated	24,200	6.7	17.2	122	3.7	3.8	8.3	72.9
AVAIL	23,600	6.5	17.0	123	3.6	3.7	8.4	73.0
P-Max	23,700	6.6	17.0	122	3.7	3.6	8.4	73.0
LSD (*P*=0.05)	NS	NS	NS	NS	NS	0.1	NS	NS
P-value	0.51	0.83	0.54	0.83	0.74	0.01	0.74	0.63

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

Table 11. P stabilizer effect on tissue N, tissue P, tissue K, and apparent P recovery efficiency (APRE). Data were combined over site-year, placement, monoammonium phosphate (MAP) rate except for tissue P which was combined over site year, and MAP rate.

		Tissue P			
P Stabilizer	Tissue N	Broadcast	Strip-till	Tissue K	APRE
	lbs/acre	-------lbs/acre-------		lbs/acre	%
Non-treated	375	35.3	34.0	250	16.1
AVAIL	384	33.9	35.5	249	13.1
P-Max	400	35.7	30.4	255	3.8
LSD (*P*=0.1)	NS	----------3.7----------		NS	NS

Table 12. Plant population, grain moisture, yield, grain oil, protein, and starch results based on liming rate. Data were combined over 2010 and 2011 at Novelty, and at Portageville in 2010, P source, and P stabilizer except for yield and plant population.

	Plant population				Yield				
	Novelty			Grain					
Liming Rate	2010	2011	Portageville	moisture[†‡]	Novelty	Portageville	Oil[†‡]	Protein[†‡]	Starch[†‡]
	----------plants/acre----------			%	-----bu/acre-----		%	%	%
None	24,200	23,500	15,200	25.4	151	105	3.9	9.1	71.7
Recommended[§]	26,100	22,500	14,300	25.5	146	117	3.9	9.0	71.8
LSD (*P*=0.05)	NS	1,000	NS	NS	NS	4	NS	NS	NS

[†]Novelty location only.
[‡]Data were combined over years (2010 and 2011).
[§]The recommended liming rate was 3.6 ton/acre at Novelty in 2010, 1.5 ton/acre at Novelty in 2011, and 2.0 ton/acre at Portageville in 2010.

Table 13. P source effects on silage dry weights, grain moisture, yield, grain oil, protein, starch, tissue N, and apparent P recovery efficiency (APRE). Data were combined over 2010 and 2011 at Novelty, and at Portageville in 2010, liming rate, and P stabilizer except for silage dry weight.

	Silage dry weights								
	Liming rate		Grain						
P source	None	Recommended[‡]	moisture[§]	Yield	Oil[§]	Protein[§]	Starch[§]	Tissue N	APRE
	----------ton/acre----------		%	bu/acre	%	%	%	lbs/acre	%
Non-treated	6.5	7.5	26.2	132	3.9	9.1	71.7	418	
DAP[†]	6.8	7.2	25.3	135	3.9	9.0	71.8	420	4.8
TSP[†]	7.4	7.1	24.9	137	3.9	9.0	71.9	439	-3.8
LSD (*P*=0.05)	----------0.7----------		0.8	5	NS	NS	NS	NS	NS

[†]DAP and TSP was applied at a 105 lbs P_2O_5/acre at Novelty in 2010, 100 lbs P_2O_5/acre at Novelty in 2011, and 50 lbs P_2O_5/acre at Portageville in 2010.
[‡]The recommended liming rate was 3.6 ton/acre at Novelty in 2010, 1.5 ton/acre at Novelty in 2011, and 2.0 ton/acre at Portageville in 2010.
[§]Novelty location only.

Table 14. P stabilizer effect on plant population, silage dry weights, grain moisture, yield, grain oil, protein, starch, tissue N, and apparent P recovery efficiency (APRE). Data were combined over 2010 and 2011 at Novelty, and at Portageville in 2010, liming rate, and P source.

P stabilizer	Plant population	Silage dry weights	Grain moisture†	Yield	Oil†	Protein†	Starch†	Tissue N	APRE
	plants/acre	ton/acre	%	bu/acre	%	%	%	lbs/acre	%
Non-treated	21,100	7.2	25.6	135	3.9	9.0	71.8	442	6.1
AVAIL	21,400	7.2	25.6	134	3.9	9.1	71.7	422	1.7
P-Max	20,400	6.9	25.3	136	3.9	9.0	71.7	414	-6.3
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS
P-value	0.31	0.48	0.69	0.65	0.44	0.97	0.48	0.45	0.43

†Novelty location only.

Table 15. Tissue N, tissue P, tissue K, and apparent P recovery efficiency (APRE) as affected by liming rate. Data were combined over 2010 and 2011 at Novelty, and at Portageville in 2010, P source, and P stabilizer except for Tissue P.

		Tissue P			
Liming Rate	Tissue N	Novelty	Portageville	Tissue K	APRE
	lbs/acre	----------lbs/acre----------		lbs/acre	%
None	421	29.3	45.1	254	7.2
Recommended†	430	32.3	43.9	258	-6.2
LSD (*P*=0.1)	NS	2.8	NS	NS	13.0

†The recommended liming rate was 3.6 ton/acre at Novelty in 2010, 1.5 ton/acre at Novelty in 2011, and 2.0 ton/acre at Portageville in 2010.

Table 16. P stabilizer effect on tissue P and tissue K. Data were combined over 2010 and 2011 at Novelty, and at Portageville in 2010, and liming rate except for tissue K.

	Tissue P				Tissue K				
	Novelty				Novelty				
					2010				
	P source				P source				
P stabilizer	Non-treated	DAP†	TSP†	Portageville	Non-treated	DAP†	TSP†	2011	Portageville
	----------lbs/acre----------				----------lbs/acre----------				
Non-treated	28.6	36.0	28.0	47.3	258	253	191	271	248
AVAIL	26.1	32.8	35.7	42.0	197	241	326	286	243
P-Max	31.5	29.0	29.4	44.1	261	229	237	297	229
LSD (P=0.1)	----------5.9----------			NS§	----------66----------			NS	NS
P-value	----------0.033----------			0.365	----------0.010----------			0.438	0.563

†DAP and TSP was applied at 105 lbs P_2O_5/acre at Novelty in 2010, 100 lbs P_2O_5/acre at Novelty in 2011, and 50 lbs P_2O_5/acre at Portageville in 2010.

Table 17. Phosphorus placement effect on soybean plant population, soybean dry weights, and yield. Data were combined over site-year, monoammonium phosphate (MAP) rate, and P stabilizer.

Placement	Plant population	Soybean dry weights	Yields
	plants/acre	tons/acre	bu/acre
Broadcast	151,000	3.20	45.4
Strip-till†	148,200	3.23	44.6
LSD (*P*=0.1)	NS	NS	0.7

†Strip-till treatment was for corn the previous year and soybean were no-till seeded the following year.

Table 18. Soybean dry weights and yields as affected by monoammonium phosphate (MAP) rate. Data were combined over site-year, placement, and P stabilizer.

P source	Soybean dry weights	Yields
lb P_2O_5/acre†	tons/acre	bu/acre
0	3.21	44.6
50	3.16	45.1
100	3.27	45.3
LSD (*P*=0.1)	NS	NS

†Phosphorus fertilizer was applied the previous year for corn production.

Table 19. The effect of P stabilizer on soybean plant population, soybean dry weights, and yield. Data were combined over site-year, placement, and monoammonium phosphate (MAP) rate except for plant population.

	Plant population				
	MAP rate (lb P_2O_5/acre)†				
P stabilizer	0	50	100	Soybean dry weights	Yields
	----------plants/acre----------				
Non-treated	152,900	150,300	145,400	3.25	44.8
AVAIL	148,500	150,100	152,800	3.20	45.4
P-Max	149,600	142,000	154,500	3.19	44.9
LSD (*P*=0.1)	----------7,600----------			NS	NS

†Phosphorus fertilizer and stabilizer were applied the previous year for corn production.

Table 20. P stabilizer effect on soybean dry weights. Data were combined over 2010 and 2011 at Novelty, and at Portageville in 2010, and P source.

	Soybean dry weights			
	Novelty		Portageville in 2011	
	Liming Rate		Liming Rate	
P stabilizer	None	Recommended[†]	None	Recommended
	----------tons/acre----------		----------tons/acre----------	
Non-treated	2.58	2.35	4.07	4.46
AVAIL	2.40	2.19	4.52	3.89
P-Max	2.36	2.43	4.35	3.98
LSD (*P*=0.1)	----------0.17----------		----------0.45----------	

[†]The recommended liming rate was applied to corn at 3.6 ton/acre at Novelty in 2010, 1.5 ton/acre at Novelty in 2011, and 2.0 ton/acre at Portageville in 2010. Soybean was planted in the same plots the following year.

Table 21. Soybean dry weights and yield results based on P source. Data were combined over 2010 and 2011 at Novelty, and at Portageville in 2010, liming rate, and P stabilizer except for yield.

		Soybean Yield					
		Novelty 2011			Portageville		
		Liming Rate			P stabilizer		
P source	Soybean dry weights	None	Recommended[‡]	Novelty 2012	Non-treated	AVAIL	P-Max
	ton/acre	----------bu/acre----------		bu/acre	----------bu/acre----------		
Non-treated	2.92	47.4	47.2	20.6	56.3	56.8	55.6
DAP[†]	3.03	47.9	45.6	18.8	60.5	61.8	63.4
TSP	3.04	47.8	48.0	19.7	62.1	62.4	59.6
LSD (*P*=0.10)	NS	----------1.4----------		1.1	----------1.8----------		

[†]DAP and TSP were applied to corn at a 105 lbs P_2O_5/acre at Novelty in 2010, 100 lbs P_2O_5/acre at Novelty in 2011, and 50 lbs P_2O_5/acre at Portageville in 2010. Soybean was planted in the same plots the following year.

[‡]The recommended liming rate was applied to corn at 3.6 ton/acre at Novelty in 2010, 1.5 ton/acre at Novelty in 2011, and 2.0 ton/acre at Portageville in 2010.