Enhanced Efficiency Phosphorus Application for a Corn-Soybean Rotation

Investigators:
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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. This project was expanded to include additional P-enhancing products. 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, MAP, 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 (Table 1 and 2). Soil test P (Bray P1) 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. Phosphorus fertilizer efficiency was calculated as [((lbs tissue P/acre)/(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 yield data from 2011 is currently being analyzed (data not presented).

P placement, rate, and enhancer. Sites to accomplish objective 1 included Novelty and Albany. 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 to 15 by 70 ft. 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 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. Tissue samples were collected to determine crop P uptake due to the effects of the treatments at both

locations and 2011 samples are currently being analyzed by the University of Missouri Soil and Plant Testing Laboratory.

P source, P enhancer, and ag lime. Research to accomplish objective 2 was conducted at Novelty in 2010 and 2011 and Portageville in 2010. Treatments include a factorial arrangement of a P source [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 40 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) and grain (Novelty) samples were collected to determine crop P uptake and are currently being analyzed by the University of Missouri Soil and Plant Testing Laboratory.

Results:

P placement, rate, and P stabilizer. 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 showed had 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. No-till/broadcast increased tissue K 14 lbs/acre over strip-till/deep banding, while no effect of placement tissue N and P fertilizer efficiency was observed (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 and tissue P uptake was not affected by MAP rate (Table 9). However, MAP at 0 and 100 lbs P_2O_5/acre increased tissue K by 19 to 31 lbs/acre over MAP at 50 lbs P_2O_5/acre. At both locations, MAP at 50 lbs P_2O_5/acre had a higher P fertilizer efficiency than MAP at 100 lbs P_2O_5/acre in 2010.

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, P fertilizer efficiency, and plant K uptake were not affected by P stabilizer (Table 11). Tissue P concentrations were affected by fertilizer placement and P stabilizer. No-till/broadcast MAP with P-Max increased tissue P concentration 8 lbs/acre compared to a strip-till/deep banding, but AVAIL increased tissue P concentration 6 lbs/acre with strip-till/deep banding compared to a broadcast surface application. However, no increase in tissue P uptake with P enhancers compared to the non-treated control was observed.

P source, P stabilizer, and ag lime. 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, and starch concentration was not affected by P source. Enhanced efficiency P products did not affect plant populations, silage dry weights, grain moisture, yield, grain oil, protein, or starch (P= 0.31 to 0.97) compared to the non-treated control (Table 14).

Plant tissue N, tissue P at Portageville, P fertilizer efficiency, and tissue K was not affected by a lime application (Table 15). However, the recommended lime treatment increased tissue P concentration 15 lbs/acre compared to the non-limed control with P at 0 lbs/acre. In the non-limed control, tissue P uptake was 12 lbs/acre greater when TSP was applied. Tissue K and P fertilizer efficiency was affected by location, P source, and P stabilizer (Table 16). The non-treated P source and non-treated P-stabilizer treatment had K uptake that was 258 lbs/acre. K uptake was lower in the non-treated control when TSP was applied, but K uptake increased 129 lbs/acre when TSP was treated with AVAIL. P fertilizer efficiency was 26 and 30% greater with AVAIL treated TSP than the P-Max and the non-treated control, respectively at Novelty in 2010. TSP increased P fertilizer efficiency 32% compared to MAP at Portageville in 2010; however, P fertilizer efficiency was 27% greater with DAP compared to TSP at Novelty in 2010.

Summary and Accomplishments for Years 1 and 2:

- Strip-till increased plant populations 6,200 plants/acre at Novelty and 1,400 plants/acre at Albany. 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.
- Enhanced efficiency P products did not affect cor plant population, dry weights, grain moisture, or yield in either objective at any of locations or site years.
    - In objective #1, no-till/broadcast MAP with P-Max increased tissue P concentration 8 lbs/acre compared to a strip-till/deep banding while AVAIL increased tissue P concentration 6 lbs/acre with strip-till/deep banding compared to a broadcast surface application in 2010. However, no increase in tissue P uptake with P enhancers compared to the non-treated control was observed.
    - In objective #2, P fertilizer efficiency was 26 and 30% greater with AVAIL treated TSP than the P-Max and the non-treated control, respectively at Novelty in 2010.
- TSP increased 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 corn plots will rotate into soybean for the 2012 growing season. Soybean data in 2011 is currently being analyzed.

Objectives for Year 3:

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.

We will complete the soybean portion of the experiment in 2012.

Timetable:

2012

April/May	Soybean planting in 2011 trial
July	Tissue sampling
September	Harvest and grain sample for soybean
Oct/Nov	Soil sample from all treatments following soybean harvest
December	Submission of final report

Budget:

CATEGORIES	Year 3 (2012)	Total*
A. Salaries Technical assistance or graduate research assistant (50%)	$14,670	$42,875
B. Fringe Benefits Fringe for graduate student	$2,095	$6,080
TOTAL SALARIES AND FRINGE BENEFITS	$16,765	$48,955
C. Travel Travel to field site To present research findings at National Meetings	 $0 $1000	 $0 $1000
TOTAL TRAVEL COSTS	$1000	$1000
D. Equipment	$0	$0
TOTAL EQUIPMENT use and maintenance COSTS	$0	$0
E. Other Direct Costs Soil analysis Grain analysis Tissue analysis Field supplies Publication cost Off-site PI's (2)	 $1020 $2560 $2560 $500 $500 $6,000	 $4080 $7680 $7680 $1500 $500 $18,000
TOTAL OTHER DIRECT COSTS	$13,140	$39,440
TOTAL REQUEST	**$30,905**	**$89,395**

*Included the 2010 and 2011 (Year 1 and 2) budget.

Budget narrative:
Salaries and fringe benefits: Funds are requested for partial support of a research technical support and/or graduate research assistant.
Presentations, publications, and documentation: This will help defray cost of publication and documentation of results and conclusions as well as assist travel and board for presentation of results
Other Direct Costs: Covers cost of analysis, sample containers, fertilizer, seed, plot preparation, planting, weed control harvesting, flags, and other field supplies and operations.

References:

Blevins, D. 2009. Missouri Corn. Online at http://www.chooseavail.com/research.aspx?region=midwest. Accessed July 16, 2010.

Dunn, D. 2009. Missouri Rice. Online at http://www.chooseavail.com/research.aspx?region=midwest. Accessed July 16, 2010.

Dunn, D. 2009. Missouri Soybean. Online at http://www.chooseavail.com/research.aspx?region=midwest. Accessed July 16, 2010.

Minor, H. C., J. Stecker, and J. R. Brown. 1993. Phosphorus in Missouri Soils. Uni. of MO Ext., G9180.

Pierzynski, G.M., R.W. McDowell, and J.T. Sims. 2005. Chemistry, cycling, and potential movement of inorganic phosphorus in soil. p. 53-86. In Sims, J.T., and A.N. Sharpley (eds.) Phosphorus: Agriculture and the environment. Agronomy #46. American Society of Agronomy, Madison, WI.

Rosen's Diversified Inc. 2010. Rosen's Inc. - Serving Agribusiness. http://rosensdiversifiedinc.com/contentpage.asp?contentid=10. Accessed July 16, 2010.

Table 1. Soil analysis information for the P placement, rate, and enhancer experiment at Novelty and Albany in 2010 and 2011(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 2011(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 . Field and management information for the P placement, rate, and enhancer experiment at Novelty and Albany in 2010 and 2011.

	Novelty		Albany	
Management Information	Corn 2010	Corn 2011	Corn 2010	Corn 2011
Previous crop	Soybeans	Soybeans	Soybeans	Soybeans
Plot size	10 by 75 ft	10 by 75 ft	10 by 75 ft	10 by 75 ft
Hybrid or cultivar	DK 62-54	DK 62-54 VT3	DK 63-84	DK 63-84
Planting Date	14 Apr.	31 Mar.	30 May	13 April
Seeding rate	30,000 seeds/acre	30,000 seeds/acre	30,000 seeds/acre	29,500
Tissue harvest date	7 Sep.	25 Aug.	9 Sep.	26 Aug.
Harvest date	30 Oct.	8 Sep.	15 Oct.	27 Sept.
Fertilizer				
P application (date & 1x rate)	13 Apr., 100 lbs P_2O_5/acre	30 Mar., 100 lbs P_2O_5/acre	15 Apr., 100 lbs P_2O_5/acre	15 Nov., 100 lbs P_2O_5/acre
Additional fertilizer (date, source, & rate)	6 May, Urea (180 lbs N/acre)+ Agrotain (1 gal/ton)	NA	19 Apr., urea (150 lbs N/acre)+ Agrotain (1 gal/ton)	14 Apr., urea (150 lb)
Weed management				
Burndown	NA	11 Apr., Roundup PowerMAX (22 oz/acre)+ 2,4-D (2/3 pt/acre)+ Quest (7 oz/acre)	NA	NA
Preemergence	16 Apr., Lumax (3 qt/acre)+ Banvel (1 pt/acre)	13 Apr., Keystone (2.8 qt/acre)	15 Apr., Lumax (3.2 qt/acre); 30 May, Balance Pro (4 oz/acre)	16 April., Lumax (3.2qt/acre)
Postemergence	22 June, Roundup PowerMAX (30 oz/acre)+ AMS (17 lbs/100 gal)	NA	21 June, Roundup PowerMAX (24 oz/acre)	7 June, Roundup PowerMAX (24 oz/acre)
Insect management	16 Apr., Warrior (1.5 oz/acre)	NA	NA	NA

†Abbreviations: NA, None applied.

Table 4. Field and management information for the P source, P enhancer, and ag lime experiment at Portageville in 2010 and Novelty in 2010 and 2011.

	Novelty		Portageville
Management information	Corn 2010	Corn 2011	Corn 2010
Previous crop	Corn	Wheat	Corn
Plot size	10 by 45 ft	10 by 45 ft	10 by 45 ft
Hybrid or cultivar	DK 61-69 VT3	DKC 63-42	Croplan Genetics 68-31
Planting date	26 May	10 May	7 Apr.
Seeding rate	30,000 seeds/acre	30,800 seeds/acre	30,000 seeds/acre
Tissue harvest date	7 Sep.	25 Aug.	16 Aug.
Harvest date	1 Oct.	14 Sep.	8-9 Sep.
Fertilizer			
P application (date & rate)	27 Apr. 105 lbs P_2O_5/acre	31 Mar., 100 lbs P_2O_5/acre	6 Apr. 50 lbs P_2O_5/acre
Lime application (date & rate)	1 Apr., 3.6 ton/acre	29 Mar., 1.5 ton/acre	1 Apr., 2 ton/acre
Additional fertilizer (date, source, & rate)	12 Apr., Anhydrous ammonia (235 lbs N/acre)	31 Mar., Anhydrous ammonia (180 lbs N/acre)	7 Apr., Urea (50 lbs N/acre) + Agrotain (1 gal/ton)
Sidedress N	11 June, 32% UAN (150 lbs N/acre)	NA	5 May, Urea (150 lbs N/acre) + Agrotain (1 gal/ton)
Weed management			
Burndown	21 Apr., Roundup PowerMAX (15 oz/acre)	11 Apr., Roundup PowerMax (22 oz/acre) + 2,4-D (2/3 pt/acre) + Quest (7 oz/acre)	5 Apr., Conerstone 32 oz/acre
Preemergence	21 Apr., Bicep II Magnum (1.65 qt/acre)	13 Apr., Bicep II Magnum (2.5 qt/acre)	9 Apr., Bicep II Magnum (1.5 qt/acre) + Atrazine (2 qt/acre)
Postemergence	22 June, Roundup PowerMAX (22 oz/acre)	NA	8 May, Atrazine (1 qt/acre) + Glyphosate (32 oz/acre)

†Abbreviations: NA, None applied.

Table 5. Phosphorus placement effect on plant population, silage dry weights, grain moisture, and yield. Data were combined over site-year, location, 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 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 N and K uptake, and P fertilizer efficiency. Data were combined over site-year, location, P stabilizer, and MAP rate.

Placement	Tissue N	Tissue K	P fertilizer efficiency
	lbs/acre	lbs/acre	%
Broadcast	238	185	129
Strip-till	236	171	122
LSD (*P*=0.1)	NS	12	NS

Table 8. Plant population, silage dry weights, grain moisture, yield, protein, and starch 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	Plant population	Silage dry weights	Grain moisture	Yield	2010	2011	Albany†	Novelty	Albany†
lbs/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 MAP rate on tissue N, tissue P, tissue K, and fertilizer efficiency in 2010. Data were combined over location, P stabilizer, and placement except for fertilizer efficiency.

				P Fertilizer Efficiency	
MAP rate	Tissue N	Tissue P	Tissue K	Novelty	Albany
lb P_2O_5/acre	----------lbs/acre----------			---------%---------	
0	242	38.6	192		
50	232	36.7	161	202.42	133.71
100	238	36.2	180	97.94	68.08
LSD (*P*=0.05)	NA	NA	17	28.46	17.94

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, location, placement, and MAP rate except for grain oil.

					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. Tissue N, P, and K uptake as well as P fertilizer efficiency as affected by P stabilizer in 2010. Data were combined over site-year, placement, MAP rate except for Tissue P which was combined over site year, and MAP rate.

		Tissue P			
P Stabilizer	Tissue N	Broadcast	Strip-till	P Fertilizer Efficiency	Tissue K
	lbs/acre	-------lbs/acre-------		%	lbs/acre
Non-treated	236	39	37	131	176
AVAIL	229	34	40	124	181
P-Max	247	41	33	121	177
LSD (*P*=0.1)	NS	----------5----------		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 2010, 1.5 ton/acre at Novelty 2011, and 2.0 ton/acre at Portageville 2010.

Table 13. P source effects on silage dry weights, grain moisture, yield, grain oil, protein, and starch. 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[§]
	----------ton/acre----------		%	bu/acre	%	%	%
Non-treated	6.5	7.5	26.2	132	3.9	9.1	71.7
DAP[†]	6.8	7.2	25.3	135	3.9	9.0	71.8
TSP[†]	7.4	7.1	24.9	137	3.9	9.0	71.9
LSD (*P*=0.05)	----------0.7----------		0.8	5	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 2010, 1.5 ton/acre at Novelty 2011, and 2.0 ton/acre at Portageville 2010.
[§]Novelty location only.

Table 14. P stabilizer effect on plant population, silage dry weights, grain moisture, yield, grain oil, protein, and starch. 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†
	plants/acre	ton/acre	%	bu/acre	%	%	%
Non-treated	21,100	7.2	25.6	135	3.9	9.0	71.8
AVAIL	21,400	7.2	25.6	134	3.9	9.1	71.7
P-Max	20,400	6.9	25.3	136	3.9	9.0	71.7
LSD	NS	NS	NS	NS	NS	NS	NS
P-value	0.31	0.48	0.69	0.65	0.44	0.97	0.48

†Novelty location only.

Table 15. Tissue N, tissue P, P fertilizer efficiency, and tissue K as affected by liming rate. Data were combined over P stabilizer, and P source for Novelty and Portageville in 2010 except for tissue P.

		Tissue P					
		Novelty					
Liming Rate	Tissue N	Non-treated	DAP†	TSP†	Portageville	P fertilizer efficiency	Tissue K
	lbs/acre	----------lbs/acre----------			lbs/acre	%	lbs/acre
None	393	28	37	40	45	143	236
Recommended‡	415	43	43	37	44	144	248
LSD (*P*=0.05)	NS	----------10----------			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 2010, 1.5 ton/acre at Novelty 2011, and 2.0 ton/acre at Portageville 2010.

Table 16. Tissue K and fertilizer efficiency results based on P source. Data were combined over lime treatments for Novelty and Portageville in 2010.

	Tissue K				P fertilizer efficiency			
	Novelty				Novelty			
	P stabilizer				P stabilizer			
P source	Non-treated	AVAIL	P-Max	Portageville	Non-treated	AVAIL	P-Max	Portageville
	----------lbs/acre----------			lbs/acre	----------%----------			%
Non-treated	258	197	261	247				
DAP†	253	241	229	235	99	85	78	186
TSP†	191	326	237	238	72	102	76	218
LSD (*P*=0.1)	----------66----------			NS	----------23----------			27

†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.